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THE

# GENERAL ELECTRIC REVIEW

## VOLUME XVII

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# GENERAL ELECTRIC REVIEW

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Edw Schildhauer

Electrical and Mechanical Engineer, Isthmian Canal Commission

GENERAL ELECTRIC REVIEW

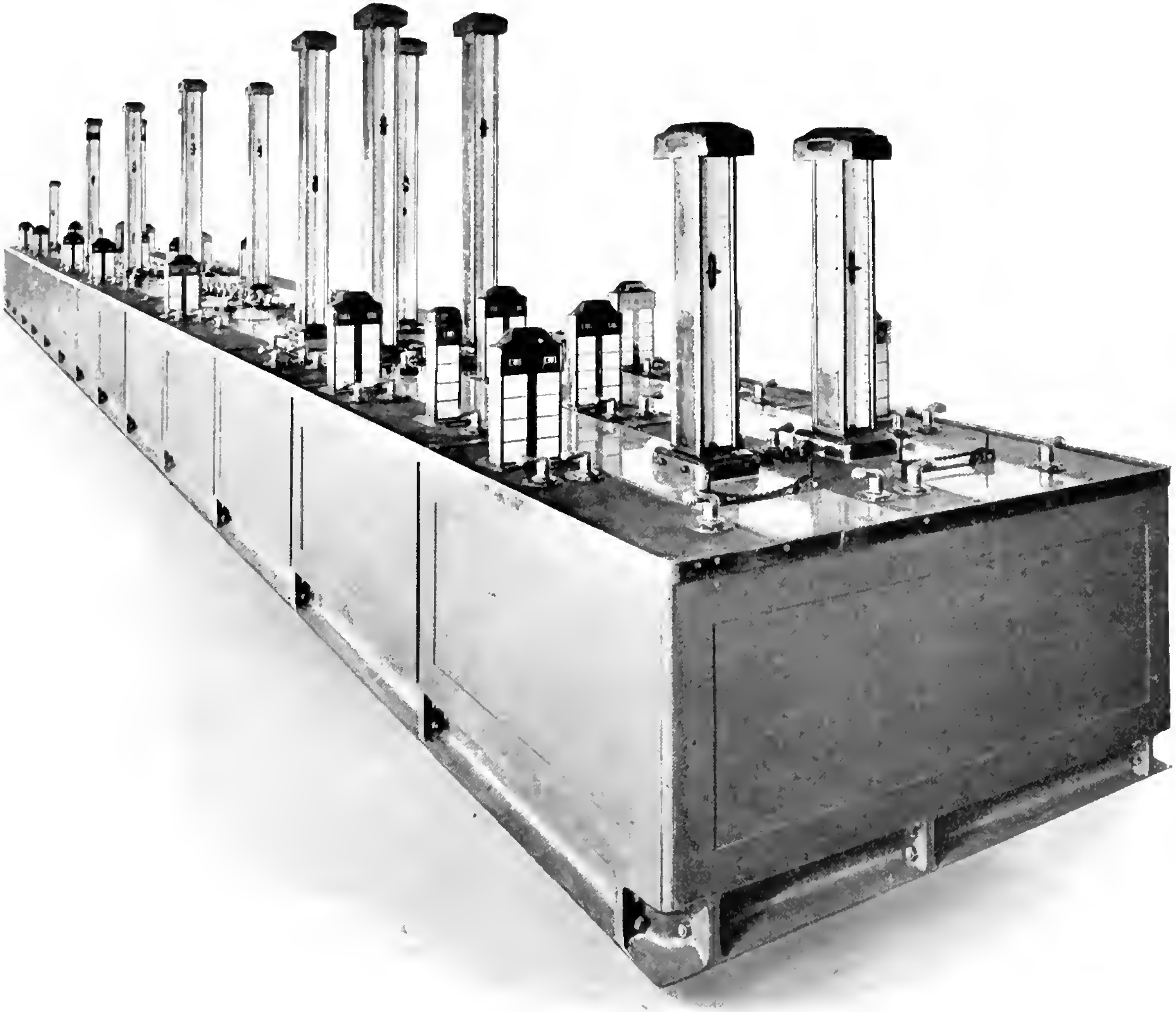
## THE PATHS OF PROGRESS

Considerable space is devoted in this issue to the control features of the Panama Canal. While a great deal has been written on this most notable national undertaking from almost every aspect of the work, we believe little or nothing has been said of this important phase. The undertaking as a whole is the largest of modern engineering undertakings and may prove to have a very far reaching influence on the world's trade so far as the routing of freight is concerned, and as the romantic side, as well as the utilitarian side, has been so thoroughly discussed, our contributions have been confined rather to the technical features of the control apparatus upon which the successful operation of the whole scheme depends.

Mr. Schildhauer, Mechanical and Electrical Engineer, Isthmian Canal Commission, begins his contribution to this issue with a most noteworthy sentence: "The preliminary studies relative to the transmission of power to the required position in the locks showed that the electrical system had decided advantages over hydraulic or air systems." While this statement will not be surprising to those who have followed the trend of modern engineering, it emphasizes the fact that where large forces have to be held under perfect control to render their maximum service and to be as reliable for continuous service as man can make them, electrical control is chosen. Last month we laid stress on the fact that electric energy owed much of its economic value to the ease and cheapness of its transportation, and here we have an excellent example of another of the greatest factors which have led to the extensive adoption of electricity, viz., the ease and the degree of perfection to which it can be controlled. Fire, water and different forms of energy are excellent servants but terrible masters. Whether they are our masters or our servants depend entirely upon the degree of perfection to which we control them.

Mr. W. L. R. Emmet's article on "Power from Mercury Vapor" will undoubtedly attract wide attention. If this process works out as Mr. Emmet predicts, it should prove to be one of the most notable developments since the introduction of the steam engine. The very thought of a new form of prime mover must be fascinating to the scientist and the engineer, and even the speculative chance of such a development maturing into a commercial reality will awaken the interest of the whole engineering world. The results of the experiments that Mr. Emmet is now making will determine the practicability of the combined mercury vapor and steam turbine units, and will decide whether this new development is to take its place in the commercial world. There are many who will view such a radical departure from previous practice with skepticism, but Mr. Emmet's work is based on wide experience in steam turbine practice and on over a year's experimenting with this particular development. The problems involved have been given most careful study, and it would seem that the practical mechanical details are the only things not yet fully matured, as the theoretical over-all efficiency of the combined mercury vapor and steam turbine units can readily be determined.

In our next issue we shall describe the apparatus already built for generating power from mercury vapor, and in the near future we shall hope to give some definite results from the experiments now being carried on and to keep our readers informed of the progress being made in this new development.



Control Board for the Miraflores Locks of the Panama Canal

# AN INSTANCE OF CO-OPERATION

## PANAMA CANAL SWITCHBOARD EQUIPMENT

By J. W. Upp

Manager, Switchboard Department, General Electric Company

Mr. Upp's article is a preface to those that follow in this issue on the Panama work. His story is of special interest as dealing with the human side of this great undertaking—the results obtained in so short a space of time were only made possible by good organization and a splendid spirit of co-operation. This article, coupled with those that follow, ought to give our readers a good idea of this important part of the Panama Canal work, the whole of which is so soon to be completed.—Editor.

The whole world is interested in the Panama Canal as, viewed from any angle, the reasons for the canal itself and the problems relating to its construction have been an absorbing subject. The daily newspapers, the popular magazines and the engineering publications have done their share in keeping our interest alive, and have furnished us with a continuous and ever growing record of accomplishment. The difficulties encountered and the methods of their solution have been so often illustrated and explained that we have all come to feel that keen personal interest that should go with all our great national undertakings. Very little, however, has been written as to the actual means that will be employed to operate the canal after its completion. Thus the collection of articles in this issue of the Review will be of particular value to those who are interested in the plans adopted for the generation and distribution of power and the problems involved in the design and application of the system of "central control" which has been developed and applied to the operation of the lock machinery required for such operation.

Control apparatus was required for thirty-six transformer stations, four substations and one generator station, and for the locks at Gatun, Miraflores and Pedro Miguel. The switchboards for transformer, substations and main stations possess many novel features, but the lock boards for "central control" are of a most unique design. They were to be miniature representations of the locks, chains and gates, and were to provide a ready means of control for operating the machinery of the main apparatus itself; besides indicating every movement and speed of motion of rising stem valves, fender chains and miter gates, and the open or closed positions of cylindrical valves and miter forcing machines. And in addition to this the control switches were to be so interlocked that an improper sequence of operations would be impossible. This part of the work involved upwards of a half million dollars for switchboard material alone.

The specifications for the entire control system were prepared under the supervision of Mr. Edward Schildhauer, electrical and mechanical engineer of the Isthmian Canal Commission, ably assisted by assistant engineers C. B. Larzelere, W. R. McCann, and others, and they will long be used as models of skilled and painstaking engineering where no detail was neglected and every contingency provided for, with all the safeguards that expert engineers could suggest. No specifications could have been more exacting or explicit as to the results to be accomplished, or have given a wider range as to the method of their accomplishment.

After the contract was let, conferences of the Commission's engineers and the manufacturers began, and because there was no previous experience to guide in the selection of designs, these conferences were continued until there was a complete understanding of the requirements, conditions and possible alternatives. These conferences were interwoven with and followed by numerous departmental consultations where factory foremen, designers and engineers were represented. Facilities were discussed and special tools considered. The preliminary plans and models were prepared. These were modified from time to time as no part was considered complete until the model had been critically inspected and tested by the engineers, both of the Commission and the manufacturer, and till all were convinced that the design and operation met every condition which had been foreseen at the time the specifications were written, or which had developed as the details were completed. It was the single aim of all concerned to produce something better, safer and more reliable than anything before undertaken.

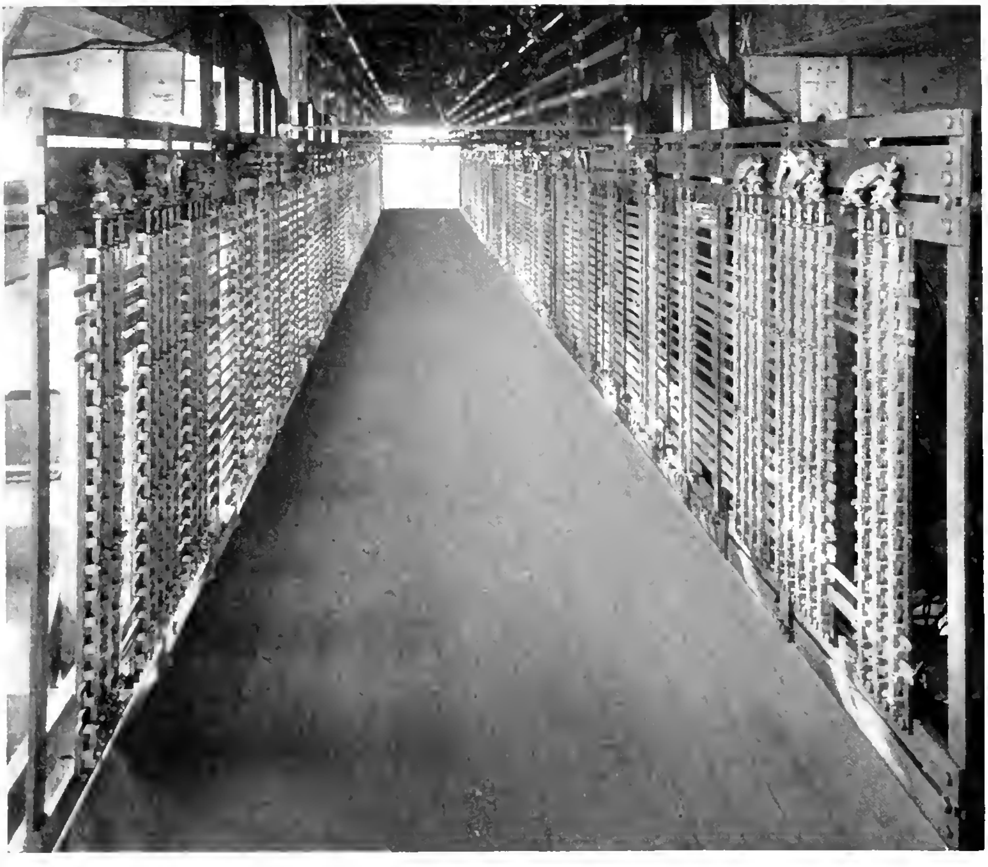
By direct conference with the engineers of the Commission and of the manufacturer, at Panama and at the factory, a co-ordinating engineer settled the thousand and one questions which constantly arose in reference to construction, design and delivery. He arranged for special consultations and tests and relieved the departments of endless worry and complication which would have resulted through long distance correspondence.

A separate manufacturing department was organized when the preliminary designs were well under way, which department, although a part of the general organization, was so arranged that its members would not be hampered by other undertakings. The best men in each section were chosen for the Panama work, and their selection has been justified by the results secured.

The Canal Commission was kept in touch with the progress of manufacture by having resident inspectors at the factory, who checked each piece of apparatus as the work moved onward.

The successful completion of this work is a most important indication of the value of co-operation. The customer and manufacturer understood and had confidence in each other and were kept in touch by frequent conferences. Designing engineers and manufacturing departments were in entire accord and were giving mutual assistance; inspectors were checking and testing at times best suited to the convenience of engineers and factory.

The Miraflores control board is shown on pages 4 and 6, the latter being a view of its intricate interlocking rack. These illustrations are sufficiently convincing to prove that the design of the apparatus which they represent would have taxed the ingenuity of any manufacturing organization or its corps of engineers, and they will be viewed with pardonable pride by everyone who has been connected with their specification, design and manufacture. When the first ship goes through the canal, collectively or as individuals they can say, "We helped to make it possible."



View Under Miraflores Lock Control Board, showing Interlocking Racks

# THE CONTROL OF LOCK MACHINERY ON THE PANAMA CANAL

By Edward Schildhauer

Electrical and Mechanical Engineer of the Isthmian Canal Commission

In this excellent article, which is, we believe, the first authentic account that has been published of the control system employed on the locks of the Panama Canal, the author describes the construction of the locks and the machinery essential to their operation. His descriptions of the culverts and the course taken by the water through them, the arrangement and operation of the gate valves and cylindrical valves and of the mitering gates and fender chains, as well as of a number of minor pieces of apparatus such as the rising and disappearing hand rails for the mitering gates, afford the reader a distinct mental picture of the locks and an understanding of the functions of the different pieces of machinery. The most novel feature of the lock machinery, however, consists of the system of remote control and indication which was specified by the Canal Commission and which governed the design and construction of the wonderful interlocking control boards that are described in detail in succeeding articles in this issue. Mr. Schildhauer's intimate association with every detail in the design of these boards makes that part of his article descriptive of the interlocking between control switches for the different machines of special interest.—Editor.

The preliminary studies relative to the transmission of power to the required position in the locks showed that the electrical system had decided advantages over hydraulic or air systems. This will be readily granted when it is known that the flight of locks at Gatun, for instance, extends over a distance of 6152 feet and the principal operating machines are distributed over a distance of 4115 feet.

From an operating standpoint the machinery was placed below the coping of the lock walls, thus affording a clear space for the maneuvering of ships and for protecting the apparatus from the weather without erecting numerous houses.

To control the machines locally meant a large operating force distributed practically along the full length of the locks, which has invariably been the practice heretofore. Such a force would be difficult to co-ordinate into an efficient operating system. The matter therefore resolved itself to centralized control, which reduces the number of operators, operating expense, and liability to accident. Moreover it fixes responsibility.

Another argument for centralized control is the fact that by having all control switches centralized on one switchboard it permits the various control switches to be interlocked in a manner to minimize, if not entirely prevent, the errors of human manipulations. These interlocks will be fully described later, but for the benefit of those who may not be familiar with the various machines in the lock walls, it will be well to enumerate them with their uses.

Water for filling and emptying the locks is conducted through three culverts, one in the middle wall and one in each side wall. The flow of water in these culverts is controlled by rising stem valves. These are located in the culverts at points opposite each end of each lock so that the culvert can be shut off at any desired point for filling a lock with water from above, or upstream, or for emptying it by allowing it to flow out and down to the next lock. Lateral culverts conduct the water from the main culverts, under the lock chambers, and up through openings in the lock floors. Since there are intermediate mitering lock gates for use in locking through short vessels, when the use of a whole lock of 1000 feet would be wasteful of water, rising stem valves are also located in the side wall culverts at points near these intermediate gates. The rising stem valves are installed in pairs; that is, the culvert is divided into two parallel halves at each valve by a vertical wall, and a valve is placed in each half. This arrangement reduces the necessary size of each valve and makes it more easily operated, although each valve is still 8 feet wide by 18 feet high. It is raised and lowered by a 40 h.p. motor requiring one minute for complete opening or closing.

In addition to these pairs of valves in parallel, each pair is duplicated at each change of level from one lock to the next. Thus if the valves cannot be closed at any point on account of an obstruction in the culvert or accident to the machinery, the duplicate pair can be closed. At the upper ends of the culverts at the side walls the duplication is accomplished by three valves in parallel called the guard valves.

The culvert in the middle wall must serve the locks on both sides, and to control this feature cylindrical valves are placed in the lateral culverts that branch out on each side. There are ten of these on each side of the culvert at each lock.

At the upper end of each set of locks there are two valves in the side wall for regulating the height of water between the upper gate and the upper guard gate, as it will be desired to maintain the level of the water between these gates at an elevation intermediate between that of the lake above and that of the upper lock when the upper lock is not at the same level as the lake. These valves are called the auxiliary culvert valves.

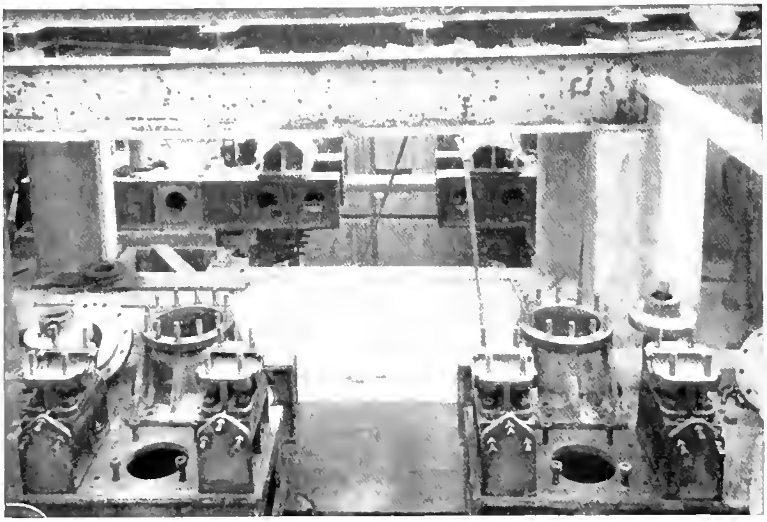


Fig. 1. Miraflores Lower Locks. Rising Stem Gate Valve Machinery Chambers Nos. 442 and 443, West Side Wall. Machinery cleaned preliminary to assembly. July 18, 1913

The mitering gates are opened and closed by a separate motor for each leaf, and the two leaves, when closed in mitered position, are locked together at the top by the miter-forcing machine which is also controlled from the central control house.

Heavy fender chains are stretched across the locks in front of all mitered gates which can be exposed to the upper level and also in front of the guard gates at the lower end. These are maintained in a taut position at all times when the gates behind them are closed, and are lowered when the gates are opened for the passage of a ship. These chains are raised and lowered by a hydraulic cylinder, in a method similar to that followed in hydraulic elevators, with the additional feature that if a ship approaches the gates at a dangerous speed and rams into the chain the chain is paid out from each end with a maximum resistance for gradually stopping a ship before it reaches the gates. Lowering the chain for the legitimate passage of a vessel and raising it again after the vessel has passed are also under the control of the operator at the control house, and each operation of raising or lowering involves the control of two motors; viz. the starting of a large motor driving the main pump supplying water under pressure, and the control of a motor-operated valve which in turn controls the direction of movement of the chain, rising or falling. These two operations are combined in one for the remote control, so that all the operator has to think about is raising or lowering the chain. Each motor is stopped automatically by a limit switch when it has performed its function. This is also true of all motors having remote control, namely, if the operator does not stop a motor when a machine has reached the end of its travel, it is automatically stopped by a limit switch.

On page 9 is a list of motors controlled from the control houses of their respective locks.

Fig. 2. Miraflores Upper Locks, Rising Stem Gate Valve Machine. June 10, 1913

There are many other motors which are not controlled from the control houses, and not included in this list, but their uses should be described briefly before proceeding. One class of these is the hand rail motors. On the top of all mitering gates a foot walk with hand-rails is provided. When the gates are opened and in the recesses provided for them in the lock walls, these hand-rails would interfere with the passing of the towing locomotive, except in the case of the lower guard gates. The hand-rails are therefore made to be raised and lowered. This is done by a motor under the foot walk, controlled from the lock wall. Near the approach to each foot walk a controller is located in the lock wall flush with the surface, this controller being operated by a foot push. If the gates are closed and the hand-rails are down, and a person desires to cross on the gates, he presses the foot push and the hand-rails are raised by their motors. This is true not only of the hand-rails on the nearer gate leaf, but of the hand-rails on the farther leaf as well. After passing across, one can, if he desires, press the foot push on the other side and both hand-rails will be lowered. Or, if he leaves the hand-rails up and the gates are opened by the operator in the control house, they will be automatically lowered so as to be out of the way when the gate is in the recess. When the gates are again closed the hand-rails will automatically rise again if the foot controller has been operated in the meantime. The control of the hand-rails is accomplished by means of the foot controller, a contactor panel in the machinery chamber in the lock wall, and another switch geared to the gate moving machinery which operates the control circuit to produce the automatic lowering and raising when the gates are opened or closed. This geared switch also provides that the hand-rails cannot be raised when the gates are opened, and that no harm

Fig. 3. Miraflores Lower Locks. Rising Stem Gate Valve Machinery Chamber Nos. 442 and 443, West Side Wall All anchor bolts set in concrete with bulkhead frame, guide rails, screws, bearings, wall brackets and subbase in place. July 18, 1913

| Machines and Operation | Motors each Machine and H P. | NUMBER OF MOTORS<br>Gatun | Pedro Miguel | Mira-flores | Total | Total Horse Power |
|---|---|---|---|---|---|---|
| Miter gate, moving, each leaf | 1–25 | 40 | 24 | 28 | 92 | 2300 |
| Miter gate, miter forcing | 1–7 | 20 | 12 | 14 | 46 | 322 |
| Fender chain, main pump | 1–70 | 16 | 16 | 16 | 48 | 3360 |
| Fender chain, operating valve | 1–½ | 16 | 16 | 16 | 48 | 24 |
| Rising stem gate valve | 1–40 | 56 | 24 | 36 | 116 | 4640 |
| Cylindrical valve | 1–7 | 60 | 20 | 40 | 120 | 840 |
| Guard valve | 1–25 | 6 | 6 | 6 | 18 | 450 |
| Auxiliary culvert valve | 1–7 | 4 | 4 | 4 | 12 | 84 |
| Totals | | 218 | 122 | 160 | 500 | 12020 |

results if the foot switch is operated while the gates are in the opened position. Thus it is seen that the hand-rails are provided with remote control, although they are not controlled from the control house.

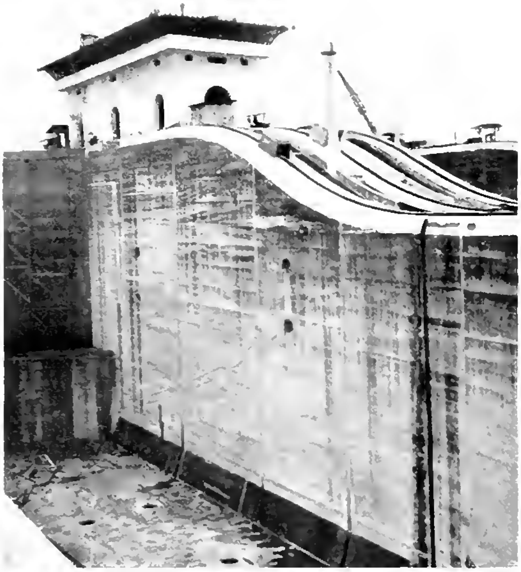


Fig. 4. Control House for Center Wall. Upper Locks at Gatun. Towing track incline between upper and intermediate locks. July 22, 1913

The spillway gates also have remote control, but these gates are entirely separate from the locks, and their control is from a separate and much smaller control board. There are also many motors driving drainage pumps, operated by float switches and starting panels, but these are standard equipment and of no special interest.

The control house is located on the middle wall at a point which affords the best view of the whole lock site, although this view is not depended upon to know the position of the gates or other apparatus, as all are provided with indicators on the control board. At Gatun the control house is located at the lower end of the upper lock, giving a view of the upper locks upstream from the control house and a view of the two lower flights in a downstream direction. At Miraflores the location is the same, that is, at the lower end of the upper pair of locks; but there are only one pair of duplicate locks downstream from the control house, the same as upstream. At Pedro Miguel the control house is at the lower end of the one pair of locks, as this position affords a view of the lower approach wall and at the same time gives the same view of the locks themselves as is obtained for the upper locks in the other cases.

The motors are started and controlled by contactor panels located near them, the contactors of which handle the main motor currents. These contactors are controlled from the control house. The smaller motors, including those for cylindrical valves, auxiliary culvert valves and miter forcing, are started by being thrown directly on the line. Two double pole contactors are used, one for forward and one for reverse. In the case of larger motors for miter gate moving, rising stem valves and guard valves, a starting point with resistance in two legs of the three-phase circuit is provided.

In all cases the contactors are operated from the control house by three wires, one for forward, one for reverse and a common return. In the case of panels having a starting point the period during which the motor remains on the resistance is automatically controlled by a dashpot, so that the starting operation at the control house is the same—

Fig. 5 Gatun Upper Locks. Miter Gate Moving Machine; Structural Steel Girders for towing locomotive track supports in foreground. June, 1912

simply energizing a forward or reverse wire as the case may be.

Indicators are used for all machines to show the operator in the control house the position of each machine at all times. In the case of certain machines, the operation of a motor lasts only a few seconds and the indication of their positions is given by the simple means of red and green lights. Such machines are the cylindrical valves, auxiliary culvert valves, and miter forcing machines. It is never expected in normal operation to stop these machines at an intermediate point in their travel, and only the completed operation is indicated by the red and green lights.

Fig. 6. Miraflores Lower Locks. Miter Gate Moving Machine No. 127. Machine installed complete except short arm and anchor casting on gate leaf. Installation of structural steel in decking commenced. June 20, 1913

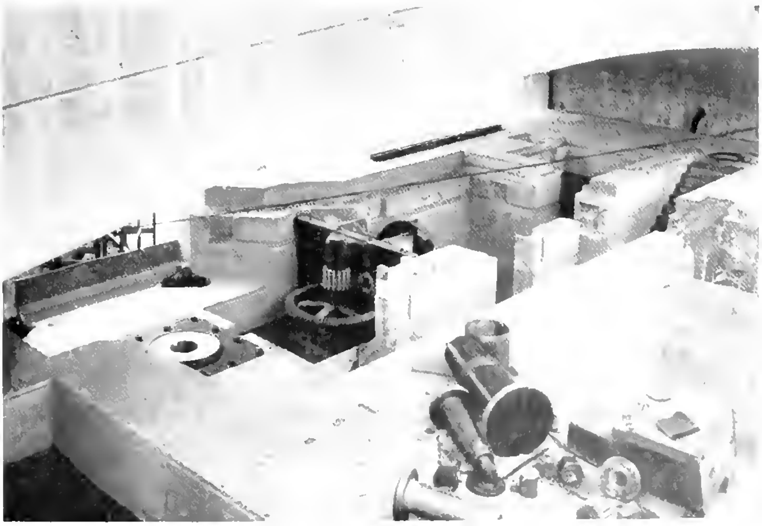


Fig. 7. Miraflores Lower Locks. Miter Gate Moving Machine No. 127, showing center pinplate bulkhead, vertical shaft, 72 in. bevel gear and 64 in. spring center gear in place. West wall, south end. May 11, 1913

For machines of more extended operation which may be stopped at intermediate points of travel, synchronous indicators are used which show at all times the position of the machine, whether in the extremes of travel or at an intermediate point. A complete synchronous indicator consists of a transmitter at the machine in the lock wall and a receiver, or indicator, at the switchboard in the control house. An indicator and a receiver are exactly similar and each consists essentially of a revolving bipolar field or rotor, supplied with alternating current from the same source for excitation. Surrounding each rotor is a stator having a distributed winding similar to that of an induction motor. From three equi-distant points of this winding of a transmitter leads run to three similar points on the winding of the receivers. The alternating current in the rotor of the transmitter (which may be considered stationary for the present), induces currents in the three wires from the stator, the relative values of these currents in the three wires depending upon the position of the field. These currents produce a magnetic flux in the receiver which draws its rotor (free to revolve in this case) into the same angular position as the field of the transmitter. Thus as the transmitter revolves the receiver revolves with it, keeping the same angular position with a very small error. In the case of the transmitter, the rotor is geared to the machine the position of which it is desired to indicate. In the case of the receiver the rotor is geared to a pointer or small model of the machine, or to some other indicating device which it drives. This is the only important difference between a transmitter and a receiver, or indicator.


Fig. 8. Gatun Spillway Gate. One complete gate with operating mechanism. Looking downstream, with gate partly open. July 15, 1913

Synchronous indicators are provided for miter gate moving machines, rising stem valves, guard valves, fender chains, and for water level indication.

The control boards are of a flat top bench board type. Each board is 32 inches high by 54 inches wide. The lengths for the three different boards are as follows:

| | |
|---|---|
| Gatun | 64 feet |
| Pedro Miguel | 36 feet |
| Miraflores | 52 feet |

The handles of the various control switches are above the surface of each board; while the switch, which is of a rotary type, has its contacts beneath the board and is wired from below. In a similar manner the indicators are mounted with the greater part of their mechanism beneath the board, but with the scales and pointers above the board. The visible portions of these indicators are of different forms in order to best indicate their respective machines. The miter gate indicator is nearly flush with the board and consists of a pointer swinging in a horizontal plane and resembling the plan view of a miter gate leaf. All these switches and indicators are located as nearly as possible in the same relative positions occupied by the machines to which they apply. While the board is essentially a control board with indicators, it is made to resemble in a measure a plan view of the locks.

The space immediately below the flat top of the board is occupied by the switch contacts, indicator motors, and connections. Vertical shafts operated by connecting rods from the control switch shafts extend downward past the electrical parts for the operation of the interlocks. These interlocks are in two vertical racks under each edge of the board and some distance below, so that they may be inspected and oiled from a floor which is about seven feet below the floor on which the switchboard stands. The latter floor does not extend across under the board, this space being open so that all parts on the underside of the board are accessible from the floor below. The numerous cables to the control switches and indicators also come to the board from below. Connection boards are provided for the cables, which are led up to them from each side, as are busses for supplying current to the control switches,


Fig. 9. The Gatun Spillway Machinery Tunnel

indicators, and the lamps that illuminate the dials of indicators. The indicators, transmitters and lamps are operated at 110 volts, while the control switches are designed for 220 volts, both circuits supplying 25 cycle alternating current.

In general the two interlock racks contain the necessary interlocks for the switches on their respective sides of the center line of the board; but where interlocking is required between switches on different sides it is accomplished by the aid of cross connecting rods and cranks. The following is a schedule of the interlocking accomplished:

### Fender Chains and Miter Gates

The fender chains are operated from each end by independent machines. The control of each end is interlocked with the control of the miter gate leaf on its side of the lock, so that the chain cannot be lowered until the control switch of the miter gate leaf has been thrown to the opening position. The miter gate cannot be closed again until the control of the fender chain has been thrown to the raising position. In this way the assurance is obtained that the fender chain will always be in the up position to protect the gate when the gate is closed. In order to avoid unnecessary complication, each end of the chain is not interlocked with both gate leaves, but with the leaf on its side of the lock only. As a rule both leaves of a miter gate, as well as both ends of a fender chain, will be operated simultaneously and further interlocking is unnecessary.

### Miter Gates and Miter-Forcing Machine

Each leaf of a miter gate is interlocked with the miter-forcing machine, which locks the leaves together at the top when in the closed position. This interlock is arranged so that the operator must unlock the miter-forcing machine before he opens the gate. Also the miter-forcing machine cannot be closed until the gates are closed.

An electrical interlock is also provided in this case, requiring the gates to be fully closed before the miter-forcing machine can be started in the closing direction, inasmuch as it is important that the first operation be completed before the next operation starts.

### Rising Stem Valves Interlocked With Each Other

Consider, for example, a side wall culvert at Gatun with its principal rising stem valves at each change of level from one lock to the next: The control of these valves is interlocked so that if the valves are opened at one particular point, the valves a lock length upstream or downstream cannot be opened. Thus the operator is limited to equalizing the water between locks and cannot allow water to flow from the upper lock past the middle lock into the lower lock, which operation, if permitted, might flood the lower lock walls and the machinery chambers in them. All rising stem valves occur in pairs side by side, each member of a pair controlling half the opening of the culvert. They may therefore be referred to as pairs. At all points where there is a change of level from one lock to the next, these pairs of valves are further duplicated by a pair in series a short distance away. In regular operation one pair can be left open as a guard pair, and the other pair will, for the time being, be the operating pair and will control the flow of water. Each of the four valves of such a group has independent control. Their control switches are interlocked so that either pair may be opened and left open as guard valves, and the interlocks become effective when the operator tries to open the first valve of the second pair. Either pair may be opened first, at the choice of the operator, the interlock becoming effective when the first valve of the second pair of duplicates is opened. This is done by a system of equalizing levers acting against the ends of the interlock bars, with a certain definite amount of lost motion which is taken up on opening the first pair of valves, thus putting the interlocks in operation on the next pair.

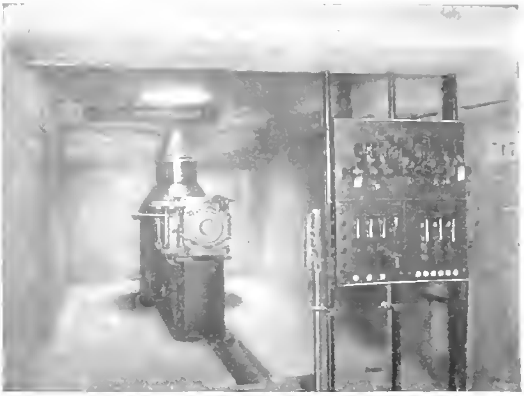


Fig. 10. Cylindrical Valve Machine and Control Panel for Middle Wall, Upper Lock at Miraflores. Chamber walls, floor, and panel partially completed. June 20, 1913

At the upper end of each lock, three guard valves take the place of the duplicate rising stem valves. These perform service exactly similar to the rising stem valves and are similarly interlocked, except that three valves in parallel in this case must conform to the same laws as the two in parallel in the other cases. If necessary to clear the interlocks at one pair of valves in order to open another pair a lock length away, both members of the pair must be closed to accomplish it, and all three must be closed in the case of the guard valves.

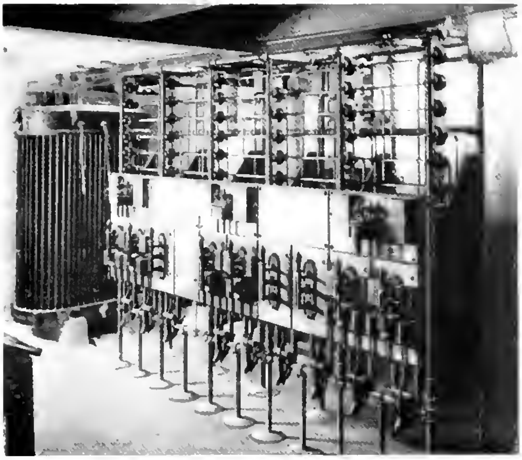


Fig. 11. High Tension Oil Switch Group, Transformer Room Equipment, Pedro Miguel. July 17, 1913

The same interlocking is effected between the successive valves of the middle wall culverts as between those of the side wall.

### Rising Stem Valves "Diagonal" Interlocking

By diagonal interlocking is meant that interlocking which is done between the rising stem valves of the side wall and those of the middle wall a lock length away. The result is interlocking between valves diagonally across a lock when the cylindrical valves are open, this being needed to prevent the flow of water from, say the upper lock by way of a side wall culvert to the middle lock, thence by way of the middle wall culvert to the lower lock, thus allowing an operator through carelessness to flood the lower lock walls. If the cylindrical valves of a certain lock are closed, then this interlock is not needed on rising stem valves of that lock; and furthermore, its existence would interfere with the proper use of the valves of its twin lock on the other side of the middle wall. For this reason this interlock is automatically removed when all ten cylindrical valves are closed on the particular lock in question, and is automatically applied again if one or more of the ten cylindrical valves are opened.

### Rising Stem Valves With Cylindrical Valves

In the use of the middle wall culvert, the cylindrical valves on one side or the other must be opened before the rising stem valves can be opened, and the rising stem valves must be closed first. This interlock is applied in order to require the operator to control the flow of water by means of the rising stem valves rather than the cylindrical valves. The latter perform a complete operation of opening and closing in about ten seconds, and their use in regulating the flows might cause dangerous surging.

Here, as in all other cases of interlocking on rising stem valves, one pair of duplicates may be left open as guard valves, the other pair used as operating valves being subject to interlocking.

The locks in most cases are divided into two parts by the intermediate miter gates. This arrangement divides the ten cylindrical valves into two groups of seven and three, respectively, for the long and short lengths. A selecting lever is provided for the foregoing interlocks, which may be set on "three," "seven," or "ten," respectively; whereupon the corresponding valves are subject to that interlock, and the others of the group of ten are locked closed if three or seven only are to be used. The failure of the operator to make his selection properly in advance will only cause him the trouble of going back and doing so, as the remaining valves are locked closed.

### Interlocks on Cylindrical Valves

The groups of cylindrical valves on opposite sides of the middle wall culvert are interlocked with each other, so that if any valves are opened on one side, all must be closed on the other. This is to prevent careless cross filling between the locks, which operation might be combined with the regular method and produce flooding. However, there may be times when it is desirable to employ cross filling to economize in the use of water from Lake Gatun in the dry season. For this reason this interlock is made removable by the use of a lock and key. The key will be placed in the hands of the chief operator.

### Rising Stem Valves of Side Wall and Miter-Forcing Machine

Interlocks are placed on the control switches of these machines so that the rising stem valves of the side wall, next above or below a miter gate, must be closed while the miter-forcing machine is open. As the miter-forcing machine cannot be closed until the gates are closed, this means that the valves either above or below the gate must remain closed until the gate itself is closed, thus preventing the operator from creating a current of water around the gates while they are open, or being moved in opening or closing. This interlock is not included on the middle wall valves for the reason that they will be used with the locks on either side and must be free for that purpose. Furthermore, the valves of the side wall immediately at the gate which is being moved will be open to equalize water level, and the diagonal interlocking previously described will prevent the opening of the middle wall valves a lock length above or below the gate being moved.

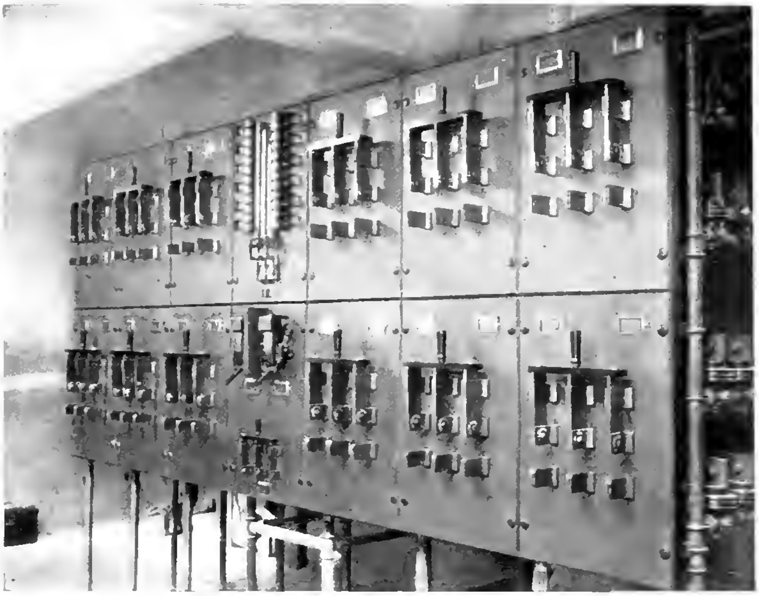


Fig. 12. Low Tension Switchboard, Transformer Room Equipment, Miraflores Lower Lock. July 17, 1913

This interlock between valves and miter-forcing machine is included on the intermediate gates, but is removable by means of a lock and key, because during the passage of large ships these gates must be left open and the valves operated independently of them. This interlock is not applied to the miter-forcing machine of the lower guard gates for the reason that these gates open toward the sea.

There are intermediate rising stem valves in the side walls at each intermediate gate, but no interlocks are applied to these for the reason that they will be used in a more or less irregular manner, and no fixed laws for their operation can be laid down in advance. Moreover, they do not control the water between different lock levels, but only between different sections of the same lock, and there is not the danger from mistakes in operation which exists in the case of the other valves between lock levels. The same is true of the small auxiliary culvert valves, by means of which the space between the upper guard gate and upper main gate is filled and emptied.

The water level indicator has an important bearing on the rate at which the lockage of a ship may be accomplished. It is proposed to limit the filling of the locks to a rate of three feet per minute, which rate may be observed on the indicator. When the water levels between two locks are very nearly equalized, the rate of equalization is slow; it is therefore very important for expeditious lockage that the operation of the lock gates be accomplished just as soon as the water levels above and below the pair of gates are equal. The water level indicators will show these levels to an accuracy of one-twentieth of a foot.

The control connections are arranged in such a manner that each individual machine may be controlled locally. This arrangement provides for emergency operation should the control circuits from the control house be out of order.

The local control was used on September 26th when the first vessel, the tug "Gatun," was passed through the locks at Gatun from the Atlantic Ocean to Gatun lake, and on the following day on its return trip.

# CENTRALIZED CONTROL SYSTEM AND POWER STATION SWITCHBOARDS FOR THE PANAMA CANAL

By E. M. Hewlett

Engineer, Switchboard Department, General Electric Company

The author shows some of the engineering features of this particularly interesting control mechanism. He takes us step by step through the sequence of operations necessary to lock a ship through the canal and brings out some of the most interesting conditions that have to be fulfilled to achieve the results accomplished. This general article will help to a thorough understanding of some of the details that follow.—Editor.

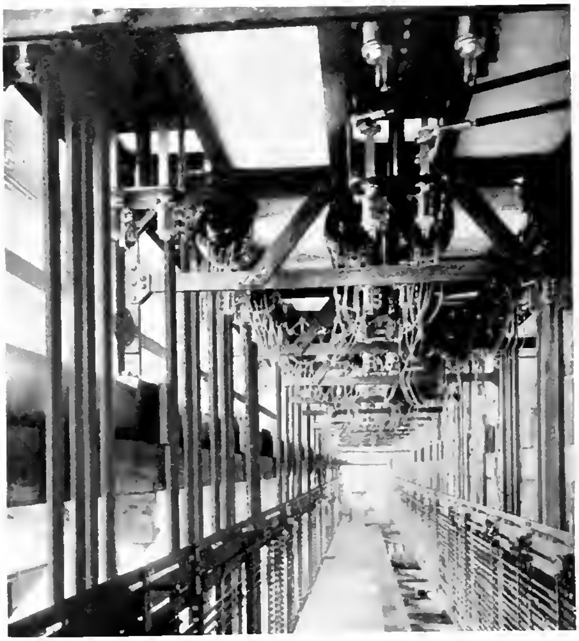
The engineering principles involved in designing and producing the apparatus to control the operation of the locks of the Panama Canal, as well as to give the operator a visual indication of the position of fender chains, gates, valves and other machinery, have necessitated the employment of much creative ability and constructive skill. In bringing this matter to a successful conclusion, it was necessary to carefully weigh and consider numerous problems which had never arisen before.

The importance of meeting in the best possible manner the requirements as laid down by the Isthmian Canal Commission is so obvious as not to require comment. It might be said, however, that these conditions were unusually severe and in many cases highly special.

In the ordinary power scheme of any great size, there exists as a rule the necessity of producing one or more special devices to meet the situation. But such devices are generally to a large extent subsidiary to the main proposition. In the Panama work, such was not the case. Practically every detail in connection with the control boards for the Gatun, Miraflores and Pedro Miguel locks was absolutely new and required special treatment. The switchboards for the distribution of power were also unusual in several respects and came in for their share of careful thought and effort.

It will not be the object of this article to go into much detail concerning the electrical apparatus that has been provided for the canal. In general it may be said that the Isthmian Canal Commission specified what it wished to have accomplished for the lock control and that they, in collaboration with the engineers of the manufacturer, devised the means.

The Commission engineers specified that the lock control boards should be as nearly as possible an operating miniature of the locks themselves, and so arranged that the indicating devices on the control boards would show the positions of the rising stem, and other valves, lock gates, and the water level as it changed in the various locks and in the forebay. It was also specified that in order to pass a vessel through any lock it should be necessary for the control board operator always to maneuver the different operating levers in a definite order corresponding to the pre-determined sequence of operation of the lock machinery necessary to pass the vessel quickly and safely through, and that the operator in control of the east bound channel of the canal must not in any way be able to interfere with the apparatus under the jurisdiction of the operator controlling the west bound channel.



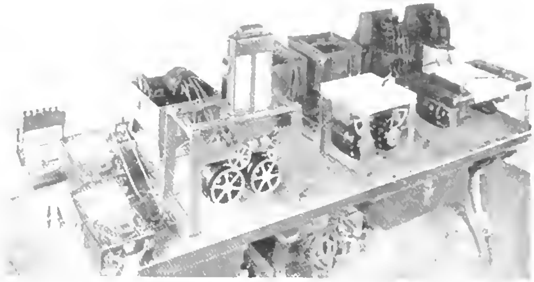
View under Gatun Control Board Showing Control Switches, Position Indicators and Connecting Rods

The imposed conditions have been fully cared for. Each lock control board will indicate to its operator the actual position of the level of the water and of the lock machinery at any instant. Also by a system of horizontal and vertical interlocking bars beneath the control board the control handles are so interlocked that only the proper handle or handles can be operated at any time in the course of a ship's travel through the locks.

The interlocking system forces the attendant to operate the chain fenders, gates and valves always in the proper sequence, and also prevents him from operating these devices in incorrect sequence; for instance, opening a gate when the chain fender is not in position or when the valves are open, etc. There is also an interlocking combination that is used in connection with the intermediate gates which divide the locks into short sections. This arrangement is fitted with a Yale lock and key so that the intermediate gates can be used only when the attendant has unlocked the combination, this also being subject to the general interlocking system. Certain valves are used to cross fill between locks. These also are interlocked so that they can be operated only in proper order and combination to equalize the water between a pair of locks and save water which would otherwise be wasted. This cross filling consists in allowing water from one lock which is full to flow into a lock by its side in the other channel until the level of the water is the same in both locks, thus using a portion of the water over again.

The fact that the control board is a working miniature of the lock which it operates shows the operator the actual condition of gates, height of water, etc., and, consequently, having the whole condition in miniature under his eye he knows what to do next and when to do it; the operator receiving his information as to the movement of the vessel from a towing master. The engineers on the locomotives which take the vessels through the locks, as well as the towing master, can see the position of the gates, but the position of the fender chains are indicated by semaphore arms on the lock walls.

Now let us take a vessel through a set of locks: It proceeds into the lock forebay either under its own power or that of a tug, and comes to a full stop. It will then proceed under the power and control of four electric locomotives two forward to take it along, one on each side, and two others astern, one on each side, to keep the vessel in the middle of the waterway and to stop it when it has reached the proper point, and to prevent it from moving forward too rapidly.



Testing Arrangement for Rising Stem, Chain Fender and Miter Gate Indicators and Transmitters

After the vessel comes to a full stop in the forebay its position is given by the towing master to the switchboard attendant who, by moving a control switch lever, causes the lowering of the fender chain and the miniature fender chain on the control board after the lock gate is in the proper position. The fender chain is stretched across the canal to prevent the vessel from striking the gates if for some reason it should get beyond control. In such an event the fender chain brings the vessel to a full stop.

Now the vessel advances into the lock by means of the electric locomotives. The fender chain is raised and then the massive gates are shut behind, the miniature control board gates in the meantime indicating this movement. When the water on opposite sides of the gates in front of the vessel has been raised or lowered, as the case may be, until the water on both sides is at the same level, as shown on the water level indicators on the control board, these gates are opened and the boat is pulled into the next compartment, and so on.

To assist in performing the necessary locking operations, several kinds of position indicators all working on the same principle and geared to the different pieces of machinery and to the different indicating devices in a suitable way to transmit the signals (or give positions), are employed. The operator is also notified by the towing master of the position of the vessel.

Turning now to the development and distribution of electric power used in connection with the Canal Zone: deviations from standard practice were made necessary because of the extraordinary care required to insure continuity of service and to guard against the rapid deterioration caused by the severe climatic conditions prevalent on the Isthmus. Switchboard fittings, operating coils, etc., could not be used as usually furnished. They had to be made proof against rapid deterioration by the application or impregnation of non-hygroscopic material.

It might be asked: "Why was electricity chosen to operate the Panama Canal locks? Why not water, steam or air?" This is answered by saying that only by the use of electricity would it have been possible to control a set of locks from a central point at each flight of locks, and at the same time to arrange the miniature indicating devices in such a way as to be at all times under the control and observation of the attendant. By the use of electricity it is possible to make a combined control and indicating board, and in no other way could a simple, practicable method of remote operation and indication have been devised, particularly since in some cases the distance between the controlling devices and the operating machinery is greater than 2500 feet.

Another problem was to make the indicating devices as simple as possible and free from a multiplicity of parts which would be likely to get out of order. Appliances with commutators, multiple contacts or ratchet mechanisms were not suitable because of the large numbers of contacts, wires and small pieces in their construction, and also because such devices move step by step and would not continuously register all points of the movements of the main machinery, the indications being only more or less approximately correct according to the number of steps in the indicators.

The solution of this problem is found in the indicating devices now on the Panama control boards, which were developed especially for this undertaking. They are known as position indicators, and, where used in connection with lock machines or water level devices, indicate accurately and continuously every movement.

These remote control devices, which indicate in miniature the position on the switchboard of the water level and the heavier machinery at the locks, are sturdy and simple structures, and consist of pairs of a novel type of galvanometer having a three-phase stator and a single-phase rotor, connected together.

One of the galvanometers is used as a transmitter and is geared to the heavy machinery, the movement of which it indicates, the other galvanometer being used as a receiver and geared to the miniature indicating device on the control board. The three-phase stators are connected in multiple; as are also the single-phase rotors, the latter being excited from a single-phase circuit. The only moving connections in these machines are the two silver collector rings and brushes required for each transmitter and receiver. The heavy machinery whose movement is to be indicated drives the transmitter, and the receiver (through the electrical connections) follows the movement of the transmitter and makes the indicator follow and show the position on the control board of the main device at the lock. The distance over which some of the transmitters operate is more than 2500 feet, but the indications could easily be given over a much greater distance if required.

In some cases it is not necessary to indicate intermediate positions of movement, and here the indications of the open or closed positions are taken care of simply by red and green lamps in the usual manner.

It was of course necessary to assemble and test the several control boards for the various locks and then to take them apart and ship them to Panama where they were re-assembled. To accomplish this with the least trouble the boards were made in sections so arranged that the minimum number of adjustments and parts would be disturbed or removed. The top parts of the boards were made in four foot sections and the interlocking portions in eight foot panels, these being the lengths of units best suited to shipment. This arrangement necessitated very careful work in the layout to establish the dividing lines between parts that could be disconnected at the factory and reconnected at Panama with little trouble.

# LOCK CONTROL BOARDS AND INTERLOCKING SYSTEM FOR THE PANAMA CANAL

By C. H. Hill and C. T. Hentschel

Switchboard Engineering Department, General Electric Company

This article constitutes a description in detail of the control boards that have been built for operating the machinery of the great locks at Panama. The large motors that perform the functions of opening and closing the mitering gates and the many valves that regulate the flow of water are all controlled from this board, as are also many other motors, such as those for the miter-forcing machines, fender chains, etc. Every movement of the mitering gates, fender chains, and rising stem valves is shown by miniature devices in imitation of the respective parts of the lock machinery; while the water level is indicated with great accuracy on vertical scales. The system of interlocking employed between control switches is discussed and illustrated in a very thorough manner, and the reader should have no difficulty in acquiring a complete understanding of the operation of the board.—Editor.

To centralize the control of the large number of machines at any one of the great locks of the Panama Canal, to indicate accurately and at all times the position of this machinery, and to so interlock the control switches that all chance of error in operation is eliminated, presented to the designers of the control boards many problems which were both interesting and difficult.

It is the purpose of this article to describe in some detail the various features of the control boards. There are three such boards, one for the lock at Gatun, one for the lock at Pedro Miguel, and one for the lock at Miraflores. As the board for the Gatun lock is the largest and its design and construction involved all problems incurred, it will be used as a basis for description.

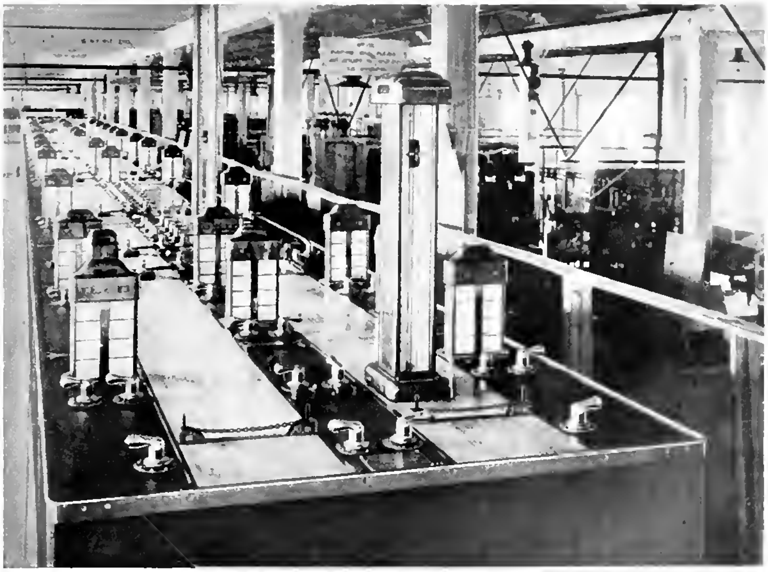


Fig. 1. Control Board for Gatun Lock

It is assumed that the reader, through some of the other articles in this issue, is familiar to some extent with the lock machinery and its use. Therefore, no attempt will be made to describe it here.

### Plan and Construction

The top of the control board (Fig. 1) is, in miniature, a plan of the lock it controls, and the indicating and controlling apparatus located thereon bear relatively the same positions with respect to each other as do the large machines on the locks themselves. The side and center walls of the lock are represented by cast iron plates having neatly matted surfaces with raised edges. Bosses are provided on which are located the various indicators and control switches, and the water is simulated by blue Vermont marble slabs between the metal plates. The outer edge of the board is surrounded by a brass trim rail, which gives a finished appearance, and the sides are enclosed with steel panels which can be readily removed for inspection. The board is supported by a wrought iron framework resting on base castings, which are in turn supported on the operating floor of the control house. Seven feet nine inches below the operating floor is located another floor, these two floors forming a compartment for the interlock racks which are mounted directly in line with the sides of the board above. (Fig. 2.) Back of the interlock racks a space is provided for bringing in and distributing the cables which run from the lock machinery to the control switches and indicating devices. The space between the two divisions of the interlock rack allows easy access to the interlocks and to the various apparatus located underneath the control board. In this space is also provided supports for the busbars, the end bells for the incoming cables, and the fuses for the various circuits.

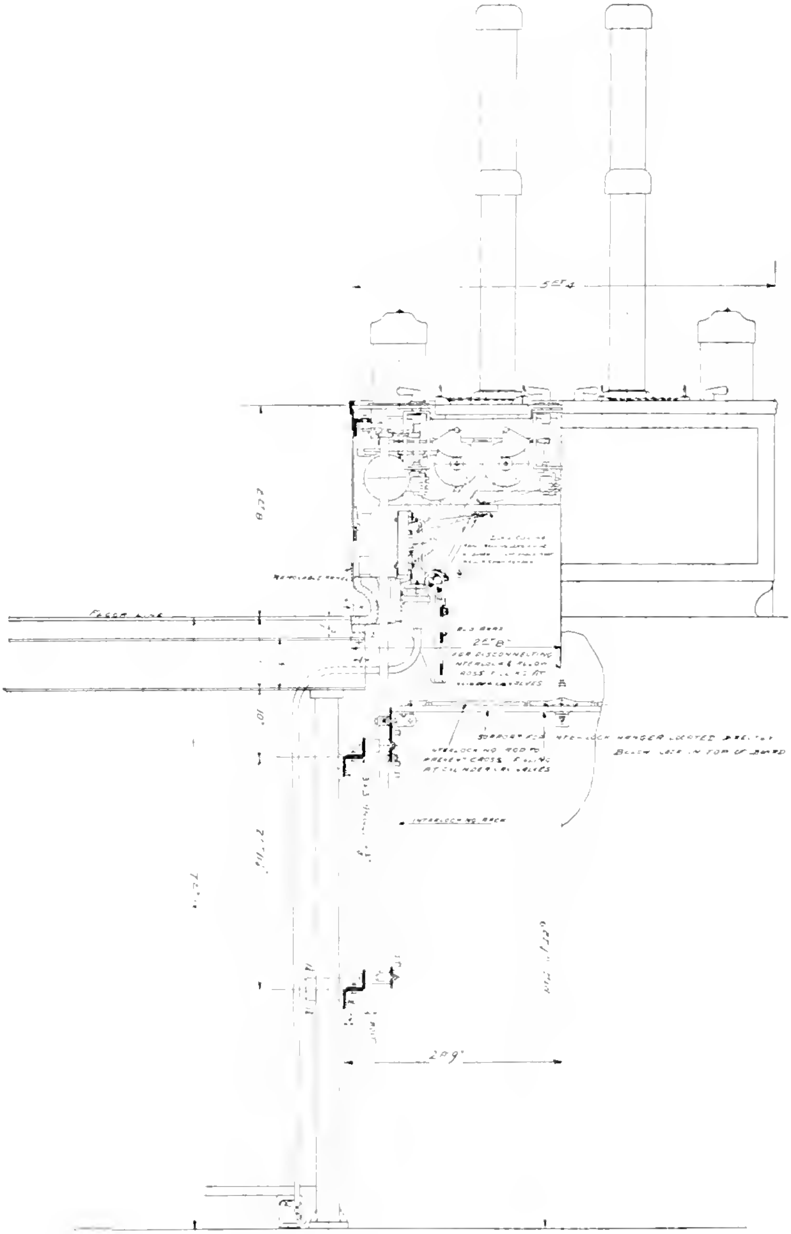


Fig. 2. Section of Lock Control Board

### Indicators

In designing the indicators, efforts were made to represent the actual machines, the operations of which were to be indicated. This was not a difficult matter in the case of the chain fender or the miter gate indicators. The rising stem valve indicators, however, were more of a problem because the valves themselves are located in a culvert and the operating machinery is below the lock wall; yet for the purpose of observation it was necessary to have the indicators project above the surface of the board. To indicate the level of the water, there being no machine to represent, it was necessary to design a gauge which would, like the rising stem valve index, project above the surface of the board.

### Chain Fender Index

The chain fender index, Fig. 3, consists of a small aluminum chain in representation of the large chain, and just as the large chain is lowered into a slot in the bottom of the lock, so the small chain is lowered into a slot in the top of the board. The ends of the miniature chain are fastened to semaphore arms, which are connected by means of adjustable links to arms on segmental gears which mesh with the driving gears on the receiver machines described in other articles in this issue Like the large chain, each end of the index chain operates independent of the other. The distance the large chain has been raised or lowered is judged by that part of the angle through which the semaphore arm on the index has moved, either from the horizontal or the vertical as the case may be. In the different locations on the lock the chain is lifted through varying heights, and in order to allow for this and to make it possible to use one design of index for all positions, the adjustable links mentioned above are provided.

### Miter Gate Index

The miter gate index, Fig. 4, comprises a pair of aluminum leaves or pointers representing a pair of the large miter gates, the leaves being shaped to correspond to the plan view of the top of the gate. The leaves move in a horizontal plane just above the marble slab which represents the water in the lock. The pivot ends are fastened to shafts extending down through the surface of the board, on the under side of which they are geared to the receivers by means of bevel gears (Fig. 5). The shafts are located in the side and center wall castings, and the leaves revolve back over these castings while the gates are traveling to the open position, and when completely opened are covered by shields to give the effect of the gates folding back into recesses in the lock walls. Each leaf operates independently, as does each of the large miter gates.

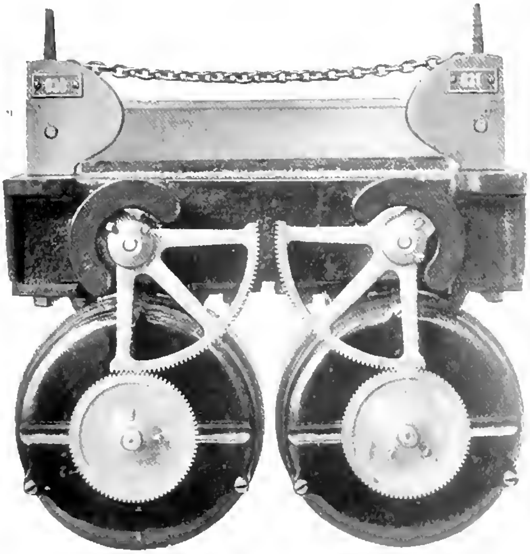


Fig. 3. Chain Fender Index

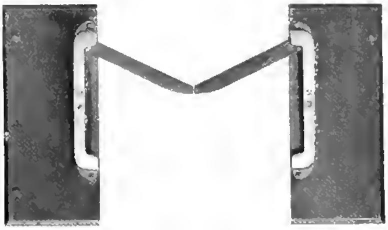


Fig. 4. Miter Gate Index

### Rising Stem Gate Valve Index

As is perhaps already understood, rising stem gate valves usually occur in pairs, and for that reason the indexes for these valves have likewise been made in pairs. These indicators might well be likened to a miniature elevator (Fig. 5), the car being used to indicate the position of the valve gate. The drum for operating the cord which raises and lowers the car is located underneath the board, and is operated by a receiver machine to which the drum is connected through a suitable train of gears. One end of the cord or cable is fastened to the top of the car, the other end being run over an idler at the top of the index and down through the side frame and around the drum to the lower side of the car. This end of the cord is then fastened to a spring, which is in turn fastened to the lower end of the car. The spring keeps a certain tension on the operating cord at all times. Great care had to be exercised in the construction of all bearings so that the cars could be moved with the minimum amount of friction in order that any error due to a lag caused by friction would be eliminated.

Fig. 5. Miter Gate Index

To have the indication visible from various points up and down the board, a novel scheme was resorted to. The under side of the car is equipped with reflectors so arranged as to reflect, parallel to the surface of the board, the light of several incandescent lamps located underneath the board. This light is reflected through openings in the index facing both up and down the board, the openings being closed with opal glass. The reflected light gives a sharp shadow of the bottom edge of the car, all portions of the index above this line being dark and all portions below being illuminated. The illuminated portion shows how far the gate of the valve is open. If the index is dark, the valve is entirely closed; likewise, if the index is illuminated, the valve is entirely open. The one-quarter, one-half and three-quarter positions of the gate are indicated by heavy black lines on the glass. The receivers for all the indicators described above are operated through an angle of approximately one hundred and seventy-eight degrees, as this was found to give the indication within the required accuracy.

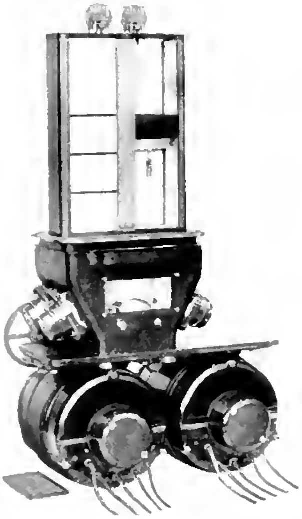


Fig. 6. Open View of Rising Stem Valve Index, Showing Transmissions, Shutter and Illuminating Lamps

### Water Level Indexes

In making up the water level indicator (Fig. 7), however, a much greater accuracy was required. It was found that if the receivers were revolved through not more than one hundred and seventy eight degrees, this accuracy could not be obtained, and it was therefore necessary to make a change and revolve the receiver through ten complete revolutions. While this solved the question of accuracy, it introduced another problem which had to be dealt with; namely, that the rotor of the receiver could be in phase with the rotor of the transmitter in twenty different positions, only one of which would give the correct reading of the level of the water. It was therefore found necessary to provide, in addition to the above receiver, a second receiver which should be operated through one hundred and seventy-eight degrees, the rotor of which could always be depended upon to have the correct position. The index for the fine indication consisted of a hollow cylinder having pointers which moved over the scales of the indicator. The coarse indication consisted of an aluminum ball enamelled red and arranged to operate inside the cylinder of the fine index. The length of the cylinder for the fine index was such that so long as the red ball was within the limits of the cylinder, the fine index could be depended upon to be in the correct position and its reading accurate. The method of operating these indexes was similar to that employed in the rising stem Stoney gate valve indicators described above; but the indication, instead of being accomplished by reflected light, was shown by pointers on the cylinder of the fine index which moved over scales arranged in the four corners of the frame of the indicator. These scales make an angle of forty-five degrees with the axis of the board, so that the level of the water can be observed from various positions up and down or across the control board, through openings in the sides of the indicator facing up and down the board, these sides being enclosed by plain glass and the other two sides of the frame being enclosed with brass panels. The scales are illuminated by tungsten lamps located in both the base and top cap of the indicator. Due to the extreme accuracy required it was deemed advisable to calibrate each indicator with a particular transmitter mechanism and to calibrate each set of scales individually.

Fig. 7. 50 Ft. Water Level Indicator

The specifications required that, the level of the water be indicated to within five-eighths of an inch of the actual level. The indicators as made attain an accuracy somewhat greater than this.

### Miter-forcing Machine Index

The indicators for the miter-forcing machines, which machines force the end surfaces of the gates into alignment (Fig. 8), are not operated by means of position indicator machines, but are only an imitation of the actual machine at the lock, and are operated by the control switch; the intention being to permit the operator to distinguish readily by observation whether the miter-forcing machine was in the open or closed position.

### Cylindrical Valve Indicators

The open and closed position of all cylindrical valves are indicated by means of red and green lamps, the intermediate positions not being indicated in any way.

### Control Switches

The control switches (Fig. 9) are, practically speaking, small controllers, the fingers being at the lower end of the frame, beneath the control board, and insulated by means of hard mica. The contact pieces are located at the end of the operating shaft, and like the contact fingers are insulated from the shaft by hard mica. The portion of the shaft just below the board and above the contacts is square, which provides a means for coupling to the interlocking mechanism, a full description of which will be given later. The handle for the control switch is located on top of the control board and operates through an angle of ninety degrees, and is provided with name plates to show the open, closed and off positions. All handles for control switches are similar in design except those for the chain fender, which are corrugated so that they may be readily distinguished from the control switches for other apparatus located nearby.

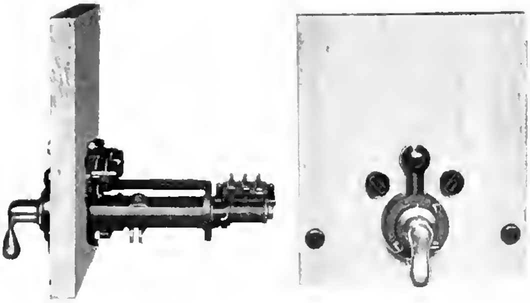


Fig. 8. Miter-forcing Control Switch, Showing Indicating Lamps and Miter-forcing Lamp Indicator

Fig. 9. Double Frame Control Switch

### The Interlock System

In designing the interlock system, the factor of human error had to be reckoned with, and the precautions taken to eliminate the possibility of mistakes by the operator have been carried to a high degree of perfection.

The interlock system takes the form of a bell crank mechanism, as illustrated in Fig. 10, connecting the shaft of the control switch directly to a movable horizontal bar located in the interlock rack, the location of which has been described above. It will be seen that a horizontal connecting rod is used between the cranks on the control switch shaft and the vertical operating shaft. This rod is made with a right-hand thread at one end and a left-hand thread at the other, and provides a ready means for adjust-

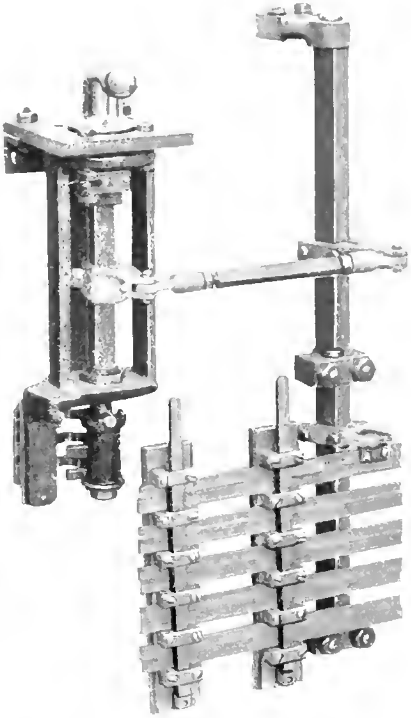


Fig. 10. Control Switch and Interlock Mechanism

ing the throw of the vertical shaft and the meshing of the bevel dogs in the rack.

The rack consists of a rigid frame constructed of three-eighths inch thick steel and having five horizontal members (see Fig. 11). Upon these horizontal members and tying them together are located at convenient intervals a set of vertical straps of three-eighth inch by two inch steel. These carry the brass posts that provide the runways for the horizontal and vertical interlock bars. The posts are firmly riveted to the vertical steel straps, and a one-sixteenth inch brass plate is provided between the posts and steel strap so that the runway is made non-corrosive.

By referring to Fig. 12 it will be seen that the back of the steel strap is grooved and countersunk in such a manner that a key is provided which prevents turning of the posts. Elaborate drill jigs and assembling tools were constructed to make the spacing and alignment of posts perfect. The racks are built in eight foot sections for convenience in shipping, eighteen of them being used in the Gatun control board, making a total length of one hundred and forty-four feet—seventy-two feet for each side of the board.

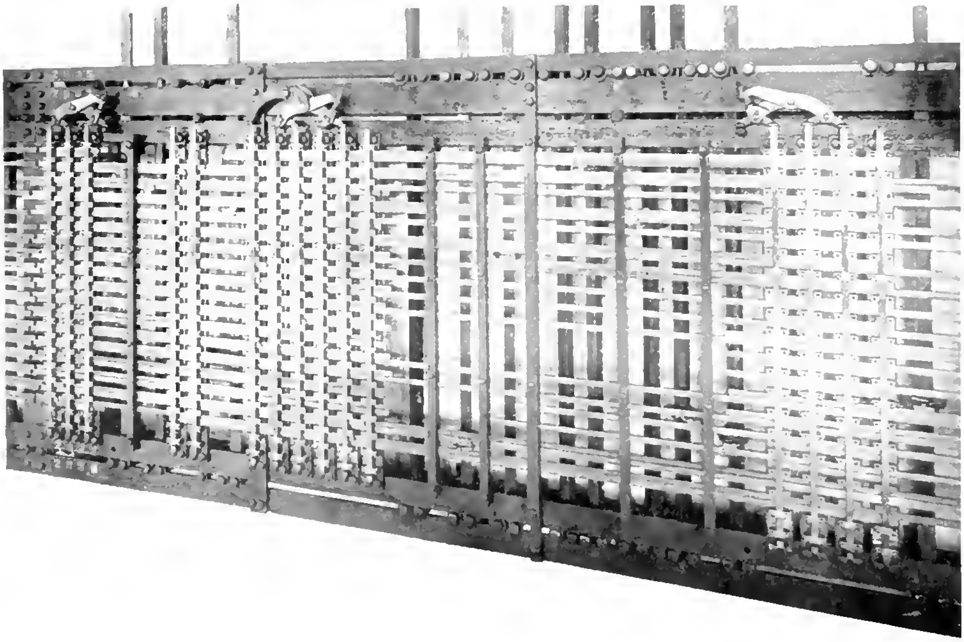


Fig. 11. Section of Interlock Rack Showing Arrangement of Vertical Operating Rods and Method of Interlocking by Means of Adjustable Whiffletrees

They are to be rigidly mounted, by means of heavy angle iron work and suitable spacers, upon the inner faces of the iron columns that carry the operating floor of the control house. Near the upper and lower edges of the racks are located the brass bearings for the vertical operating shafts, which are seven feet long and made of one inch square steel (Fig. 13), the bearing points being turned to a diameter of seven-eighths inch. On the vertical operating shafts are mounted the forked cranks that engage the horizontal interlock bars by means of a pivot block set over a pin block which is firmly riveted to the horizontal bar (Fig. 14). This provides a means of moving the horizontal bar a distance of approximately one and one-half inches by operating the control switch handles through an arc of ninety degrees.

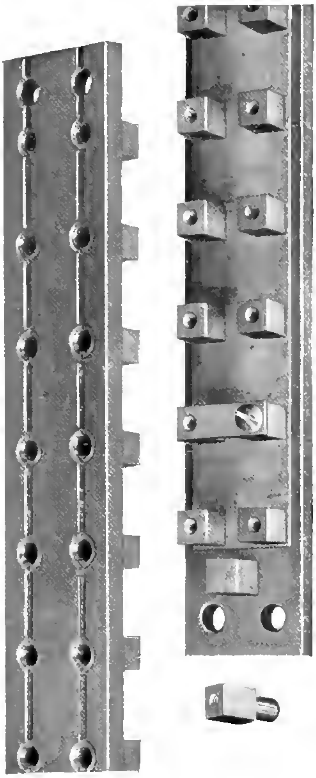


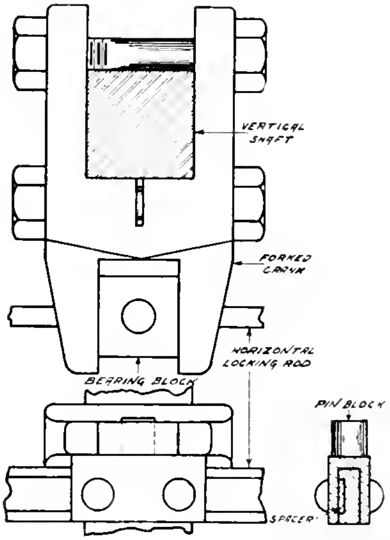
Fig. 12. Runway for Vertical and Horizontal Interlock Bars

The interlock bars are made of hard extruded brass of special shape, as shown in Fig. 15, which also shows a cross section of the bevel dogs. This section was determined upon as the best method of keeping the dogs in line with the axis of the bars when under pressure through being engaged with another dog on a vertical bar. There is a horizontal bar for every switch, but the length of the bars varies considerably, the shortest being about three feet, while the longest are fifty feet.

Fig. 13. Interlock Relieving Clutch and Auxiliary Spring for Intermediate Gates

The interlock system depends in the main on the action of bevel dogs located on the horizontal and vertical bars, these dogs so engaging that the movement of a horizontal bar tends to lift a vertical bar by means of the bevel on the dog. This is plainly illustrated in Fig. 16

The movement transmitted to the vertical dog and its bar is one-quarter inch. Referring to Fig. 17, it will be noted that a second bar has been brought forward and that it is now impossible to move the upper bar because the dog on the lower bar prevents the lifting of the vertical bar; in other words the control switch to which the upper bar is connected cannot be operated until the lower dog is withdrawn. This is the simplest type of interlock employed and forms the basis of the whole scheme.



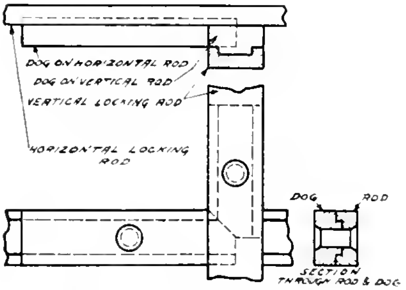


**Fig. 14** (upper)
**Fig. 15** (lower)

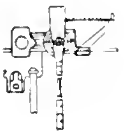


Fig. 26

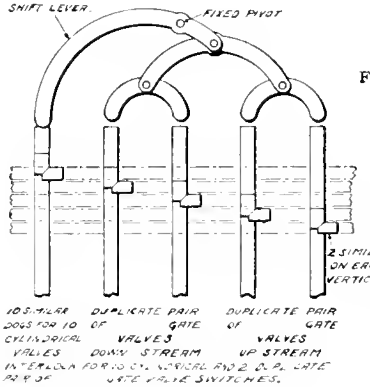


Fig. 21

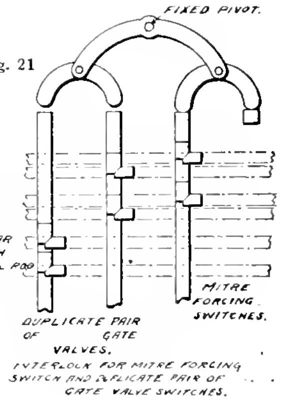


Fig. 22

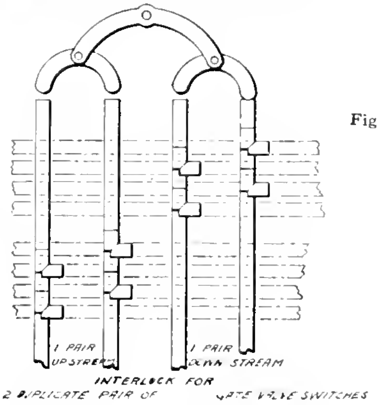
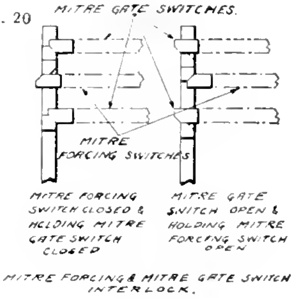


Fig. 20



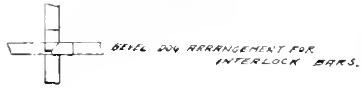


Fig. 16

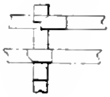


Fig. 17

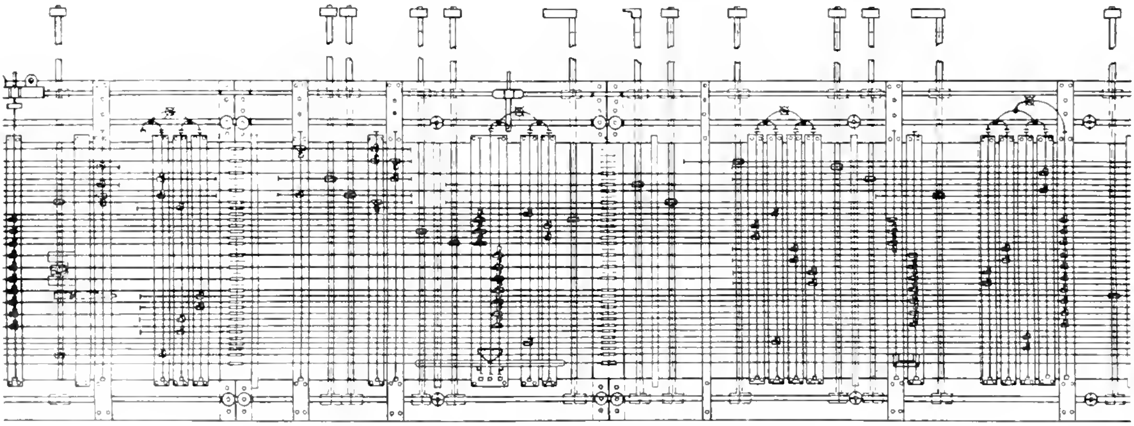


Fig. 18. Section of Detail Chart of Interlocks

Although the functions of the various machines have been described in another article, it will be necessary to touch upon them once more in order to explain how the more intricate interlocking is accomplished. Fig. 18 shows a section of an interlock detail chart covering approximately eleven lineal feet of rack construction, complete with all dogs, vertical shafts, etc., while Fig. 19 shows a section of rack.

### Interlocking of Chain Fenders and Miter Gate Switches

The interlock here prevents the chain being lowered until adjacent miter gates have been opened, and conversely, prevents the gates being closed before the chain has been raised. The gates are thus protected from damage by moving vessels. The interlock is accomplished by means of the simple arrangement shown in Fig. 20. This occurs sixteen times on the Gatun locks.

### Miter Gate and Miter-forcing Switches

These are interlocked in such fashion that miter-forcing switches must be opened before miter gate switches can be opened, and vice versa, miter gate switches must be closed before miter-forcing switches can be closed. The arrangement of dogs for this interlocking is shown in Fig. 20, and is used twenty times.

### Miter-forcing Switches and Rising Stem Valve Switches

Here the object of the interlocking is to prevent the opening of the rising stem valves with the attending flow of water while adjacent miter gates are moving into either opening or closing positions. The locking is here applied to the miter-forcing switches and these are locked with rising stem valves on the side walls only.

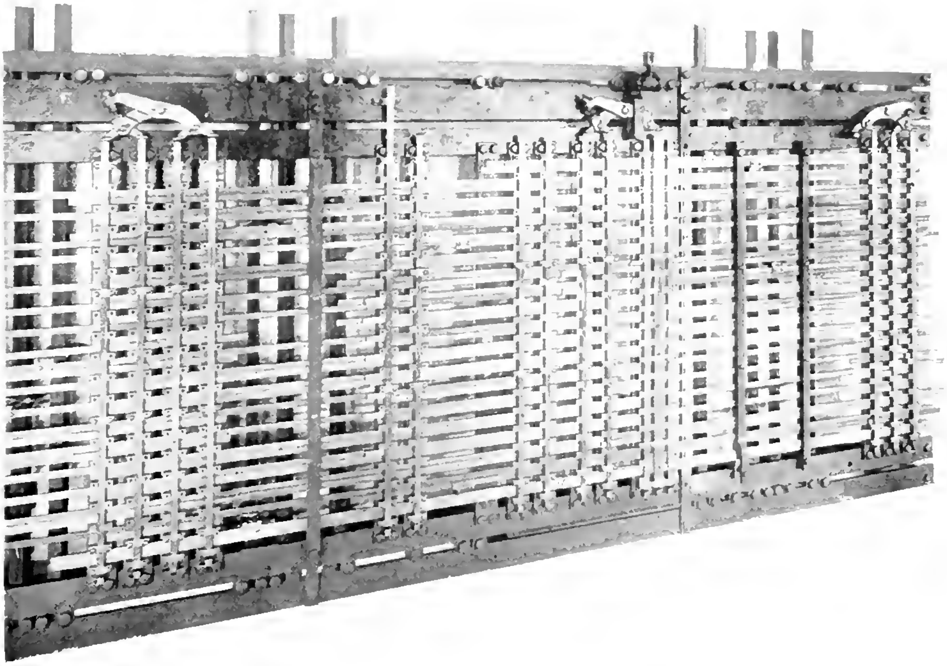


Fig. 19. Another Section of Interlock Rack

It will be noted from Fig. 21 that by operating the miter-forcing switch first, the second of a duplicate pair of rising stem valves is held closed; vice versa, if the two rising stem valves are opened, the miter-forcing switch is closed.

A novel arrangement of rocking levers, conveniently called whiffletrees on account of their resemblance to that familiar contrivance used on horse drawn vehicles, is applied here. Its function is to make the sequence of operation of the two pairs of rising stem valves selective so that either

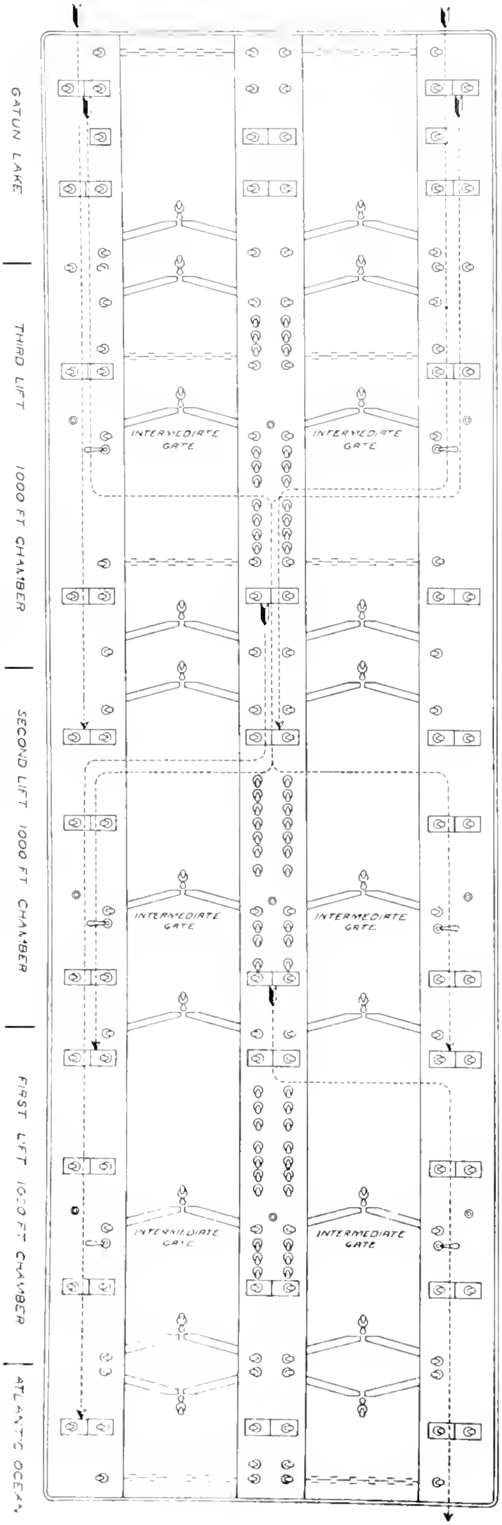


Fig. 23. Plan of Gatun Control Board

pair can be opened first, this pair being the guard pair while the second pair is the operating pair—no water flowing until the second pair is opened. The whiffletrees are equipped with a screw attachment permitting of close adjustment on the lift of the vertical bars.

It will be noted that one of the four points of the whiffletree mechanism is resting on a fixed stop, while the next point is closely in touch with the top of the vertical bar connected to a pair of rising stem valve switches. The other two points are raised one-quarter inch from the top of vertical bars connected to a pair of rising stem valve switches and a miter-forcing switch. If the latter two bars are raised, all available room is taken up and the third bar is held down; in other words, the two switches connected to that bar cannot be opened. This interlock is repeated twelve times on the Gatun board.

### Intermediate Miter Gates

The thousand foot levels are divided into two unequal sections by intermediate miter gates to permit handling small vessels without incurring the waste of water that would result from operating the vessels in the large chambers. These gates are equipped with the same interlocks as those on other gates, but provision has been made to remove all interlocks in case a large vessel is to be passed through.

The method employed here consists of dividing the shaft and installing a clutch arrangement, the lever of which is governed by a Yale lock on top of the board. The turning of a key removes the interlock and permits the gates to be thrown open, thus providing a clear thousand foot level. Fig. 13 shows this clutch.

### Rising Stem Valves

Rising stem valves are located in series in the side and middle wall culverts and are used to intercept the flow of water at proper intervals and shunt it into the various lock chambers. The culverts open into the ocean at the lower ends, and special precautions are necessary to prevent the opening of all valves in series.

The interlocking is here accomplished by the arrangement of dogs and whiffletrees shown in Fig. 22, where four vertical bars each bearing two dogs engage the horizontal operating bars of four pairs of rising stem valve switches. It will be noted that any pair can be selected for operation at will and that three pairs can be opened; the fourth pair is, however, locked closed because all the space between the whiffletrees and the tops of the vertical rods has been taken up. Therefore one of the other three pairs must be closed before the last one can be opened.

Fig. 23 shows a plan view of the control board and the relative location of the various switches. Here it is shown that the flow of water in the culverts is intercepted at eight points exclusive of the intermediate rising stem valves adjacent to the intermediate gates, which are not interlocked.

The interlock described above occurs three times in each culvert and confines the operator to the equalizing of water between levels.

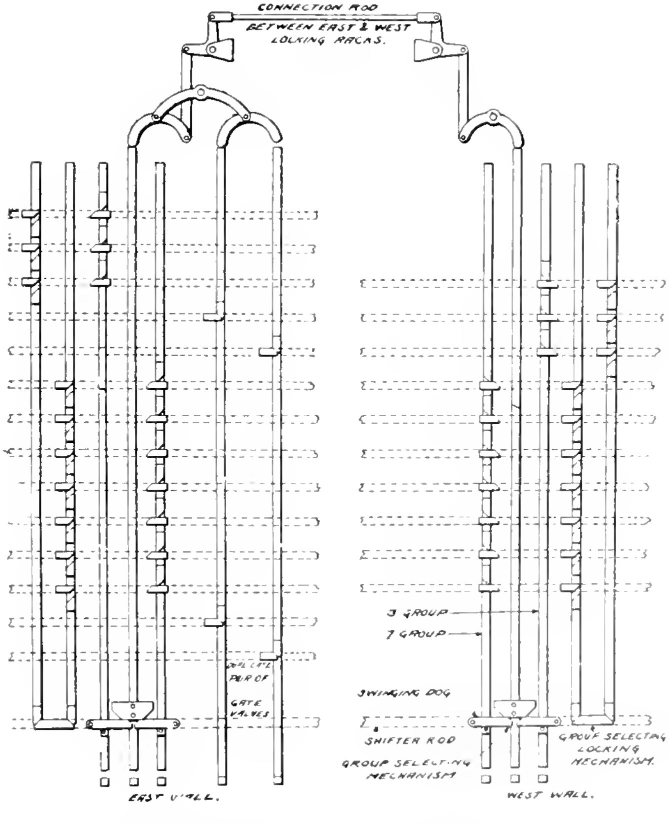


**Fig. 24.** Interlock for 10 Cylindrical Valves on East and 10 on West of Center Culvert and One Pair of Rising Stem Valves Upstream or Downstream with Group Selecting Mechanism and Interlock

### Cylindrical Valve Switches

There are sixty of these located on the middle wall and they control the cylindrical valves which permit of filling and emptying the various lock chambers from the middle wall culvert. Twenty of these switches constitute the equipment for a thousand foot level, ten for each side east and west. They are interlocked so that if one side is opened, the other side is locked closed, and the opening of one switch on a side will lock the opposite ten. Fig. 24 shows the locking system employed here with the necessary connection to the opposite rack. Here is also shown the mechanism for removing the cross locking, which is desirable in cases where two vessels come abreast in opposite basins on the same lift. A large quantity of water can be saved by using part of the water that would be wasted in lowering one vessel and allowing the chambers to equalize by opening both sets of cylindrical valves. The removal of this interlock is accomplished by means of a Yale lock placed on top of the board, the bolt of which holds a toggle extended when locked, but allows it to collapse when unlocked. (Fig. 25.)

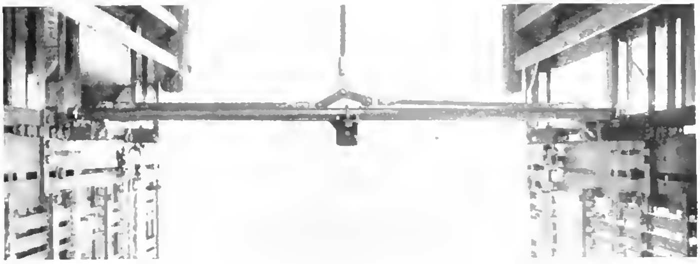


**Fig. 25.** Interlock Cutout Mechanism for Cylindrical Valves

### Cylindrical Valves and Center Wall Rising Stem Valves

Cylindrical valves are not designed to operate against a head of water, and they are therefore interlocked with middle wall rising stem valves so that a set of cylindrical valves must be opened on either side before the second pair of a duplicate pair of rising stem valves on the middle wall can be opened either up or down stream. (Fig. 26, page 26.)

### Group Selecting Levers for Cylindrical Valves

On each side wall and close to the three intermediate gates will be found three control levers. These are used in connection with groups of three and seven cylindrical valves above and below these gates. The handles have three positions, allowing three, seven or ten valves to be used. When the intermediate gates are opened, this handle is placed at the "ten" position.

Assuming that a short vessel is being passed downstream, it would first pass into a chamber having three cylindrical valves. The group-selecting lever would then be placed on the "three" position, which would permit of opening three valves above the intermediate gate but would lock closed the seven valves below it. After the vessel has been passed below the gate, the handle may be reversed, releasing the seven and locking the three switches. (Fig. 24.) The operator, however, is not confined to this operation, but may shunt the water from the upper to the third chamber. In fact, the whole method of using the group-selecting levers is left to his judgment.

### Cross Interlocking of Rising Stem Valves on Side and Middle Walls and Cylindrical Valves

Referring to Fig. 23 and following the dotted line from the culvert entrance through the culvert, through an open set of cylindrical valves, on through the center wall culvert, to and past a lower pair of middle wall rising stem valves into a lower chamber, it will be seen that it is possible to allow lake water to flow and flood this chamber. To prevent this, interlocks have been applied between these rising stem valve switches and cylindrical valve switches so that if a set of ten cylindrical valve switches on either side and a duplicate pair of rising stem valves on the respective side wall are open, the second pair of a lower duplicate pair of rising stem valves on the middle wall is locked closed; and vice versa, if the middle wall duplicate pair of rising stem valves are open and cylindrical valves are open, the last pair of the upper or lower duplicate pair of side wall rising stem valves is locked closed. Again, if all these rising stem valves are open, the cylindrical valves are locked closed.

The development of the interlock system was one of the most complicated problems encountered in connection with the Panama control boards and it was given the closest attention because the final layout of no part of the control board could be determined until the interlocking had been completely taken care of. This was made even more difficult by the fact that all the interlocking had to be shown on a chart and approved by the Commission before detail work could proceed.

The whiffletree mechanism was particularly helpful because it provided in each case the means of accomplishing with four vertical bars what would ordinarily have taken sixteen bars. For checking and final tryout, a separate sheet called the "when sheet" was prepared, which showed the interlocking between one switch and any other.

### Shipping

In designing the board, consideration had to be given to the fact that it had to be fully assembled and tried out at the factory; and further, to make its installation at the Isthmus simple, it had to be shipped with as little dis-assembling as possible. To accomplish this, the board itself was arranged to come apart in four-foot sections, while the interlock was arranged to come apart in eight-foot sections. (Fig. 7.) The top sections are shipped complete with the control switches; the indexes, however, are removed and shipped separately, with the exception of those for the mitering gates. Each section of the interlock rack is shipped complete and can be easily coupled together when re-erected on the Isthmus.

### Climatic Conditions

Another point which had to be given very careful study and thought was the selection of the material of which the board and the various devices were to be constructed because of the peculiar climatic conditions existing on the Isthmus. All bearings had to be made of non-corrosive material, and wherever steel or iron was employed it was necessary to thoroughly coat it with red lead before giving it the finishing coat of paint. All insulating material had to be non-hygroscopic. Even the cords for operating the rising stem gate valve indicators and the water level indicators were selected only after a number of samples of the highest grade silk line had been sent to the Isthmus and subjected to the climatic conditions for a considerable period to determine whether they would be suitable for the work. Anything in the nature of a metallic wire or cable could not have been used.

**Interesting Facts**

The total weight of the three boards will be approximately thirty-nine tons. To accomplish the interlocking, something over two and one-quarter miles of special interlocking rod was required. To connect the various control switches and indicators to the lock machinery will require about eleven hundred miles of control wire, this control wire being made up in five and eight conductor cables. The total number of position indicator machines used in connection with the board and the transmitters at the lock machinery is seven hundred and thirty-two. The total number of control switches required are four hundred and sixty-four. The total number of indicating lamps is about three hundred and eighty, and there are four hundred and fifty-two illuminating lamps. The control is operated at 220 volts, 25 cycles and the indication at 110 volts, 25 cycles.

# POSITION INDICATOR SYSTEM AND MACHINES FOR THE PANAMA CANAL LOCKS

By E. H. Jacobs and H. M. Stevens

Switchboard Engineering Department, General Electric Company

This article consists of a description of the transmitting and receiving devices that were evolved to show at the control board the water level and the movements and positions of the different gates, valves and other pieces of machinery that come into action in passing vessels through the locks. These devices are essentially transformers with movable cores, the stators being connected together at three points of the winding and the rotors excited with single-phase alternating current from a common source. All of the transmitters and receivers are similar, with the exception of those for the water level indicators, where the degree of accuracy required made necessary the use of two machines, geared together with a ratio of approximately 20:1. The methods employed for connecting the transmitters and receivers to the lock machinery and the indicating devices, respectively, are shown in the illustrations in most cases.—Editor.

The care with which the various details in connection with the operation of the Panama Canal lock machinery were determined, as well as the means provided to allow the operators of the control boards to know at all times the position of the lock machinery, are partly shown by the following description of some of the control indicating features.

The Isthmian Canal Commission's specifications required that, in so far as practicable, the devices used to indicate the position of the miter gates, rising stem valves guard valves, chain fenders, and water level be small models of the machines, and that the indication be progressive and synchronous with the movement of the machines. As the distance through which the synchronous movement of the indicators has to be transmitted is, in some cases, approximately 3000 ft., it can be readily seen that mechanical transmission of power from the machines to the indicators on the switchboard would be almost impossible, and therefore it was decided that only an electrical equipment could be satisfactorily used. As the result of considerable experimenting, the requirements were finally met by an arrangement known as a synchronous indicator and consisting of two machines, each having a stator and a rotor. One machine is mechanically operated by the lock machines and mounted either on or near them, and a second motor of the same type, electrically connected to the first, mounted at the control board and mechanically connected to a position indicator. The motor attached to the lock machine is known as the transmitter and the one driving the position indicator as the receiver. Both the transmitter and receiver stators are arranged with a three-phase winding, a lead from each phase being brought out (see Fig. 1) and the corresponding leads permanently connected together, but not connected to a source of power. The stator coils are energized entirely by induction from the rotor. The rotors are bi-polar and designed to be energized from a 110-volt, 25-cycle, single-phase source, the rotors of both transmitter and receiver being connected to the same circuit.

The movement of the transmitter rotor, which is mechanically operated by the lock machine, produces a field in the transmitter stator which polarizes it in the direction of the rotor axis and induces voltage in the stator coils. This voltage is transmitted by a three-phase connection to the receiver stator coils and it duplicates in them the same polarity and voltage conditions developed in the transmitter stator, but in the reverse direction. The rotor of the receiver, being energized in the same direction as that of the transmitter, is reacted upon by the polarized stator until their magnetic axes coincide and the rotors of the transmitter and receiver are in the same relative position. With the rotors in this position, there is no current flowing in the three-phase tie between the stators. Any difference in the position of transmitter and receiver rotors causes a difference of potential between them with a consequent flow of current and resultant torque which moves the receiver rotor to the same relative position as that of the transmitter rotor. The torque increases rapidly with increase in angular difference between the rotors, and, as the magnetic reluctance and the flux through the stator winding are uniform, the receiver rotor follows closely and smoothly the movement of the transmitter rotor. Thus a movement is imparted to the position indicator identical with the movement of the lock machine, although on a scale reduced to the requirements of the control board. It should be noted, in the following description of the arrangement for each lock machine, that this arrangement of position indicator control gives a sufficient accuracy of indication with considerably less than one revolution of the transmitter, with the exception of the water-level indicator which requires an accuracy of one-tenth of one per cent.

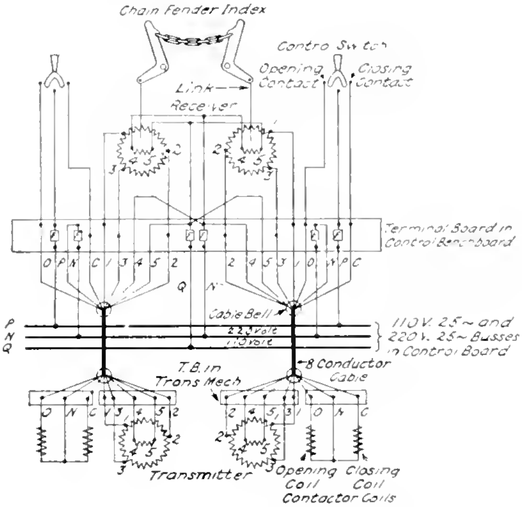


Fig. 1. Wiring for Control Switches and Position Indicators for Chain Fenders. This wiring is typical of wiring for all position indicators

Indication is given on the control boards of the main lock machinery and of the various water levels. The lock machinery consists of the miter gates, the gate valves or rising-stem valves, the chain fenders, and the guard valves.

The miter gates consist of two vertical leaves pivoted on the lock walls, with a motor-driven mechanism for operating each leaf. Each leaf of the gate is operated independently of the other, so that indication must be given of the movement of each leaf. Figs. 2 and 3 show the transmitting mechanism. The vertical operating shaft of the transmitter mechanism is connected to the operating machine and makes approximately 37 revolutions during a complete operation of the gate. The operating shaft is threaded and carries a nut on which is mounted a rack. The rack engages a gear on the motor shaft. This arrangement gives a gear ratio of approximately 75 to 1, the motor revolving 178 degrees while the operating shaft is making 37 revolutions.

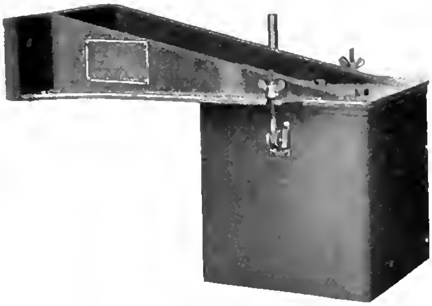


Fig. 2. Miter Gate Transmitter, Closed

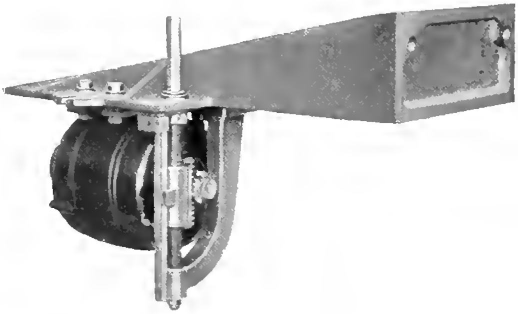


Fig. 3. Miter Gate Transmitter, Cover Removed

The position indicators for both leaves of a gate are mounted as a complete unit on the control board. The indication is given by two aluminum arms which are geared to the motors under the board, and which swing horizontally showing the location of the gates as they would appear to an observer directly above them. (See Figs. 4 and 5, page 21.)

A rising-stem valve consists of a gate carried in vertical guides with a machine for raising or lowering it in order to open or close a duct in the lock wall. The gate is 8 feet wide and has to rise 18 feet to reach the full-open position. The operating power is supplied by a motor driving two vertical screws. Figs. 4 and 5 show the position-indicator transmitter for a rising stem valve. The transmitter motor revolves approximately 178 deg. for a complete operation. The transmitter is driven by a shaft (not shown in illustrations) which makes 497 revolutions, so that the gear reduction is approximately 1000 to 1. The gearing is similar to that used on the miter gate transmitters. A screw with sixteen threads per inch is driven by a gear and pinion. The gear and pinion give approximately 6 to 1 reduction. The screw carries a nut and rack which drive a gear on the motor shaft. Eighty turns of the screw give 5 in. linear travel of the nut and rack, and as the gear on the motor shaft is 3¼ in. diameter it makes about 175 degrees revolution for a complete operation.

There are two ducts in parallel in each wall of the locks with the valves occurring in pairs, although their operation is independent. The position indicators are also built in pairs. The indicator, Fig. 6 (and Fig. 6, page 22), consists of a stack or box with a vertical partition dividing it into two compartments. Each compartment is 3 in. wide by 9 in. high by 2 in. thick. The front and back are fitted with ground glass which is marked with black lines for the ¼, ½ and ¾ positions. A small aluminum cage moves up and down in each compartment in the same manner as the cage of an elevator. Lamps in the bottom illuminate the ground-glass front and back as high as the bottom of the cage, this preventing the light from going above, so that the illuminated portion of the glass corresponds to the amount of opening of the valve. The cage shuts off the light completely when down and is raised into the metal cover for the full open position. The cage is raised and lowered by a continuous cord running over an idler at the top of the stack and over a drum at the bottom. The drum is driven by the motor through gearing. To prevent the cord slipping on the drum, the drum is threaded and several turns of the cord wound around it. A phosphor-bronze spring keeps the cord under uniform tension.

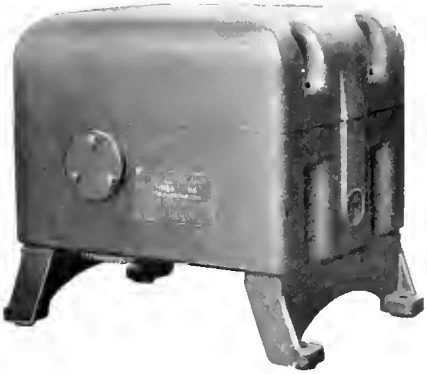


**Fig. 4.** Rising Stem Valve Transmitter, Closed

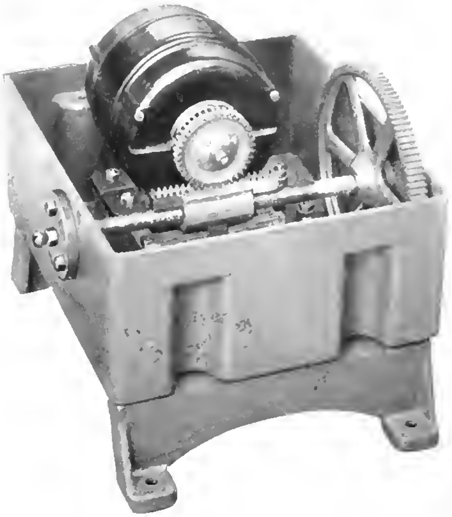


**Fig. 5.** Rising Stem Valve Transmitter, Cover Removed

The guard valves are situated at the upper end of the middle wall of each flight of locks. The machinery for operating them differs from that used for the rising stem valves, but the indication on the control board is the same.

In front of the lock gates are immense chains which are raised to prevent the gates from being rammed by a vessel. Each end of the chain is raised by a hydraulic piston, each piston being controlled independently.

The position-indicator transmitter, Figs. 7 and 8, is driven by the shaft that operates the limit switch which in turn controls the stroke of the piston. The operation of the transmitter is similar to the rising stem and miter-gate transmitters, the only difference being in the mounting and gear ratios. The indication on the board is given by a miniature chain, each end of which is connected through a crank and gearing to a receiver motor. As the receiver motors revolve, the chain is lifted out of a slot in the control board and is stretched straight. The arms which raise the chain are extended so that they form semaphores, giving an additional indication. (See Fig. 3, page 21.)

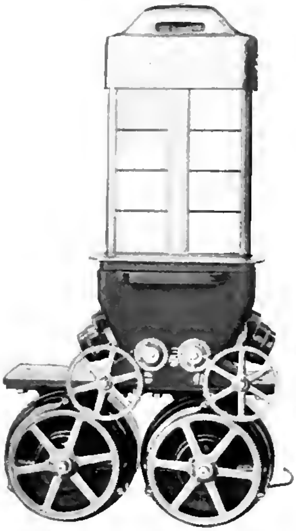


Fig. 6. Rising Stem Valve Indicator

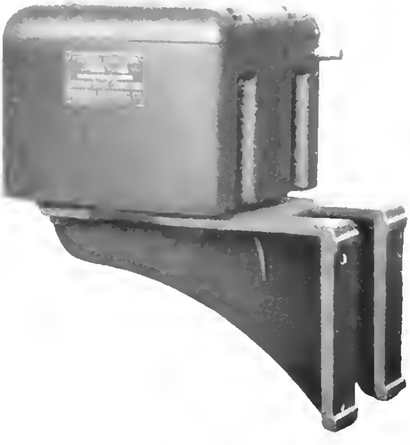


Fig. 7. Chain Fender Transmitter, Closed

The specifications covering the indications for the lock machinery, that is, for the miter gates, valves and chain fenders, required that the indicators show within 3 per cent the actual positions of the main machines. The specifications for the water level indicators, however, required that the indication be within one-twentieth of a foot of the actual water level. For a 50-foot range in water level this necessitated an indication within one-tenth of 1 per cent. To insure of the indicating apparatus being self-synchronizing, it was necessary to give the full range of indication with less than a 180-degree revolution of the indicating motor. As the inherent lag of the receiving motor behind the transmitter motor amounts to about $1\frac{1}{2}$ per cent in 180 degrees, it was impossible to give the required accuracy with one motor. A design was adopted by which an approximate indication is given by one motor, making a 178-degree revolution for the complete range, while accurate indication is given by another motor making ten revolutions for its complete range. The accurate or fine indication will be either correct or one or more turns of the receiver motor away from the correct position. If the pointer giving fine indication is a turn of the motor away from the pointer giving the approximate indication it is apparent to the operator, and the fine indicator can be returned to its correct position by turning the motor by hand. The motor making ten revolutions is thus acting as a vernier for the approximate or coarse indication.

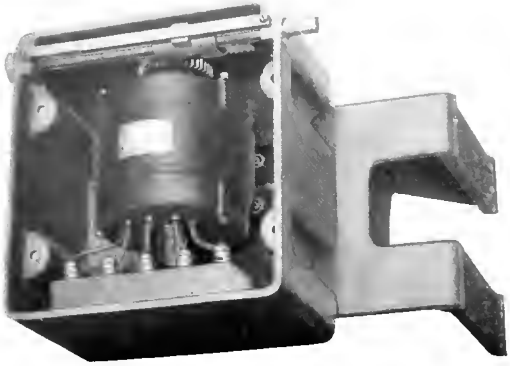


Fig. 8. Chain Fender Transmitter, Cover Removed

The water-level indicator or index is a vertical stack $5\frac{1}{2}$ inches square, the height depending on the length of the scale plates, with clear glass forming two sides. Each side has two graduated scale plates arranged so that the water level may be read from almost any position. The graduation is on a scale of 1 in. to the foot, requiring a scale plate 50 in. long for a 50-foot range of water level. The receiver motors are mounted underneath. The motor for coarse indication drives a threaded drum through light gearing. A continuous cord with several turns around the drum is carried up one side of the stack, over an idler at the top, returning down the center of the stack to the drum. A small aluminum ball, enameled red, is carried by the cord. The motor for fine indication drives two drums on a single shaft, with two cords running up to the top, over idlers, and back to the drums. A vertical aluminum tube 2 in. in diameter and 4 in. long is carried by the two cords, with small pieces of the tube bent out to form a pointer for each scale plate. This arrangement allows the small aluminum ball, giving the coarse indication, to move freely and independently through the tube. When the fine indication is correct the aluminum ball is inside the tube. If the fine indication is $\frac{1}{2}$ turn of the rotor (or more) away from the correct position the red ball is exposed above or below the tube, showing that the fine indication is not correct. Enameled silk cords are used to carry the pointers. Samples of this cord were sent to the Isthmus and, after being exposed to the severe climatic conditions, showed that they would last for a long time without renewal. Illuminating lamps are mounted in top and bottom of the index with glass reflectors to concentrate the light on the scale plates. The index is shown in Fig. 7, page 22.

**Fig. 9. Water-Level Transmitter with Float, Weight and Belt**

Figs. 10 and 11 show the water-level transmitter. Wells 36 in. square are provided in the lock walls to take the float. Communication between the lock and the float is made by a small opening at the bottom of the well which will dampen surges. The float is a welded steel box 30 in. square by $9\frac{1}{2}$ inches deep. It weighs 200 lb. and has a draft of 6 inches. A phosphor-bronze belt $2\frac{1}{4}$ inches wide by 0.010 in. thick transmits the movement of the float to a sheave on the transmitter mechanism. The sheave is studded with pins and the belt punched to fit these, to prevent slipping. A 30 lb. weight is fastened to the belt after it passes over the sheave. As it requires about 1 lb. pull on the belt to turn the transmitter, error at this point is almost eliminated, for 1 lb. pull on the belt lifts the float only $\frac{1}{32}$ in. The error due to transferring the belt from one side of the sheave to the other is partially compensated for by the displacement of the float. The variation in temperature is slight, so that the total error in transmitting the movement of the float will be not over $\frac{3}{16}$ in. on a 50-foot range. The sheave is 6 ft. in circumference with pins spaced 3 in. apart, or a total of 24 pins. This gives $6\frac{1}{3}$ revolutions of the sheave for 50 ft. travel of the belt. The sheave is carried in ball bearings with oil cups for lubrication and pet cocks at the bottom to allow water which may work into the bearings to be drawn off. The remainder of the transmitter consists only of the two motors, the gearing and the enclosing box.

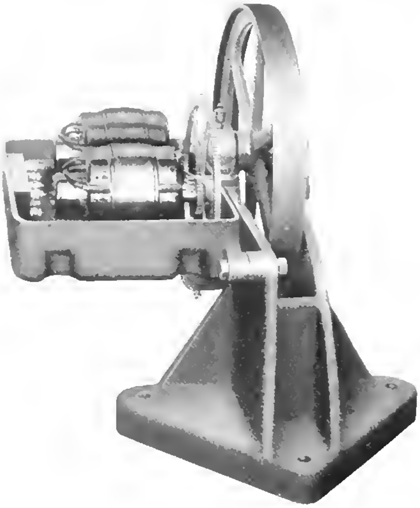


**Fig. 10. Water-Level Transmitter, Cover Removed**

# SWITCHING, DISCONNECTING, AND BUS ARRANGEMENT FOR A-C. POWER CIRCUITS

## PANAMA CANAL LOCKS

By E. H. Jacobs and H. M. Stevens

Switchboard Engineering Department, General Electric Company

On the switchboards described in this article, the thorough insulation of all live parts was made a special feature, in accordance with specifications issued by the Canal Commission. The busbars are located in fireproof compartments, the connections passing through porcelain bushings in the walls of these compartments, and all conductors insulated. The oil switches and disconnecting switches are in a measure combined, and the outside contacts surrounded by an insulating shield. An interlock is provided to prevent the closing or opening of the disconnecting switches when the oil switches are closed. Non-corrosive metal was used for all moving parts, and special insulation for the solenoid and trip coils, owing to the climatic conditions on the Isthmus.—Editor.

The Isthmian Canal Commission specifications covering the high-tension apparatus require that safety to life be considered of paramount importance. The insulation of all live parts was considered advisable and the arrangement used to accomplish this purpose is novel and also of especial interest, in view of the general tendency to more thoroughly eliminate the possibility of station attendants coming in contact with the current-carrying parts of switching apparatus and connections.

The busbars are of solid copper rod and are placed in fireproof compartments. See Fig. 2. The connections to the busses are also of solid copper rod and are of sizes such as will make a very rigid construction. These rods pass through porcelain bushings, cemented into the bus compartment wall, and are threaded into terminals which are clamped to the bus.

All high-tension leads are thoroughly insulated after they are installed. For the oil switches and air-break disconnecting switches, an arrangement was designed which allows the live parts at these points to be completely covered. Fig. 1 shows the arrangement for the 2300-volt hand-operated oil switches and disconnecting switches.

A rigid pipe framework supports vertical metal guides which carry the oil-switch operating mechanism and a slate base, the latter forming a section of the switchboard panel. A lever and toggle mechanism is provided, by means of which the oil switch and all other parts carried on the guides may be raised or lowered. Above the oil switch is a stationary base, mounted on the pipe framework, which carries the disconnecting-switch studs. These are mounted in porcelain insulators of the same design as those used in the oil switch and are arranged to be clamped to a metal supporting base. The disconnecting-switch studs are similar in design to the oil-switch studs, i.e., the high-tension leads are connected to the tops of the disconnecting-switch studs and the bottom

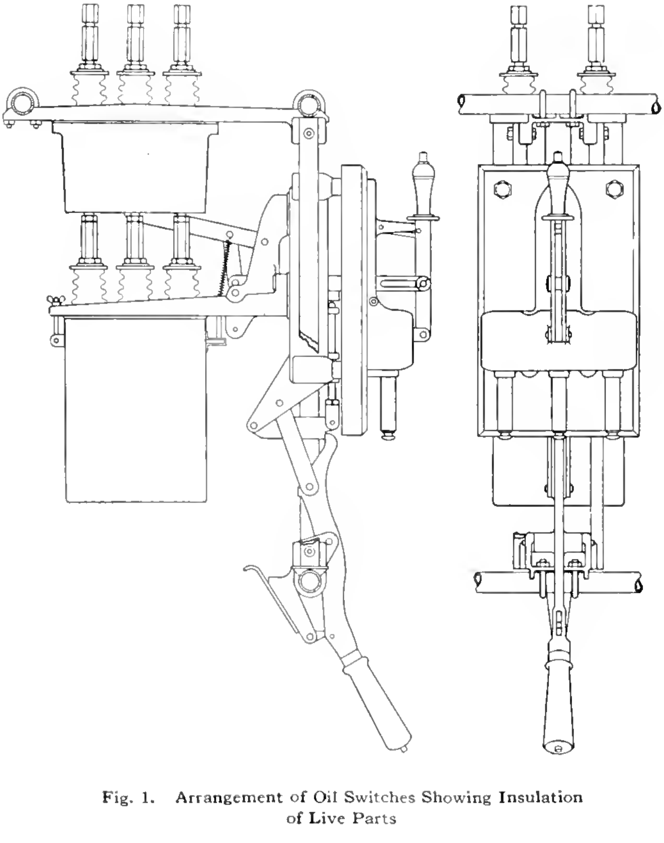


Fig. 1. Arrangement of Oil Switches Showing Insulation of Live Parts

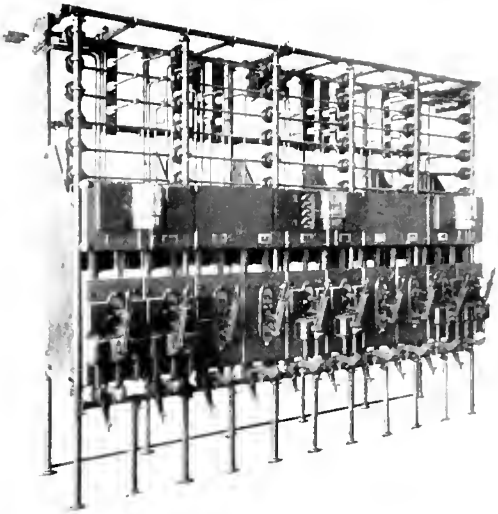


Fig. 3. 2300-Volt Transformer Switchboard for Panama Canal Locks, Showing Oil Switch Disconnecting Switches and Oil Switch Panels

of each stud is equipped with a flared finger contact. On the top of each oil-switch stud is mounted a short wedge-shaped contact blade. When the oil switch is raised, these blades engage the flared contacts on the bottom of the disconnecting-switch studs which, in the closed position, form extensions of the oil-switch studs. Moulded insulating shields completely surround each disconnecting switch contact, except at the bottom. At this point, the shields extend so far below the contact fingers that these are sufficiently insulated to prevent accidental contact, whether the disconnecting switch is open or closed. After being installed, all live parts, not covered by moulded shields or porcelain insulators, are thoroughly taped so that, with the oil switch raised and the disconnecting switch closed, all live metal parts are completely protected. When the oil switch is lowered, contact is broken at each disconnecting-switch stud, so that the oil switch is completely isolated from the circuit. The mechanism for raising and lowering the oil switch consists of a lever and toggle joint, the toggle being just over-center when the oil switch is in the raised position. This arrangement gives sufficient power to force the disconnecting switch contacts together, and always raises the switch to a fixed height, at which point it is latched. An interlock is provided which prevents the oil switch from being either raised or lowered unless the oil-switch contacts are open. This is necessary to guard against the circuit being closed or opened by the disconnecting-switch contacts. An interlock is also used in some instances to make two single-throw switches into a double-throw switch, and to prevent both switches being closed at the same time. Fig. 3 shows the front of a bank of panels equipped with these switches, and Fig. 4 shows a back view of the same arrangement.

For remote-control solenoid-operated switches, the same form of disconnecting switches are used; but the solenoid for operating the switches is mounted rigidly on a concrete-cell structure, and the connecting mechanism to the oil switch is provided with a vertical slotted link, which allows the oil switch to be raised and lowered by hand

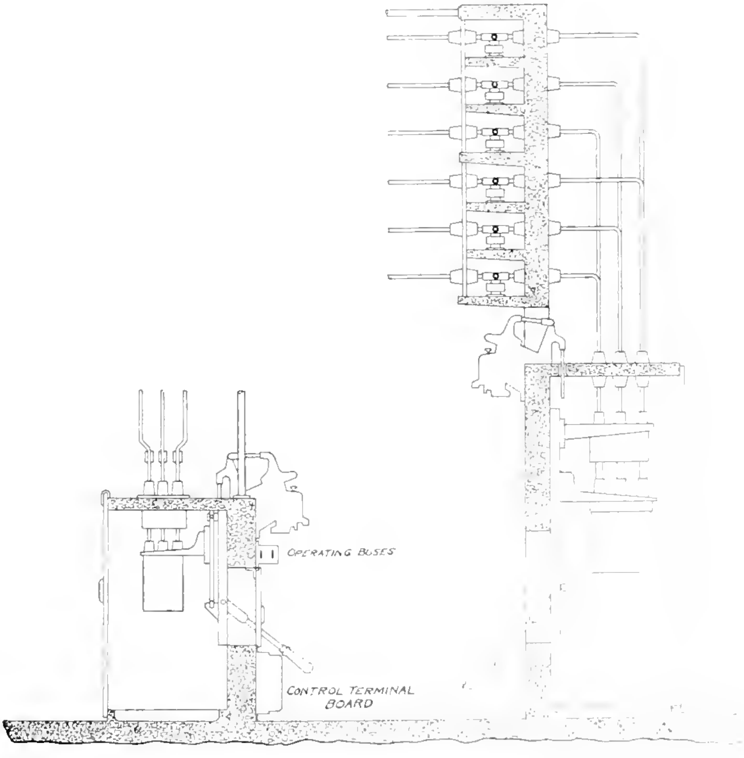


Fig. 2. Bus Compartments, Connections and Oil Switch Arrangement, 2300 Volts

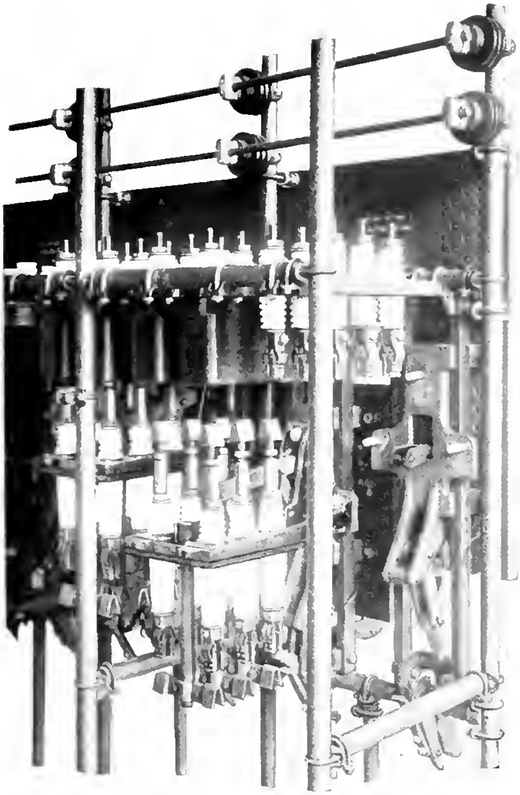


Fig. 4. Back View of Fig. 3

without being disconnected from the solenoid mechanism. A mechanical interlock is also arranged to prevent the raising or lowering of the oil switch while in the closed position. Fig. 5 shows a solenoid-operated switch with the switch in the lowered position. Fig. 6 shows the switch in the raised position, with one of the insulating shields removed from the disconnecting-switch contacts. The disconnecting device for the cell-mounted oil switches is, in the case of the smaller type oil switches, arranged as a part of the cell top, the disconnecting being done in the cell and the disconnecting switch insulators acting in the capacity of bushings through the cell top. The disconnecting device for the larger type cell-mounted oil switches is supported on a metal frame, similar in design to the top frame of the oil switch, and the whole is entirely enclosed in the switch cell, additional bushings being used in the cell top. In each case the oil switches are raised and lowered by means of a handle extending through the back of the cell. It may also be of interest to note that the oil-switch solenoid-control bus is mounted in a small closed compartment on the back wall of the switch cell, and that the leads from the bus to the switchboard and to the solenoids are also entirely enclosed.

Owing to the climatic conditions on the Isthmus, it was necessary to use non-corrosive metal for the moving parts of the operating mechanisms and special insulation for the solenoid and trip coils.

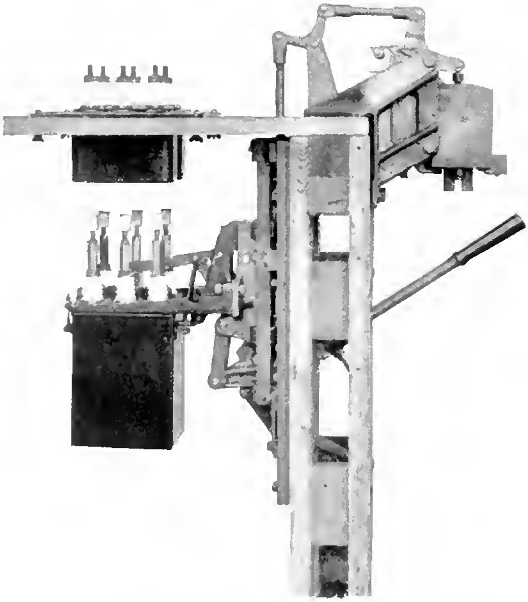


Fig. 5. Triple Pole, Single-Throw, 2500-Volt, 300-Amp. Oil Switch with Solenoid Operating Mechanism and Disconnecting Device. Circuit Open

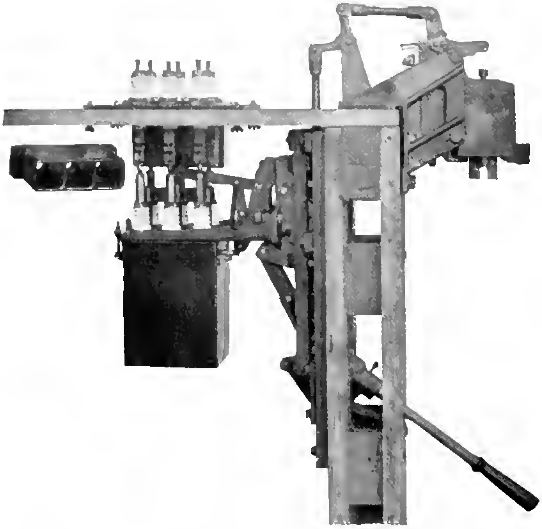


Fig. 6. Same Apparatus as Shown in Fig. 5 but here the Circuit is Closed

# SWITCHBOARDS AND DISTRIBUTION SYSTEM FOR THE PANAMA CANAL

By S. W. Mauger and Emil Bern

Switchboard Engineering Department, General Electric Company

For the generation and distribution of power for operating and lighting the Panama Canal, there have been erected two power stations and four substations. The power stations, one of which is a steam-electric plant (now held in reserve) and the other a hydro-electric plant, are located respectively at Miraflores and Gatun, while the substations are located at Cristobal, Gatun, Miraflores and Balboa. Alternating current is generated at 2200 volts and transformed at the Gatun substation to 44,000 volts and transmitted to the other substations, where it is re-transformed to lower potentials for local use. Wiring diagrams are included in the article which show the general system of transmission and distribution, and the arrangement of the transformers in the lock walls that supply low voltage current to the lock motors and towing locomotives. Descriptions are also given of the more important features of construction involved in the power station switchboards and control apparatus.—Editor.

In the operation of the great locks of the Panama Canal there is involved the necessity of generating and distributing electric current. The word "operation" is used above in the broadest sense, covering the control of the motors actually operating the lock devices, the locomotives for towing the vessels through the locks, the lights for the locks and government buildings, and the motors for the various duties not directly connected with the lock operation.

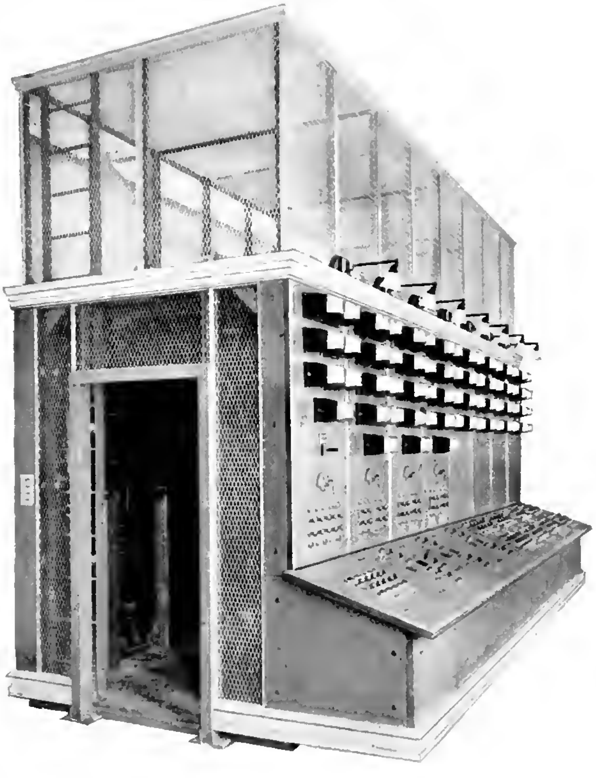


**Fig. 1. Instrument and Control Benchboard for Gatun Hydro-Electric Station, with Gallery for Field Rheostats**

Besides the usual requirements for operation, which are to some extent different from those found in the ordinary systems of power distribution, there are the severe conditions imposed by climate, the necessity of continuous service, in spite of being so far away from the manufacturer of electrical supplies, and the importance of having all parts as near "fool-proof" as possible. All this has entailed a great deal of study and care on the part of the Isthmian Canal Commission engineers in preparing the specifications, and on the part of the manufacturer in building the apparatus to meet these conditions.

The power distribution system is composed of:

1. A 2200-volt hydro-electric power plant at the Gatun dam spillway.
2. A steam-electric power plant at Miraflores erected a few years ago to supply power for construction work, but which will now be held for emergency conditions.
3. A double 44,000-volt transmission line across the Isthmus, connecting Cristobal and Balboa with the two power plants.
4. Four 44,000/2200-volt substations, stepping down at Cristobal and Balboa, and up or down at Gatun and Miraflores, depending upon which of the two plants supplies the power.
5. Thirty-six 2200 240-volt transmission stations for power, traction, and light at the Gatun, Pedro Miguel, and Miraflores locks.
6. Three 2200 220 110-volt transformer stations for the index and control boards at the three locks.
7. Similar stations to (6) at Cristobal and Balboa for coal handling plants, machine shops, and dry dock.

The Gatun hydro-electric station is located at the dam of the artificial Gatun Lake, so that the water from the wheels, together with that from the spillways, discharge into the original channel of the Chagres River. The present installation consists of three 2000-kw., 2200-volt, 25-cycle, three-phase General Electric alternators direct connected to 250 r.p.m. vertical Pelton-Francis reaction-type waterwheels provided with direct-connected exciters, as well as two induction motor-driven exciters with a generator voltage regulator. The station plans anticipate the possibility of three additional generators, should the Panama Railroad be electrified and its traffic be increased to require that amount of power. All switches for the control of machines and 2200-volt feeders are electrically operated (including rheostats, exciters, and field switches) by a storage battery, which also provides emergency lighting for the station through automatic transfer switches in case of failure of the alternating current lighting source.

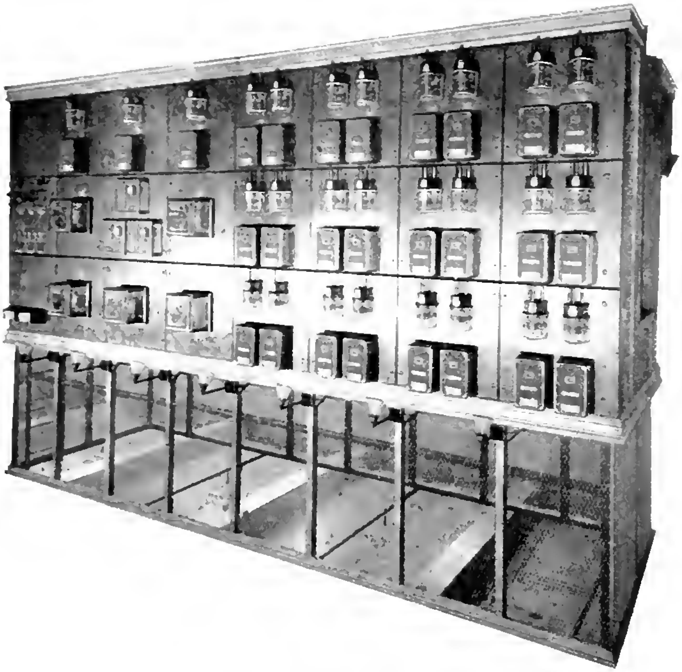


Fig 2. Meter and Relay Panels of Benchboard for Gatun Hydro-Electric Station

The system of connection is a double bus, double-switch scheme, with provision for completely disconnecting either oil switch for cleaning or repair without interrupting the circuit. The generator and feeder oil switches are all solenoid-operated and installed in concrete cells, above which are the concrete compartments for the two sets of busses. The busses and connections consist of copper rods firmly supported, which, after assembling, are covered by several layers of varnished cambric and asbestos tape. The bus compartments as well as all the oil-switch cells are enclosed by asbestos doors, and in a similar manner all current and potential transformers are protected.

The instrument and control board, shown in Figs. 1 and 2, is built of natural black slate, as are all the switchboards for this power system. It is totally enclosed by means of grille work, with doors at each end; a metal moulding surrounding the structure at the top and bottom giving a massive, yet artistic appearance to the whole. A novel feature of this construction is the gallery provided above the board proper for the electrically operated generator and exciter rheostats. This gallery is enclosed by grille work, and is accessible by means of a ladder inside the switchboard structure. On and above the bench are placed the control and instrument equipments requiring the attention of the operator, while the rear panels contain the relays, watthour meters, curve-drawing instruments, and the control battery equipment, including 'the automatic transfer switches for emergency lighting. Testing links are provided on the rear side of the panels so that connections can easily be made inside the board for testing the instruments, meters, and relays.

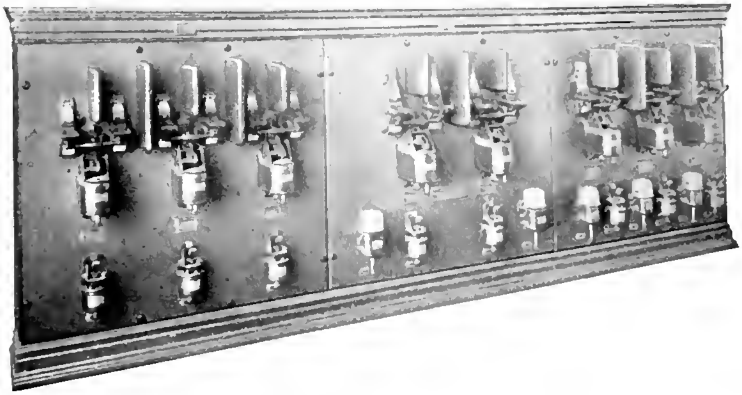


Fig. 3. 125-Volt Exciter and Field Switchboard for Gatun Hydro-Electric Station

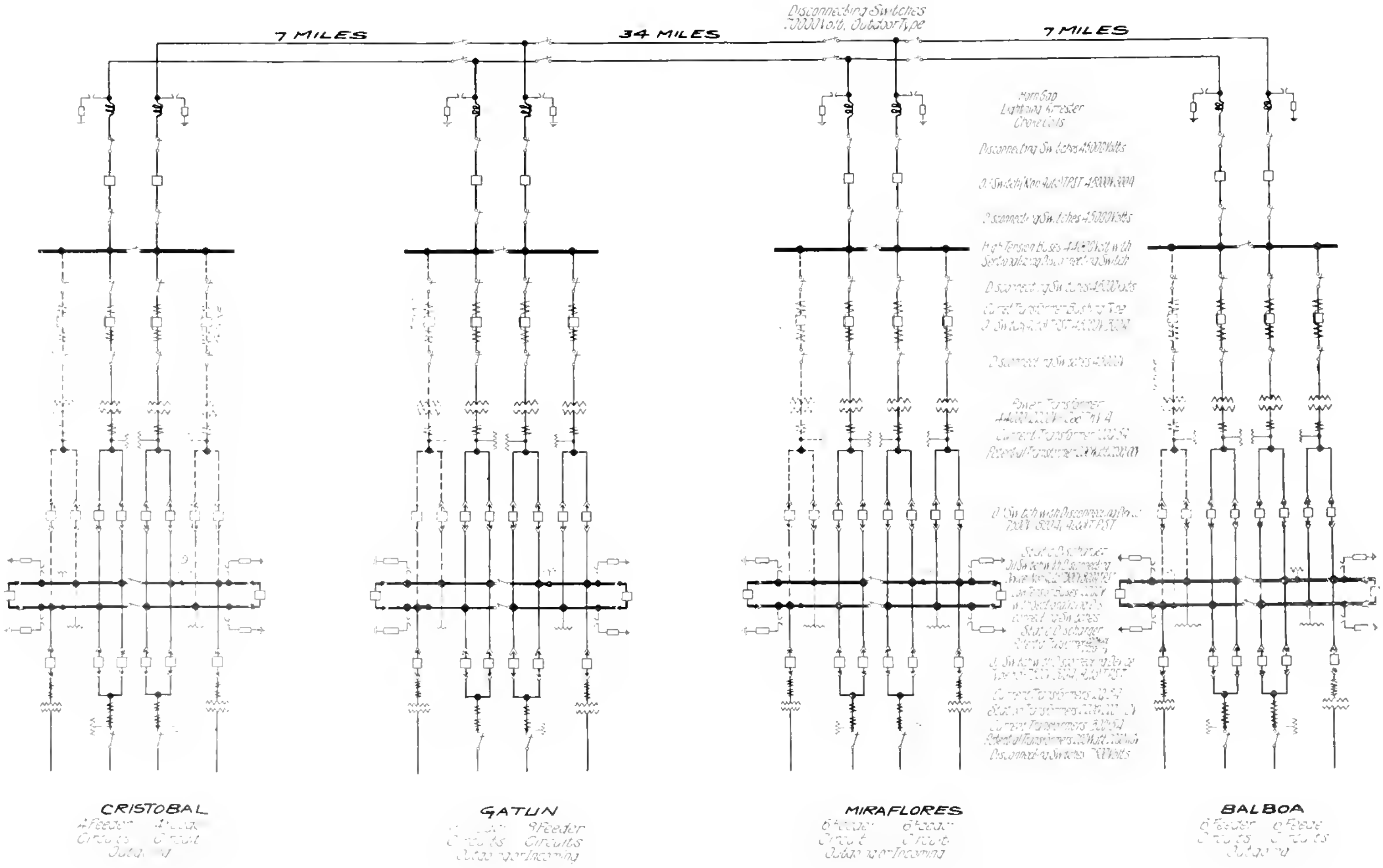


Fig. 4. Single Line Diagram of the Four Substations with High Tension Transmission Line Across the Isthmus

The field switches for the generators and the circuit breakers for the exciters are electrically operated and are mounted on a separate board, shown in Fig. 3. This eliminates the exciter busses and the main leads from the switchboard, but still leaves the control of the exciter equipment in the hands of the operator at the bench.

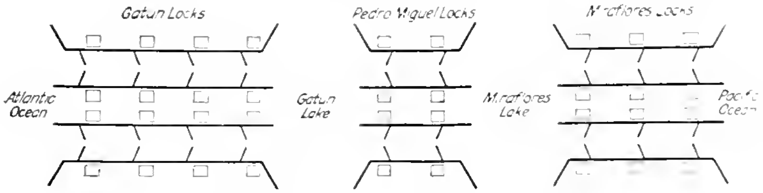


**Fig. 5.** Location of the Thirty-Six 2200 240 Volt Transformer Stations in the Concrete Walls of the Different Locks. For Simplicity the Main Gates only are Indicated

The 2200-volt feeders from this station connect with the incoming feeders in the Gatun substation, and thereby feed the whole transmission system as indicated by Fig. 4, which is a single-line diagram of the four substations with transformers and duplicate 44,000-volt transmission lines across the Isthmus.

These two three-phase transmission lines consist of No. 00 copper cables with ground conductors of the same size and material, all supported by steel towers placed on both sides of the relocated Panama Railroad. The duplicate steel towers on each side of the railroad are tied together by skeleton steel bridges, some twenty-four feet above the tracks, from which catenary trolleys may easily be suspended should the railroad be electrified.

The four substations are almost identical in size and equipment, although the number of 2200-volt feeders is somewhat different, as noted in Fig. 4. The Cristobal and Balboa stations have only outgoing feeders, as they are distributing stations for power to coal handling plants, dry docks, machine shops, etc., where the current is again transformed from 2200 volts to the most suitable voltage for the local conditions. The Gatun and Miraflores stations both receive and distribute 2200-volt current. As already stated, the Gatun substation normally feeds the entire transmission system from the hydro-electric plant; and from the 2200-volt busses in this substation the current for operating the Gatun locks is also distributed. The Miraflores substation is similarly arranged in order that it may, under emergency conditions, feed the transmission system from the

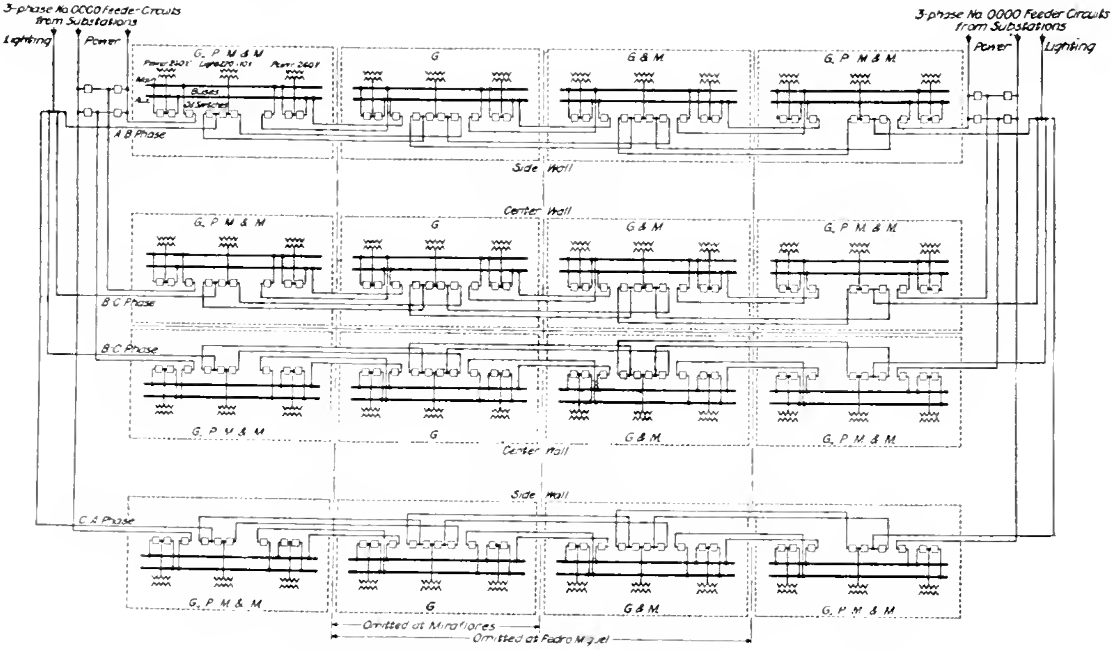


Fig. 6. Single Line Diagram of 2200-Volt Connections for the Thirty-Six 2200/240 Volt Transformer Stations. G indicates stations at Gatun Locks, PM at Pedro Miguel, and M at Miraflores

steam-electric plant, and also supply the current for operating the Miraflores and Pedro Miguel locks.

Each of the four stations is laid out to control four three-phase, 2667 kv-a., 44,000/2200-volt, self-cooled, radiator type, step-up or step-down transformers; all of these will, however, not be installed at present. There are also provided duplicate three-phase 35 kw., 2200/220/110-volt transformers for lighting, auxiliary power, and mercury rectifier for the control battery. The double-bus, double-switch system with disconnecting devices for the oil switches is used on the 2200-volt side; and, with the addition of bus-tie and bus-section switches, the flexibility of a ring bus has been obtained. To each section of the bus is connected a three-phase aluminum cell static discharger, because of the lead-covered cable forming part of the distributing system. The 44,000-volt lines are protected by aluminum cell lightning arresters and choke coils. All oil switches are solenoid-operated; those on the 2200-volt circuits being interchangeable with and arranged in concrete cells in a manner similar to the switches in the hydro-electric station. The high-tension switches on the transformers and line circuits are of the sliding-wedge, tank type, and all 44,000-volt busses and connections consist of copper tubing suspended from the station steel work.

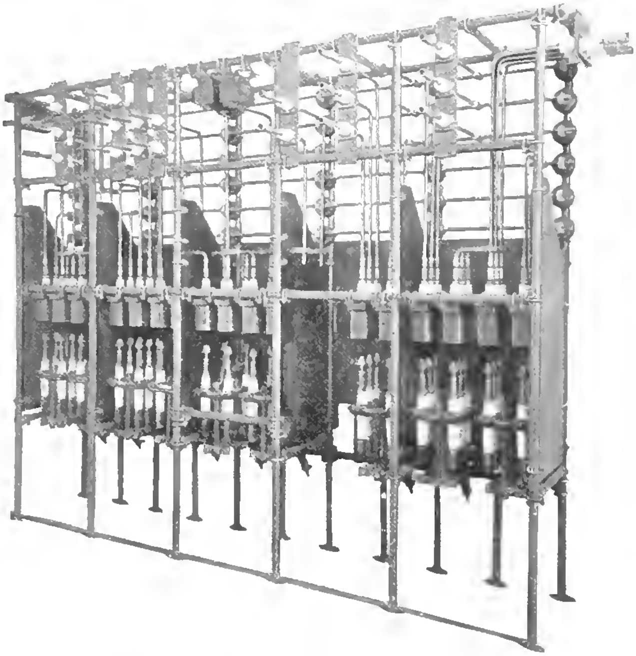


Fig. 8. Rear View of 2200-Volt Transformer Switchboard. Disconnecting devices open and oil switch cans removed

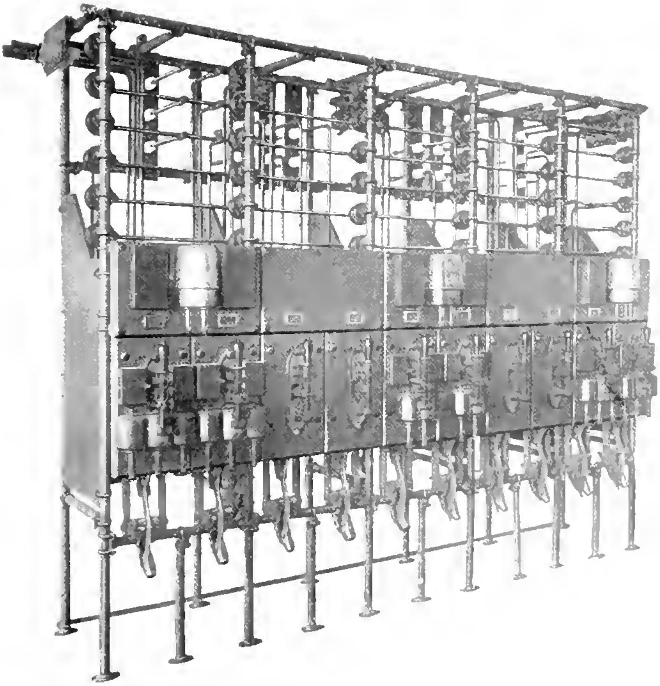


Fig. 7. One of the 2200-Volt Transformer Switchboards for the Locks. Elevated floor and grille work not shown

The switchboards for these substations are of the vertical type, consisting of three-section panels 24 in. wide. The control apparatus and mimic connections are symmetrically arranged on the middle section of the panels. A plain metal moulding finishes the top and bottom, as on the benchboard, Fig. 1. The rear of the board is enclosed by means of grille work, with doors at each end.

The motors for the lock machinery and towing locomotives require about 240-volt, three-phase current. On account of the great distances and the comparatively low potential, it is necessary to transform this current from the 2200-volt system in the immediate vicinity where it is to be used; therefore, a number of transformer stations are arranged in the concrete walls of the different locks approximately as shown in Fig. 5. Each of these stations contain duplicate 200 kw., three-phase, 2200/240-volt transformers for power; and one 25 kw., single-phase, 2200/220/110-volt transformer for lighting. Even here the double-bus, double-switch system is used, as shown in Fig. 6, which represents a single line diagram of the 2200-volt connections for the thirty-six transformer stations at the three locks. Without going into superfluous duplication, the Commission's engineers have evidently looked far into emergency conditions in planning the most flexible system on which testing, cleaning, and repairs can be performed without interruption of service. These transformer stations, while normally fed from the 2200-volt busses in the 14,000/2200-volt substations, can also be operated from the power plants; the ones at Gatun locks from the Gatun hydro-electric station, and the ones at Miraflores and Pedro Miguel locks from the Miraflores emergency steam plant. On account of the limited space for these stations in the concrete walls, the switchboards had, of course, to be very compact. Each station contains a high-tension and a low-tension board facing each other. Figs. 7 and 8 show front and back views of a 2200-volt switchboard as assembled at the factory with busses and connections in place. After installation the busses and connections, which consist of copper rods, are wrapped with varnished cambric and asbestos tape. The oil switches used on the switchboard illustrated in Figs. 7 and 8 are shown in Fig. 8 in open position, and disconnected from their circuits. Mechanical interlocks are provided, so that each set of two switches acts as a double-throw switch on the two sets of busses to which it is connected. Asbestos barriers are also installed between the different circuits as a safety precaution when working on a switch adjacent to a live circuit.

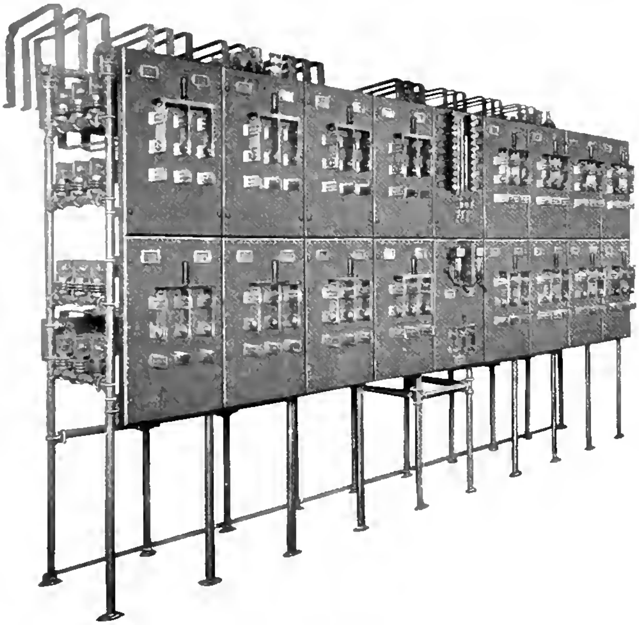


Fig. 9. A Low Tension Switchboard for Power, Traction and Light. Elevated floor and grille work not shown

The low-tension boards, one of which is illustrated in Fig. 9, are also equipped with duplicate sets of busses connected to the 240-volt secondaries of the two power transformers. By means of the triple-pole, double-throw lever switches any of the several power and track feeders can be connected to either transformer. From the hinge studs of the lever switches, the feeder circuits pass through link fuses mounted on slate bases back

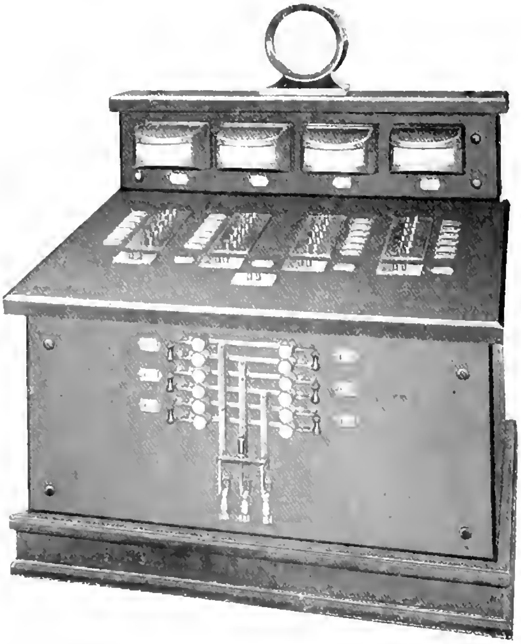


Fig. 10. Control Board for Exterior Lighting of Locks. Installed in the central control station at each lock

of the busses; and from the fuses, copper connections are made to the cable bells in which terminate the lead covered cables leading to the motors. The cable bells for the circuits connected to the lower row of switches are placed below the fuse bases, while those for the upper row are arranged on the wall just back of the board; and to these the copper connections run overhead, as shown in the upper part of the illustration. The center panel in this board is for lighting, and connects to the 220/110-volt three-wire secondary of the single-phase transformer. On this panel are also mounted two double-pole hand or electrically operated switches for the exterior lighting at the locks. For operating these switches in the several transformer stations, there is installed in the central control station at each of the three locks a small benchboard of the type shown in Fig. 10. The small control switches on this benchboard operate these lighting switches, either singly or in groups. The four ammeters at the top of the boards indicate the current in the four 2200-volt power feeders which supply each set of locks, as indicated in Fig. 6.

# NOTES ON PRODUCTION OF THE PANAMA CANAL SWITCHBOARDS

By W. B. Connolly

Switchboard Department, General Electric Company

This, the concluding contribution to our group of Panama articles, deals with some of the special features met with in this undertaking. Much of this special work was necessitated by the climatic conditions in the Canal Zone. Some of the special precautions that had to be taken against corrosion of metal parts and against the deterioration of insulation are cited. The article is concluded with a list of the quantities of the various materials used.—Editor.

As there were so many conditions peculiar to the Panama work which had to be followed throughout, it will be of interest to enumerate some of the most important. For instance, all small metal parts had to be non-corrosive, and were either made of copper, brass, bronze, Monel metal, or of sherardized iron or steel. All iron or steel parts had to be brush-painted with two coats of red lead and one coat of "egg shell" paint. No bolts, tie rods, studs or other threaded parts could be put through the sherardizing process without first being "undercut," to make allowance for the deposits. As far as possible, everything had to be moisture-proof, which meant that all solenoid, relay, circuit breaker, current transformer, and other coils had to be specially impregnated with non-hygroscopic compounds. Mica was largely used instead of fiber, and in many instances, such as potential and current transformer covers, cell doors, relay terminal blocks and barriers, cabinets, etc., asbestos lumber, specially treated, was used.

In the construction of the oil switches, disconnecting devices, operating levers, valve operating mechanisms, transmitters and indicators—such bearing surfaces as would have been in iron or steel were brass bushed. Bearing pins were made of Tobin bronze. Wherever possible, springs were made up of phosphor bronze. Small moulded parts were boiled in paraffine. Iron and steel parts, too long for sherardizing, such as tie rods, rolled metal sections, etc., were copper plated.

All gears, drums and idlers were cut from brass or aluminum. Structural steel members of frameworks, too cumbersome for non-corrosive treatment, were thoroughly "red-leaded."

Over forty of the fifty-eight thousand feet of copper rod and bar was machine bent and formed, insuring perfect uniformity of multiple parts. Instrument lead covers were made up of a special rawhide fiber, saturated with an insulating varnish.

Perfect alignment of all parts on the three lock control boards was absolutely imperative. The import of this condition can better be realized when it is recalled that in order to "condense" the boards to the Commission's requirements, certain clearances in and about the network of cross levers, shafts, control switches, motors, gears, etc., had been estimated down to three-sixteenths of an inch. The Commission wanted the Gatun board to be about 65 ft. whereas the permissible layout showed 81 ft. To settle this point satisfactorily with the canal engineers, it became necessary to make a full scale top view drawing, which was so large (81 ft.) that it was mounted on two rollers. To insure the unusual alignment necessary, all component frames were drilled, machined, hot-riveted to gauge.

The degree of accuracy called for in the government specifications was so exacting that much of the work on the position indexes and transmitters had to be done with watchmakers' precision. To meet these and other rigid requirements of interchangeability, necessitated the making of extremely accurate jigs, tools and templates.

It is interesting to note that some seventeen hundred and fifty drawings were made. This means about nine thousand detail part numbers, many of which again subdivide, totalling to something over twenty-two thousand individual parts entering in various quantities into the work. Up to November 1, 1913, seventy-three carloads of switchboard material had been shipped to Panama. The following list of approximate quantities will give some idea of the extent of the undertaking.

| | |
|---|---|
| Special slate bases | 1,300 |
| Small castings | 160,000 |
| Screw machine parts | 1,200,000 |
| Copper rod and bar | ft. 58,000 |
| Asbestos lumber | sq. ft. 9,000 |
| New patterns | 650 |
| New jigs, templates, tools, etc. | 625 |
| Porcelain parts | 18,000 |
| Special bus supports | 6,800 |
| Gal. pipe (framework) | ft. 21,000 |
| Special gears | 2,300 |
| Special indicator motors | 730 |
| Special instruments | 642 |
| Miscellaneous sherardized pieces | 300,000 |
| Cases for boxing | 4,150 |

# POWER FROM MERCURY VAPOR

By W. L. R. Emmet

Consulting Engineer, General Electric Company

The author states the general formula for obtaining the theoretical limits of efficiency in any thermodynamic process, and then cites the limits existing in actual commercial practice in the case of the steam engine, continuing to show the higher limits which can be obtained by the use of mercury vapor. Some important data concerning mercury vapor are given, and this is followed by the methods applied in the process of deriving power from mercury vapor. Both the advantages and disadvantages of the process are discussed. The apparatus used for generating power from mercury vapor will be described and illustrated in our February issue.
—Editor.

The theoretical limit of efficiency in a thermo-dynamic process is the ratio of the temperature range embraced by the process to the maximum absolute temperature used, $\frac{T-T_1}{T}$. In all processes available for commercial power development, the lower limit is fixed by the temperature of the cooling water available, and is therefore not susceptible of variation. The possible upper limit is the temperature which can be produced by our fuel when burned with air, which in practice is about 2700 deg. F.

The purpose of the process here described is to utilize some of the energy available in ranges above that which can conveniently be utilized with steam. The theoretical efficiency of steam processes can be increased by using higher pressures, but since with rise of temperature the increase of pressure is very rapid, and since the steam turbine has limitations in the efficient use of high pressure, prospects of gain in this direction are not very attractive.

Mercury boils at 677 deg. F. at atmospheric pressure and condenses in a 28 in. vacuum at 457 deg. F. It is therefore well adapted at least by pressure and temperature conditions for use in a temperature cycle above that now used by steam. Its use to greatly increase the temperature range available and so to increase efficiency is the object of the development here described.

Before going further, the writer desires to explain that the broad principle involved in this process was suggested to him by Mr. Chas. S. Bradley, who proposed and patented a process in which he intended to use certain other substances of high boiling point and relatively high vapor density. Consideration of the possibilities suggested by Mr. Bradley led the writer to study the characteristics of mercury, and from this study and a long course of experimenting the plans of procedure here shown and explained have been evolved. A set of apparatus suited to the production of about 100 h.p. has been nearly completed and it is hoped that experiments on a scale and of a character approaching commercial conditions may be made within a month or two. Anything so completely novel and so essentially complicated is naturally liable to delays, so that the prospect of successful tests cannot be confidently predicted. Since the process has been talked about and since a good deal of interest has been expressed, the writer has thought best to record his expectations and to make explanation of the plans which have so far been formed.

In studying the thermo-dynamic possibilities of a substance like mercury, we proceed exactly as we do in the case of steam, and for the sake of convenience it may be well to give here some data relating to the subject.

Boiling point of mercury at atmospheric pressure, 677 deg. F. (358 deg. C.).

Boiling point of mercury at 28 in. vacuum, 457 deg. F. (236 deg. C.).

Vapor density is in the ratio of atomic weight and absolute temperature; as compared with water it is therefore 6.56 times as great at the boiling point and 6.8 times as great at 28 in. vacuum.

Specific heat of mercury liquid, 0.0373.

Specific heat of mercury gas (constant pressure), 0.0248.

(According to Kurbatoff; Z. Phys. Chem. 43, 104, 1903.)

### Latent Heat of Vaporization

At 25 lb. abs. $r = 117$ B.t.u.
At 15 lb. abs. $r = 118$ B.t.u.
At 28 in. vacuum, $r = 121$ B.t.u.
At 29 in. vacuum $r = 121.5$ B.t.u.

(Calculated from formulæ by Kurbatoff.)

The boiling point of mercury at various pressures is shown by an accompanying curve, and curves are also given showing the energy theoretically available from mercury vapor within various pressure ranges. These curves are calculated from Rankine's formula:

$$E = 778\left(Q_1 - Q_2\left[1 + \log.\frac{Q_1}{Q_2}\right] + \frac{x_1 r_1}{Q_1}[Q_1 - Q_2]\right)$$

$E$ = energy in ft. lbs.
$Q$ and $Q$ = heat of liquid.
$X$ = dryness factor.
$r$ = latent heat.

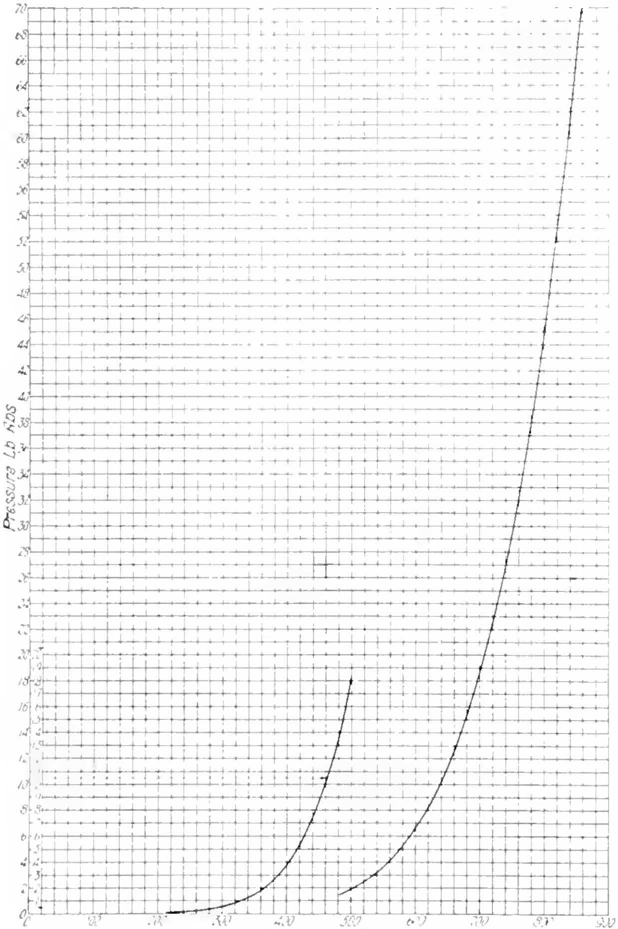


Fig. 1. Curve showing Boiling Point of Mercury at Various Pressures

The data above stated may not have been as accurately determined as that which is available for steam calculations, but its substantial accuracy is indicated by the fact that in our experiments the measured flow of vapor through nozzles has closely checked the calculations.

The method applied in this process may be stated briefly as follows: Mercury is vaporized in a boiler heated by a furnace of ordinary type. From this boiler, it passes at a pressure near or not much above the atmosphere, to the nozzles of a turbine which drives a generator or other utilizer of power. From this turbine it passes to a condensing boiler where it is condensed on the outer surface of tubes which contain water, and this water is vaporized by the heat delivered, and the steam produced is used to drive other turbines or for any other purpose. This condensing boiler is preferably placed at a level above the mercury boiler, so that the condensed liquid will run back into the mercury boiler by gravity without the aid of a pump. Since the mercury vapor is much hotter than the steam, the gases will normally leave the mercury boiler at higher temperatures than they have in leaving a steam boiler. To utilize this excess heat, in the gases, it is proposed to convey them, first, after leaving the mercury boiler through a heater which raises the returning liquid near the boiling point, second, through a superheater which superheats the steam delivered by the condensing boiler, and third, through an economizer which heats the feed water for the condensing boiler and so reduces the gases to the lowest practicable flue temperature.

By careful study and experimental development, which will be explained later, means have been devised for reducing the amount of mercury used, for effectively preventing its loss or dissipation, and for immediately detecting any failure in such prevention.

The disadvantages of mercury for such a process are: First; that it is very expensive, its cost being about 60 cents per lb. Second; that it is poisonous and is capable of pervading the atmosphere in a very finely divided state in the neighborhood of places where the vapor can escape. Third; there are certain difficulties in confining both the vapor and the liquid, although these, with proper methods, are not serious.

Mercury's advantages as a thermo-dynamic fluid for the purpose desired are many. First; its boiling points at desired pressures are convenient. Second; its high specific gravity makes possible the use of gravity feed, sealing of valve stems, etc., by gravity and centrifugal sealing of turbine packings. Third; at the temperatures used it is completely neutral to air, water, iron, and such organic substances as it may come in contact with. Fourth; it carries nothing in solution which can adhere to or affect heating surfaces; consequently the interior of boiler is always perfectly clean. Fifth; its vapor density is so high that it gives a very low spouting velocity, and consequently a very simple type of turbine can be used. Sixth; it does not wet the surface of turbine blades and consequently gives apparently no erosion. It is believed that the action between the vapor with its accompanying liquid and the blade surface will conduce to a high economy in a turbine, although no positive data on this subject has yet been obtained. Seventh; its volume at convenient condensing temperatures is such that it can be used in turbines without excessive bucket heights. One of the greatest limits of design in steam turbines is the large area required for the efficient discharge of the low pressure steam. With mercury vapor, this difficulty does not exist. Eighth; delivering its heat at the temperature and in the manner which it does, the condensing boiler in which this heat is used to make steam is very small and simple as compared with a steam boiler. Steam boilers transmit an average of about 6 watts per sq. in. with an average temperature difference of about 1100 deg. F. A surface condenser transmits 18 watts per sq. in. with 20 deg. F. temperature difference. The mercury boiler is about equivalent in dimensions to a surface condenser, and since there is no high temperature involved, there will be no possibility of scaling or burning.

Thus in this process we have low pressure and a clean boiler interior at the hot end, and small and perfectly distributed temperature differences at the low temperature end of the process where steam is made. High temperature, unequal distribution of heat, and the necessity for large heating surface constitute the principal difficulties of boiler construction. All of these are overcome in this method of making steam.

In this process the mercury vapor acts automatically as a conveyor of heat from the fire to the condensing steam boiler. If, through loss of load or other reasons, the mercury turbine admission is shut off, the vapor by-passes through a safety valve provided for the purpose, so that all the heat delivered to the mercury is immediately put into the steam boiler, except the fraction which is converted into power by the turbine.

Thus the fireman in this process will maintain steam pressure just as he now does. The steam produced will be used just as it now is in existing apparatus, and the output of the mercury turbines will be simply a by-product which is additional to the power which is now obtained. Studies have indicated that if this process works out as expected, the apparatus described can, in many cases, be put into the building space now occupied by steam boilers, so that the act of changing existing steam plants to this process should retain in use most of the existing investment.

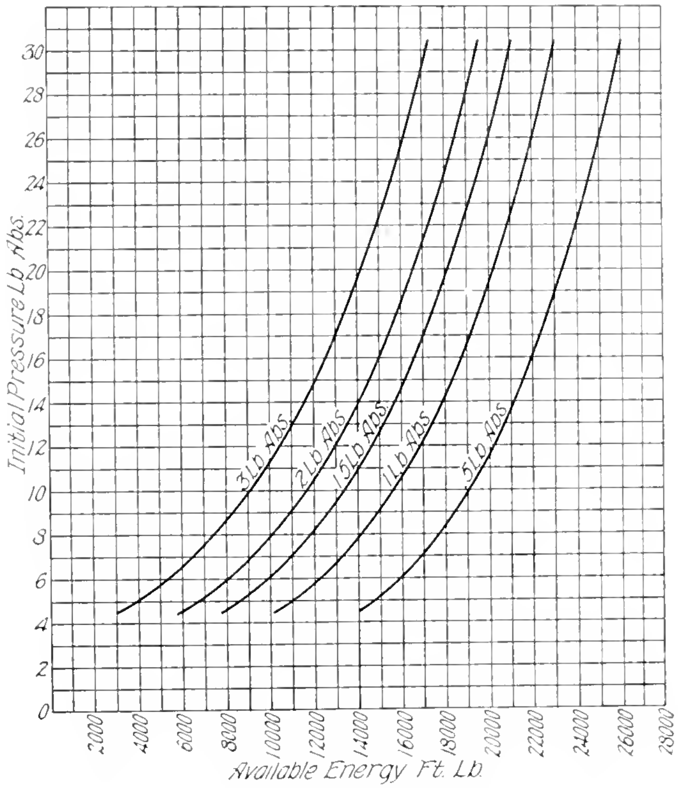
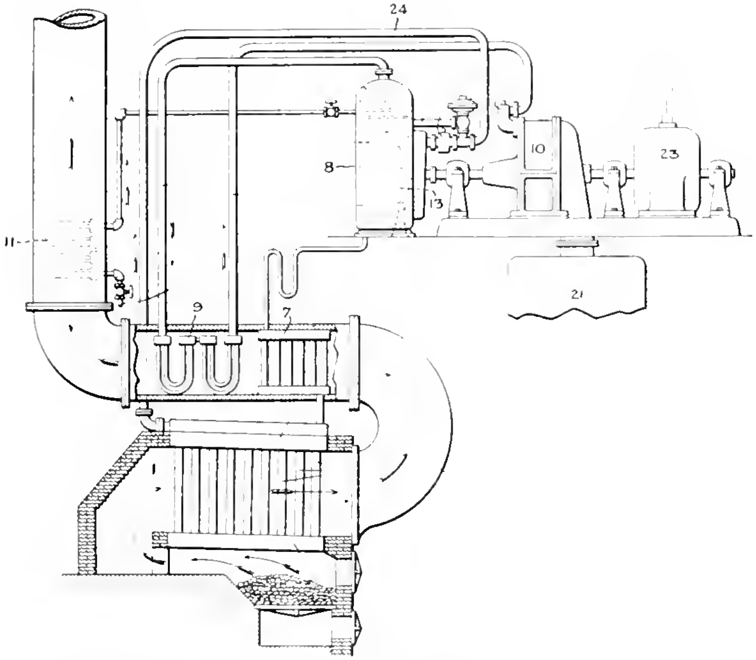


Fig. 2. **Energy Theoretically Available from Mercury Vapor within Various Pressure Ranges**

Before entering into the details of experiments or of the methods by which it is hoped to accomplish these results, it may be well to state the degrees of economy which should be accomplished if this development succeeds. Assuming heat deliveries to surfaces exposed equal to those in steam boilers under equivalent conditions of temperature difference, gas velocity, and radiation, and assuming a turbine efficiency equal to that of steam under equivalent velocity conditions, the calculation shows that in an efficient modern power station, the same amount of steam can be delivered to the turbines at the same superheat, thus giving the same turbine output, and that in addition about 66 per cent of the power so delivered can be delivered by mercury turbines, the fuel required being only about 15 per cent greater than that which would be used with the steam alone. Thus the gain in capacity of an existing station would be approximately 66 per cent and the gain of output per pound of fuel would be about 44 per cent. This calculation is based upon a mercury vapor pressure 10 lb. above the atmosphere and a vacuum of 28.5 in. at the steam turbine outlet.



| | | | |
|---|---|---|---|
| 1 | Mercury Boiler | 11 | Feed Water Economizer |
| 7 | Heater for Liquid Mercury | 13 | Mercury Turbine |
| | Condenser Boiler | 21 | Steam Turbine Condenser |
| | Superheater for Steam | | Electric Generator |
| 10 | Steam Turbine | 24 | Mercury Vapor Pipe |

Fig. 3. Diagrammatic View of Apparatus to Generate Power from Mercury Vapor

About 10 lb. of mercury would be evaporated for each pound of steam produced, the steam pressure being about 175 lb. gauge, superheat 150 deg., and the final temperature after the gas leaves economizer being about 300 deg. The vacuum in both steam and mercury turbines can be maintained by the same air pump, means being employed to separate all mercury vapor from the air in a suitable cooler. The vapor velocity would be about 1200 ft. per second, requiring only one turbine wheel

Since the mercury process can be super-imposed upon a non-condensing steam process as well as upon a condensing steam process, it is obvious that with the mercury combination the non-condensing plant can be made almost as economical as the best existing condensing plants, the percentage of output added by the mercury in such cases being greater than that which would be added by the use of condensers. It is also obvious that where the mercury process is added where steam is less economically used than in modern power stations, the gain will be relatively greater. The purpose of the process is to replace steam boilers wherever they are used and to obtain power from mercury turbines as a by-product.

Experimental data indicates that not more than $10 worth of liquid mercury per kilowatt output of mercury turbine will be required for such a process, and it is probable that with suitable arrangements, this amount can be considerably reduced. The general application of such a process would require immense quantities of mercury, but inquiry has indicated that the sources of supply are such that the largest conceivable demand for such a purpose would not permanently increase the price.

In the experimental applications of this process which have so far been made, the vapor has been produced in heating elements similar to those proposed for an actual boiler under the most severe condition of heat delivery by gas flow and radiation. The vapor has been carried from such boiler elements to a nozzle and this nozzle has been exhausted into a condenser from which the liquid was drained back into the boiler by gravity, the vacuum being maintained in the condenser by an air pump.

In these experiments, pressures and amounts of liquid condensed were measured, and these measurements show that the flow of vapor through the nozzle was in agreement with calculations from the data above stated.

In all the tests which have been made with these experimental elements, there has not been a trace of chemical action upon the mercury or steel, although air, water, oil, and various kinds of dirt have been present in considerable quantities, and although very extreme temperatures have at times been used.

Investigation of the conditions of heat transference and circulation in the production of mercury vapor has involved much labor in study and experimenting, and through this work certain data has been collected which in combination with known data concerning the action in different parts of steam boilers has been applied to the design of a boiler of considerable size which is now nearly completed. This boiler would appear to be the only part of the process which involves any difficulty, and it is hardly fair to expect that it will be in every respect satisfactory or in accordance with calculations, although the evidences in its favor seem to be very strong, and although every detail which enters into it has been the subject of successful experimenting. It is believed, however, that any difficulties which may arise can be corrected and that this process is practicable for approximately such results as have been stated. A turbine of suitable design has also been produced and a condensing boiler with all the auxiliary apparatus necessary to the trial of the process as it might be applied commercially.

*(To be Continued)*

# MECHANICAL REFRIGERATION

## WITH SPECIAL REFERENCE TO SMALL PLANTS

## PART II

By R. F. Massa

Manager of the General Refrigerating Department, H. W. Johns-Manville Company

Part I of this article, which appeared in the December issue, covered in a broad manner the generation of "cold," the method of calculating the necessary size of the generating machine for a given requirement, and gave a description of the common types of generating machines. The present part of the article, which takes up the utilization of the "cold" generated, explains the method of calculating, designing, and laying out drinking-water systems, refrigerators, and pipe mains. It concludes with a digest of the commercial systems of ice manufacture.—Editor.

### DRINKING WATER SYSTEMS

In a drinking-water cooling system, refrigeration must be supplied for three purposes:

First: To cool the water actually supplied to and drawn from the system.

Second: To absorb the heat flowing into the water as it circulates through the insulated mains.

Third: To overcome the friction loss of the water in the pipes.

Of these three, the heat inflow through the piping is very frequently the largest item. It follows, therefore, that the piping system should be as short as it can be made. This often results in better economy being secured by establishing more than one center for cooling and distributing the water.

It is understood, of course, that in practically all cases it is necessary to keep the water circulating in order to deliver it at satisfactory temperatures at the fountains. This involves arranging the piping system in loops. In some cases, however, the water can pass through a series of fountains and then, when it has warmed to the upper limit of palatability, a second refrigerating machine can be placed in the line to pull down the temperature again.

It is occasionally possible to arrange a system without loop circulation by simply bleeding away enough water at the dead end to keep the temperature at a satisfactory level. The cases where this arrangement can be used, however, are comparatively rare.

The information as to how to lay out a cooling system follows:

It will be necessary to determine the location of the water source, the temperature of the water supplied, and also the temperature desired at the fountains. This latter will usually be fifty to fifty-five degrees. Lower temperatures are, in general, too cool; temperatures above sixty degrees are unsatisfactory.

The location of the fountains should also be determined approximately, and some indication should be made of whatever barriers there may be to various possible piping arrangements, such as, streets, railway rights of way, etc.

The number of persons to be served at each fountain should be known approximately or assumed, and the quantity of water each person will use. This varies through comparatively wide limits. Usually, however, the amount runs from one to two gallons per person per day, the larger figure being taken from results in a large steel works. In schools, the figure will often run as low as one-half gallon per person.

A tentative lay out may now be made of the piping system, and the size of the pipe to be used may be assumed. The heat inflow through the piping system can now be calculated, assuming the insulation to be used and the approximate atmospheric temperatures.

The amount of water to be circulated through the system is determined by the rise of temperature permissible in the circuit. Having calculated the heat inflow, the quantity of water to be circulated may be determined if, say, a five-degree rise is decided upon as satisfactory.

It now becomes possible to calculate the velocity of the water and, by reference to a pipe friction table, the friction head may be calculated. If the assumed pipe sizes are such that the friction head is excessive, larger pipe must, of course, be substituted and the calculation repeated. In the same way, if a smaller size pipe would not run the friction up too high, the pipe size should be reduced on account of the reduced heat inflow that will follow.

One other consideration is of importance in determining the size of pipe. This is, the pipe should be sufficiently large that the opening or the closing of one fountain on the line will not cause an appreciable change in the pressure on any other fountain which may be running. In addition to the size of the pipe being sufficient for this purpose, it is necessary to have some storage of water in the line, either in the way of an air chamber or an elevated open tank to maintain the pressure. Storage is important also in order to take care of the variable demand which occurs in a great many cases, as, for instance, in schools at the noon hour and between classes, and at the noon hour in factories.

The selection of a proper drinking fountain is of great importance in refrigerated water systems. The preferable design, from the point of view of the refrigerating engineer, is one in which the largest portion of the water flowing is drunk. From this point of view, the so-called bubbler type, which operates continuously, is much less satisfactory than those in which a jet of water, about the size of a lead pencil, rises to a steady height upon the opening of a spring faucet. In this latter kind of fountain the larger part of the water flowing will often be drunk; whereas, in the former designs, by far the larger part of the water is wasted.

## DESIGN OF REFRIGERATORS

### Disposition of Cooling Surfaces

No attempt will be made to describe all of the many arrangements of refrigerated compartments found in service. The intention is to point out some of the more important things to be considered in determining the design of a box.

It is desirable in a refrigerator to produce not only a low temperature, but a relatively dry atmosphere. To secure a box of satisfactory dryness it is necessary to have a relatively low temperature in the refrigerant. The air which passes over the cooling surfaces is practically in a saturated condition when it leaves them. If it is to be "dry", at the temperature required in the box, it must therefore have been cooled well below the box temperature. For instance, in a box held at 35 deg. F. the brine should be run at a temperature of about 20 to 25 deg. F. It is further desirable to so locate the cooling surface that the frost in melting will pass

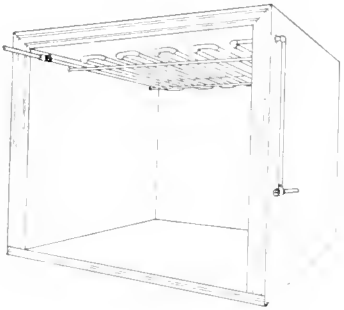


Fig. 15

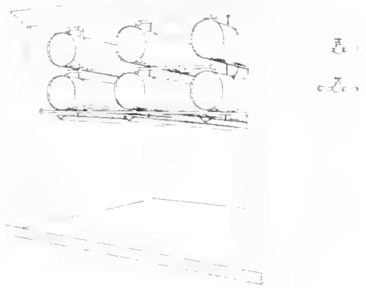


Fig 16

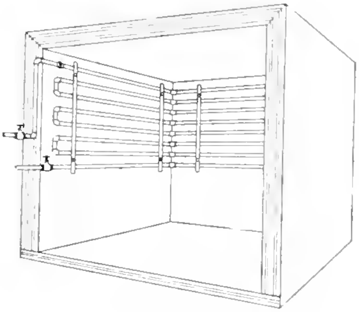


Fig. 17

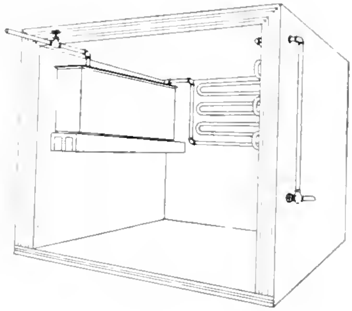


Fig. 18

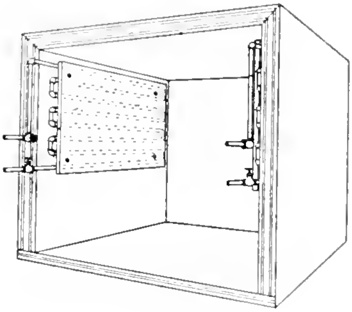


Fig. 19

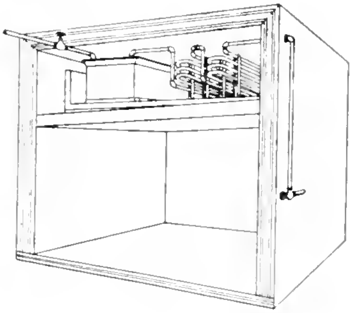


Fig. 20

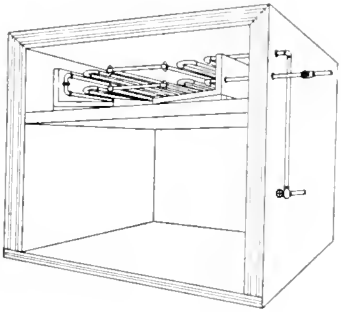


Fig. 21

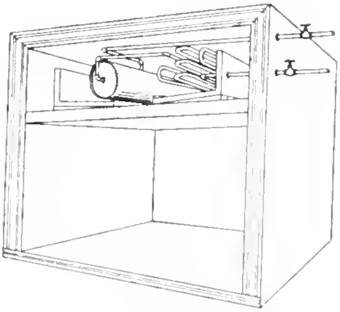


Fig. 22

Various Cooling-Pipe and Tank Arrangements in Refrigerators out of the box quickly and not remain to be re-absorbed by the air in the box.

The following arrangements of cooling surface in refrigerators are the ones commonly used. In Fig. 15 the coils are arranged overhead, but directly in the compartment to be cooled. This is one of the most efficient ways in which cooling surfaces can be arranged, so far as the cooling effect alone is concerned. It is not in general a good arrangement, however, since any frost melting from the coils drips onto the goods.

A modified form of this arrangement gives excellent results. This is illustrated in Fig. 16, in which closed cylindrical brine tanks are arranged horizontally and carried from the roof of the box. Drip from melting frost is caught in the insulated troughs shown. These troughs may be made quite narrow as all of the drip runs to the center line of the tank before it falls. It is advisable to insulate the drip troughs because they are apt to become cold enough while the box is shut that moisture will condense on them when the box is opened again, with the result of some little dripping in case they are not insulated.

The arrangement shown in Fig. 17, with the cooling surfaces on the wall, is to be preferred to the ceiling arrangement, so far as drip is concerned. It has the disadvantage that goods placed close to the wall are apt to be over-chilled, while goods near the center of the compartment are not cooled quickly enough. It also wastes floor space, because it is not practicable to pack goods close to the coils on account of possible over-chilling, also because of the liability of retarding the air circulation. The wall arrangement of cooling surfaces is, nevertheless, often the most practicable method.

Fig. 18 indicates a modified form of wall coil arrangement, where a brine storage tank is used to assist in maintaining the temperature when the machine is shut down.

A further modification is often introduced as shown in Fig. 19, in which a partition or baffle plate is used in front of the coils.

The best type of box arrangement is that embodied in the various refrigerator sections shown in Figs. 20, 21 and 22. In all of these designs the cooling surface is separated from the storage space and is so arranged as to secure an active circulation of the air over the coils and through the compartments.

In all of these designs the one point calling for the greatest care is that the air passages shall be as direct as possible and be of ample size. The force causing the air to circulate, viz., the difference in weight, due to difference in temperature and density between the column of air in the coil compartment and that in the storage compartment, is so extremely small that any slight interference is a serious matter. An extra turn in the passage or a slight reduction in the size of the passage will produce a marked effect. A good rule to follow is to make the passage as large as possible without allowing drip to reach the storage compartment. This will work out in many cases to give a ratio of one to eight or nine between the area of the passage and the floor area of the compartment, but even one to six is just that much better if it can be secured.

The matter of proportioning the size of the air passage is of much less importance where the air is circulated by fans. Forced circulation is not usual, however, except in large storage refrigerators.

It is important in arranging cooling surfaces, especially in small and frequently opened boxes, to avoid undue cooling of walls or ceilings that are exposed to currents of warm air when the door is opened. Moisture from the incoming air deposits on these surfaces, causing the offensive so-called "sweating" of the box. This is most often seen on the storage compartment side of non-insulated coil compartment floors or partitions, and also occurs on walls or ceilings where the cooling pipes are set very close to these surfaces. The obvious and effective cure is to insulate the partition between coil compartments and storage compartments, and to keep cooling surfaces well away from the walls or ceilings, e.g., 3 in. to 8 in., depending upon the temperature of the brine.

### Calculating Necessary Cooling Surface

No hard and fast rule can be given regarding the proper amount of cooling surface for compartments of various sizes, since the design and arrangement of the cooling surface and the freedom with which the air circulates over it greatly affect the amount required. As a guide, however, and where the conditions are such as to permit good circulation of the air, the following formula will give good results. It will be understood, of course, that the refrigeration required in the given room has been determined as indicated in the section on "Calculating Machine Capacities."

The cooling surface required, in square feet, per ton of refrigeration equals $\frac{4700}{T-t}$, where *T* equals the temperature desired in the compartment, and *t* equals the average temperature of the brine.

### Incidental Notes on Refrigerators

(a) *Drawers:* In restaurant kitchens and elsewhere, it is sometimes convenient to have a box fitted with a number of refrigerated drawers. Here the heat leakage is very great, due to the slides invariably being only partially closed and to the poor insulation of the drawers. Where it is at all possible to do so, it is best to arrange an insulated door to cover the entire drawer space.

(b) *Ante-Rooms:* In storage rooms of medium or large size, the air interchange caused by the opening of doors is reduced to a minimum by arranging an ante-room or entry with double doors. This arrangement permits the outer door to be closed before the door to the storage room proper is opened. Where two rooms are side by side, it is often possible to reduce the air interchange by treating the one as the ante-room of the other, having but one door open to the outside air.

(c) *Doors:* Special note should be made as to the design of doors for refrigerated rooms or boxes. There is a common idea that a refrigerator door should be beveled, but as a matter of fact no more certain means of insuring air leakage could be devised.

A perfectly fitted beveled door, if hung accurately, could perhaps be made tight in the beginning, but in service it at once begins to sag, since a refrigerator door is always heavy. It immediately becomes impossible to force it to a tight seat and continuous air leakage begins.

A refrigerator compartment door is most readily made tight by having a flat surface on the door come up against a corresponding surface on the frame, with a soft gasket of some kind between them.

There are several well-made refrigerator doors on the market at prices low enough to make it of doubtful economy to attempt the home-made article.

### Arrangement of Brine Mains

In laying out mains to carry brine from the refrigerating machine to the refrigerator, there are a few simple points which require consideration.

For the convenience of the pipe-covering man, the flow and return lines should be placed sufficiently far apart to enable him to cover each pipe without cutting the covering or else they should lie side by side so as to be covered together.

A common difficulty experienced in brine systems of refrigeration, where the cooling coils in several compartments are fed from the same main, is that when a change of adjustment is made in the valve controlling the flow of brine through one coil it upsets the adjustment of the whole system. This is due to the mains or the pump being too small or both. A similar action is observed when the opening of a faucet on a water pipe checks the flow from other open faucets on the line.

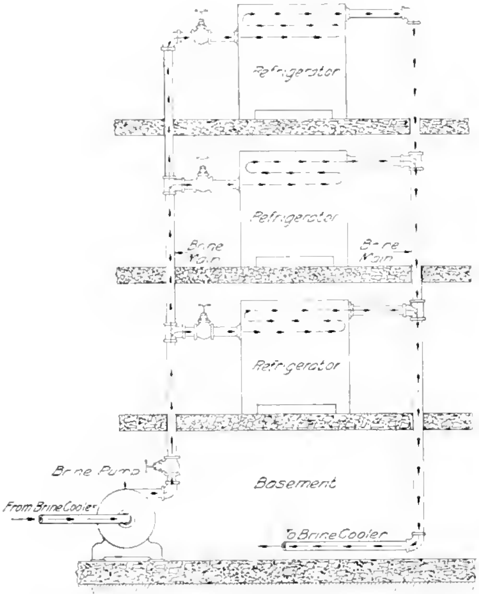


Fig. 23. A Method of Laying Out Brine Mains Which May Cause the Draining of the Top Cooling Coils

The ideal cross-sectional area of the brine mains is as nearly as possible equal to the combined cross-sectional area of all the coils which they serve at any one time.

Even with this proportion, however, it is not possible to absolutely insure that the lower coils will not rob the upper ones, or even drain them completely where the system is piped as shown in Fig. 23.

A most effective, even if somewhat expensive method of overcoming this difficulty, is by the addition of a third main, as indicated in Fig. 24. In this arrangement it is not possible for one coil to rob another to the point of draining it.

## ICE MAKING

### Physics of Ice Making

If the following physical facts are kept in mind, in considering methods of making ice, the results obtainable may be better understood or predicted.

(1) Chemically pure water will freeze solid and clear.

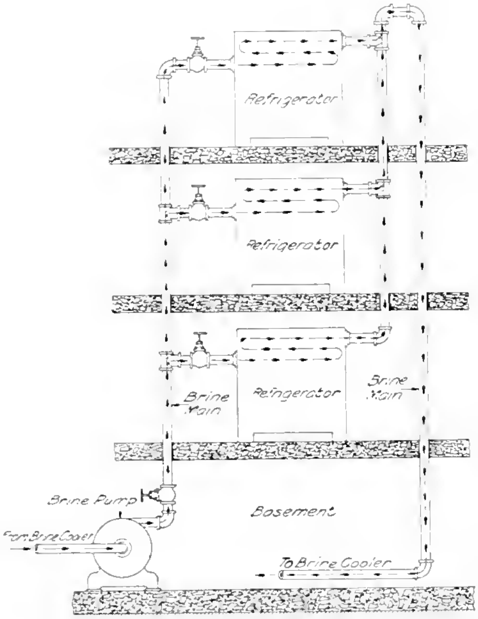


Fig. 24. A Method of Laying Out Brine Mains Designed to Prevent the Possible Draining of the Top Cooling Coils

(2) Water containing impurities in solution tends in freezing to force these impurities out of solution. The slower the process of freezing the more completely is the purification effected.

(3) Ice forming in still water sends out long slender crystals which increase in number and size, forming a mesh work that gradually becomes a solid mass.

(4) Agitation of water during freezing aids in the separation of impurities and facilitates the forming of solid, clear ice.

(5) Practically all natural waters contain more or less organic or inorganic material in solution and invariably contain air. These substances as they pass out of solution during the freezing process tend to make the ice formed opaque, those that are light tending to rise and collect near the surface and the heavier ones tending to sink.

(6) The rate of freezing of ice decreases directly with the thickness already frozen. Therefore, the time required to freeze increases in proportion to the square of the thickness to be frozen. In the formation of natural ice the freezing is from the top down and the impurities which are frozen out of solution fall. This and the motion of the water, especially in quiet running streams, tends to make natural ice freeze transparent American manufacturers of ice have always tried to duplicate this clearness.

### Distilled Water Ice Making

The method first adopted in this country was to use distilled water. From a sanitary point of view such ice would be theoretically ideal.

Practical difficulties, however, make it almost impossible to produce pure ice in this way. Some of these difficulties are:

(1) The removal of oil from distilled water. Engine cylinders are lubricated by allowing oil to drip into the steam supply, and some, if not all, of this oil is ultimately carried out in the exhaust. It is very difficult to remove the oil, and it is practically impossible to remove it if any organic oil is present.

(2) The lack of assurance that the filters are in proper condition. This assurance is often impossible to obtain, since this apparatus is ordinarily used throughout the season without overhauling.

(3) The possibility of contamination in the storage tank where the distilled water is held and usually "pre-cooled" to as near 32 degrees as possible before passing to the freezing cans, thus saving time in the freezing process in the tank.

(4) The possible contamination from handling the cans and the wooden covers over them. These covers form the top of the freezing tank in which the cans of water are immersed in cold brine for freezing, and are tramped over by the ice harvester with the consequent possibility of dirt getting into the cans.

### Plate System of Ice Making

A second system of ice making in common use in this country is the "plate system." In this process the ice is formed on vertical steel plates. Natural or raw water is used and the bath is agitated by various methods. The ice thus produced is very clear and dense.

In this system when the ice is formed to the desired thickness, usually about 12 inches, it is loosened from the freezing plate by various thawing arrangements in different forms of the apparatus. The ice plates, often nine feet by sixteen feet by twelve inches in thickness, are lifted from the tanks by overhead cranes and carried to a table where they are cut to commercial size.

While the plate process is usually very slow on account of the fact that the freezing is from one side only, it is largely employed because it permits the using of an economical steam engine. In the old style, distilled water, ice-making plant the amount of steam that must be provided in order to get sufficient distilled water to fill the ice cans was more than an economical engine would use in driving the refrigerating machine to freeze this ice. There is therefore with this type of plant nothing to be gained by installing an economical engine.

### Raw Water Can Ice Making

One modified form of the above systems now coming into considerable favor is arranged so that stationary cans are filled with raw water, which is constantly agitated by air bubbling up through the water. When the freezing has progressed part way, the remaining water is drawn off and replaced by fresh water, thus removing most of the impurities that have been frozen out of solution. Fig. 25 is a diagram of the freezing chamber of a representative installation of this type.

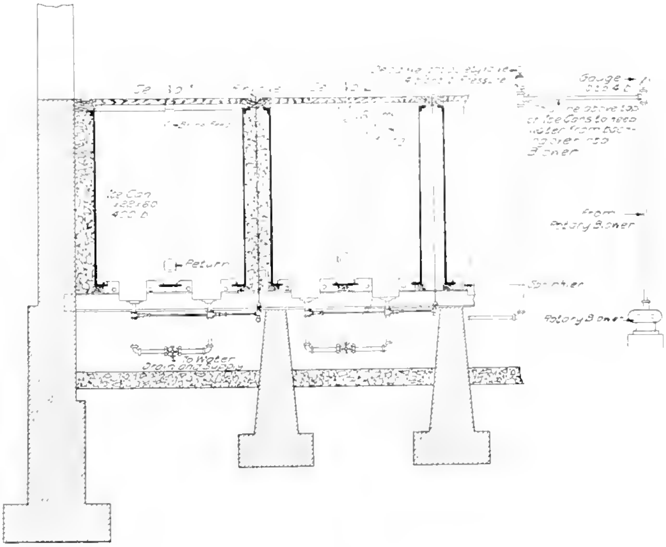


Fig. 25. Sectional View of the Freezing Chamber of a Stationary Can Ice Plant for Making Clear Ice from Raw Water

### General

Various other modifications of these systems of ice making have been and are being developed. All of them depend, however, upon the series of physical facts noted at the beginning of this section.

## RELATIVE ECONOMY OF MECHANICAL AND ICE REFRIGERATION

### Cost of Ice

In determining the cost of refrigeration by ice, account must be taken not only of the cost of the ice, but of meltage, of uncertain ice harvest, of the amount of ice left over at the end of the season, and of that which freezes together in the storage and becomes therefore practically useless.

Regarding the meltage, this may run anywhere up to fifty per cent of the total ice harvest. As to what will be the quantity of ice left over at the end of the season it is impossible to make estimate. In many cases, however, it is a very large item.

The loss by the ice freezing together in the storage can be reduced to a very small quantity if the ice is properly packed with distance strips between the ice cakes. Proper packing is much more readily carried out, however, where artificial ice is stored than where natural ice is held, and a mechanically-cooled ice storage is less subject to this difficulty, since the temperature is, of course, held constantly below the melting point of ice.

### Items Making up Cost of Mechanical Refrigeration

The cost of refrigeration produced mechanically is made up of power, water, oil, refrigerant (usually ammonia), labor and attendance, insurance and interest and depreciation on the investment. The figures on these items vary between wide limits. The following figures, however, will be of interest as they are taken from the annual costs of an ice manufacturing company having a capacity of 1500 tons per day in plants ranging in size from 50 to 100 tons per day each.

| | | |
|---|---|---|
| Coal | $0.40 | per ton of ice produced |
| Labor | .50 | " " " " " |
| Ammonia | .10 | " " " " " |
| Water | .05 | " " " " " |
| Wasted power, oil, etc. | .10 | " " " " " |
| Total | $1.15 | " " " " " |

# A MINIATURE ELECTRIC NIGHT LAMP

By John T. H. Dempster

Research Laboratory, General Electric Company

In this article the author defines the field of this new device, describes its construction, names its electrical characteristics, and furnishes figures on its cost of operation.—Editor.

With the advent of electric light the need for a small low candle-power lamp has been felt. Up to the present time this has not been successfully met. To fill the need of a small electric light, which could be applied to the ordinary distribution voltage and yet be of sufficiently low watt consumption to create a wide-spread use as a night light, a combination transformer and drawn-wire tungsten lamp has been developed.

It is well known that hospitals and sick rooms demand a lamp of low candle-power in order that the nurse or attendant may seek assurance as to the patient's comfort in the matter of bedclothes, ventilation, or temperature of the room, all without the disturbance incident to the operation of switches and the glare of high power lamps. There is a wide field for such a miniature lamp, however, that has been previously handicapped by the much greater total current consumption of the previously lowest candle-power lamp that has been available to be burned directly on the service voltage.

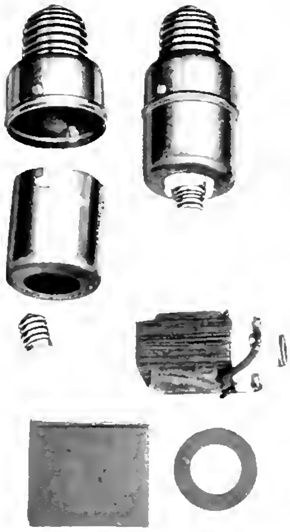


Fig. 1. Exploded and Assembled View of Night Lamp

In a residence, such as the average flat or cottage, a night lamp burning in the hall, bathroom, sitting room, or at the cellar stairs during the evening or all night is a convenience to be tried to realize its value fully.

In the matter of cost of operation, a small lamp such as has been heretofore available, taking about 20 watts, would, if used as a night lamp burning 10 hours per day for 30 days, cost in the neighborhood of 50 to 60 cents per month, figured according to the prevailing rate for energy. This is a prohibitive figure for the ordinary householder, and would not tend to make universal the use of electric service during the night.

However, the device herein described will, at a cost of only a few cents per month, sufficiently light the rooms in an ordinary house throughout the night to permit a person's safely passing to and fro. As an example of an average house, the installation would probably be as follows: one lamp located at each of the following places; the name and number-plate on front door, front hall, bathroom, one bedroom, and cellar or rear stairs, making in all five lamps. The energy required for the five transformers and lamps would be about 6 watts, and for 30 days at four hours per night would cost about 7 cents. For a 10-hour night service the cost would only amount to about 18 cents per month. Such a low cost of operation for light in so many places warrants the all night use and makes a pleasure of what would otherwise be a burdensome luxury.

The complete device consists of a miniature transformer contained within a brass shell and adapted to screwing into the standard lamp socket in place of the usual incandescent lamp. The shell carries at the other end a candelabra socket to take miniature plain or frosted lamps which are ordinarily rated at about one candle-power.

The miniature transformer is wound to operate on 60-cycle alternating current circuits of 100 to 125 volts. It is well insulated, of course, and has a shell-type laminated iron core working at moderate magnetic density. The windings operate at an ordinary current density, are separately insulated, and have a ratio of 10 to 1. The temperature rise of the transformer in operation is barely perceptible, being usually only about one or two degrees, which proves the high economy of the device. At no load the average energy taken by the transformer is about 1/5 of a watt; and when loaded with a lamp giving about one candle-power, the input is about $1\frac{1}{4}$ watts.

The device fills a long felt want for a very small light unit which can be operated alone or in groups without having to recourse to wasteful dead resistances or several lamps in series to consume the average 110 volts of the lighting circuit.

# NOTES ON INTERNATIONAL STANDARDIZATION OF ELECTRICAL MACHINERY

By A. R. Everest

Chief A-C. Designing Engineer, The British Thomson-Houston Company

On the 10th of last month the Institution of Electrical Engineers (of Great Britain) held a meeting at Birmingham, at which International Standardization was the subject under discussion. On this occasion Mr. A. R. Everest, who was a delegate at the recent Berlin Conference of the International Electrotechnical Commission, contributed the following paper which sets forth particularly clearly the objects in view and the extent to which these objects have been accomplished. As explained by Mr. Everest, there was complete international agreement in the matter of standardizing temperature values which shall be regarded as representing approved practice for continuous operation, but which shall never be exceeded. The prospective international ambient temperature of reference is 40 deg. By deducting this value of 40 deg. from the standardized values for permissible observable temperature given in the table in Mr. Everest's article, we obtain values for the limiting temperature rise to which the international rating of any machine will correspond. As soon as this value of 40 deg. for the ambient temperature of reference is officially adopted by the I.E.C., a machine can be stated to have an international rating of, for example, 1000 kw. when, with an ambient temperature of 40 deg., a load of 1000 kw., will not occasion higher "observable" temperatures than those set forth in the table in Mr. Everest's article.—Editor.

In order to properly discuss the work of the International Electrotechnical Commission it is necessary to clearly distinguish between an "international standard of quality" and an "international rating" for machines.

The rating of a machine is the output for which it is sold and which is marked on its name plate (rating plate). This output is the "rated output" of the machine.

(*a*) *I.E.C. Standard of Quality.* If the rated output of a machine is such that when working under the particular cooling conditions for which it is designed the machine keeps within the I.E.C. limits of temperature, this machine, for its particular application, conforms to I.E.C. Standard of Quality.

The I.E.C. Standard of Quality is valuable particularly for important individual and special applications. Various machines in this class from different sources would still not be directly comparable since they would not have equal temperature rise if primarily intended for different conditions.

(*b*) *I.E.C. Rating.* If the rated output of the machine is such that *when working under the I.E.C. standard conditions of cooling,* the machine keeps within I.E.C. limits of temperature, the rating of this machine is the I.E.C. Rating.

Thus the I.E.C. Rating establishes temperature rise as well as maximum temperature. All machines with the I.E.C. Rating would be directly comparable amongst themselves since they would all have the same temperature rise at their rated output.

The rules adopted at the recent I.E.C. meeting in Berlin establish the I.E.C. Standard of Quality (as regards temperature) for electrical machinery.

Agreement was not reached upon the further question of an I.E.C. Rating, due to differences of opinion regarding the value for cooling air temperature.

Before referring further to this feature it may be well to briefly review that part of the work which has been completed by the I.E.C.

These rules are the outcome of deliberations in the various National Committees and at the meetings of the Special Committee on Rating held in Paris, Zurich and in Berlin prior to the Plenary Meeting.

The rules so far adopted are based on considerations of the highest safe temperatures for various insulating materials, the joint effect of time and temperature, also probable difference between observable temperature and maximum internal temperature.

From these considerations international agreement was reached regarding permissible limits of temperature for various insulating materials employed in modern electrical machinery.

In connection with these permissible temperature limits, rules are provided regarding the proper determination of the temperature of the cooling air, a knowledge of which is necessary to ascertain the temperature rise which must not be exceeded at the rated load of the machine.

Finally rules are provided dealing with differences which may exist between the temperature rise on test and under service conditions due to variations in cooling temperature, and barometric conditions.

Thus the I.E.C. Standard of Quality has now been established as regards temperature, and therefore life, for any machine working under the conditions for which it is sold.

### Method by which Temperature is to be Observed

(1) While the hottest internal temperature at any point affects the life of the insulation affected, the I.E.C. does not consider

it feasible to make this the subject of ordinary commercial investigation. Information obtained from laboratory investigations with exploring coils and thermo-couples built into specially prepared machines appears to justify the conclusion that for modern machines wound for not more than 4000 volts or for transformer coils for not more than 10,000 volts, the hottest internal spot will not exceed the temperature *observed by ordinary methods* by more than ten degrees C. Accordingly the limiting *observable* temperatures permitted which are shown in the table on this page apply to measurements by rise of resistance of the winding (wherever practicable) together with the use of thermometers, the highest reading found being always considered.

Electrical thermometers and thermo-couples applied to any accessible part of a completed machine are classed with thermometers.

### The Question of Overloads

(2) A great deal of confusion exists between different countries at present concerning the relation between the so called "full load" rating of a machine and the highest load it is actually expected to carry. Further, the various overloads are rated for different lengths of time and in some cases are not allowed at all when the machine has been heated up by its ordinary "full load."

The I.E.C. has decided that any machine intended for continuous service should be ordered, designed, and rated for the highest load it is expected to carry, and that it should be capable of carrying this rated load continuously without exceeding the temperature limits of the table given herewith. No overloads are permissible beyond this rated load.

In the case of a machine subject to peak loads in excess of the ordinary load; if the peak endures for more than a short time it must be included in the rating. But if the peak load is to be endured for brief periods only, the rating must be sufficiently above the ordinary load to give a continuous thermal capacity equivalent to that required on the brief peak loads without exceeding the permissible temperature limits.

### Intermittent Service

(3) A machine for intermittent service may for the purpose of test have either a continuous rating which is thermally equivalent, or a "short time" rating which, when starting cold, and running at rated load for the specified time, shall not at the end of that time occasion temperatures in excess of those allowed by the table.

### Permissible Limits of Observable Temperature

(4) Upon these considerations the I.E.C. decided to standardize limiting values for temperature which should apply to "observable temperatures" measured by the means and methods specified and which should be set with due allowance for such excess internal temperatures above those "observable," as would be associated with the approved methods of test.

The temperatures were to be such as might be endured continuously without prejudice to a reasonably long life, but they were to be limits which *must not be exceeded.*

Accordingly values have been standardized as shown in the following table.

### LIMITS OF "OBSERVABLE" TEMPERATURE ADOPTED BY THE I.E.C. SEPTEMBER, 1913

| | |
|---|---|
| Non-impregnated cotton | 80 deg. C. |
| Impregnated cotton or paper (general) | 90 deg. C. |
| Impregnated cotton single layer field coils stationary or moving | 95 deg. C. |
| Impregnated cotton stationary coils solidly impregnated throughout | 95 deg. C. |
| Impregnated cotton rotor and stator windings having the slot portion solidly impregnated or moulded | 95 deg. C. |
| Enamelled wire (without cotton) | 105 deg. C. |
| Mica, micanite, asbestos (general) | 115 deg. C. |
| Mica, micanite single layer field coils stationary or moving | 120 deg. C. |
| Mica, micanite stationary coils solidly impregnated or moulded | 120 deg. C. |
| Windings permanently short circuited { Insulated | 100 deg. C. |
| Windings permanently short circuited { Non-insulated | 110 deg. C. |
| Commutators, slip rings | 90 deg. C. |
| Bearings | 80 deg. C. |

NOTE. When the insulation is composed of several different insulating materials the lowest of the temperatures corresponding to the various insulations employed must be taken as the temperature limit. The insulation even when forming a support is always considered as part of the winding.

(Material employed in small quantity in the construction and not relied upon continuously as a support for the insulating material is not regarded as part of the insulation under this rule.)

### Statement of Cooling Air Temperature

(5) Permissible limits of temperature are useless to the designer except in conjunction with information regarding the cooling temperature, since the difference between these two values is the "temperature rise" which the machine may create when carrying its rated load.

Hitherto in the I.E.C. proceedings as well as in the various national rules, the value mentioned as cooling air temperature has been the "ordinary" or average value. Obviously such value cannot be used directly in connection with a table of limiting temperatures "which must never be exceeded."

The corresponding value of air temperature employed must be the highest which is likely to occur.

The British and United States committees agreed in recommending that in future 40 deg. C. should be taken as the reference air temperature, instead of 25 deg. C. as hitherto indicated in the national rules.

(Unfortunately some confusion arose because the reason for this sudden jump from 25 deg. C. to 40 deg. C. on the part of the British and United States committees was not explicitly given.)

The I.E.C. rules now require that the maximum and not the average temperature of cooling air shall be stated, but agreement was not reached regarding an International Standard Reference Air Temperature. This will be referred to again in the section under "I.E.C. Rating."

### Correction for Room Temperature at Test

(6) Extended investigations made by the United States National Committee show that the variation in temperature rise with a given load when tested with cooling air at different temperatures is a small and uncertain quantity, sometimes positive, sometimes negative, according to the characteristics of the particular machine.

The I.E.C. decided that no correction shall be made in practice for such difference between conditions of test and of final service.

### Corrections for Difference of Altitude

(7) No correction is to be made for variation in the cooling properties of the air at a given temperature at altitudes not exceeding 1000 meters.

For higher altitudes it is recognized that a correction is necessary but the I.E.C. is not yet in a position to furnish an official correction factor.

### "I.E.C. Rating" for Machines

(8) Although the I.E.C. states that "wherever possible the temperature of the cooling air shall be stated and the machine constructed for this cooling condition," it is also proposed to establish a value which shall be taken as maximum temperature of the cooling air when no specific information is available. Probably more than 90 per cent of all the machines sold come under this class and the establishment of an International Reference for Air Temperature in connection with the table of limiting temperatures already provided would at once fix the temperature rise permissible at rated load, and in connection with the rulings given regarding overload would completely establish the capacity of any machine sold with "I.E.C. rating."

With such uniform rating adopted, a buyer of standard machines could compare without misunderstanding or possibility of mistake, tenders received from various makers even from different countries. He would know that all the machines offered would carry their rated loads continuously with the same temperature rise (and also with uniformity in other characteristics such as commutation as far as these might be defined by the I.E.C. rules).

It is evidently desirable that the I.E.C. Rating shall also be the domestic standard rating of the same machine in the countries in which they are produced. The Reference Air Temperature must then be set at such value as *shall not be exceeded by the hottest conditions likely to occur in service at any time of the year in any temperate climate.*

At Berlin a majority of the delegates including those from Great Britain and the United States desired to set this reference temperature at 40 deg. C. but a minority desired 35 deg. C.

Examination of the meteorological records for various temperate countries, including Great Britain, Germany and the temperate part of the United States, shows that 35 deg. C. is not sufficiently high to cover even the highest *outdoor* shade temperatures which are occasionally recorded, so that with a temperature rise based on the 35 deg. C. assumption the limiting temperatures of the I.E.C. table would certainly be exceeded at times. But such is contrary to the express conditions under which the limiting temperatures were adopted by the I.E.C.

In order to justify a *nominal* "maximum" temperature for cooling air which would exclude the highest peaks occasionally occurring, it would be necessary to reduce all the values shown in the table of permissible limiting temperatures by a margin sufficient to allow for such occasional peaks.

This proposition was suggested at Berlin but was not accepted by those desiring the lower reference temperature. Finally this entire question was referred back to the various national committees, and it is to be hoped that an early settlement will be reached, as upon this question hangs in reality the whole problem of international standardization in the rating of electrical machinery.

# THE ENGINEERING PROBLEM OF ELECTRIFICATION

By A. H. Armstrong

Assistant Engineer, Railway and Traction Department, General Electric Company

This is an important contribution to electric railway literature, and, owing to the author's reputation, should attract a great deal of attention. He analyzes the three systems which would be considered for main line electrification, viz., the single-phase alternating current, split-phase alternating current, and high voltage direct current systems, and shows the present standing of each as regards their use on important roads. The list of railways using single-phase and high voltage direct current are impressive, and the fact that so many systems originally equipped with single-phase have now changed to higher voltage direct current, and that no high voltage direct current installations have been changed to any other system speaks more eloquently than words for the good inherent qualities of the high voltage direct current apparatus. The illustration showing the comparative size of the split-phase alternating current and the 2400 volt direct current locomotive will speak more convincingly than many paragraphs of text. The efficiency of the different systems is reviewed from many different standpoints. This paper was read before the Canadian Society of Civil Engineers in Montreal on December 18, 1913.—Editor.

The broad question of whether electrification will show an attractive return upon the large capital investment required can best be determined by a detailed investigation of the local conditions obtaining in any given case. Any estimate of a general character is at best more or less misleading when applied to a specific problem. The electric locomotive possesses many operating characteristics not shared by the steam engine and its introduction opens up possibilities in operating methods that may make it desirable to effect sweeping changes in train operation as now carried on with steam engines. Until one or more engine divisions are electrically operated, perhaps we may not fully appreciate what it means to the railway operator to be relieved of many of the limitations of the steam locomotive.

For example, given an electric locomotive capable of hauling an 800 ton passenger train at sixty miles per hour on level track and without assisting locomotives, haul the same train up gradients of 2 per cent at a speed of twenty-five miles per hour, it is possible to make radical improvements in schedule. When it is considered furthermore that such an electric locomotive requires no stops for fuel and water and can operate 1200 miles or more between inspections, it is evident that electrification calls for considerable readjustment of steam railway traditions.

Failure to fully grasp the possibilities of electrical operation may result in running up the first cost of proposed electrification to an extravagant total upon which no adequate return is possible. So much local color is required to intelligently discuss the question of "will it pay to electrify," that no attempt will be made in this paper to discuss the financial aspect of the matter. The several important installations now under construction and the even larger projects upon which favorable decision has been reached, all point to the fact that electrification must be attractive in some instances at least. There are, however, certain fundamental data governing the operation of all electric locomotives and it is the purpose of this paper to discuss some of the engineering questions involved.

At the outset, it is found that the electrical engineer has perfected several types of locomotives and different methods of distributing electric power to them, thus giving rise to what is known as several different "systems of operation." The term "system" is generally applied to the combination of locomotive and trolley or third rail distribution as the question of power generation and transmission is common to all. While it is true that the single-phase and split-phase locomotives call for a supply of single-phase 25 cycle power, it is only in isolated instances that this kind of electric power can be economically generated and used exclusively by the railway company. Large power installations are now so well equipped to give attractive power rates over extended areas and economical electric power production is so completely an industry in itself, that local conditions must be very favorable to justify the installation of a separate power house devoted exclusively to railway load. Even should such a separate installation be made, it may be considered sound engineering to look to future possibilities and install apparatus similar to that in neighboring systems where the frequency and voltage are standardized. Different frequencies are not as serious as conflicting track gauges, but they do involve the burden of expense and loss in efficiency of frequency changing sets which it may some day be found expedient to install in order to tie the two systems together. Hence the statement is again made that the generation and transmission of power offers the same problem without regard to the system of electrification favored.

It is proposed to replace the steam engine with a type of motive power that offers superior advantages in the hauling of heavy trains. In other words, the electric locomotive itself constitutes the main argument in favor of electrification, and no marked excellence of distribution system can offset the failure of the electric motive power. The steam locomotive it is proposed to replace is a highly developed machine of great reliability and the result of the experience born of a great many failures. It cannot be too strongly emphasized therefore that the electric motive power is the controlling factor in main line electrification, a point of view that is sometimes overlooked.

The three electric systems considered for main line electrification are as follows:

1. Single-phase—alternating current.
2. Split-phase–alternating current.
3. High voltage—direct current.

The single-phase commutating motor has been in operation upon interurban electric railways for some years, and a study of the history of these installations reveals some of the fundamental reasons why this type of motive power has not been more generally adopted. It has been found that the initial expense and cost of upkeep of rolling stock equipped with single-phase commutating motors is fully double that of cars having the same seating capacity and equipped with direct current motors. No new installations have been made for the past two years, and the several single-phase roads are being changed over to direct current as fast as financial conditions will permit. Following is a list of the single-phase installations and on those roads starred the single-phase motors have been replaced with the direct current type.

The introduction of the single-phase system was a result of the success of suburban and interurban electric railway operation and the extension of these lines over large areas, thus bringing into prominence the question of economical power distribution. It was recognized that a voltage higher than the com-

## SINGLE-PHASE RAILWAY INSTALLATIONS IN UNITED STATES AND CANADA

| Name of Railway | Year |
|---|---|
| Indianapolis & Cincinnati | 1904 |
| * Atlanta Northern Ry. | 1905 |
| * Illinois Traction Co. | 1905 |
| Long Island R. R.—Sea Cliff Division | 1905 |
| San Francisco, Vallejo & Napa Valley, California | 1905 |
| * Warren & Jamestown | 1905 |
| Westmoreland County Traction, Derby to Latrobe, Pa. | 1905 |
| Spokane & Inland Empire R. R. | 1906 |
| * Toledo & Chicago Ry. | 1906 |
| * Anderson Traction, S. C. | 1907 |
| Erie R. R. | 1907 |
| Fort Wayne & Springfield | 1907 |
| * Milwaukee Electric Railway | 1907 |
| New York, New Haven & Hartford | 1907 |
| * Pittsburg & Butler | 1907 |
| Richmond & Chesapeake Bay | 1907 |
| Windsor, Essex & Lake Shore | 1907 |
| * Baltimore & Annapolis, S. L. | 1908 |
| Chicago, Lake Shore & South Bend | 1908 |
| Colorado & Southern: | |
| Denver & Interurban R. R. | 1908 |
| Grand Trunk Ry.: | |
| Sarnia-Port Huron Tunnel | 1908 |
| Hanover & York Ry., Pa. | 1908 |
| Shawinigan Ry., Quebec | 1908 |
| Visalia Electric Ry., California | 1908 |
| * Washington, Baltimore & Annapolis | 1908 |
| Rock Island Southern: | |
| Rock Island to Monmouth | 1910 |
| New York, Westchester & Boston | 1911 |
| Boston & Maine: | |
| Hoosac Tunnel | 1911 |

* Changed from alternating current to direct current motors.

monly accepted standard of 600 volts was desirable upon the trolley in order to minimize the cost of installing feeder copper and substations. While the single-phase motor was being developed and installed upon interurban railways careful attention was also being given to the question of the possibility of using direct current motor equipments at higher voltages and resulted in the installation of the first 1200 volt road, the Indianapolis & Louisville Traction Railway, operated in 1907. The success attending this operation lead to other similar installations at both 1200 and 1500 volts until it is now generally recognized that the high voltage direct current system is without a competitor for all classes of suburban and interurban electric railways. It is a safe prediction to make that no more single-phase motor equipments will be placed in operation in this country on new roads unless these roads virtually form an extension of existing systems.

Following is listed the several high voltage direct current installations in the United States and Canada.

The history of the battle of the systems and the elimination of the single-phase motor as being unsuitable for the equipment of light electric railways has an important bearing upon the selection of systems for main line electrification. The limitations of the single-phase motor that lead to its failure in the interurban railway field do not appear to be lessened when considering it for locomotive equipment with the result that it is in use on but three of the twelve roads that are truly representative of electrified steam roads operating large electric locomotives.

There are other electrified steam lines but the service on them more nearly approaches that of high class electric interurban railways.

### HIGH VOLTAGE DIRECT CURRENT RAILWAY INSTALLATIONS IN UNITED STATES AND CANADA

| Road | Voltage | No. of Equipments | Date |
|---|---|---|---|
| Indianapolis & Louisville Trac. Ry. Co., Scottsburg, Indiana | 1200 | 13 | Oct., 1907 |
| Central California Traction Co., Stockton, California | 1200 | 22 | June, 1908 |
| Pittsburg, Harmony, Butler & New Castle Ry., Bidenau, Pa. | 1200 | 30 | July, 1908 |
| Washington, Baltimore & Annapolis Elec. Ry., Baltimore, Md. | 1200 | 47 | Feb., 1910 |
| Milwaukee Elec. Ry. & Lt. Co., Milwaukee, Wis. | 1200 | 32 | Mar., 1910 |
| Aroostook Valley Ry. Co., Presque Isle, Me. | 1200 | 6 | July, 1910 |
| Oakland, Antioch & Eastern Ry., San Francisco, Cal. | 1200 | 25 | 1910 |
| Southern Cambria Ry. Co., Johnstown, Pa. | 1200 | 10 | 1910 |
| Shore Line Electric Ry. Co., Saybrook, Conn. | 1200 | 22 | Sept., 1910 |
| Southern Pacific (Oakland, Alameda & Berkeley Div.), Cal. | 1200 | 82 | April, 1911 |
| Ft. Dodge, Des Moines & Southern Ry., Boone, Iowa | 1200 | 29 | Sept., 1911 |
| Southwestern Traction & Power Co., New Iberia, La. | 1200 | 3 | May, 1912 |
| Oregon Electric Ry., Portland, Oregon | 1200 | 72 | July, 1912 |
| Davenport & Muscatine Railway Co., Davenport, Iowa | 1200 | 7 | Aug., 1912 |
| Kansas City, Clay County & St. Joseph Ry., Kansas City, Mo. | 1500 | 22 | June, 1913 |
| Piedmont Traction Co., Charlotte, N. C. | 1500 | 43 | 1913 |
| Nashville, Gallatin Interurban Ry., Nashville, Tenn. | 1200 | 6 | April, 1913 |
| Butte, Anaconda & Pacific Ry., Butte, Montana | 2400 | 17 | June, 1913 |
| United Railways Co., Portland, Oregon | 1200 | 8 | June, 1913 |
| Southern Traction Co., Dallas, Texas | 1200 | 30 | Oct., 1913 |
| Pittsburg & Butler Ry. Co., Pittsburg, Pa. | 1200 | 13 | 1913 |
| Pacific Electric (San Bernardino Division), Los Angeles, Cal. | 1200 | 54 | Building |
| Tidewater Southern R. R., Stockton, Cal. | 1200 | 4 | 1913 |
| Portland, Eugene & Eastern Ry. Co., Portland, Oregon | 1500 | 38 | Building |
| Southern Illinois Ry. & Pr. Co., Harrisburg, Ill. | 1200 | 5 | Sept., 1913 |
| Jefferson County Trac. Co. (Eastern Texas Elec. Co., S. & W.) Beaumont, Texas | 1200 | 7 | Building |
| St. Paul Southern Electric Ry., St. Paul, Minn. | 1200 | 5 | Building |
| Michigan United Traction Co., Jackson, Mich. | 2400 | 20 | Building |
|  | 1200 | 40 | Building |
| Canadian Northern Ry. Co., Montreal, Canada | 2400 | 14 | Building |
| Canadian Pacific Ry. Co., Rossland, B. C. | 2400 | 4 | Building |

All the above roads are operating with the highest degree of success and no change of type of equipment has been made or any such contemplated.

MAIN LINE ELECTRIFICATION—UNITED STATES AND CANADA

| Installation | Year | Type Locomotive | System | Voltage |
|---|---|---|---|---|
| St. Clair Tunnel | 1908 | Geared | Single-phase alternating | 3300 |
| N. Y., N. H. & H. | 1907 | Gearless | Single-phase alternating | 11000 |
| Hoosac Tunnel | 1911 | Geared | Single-phase alternating | 11000 |
| Cascade Tunnel | 1909 | Geared | Three-phase alternating | 6600 |
| * Norfolk & Western | 1914 | Geared side rod | Split-phase alternating | 16500 |
| Baltimore & Ohio Tunnel | 1895 | Geared | Direct current | 600 |
| New York Central | 1906 | Gearless | Direct current | 600 |
| Detroit Tunnel | 1910 | Geared | Direct current | 600 |
| Pennsylvania Terminal | 1910 | Side rod | Direct current | 600 |
| Butte, Anaconda & Pacific | 1913 | Geared | Direct current | 2400 |
| * Canadian Northern | 1914 | Geared | Direct current | 2400 |
| * Canadian Pacific | 1914 | Geared | Direct current | 2400 |

* Under construction.

Also there are interurban systems where electric locomotives of considerable capacity are operated, but the class of service does not approach the exacting demands of main line passenger and freight operation. The above table, however, comprises converted steam lines where the service consists of hauling main line passenger and freight trains behind electric locomotives of large capacity.

It is a noteworthy fact that the use of the single-phase motor has not extended beyond the two original roads installing this type of equipment, the Grand Trunk and New York, New Haven & Hartford (including Hoosac Tunnel) whereas direct current motors have been universally adopted in all the more recent electrifications with the single exception of the proposed split-phase installation on the Norfolk & Western Railway.

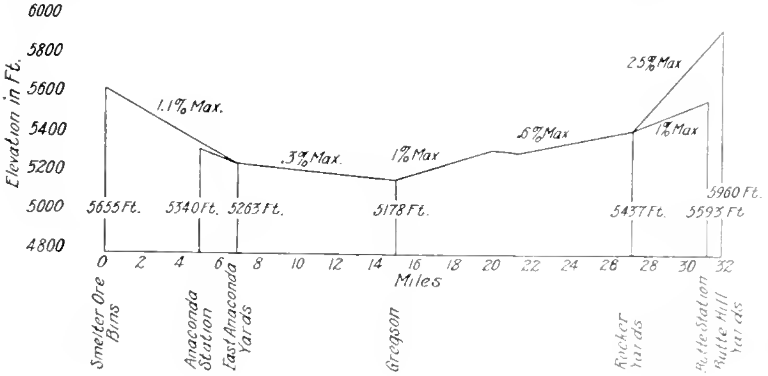


Fig. 1. Profile of Butte, Anaconda & Pacific Railway

The so-called "split-phase" system is a comparatively new comer in the electric traction field and it has not yet been subjected to the test of actual operation. The proposed system offers many attractive features, however, and it is worthy of careful study in order to understand its fitness for heavy electric railway service. From experimental tests made, it seems reasonably certain that the split-phase locomotive can meet the demands of commercial operation with satisfactory reliability.

The split-phase locomotive was first described by E. F. W. Alexanderson, and reference is made to his articles for a full understanding of its underlying principles.*

Confronted with the problem of main line electrification and the demand for a distributing system which would provide for the economical distribution of large units of power over an extended area, the need of higher direct current voltage was appreciated and resulted in the first installation of 2400 volts direct current upon the Butte, Anaconda & Pacific Railway, first operated May 28th of this year. This installation marks an epoch in electric railway progress, as its success offers substantial proof that direct current motor equipments can be constructed at a reasonable cost and operated in an efficient and reliable manner with trolley potentials as high as 2400 volts.

It has been characteristic of the installations operating at 1200 and 1500 volts that

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* A.I.E.E. Proceedings, 1911, Induction Machines for Heavy Single-Phase Motor Service. G. E. REVIEW, October, 1913 "The Split-Phase Locomotive."

the reliability of the direct current motive power has been in no way impaired by reason of using a higher trolley voltage, in fact, the maintenance of 1200 volt motor equipments shows no increase over that of 600 volt equipments. A brush life of over 150,000 miles gives evidence of good commutator performance with practically no wear and the increased insulation and creepage distance provided has been ample to ensure reliability and low cost of maintenance.

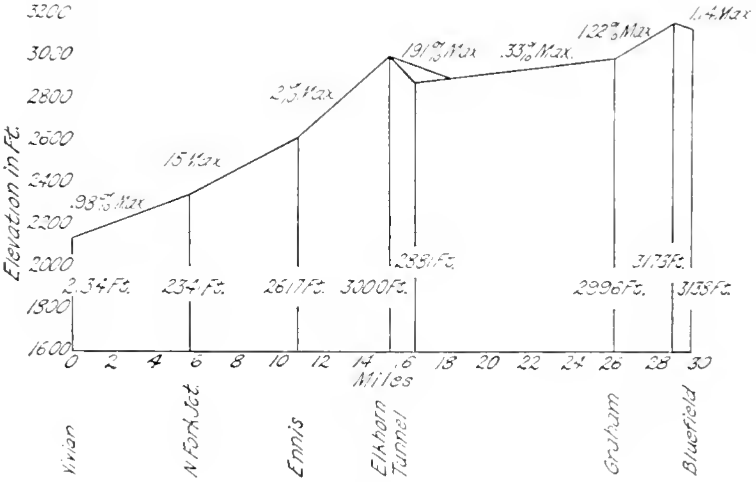

Fig. 2. Profile of Norfolk & Western Railway—Elkhorn Division

The transition from 1200 to 2400 volts direct current has also resulted in completely successful operation at this potential. The operating record of the Butte, Anaconda & Pacific 2400 volt direct current system has been truly remarkable and can best be expressed by quotation from letter published in the Electric Railway Journal by Mr. H. A. Gallwey, General Manager.

"To the Editors:

"In reply to your inquiry I would say that on Oct. 1, 1913, the Butte, Anaconda & Pacific Railway established regular electric passenger service between Butte and Anaconda. For approximately four months previous to this the freight service between East Anaconda yards and the smelter had been handled electrically. During this period electric locomotives have made approximately 55,000 miles and have delivered to the smelter about 1,500,000 tons of ore. Since starting the electric service there has been no failure of any of the electric apparatus and no delay in any way attributable to electric operation.

"The substation at Anaconda has been in continual service twenty-four hours a day with no more than ordinary care and without replacement of any parts. The locomotives have been operated by the steam locomotive enginemen and have been maintained by the regular shop force with the addition of one man experienced in electric operation. They have met every requirement and there has been no failure or replacement of locomotive parts.

"The overhead contact system has been highly successful, and there have been no failures and no accidents. The wear of the contact wire is inappreciable. The original pantograph rollers on the locomotives are still in use and show very slight wear notwithstanding the severe conditions imposed by the smoke and soot deposited on the wire from the steam locomotives during the several months of construction. Our experience up to the present time indicates the complete success of our electrification and justifies the existing optimism and enthusiasm for heavy railroad electrification.

"(Signed) H. A. Gallwey,
"General Manager."

The success of high voltage direct current installations has not been marred by a single instance of failure due to fundamental defect in the type of apparatus used, and justifies the conclusion that the 2400 volt, 1200 volt and the 600 volt direct current equipments are all part of the same general direct current system, and that the only difference is the need of more insulation in one case than in the other. The 2400 volt direct current installation of the Butte, Anaconda & Pacific cannot be looked upon therefore as in any way constituting a new "system" of electrification, but rather as a natural development along the lines of higher voltage of the same well known direct current system which has rendered such excellent account of itself in the past on all our city and practically all of our suburban and interurban electric lines. This has an important bearing upon the general electrification of the steam roads, as it places the status of the direct current system as applied to such service.

Fully appreciating the grave responsibility of selecting a type of motive power for a proposed electrification that holds promise of special fitness for the immediate service contemplated and also is capable of meeting the demands of unlimited future extensions, this paper will briefly touch upon the comparative characteristics of the split-phase and 2400 volt direct current systems of operation. The choice seems to lie between split-phase and direct current inasmuch as the history of the single-phase motor equipment does not seem to justify its further consideration for heavy electric railroading.

The general scheme of distribution to the split-phase locomotive is shown in Fig. 5 which has special application to western railways where 60 cycle power supply is universally standardized. A corresponding diagram of the 2400 volt direct current system is shown in Fig. 6, this also being adapted to 60 cycle power supply.

Starting first with a comparison of the two types of locomotives it is necessary to make some general assumption as regards service conditions in order to draw conclusions as to relative locomotive characteristics. The electric locomotive is capable of being constructed in very large units, but convenience in shopping and simplicity in construction both point to a unit of approximately 100 tons total weight on drivers. These 100 ton units can be coupled together and operated as a single locomotive of any desired capacity, though probably a two unit locomotive weighing 200 tons and giving a starting tractive effort of 120,000 lb. is as large as the draft gear will stand.

Experience with steam locomotive practice seems to point to a locomotive rating on ruling grade that calls for a tractive effort corresponding to approximately 18 per cent coefficient of adhesion on drivers. Thus the conditions obtaining upon a 2 per cent ruling gradient will be as follows:

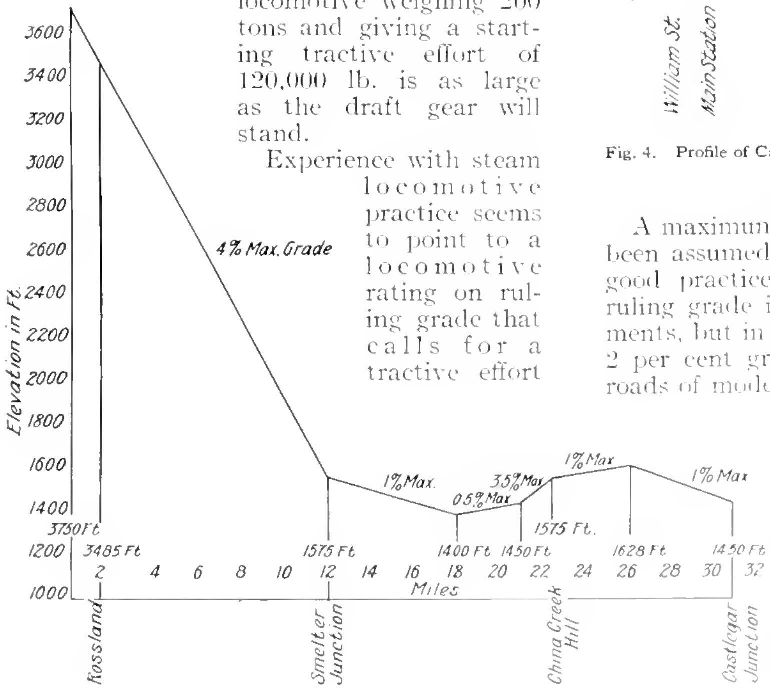

Fig. 3. Profile of Canadian Pacific Railway—Rossland Subdivision

| | |
|---|---|
| Tractive effort due to 2 per cent grade | 40 lb. |
| Tractive effort due to train resistance | 6 lb. |
| Tractive effort due to curve resistance | 2 lb. |
| Total per ton | 48 lb. |

| | |
|---|---|
| Total weight on drivers | 200,000 lb. |
| Rating at 18 per cent coefficient of adhesion | 36,000 lb. |
| Gross train weight | 750 tons |
| Trailing train weight | 650 tons |
| Speed | 15 m.p.h. |
| Net output at drivers | 1450 h.p. |

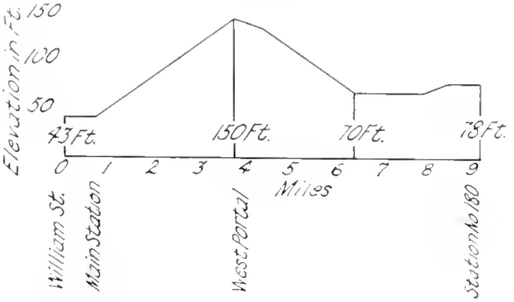

Fig. 4. Profile of Canadian Northern Railway—Montreal Tunnel & Terminal Electrification

A maximum load of 50,000 lb. per axle has been assumed as being within acceptance of good practice. The question of speed on ruling grade is one subject to local requirements, but in general a speed of 15 m.p.h. on 2 per cent grade is as high as desirable on roads of moderate tonnage.

As ruling grade generally extends unbroken over comparatively short distances, it is possible to take advantage of this fact in electric locomotive design and proportion the motive power for a continuous capacity of say 16 per cent coefficient of adhesion without danger of exceeding safe temperature limits in operation. The continuous capacity of the 100 ton unit would therefore be 32,000 lb. tractive effort at somewhat more than 15 miles per hour, based upon 16 per cent coefficient of adhesion of the weight upon the drivers.

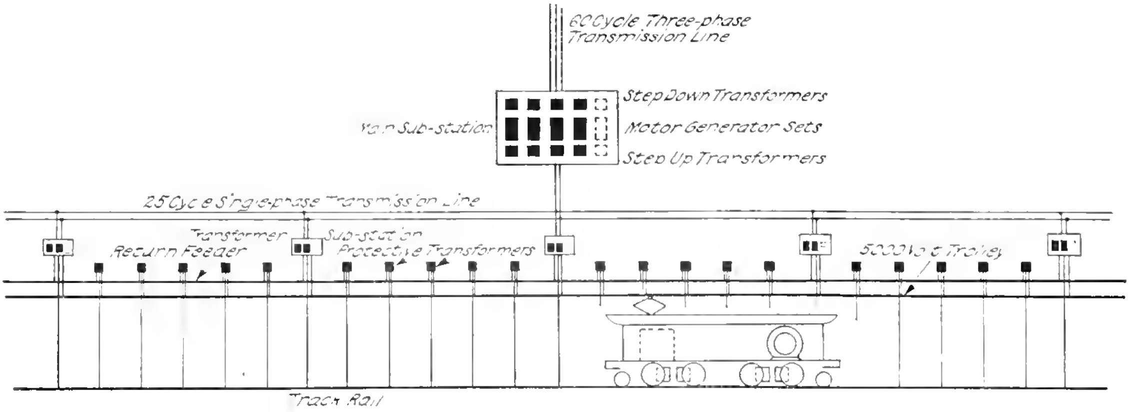

Fig. 5. General Scheme of Split-phase Alternating Current System

Owing to the moderate speeds at which a freight locomotive will operate, it is entirely feasible to consider a construction wherein the motors are geared direct to the driving axles by twin gearing, in this respect following the practice of the Detroit Tunnel, Cascade and B. A. P. locomotive which has proven very successful.

For the purpose of this comparison, it is assumed that both split-phase and direct current locomotives will be of similar construction and employ twin geared motors of equal weight and efficiency. A comparison of weight distribution in the two types of locomotives is presented herewith. See page 69.

As the direct current locomotive of 100 tons carries no ballast, it is evident that the 40,000 lb. comprising the phase converter and transformer of the split-phase locomotive must be carried on idle wheels together with the additional weight of cab and running gear required to carry this excess weight. The net result is a split-phase locomotive of fully 35 per cent more weight than a direct current locomotive of equal capacity and of similar construction. This weight comparison is based upon the assumption that 50,000 lb. per axle constitutes the limit allowable, thus forcing the introduction of guiding axles to carry the excess weight of the split-phase equipment. For locomotive construction of less capacity, permitting the split-phase to come within axle weight limits, both types of locomotives would comprise four axles with no guiding wheels and the split-phase locomotive may not total more than 20 per cent more weight than the equivalent direct current type.

It is evident that the split-phase locomotive is not only considerably heavier for equal capacity, but also more complicated and inefficient than the direct current locomotive.

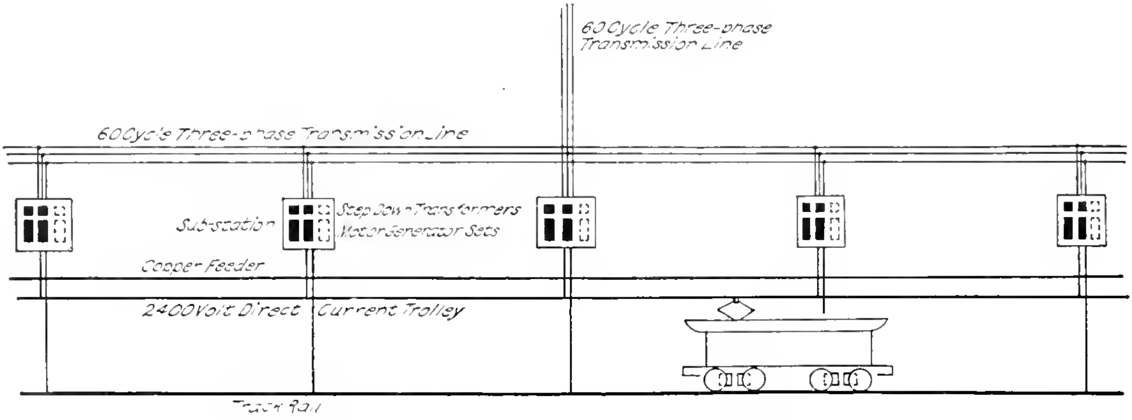

Fig. 6. General Scheme of 2400 Volt Direct Current System

The power from the trolley must in turn pass through transformer, phase converter, control, motors and gears. The efficiency of the complete locomotive in operation will depend upon its output and hence in the following comparison, efficiency has been computed for operation on both ruling grade and level track. The average efficiency of a day's run will obviously lie somewhere between these values, assuming that portion of the run when the locomotive is taking power.

### COMPARATIVE WEIGHT OF LOCOMOTIVE
CONTINUOUS CAPACITY, 32,000 LB. 15 M. P. H.

| | Split-Phase | 2400 Volts Direct Current |
|---|---|---|
| Four motors | 44,000 lb. | 44,000 lb. |
| Control apparatus complete | 17,000 lb. | 27,000 lb. |
| Air compressor | 4,000 lb. | 4,000 lb. |
| Air brake equipment | 3,000 lb. | 3,000 lb. |
| Miscellaneous | 2,000 lb. | 2,000 lb. |
| Phase converter | 22,000 lb. | . |
| Transformer | 18,000 lb. | . |
| Cab and running gear | 160,000 lb. | 120,000 lb. |
| Total | 270,000 lb. | 200,000 lb. |

### FREIGHT LOCOMOTIVE EFFICIENCY
DETAILED COMPARISON

| | SPLIT-PHASE | | 2400 VOLTS DIRECT CURRENT | |
|---|---|---|---|---|
| | Ruling Grade | Level | Ruling Grade | Level |
| | Per Cent | | Per Cent | |
| Motors and gears | 89.3 | 86.0 | 89.3 | 86.0 |
| Blower | 97.8 | 95.8 | 97.9 | 95.9 |
| Starting resistances | 98.6 | 98.0 | 99.2 | 99.4 |
| Phase converter | 96.3 | 94.7 | | |
| Transformer | 98.0 | 97.0 | | |
| Wheel correction | 98.0 | 98.0 | | |
| Weight efficiency | 95.0 | 97.0 | | |
| Combined efficiency | 75.7 | 70.5 | 86.6 | 82.0 |
| Average of grade and level | 73.1 | | 84.3 | |

*Motor and gears* are assumed to be of equal efficiency for both split-phase and direct current, as the advantage of one type motor over the other will be small at best and will not materially affect the values given.

*Blower efficiency* is based upon the fan blower required to cool the motors and auxiliaries taking 30 kw. split-phase and 25 kw. direct current.

*Starting resistances* consume a portion of the power required to start the train, and efficiency of the locomotive is based upon the assumption that the train is started from rest once in two hours. This starting resistance loss is greater with the split-phase than with the direct current locomotive, being twice as large up to speeds of 15 miles per hour on ruling grade and four times as large up to speeds of 30 miles per hour on level track.

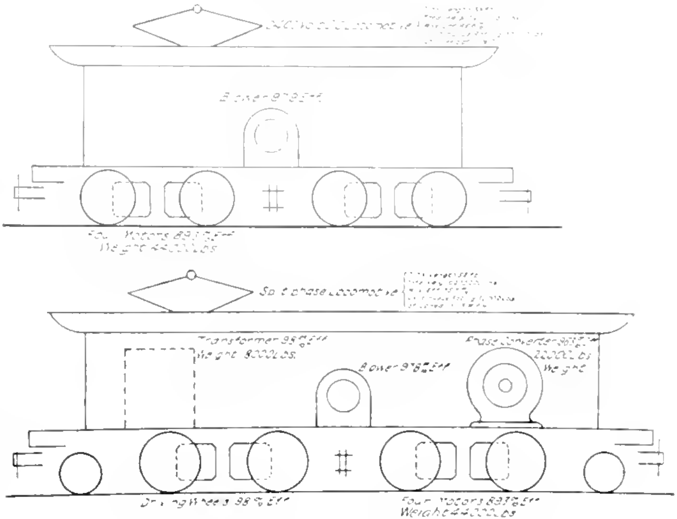

Fig. 7. Comparative Elevations of Split-phase and 2400 Volt Direct Current Locomotives of Equal Capacity

*Phase converter* efficiency is determined by assuming that the capacity of the converter will approximate 75 per cent of that of the four motors it controls.

*Transformer* efficiency values given require no comment.

*Wheel correction* is determined as follows:

Induction motors run at nearly synchronous speed, the slip being proportional to the total secondary non-inductive resistance, hence all wheels upon the same locomotive must be very closely of the same diameter in order to ensure equal loading of the several motors. When one pair of wheels is turned, all must be turned equally. This would not be a very serious handicap were it not for the fact that several locomotives will operate in the same train thus necessitating equal wheel diameters on all such locomotives. It is therefore evident that all locomotives must be interchangeable and any group of two or more be capable of running in the same train or the operating department will be seriously handicapped.

The diameter of new and turned wheels may vary fully 4 per cent, an amount sufficient to cause a prohibitive load distribution between motors. Hence it is proposed to install a variable secondary resistance and so adjust this resistance in the several motor secondaries that all wheel peripheral speeds will conform to the average diameter of new and worn wheels. This will entail an average loss of say 2 per cent when operation has continued long enough to require turning wheels to the minimum diameter allowable. Direct current motors have such a variable speed characteristic as to require no adjustment for varying wheel diameters.

*Weight efficiency* is a relative value based upon comparison with the direct current locomotives taken at 100 per cent.

### COMPARATIVE WEIGHT EFFICIENCY
#### FREIGHT LOCOMOTIVES

| | Split-Phase | 2400 Volts Direct Current |
|---|---|---|
| Rated t.e. on ruling grade | 36,000 lb. | 36,000 lb. |
| Gross train weight | 750 tons | 750 tons |
| Trailing train weight | 615 tons | 650 tons |
| Per cent trailing to gross | 82% | 86.7% |
| Weight efficiency | 94.7% | 100% |

On level track it is assumed that pushing locomotives will be dropped and train weight per road locomotive will be double the ruling grade values. On this basis the split-phase locomotive weight efficiency will be 97 per cent for level track runs. Both values of split-phase locomotive weight efficiency are based upon the assumption that locomotives will be loaded to 100 per cent capacity on ruling grades. As such will not always be possible in regular operation it is evident that the values quoted above will be lower under actual service conditions.

The combined efficiency of the complete locomotive shows that the split-phase freight locomotive will demand 15 per cent more power input from the trolley than a direct current locomotive of equal hauling capacity and similar mechanical drive.

For passenger service it is reasonable to expect the locomotive running gear to be so constructed as to permit maximum speeds approaching 75 miles per hour without danger of derailment or exceeding safe limits of motor and drive construction. Neither of the forms of construction in Fig. 7 are well adapted for very high speeds, and to secure good running qualities it is probably necessary to adopt different types of construction for freight and passenger locomotives however desirable it may be from an operating standpoint to have them interchangeable.

With direct current motors several forms of construction are available that will all operate successfully at high speeds. The most efficient construction is unquestionably to mount the motor armatures upon the driving axles and eliminate the losses, weight and complications of any form of mechanical drive. It is assumed in this comparison that gearless construction will be adopted for direct current high speed passenger locomotives.

The split-phase locomotive motor is of the multiphase induction type and not adapted to gearless construction except by the introduction of quills and springs. This form of construction has not been so successful in operation as to justify considering its general adoption. It is assumed therefore that in order to get a locomotive of good riding qualities at high speeds, it is necessary to resort to side rod drive from a jack shaft and house the motors in the cab. In this comparison it is assumed that motors drive the jack shaft through gears rather than by rods as offering a lighter form of construction requiring less space. The same form of drive is equally available with direct current motors, but gearless construction offers great advantages such as extreme simplicity, accessibility and high efficiency so that comparison will be based upon geared side rod split-phase and gearless direct current motor locomotives.

It appears reasonable to expect the efficiency of mixed passenger and freight locomotive operation to approximate 85 per cent for direct current and not much exceeding 68 to 70 per cent for split-phase locomotives.

### PASSENGER LOCOMOTIVE EFFICIENCY
#### DETAILED COMPARISON

| | SPLIT-PHASE | | 2400 VOLTS DIRECT CURRENT | |
|---|---|---|---|---|
| | Ruling Grade | Level | Ruling Grade | Level |
| | Per Cent | | Per Cent | |
| Motors and gears | 89.3 | 83.0 | 87.5 | 94.0 |
| Blower | 97.8 | 84.8 | 97.9 | 95.5 |
| Starting resistances | 98.6 | 97.8 | 99.2 | 99.3 |
| Phase converter | 96.3 | 94.0 | .. | |
| Transformer | 98.0 | 96.0 | | |
| Wheel correction | 98.0 | 98.0 | | |
| Weight efficiency | 92.5 | 92.5 | | |
| Jack shaft | 97.0 | 93.0 | | |
| Side rods | 97.0 | 93.0 | | |
| Combined efficiency | 69.3 | 54.5 | 85.0 | 89.2 |
| Average of grade and level | 61.9 | | 87.1 | |

This efficiency in each case is based upon that portion of the run during which power is delivered to the locomotive. If transformer, phase converter and blower are kept running during coasting periods or when standing, the standby losses thus introduced will seriously reduce the all day efficiency in commercial operation. It is evident that such standby losses are much greater in the split-phase than in the direct current locomotive and the 20 per cent saving in power for mixed freight and passenger service credited to the direct current motive power may be materially increased in actual service.

Before concluding the general discussion of the locomotive it is necessary to touch upon the question of braking. One of the strongest arguments advanced for the adoption of the induction motor locomotive is that this type of motor offers an ideal electric brake by reversing its function on down grade and returning power to the trolley circuit. A regenerative braking method of control has been perfected for use with the direct current motor which offers even greater advantages in service operation than induction motor braking. Just as the direct current locomotive is the more efficient in hauling a given trailing tonnage so also it will return to the system a larger percentage of the mechanical power given the locomotive by the descending train. Hence whatever claims are advanced for regenerative electric braking with the split-phase locomotives are even more applicable to the direct current type.

Referring again to Figs. 5 and 6, showing the general plan of distribution respectively for the split-phase and direct current systems, it is of interest to compare the two in order to see how much of the split-phase locomotive loss is recouped by its more efficient distribution system. The following comparison is therefore submitted.

### EFFICIENCY OF DISTRIBUTION SYSTEM
#### DETAIL COMPARISON

| | Split-Phase | 2400 Volts Direct Current |
|---|---|---|
| | Per Cent | Per Cent |
| Step-down transformers | 97.5 | 96.5 |
| Motor-generator sets | 87.0 | 81.0 |
| Step-up transformers | 97.5 | |
| Railway transmission line | 96.0 | 96.0 |
| Line transformers | 96.0 | |
| Protective transformers | 96.0 | |
| Trolley, track and feeders | 96.0 | 88.0 |
| Combined efficiency | 70.5 | 66.0 |

Protective transformers appearing in above table are for the purpose of neutralizing the inductive disturbance caused by single-phase trolley upon neighboring telephone, telegraph and signal circuits.

There is every reason to expect that the split-phase system will demand fully 15 per cent more power input than the direct current system of 2400 volts for equal trailing tonnage movement, actual figures depending upon the proportion of freight and passenger tonnage. This figure is based upon 60 cycle power supply for the reason that many of the immediate electrification projects under construction or contemplated are located in territories where this frequency is firmly established.

### TOTAL EFFICIENCY
#### DISTRIBUTION SYSTEM AND LOCOMOTIVE

| | Split-Phase | 2400 Volts Direct Current |
|---|---|---|
| | Per Cent | Per Cent |
| FREIGHT SERVICE | | |
| Distribution | 70.5 | 66.0 |
| Locomotives | 73.1 | 84.3 |
| Combined efficiency | 51.5 | 55.7 |
| PASSENGER SERVICE | | |
| Distribution | 70.5 | 66.0 |
| Locomotives | 61.9 | 87.1 |
| Combined efficiency | 43.6 | 57.5 |

Where 25 cycles is available, single-phase power may be taken direct from the three-phase supply provided phase and voltage balance is maintained by suitably located substations containing step down transformers and phase converters. Direct current supply will be more efficiently obtained through rotary converters in place of motor-generator sets. The efficiency of the distribution system, as given above, will therefore need correction for 25 cycle power supply but will result in no material change in the relative efficiency figures quoted for the two systems.

Installing a power house to generate single-phase current at 25 cycles or less introduces all the serious handicaps encountered in single-phase generation as well as raises questions of general expediency and adequate return on the capital invested in a power plant devoted to supplying railway load only. Advocates of single-phase trolley distribution have sometimes failed to fully consider the question of power supply available as having any bearing upon the broad question of electrification. Not every railway is so situated by reason of character of load, cheap fuel or other favoring local conditions as to justify the large expenditure for a generating station containing ample reserve capacity. The somewhat higher efficiency of the distributing system alone in cases where single-phase power is available is so relatively unimportant that it may be looked upon as a special condition applying only to favored and restricted localities.

A study of the general plan of distribution as given in Figs. 5 and 6 discloses the fact that where 60 cycle power supply is available at attractive rates, the general statement can be safely made that the total amount of electrical apparatus is greater and therefore the first cost higher and efficiency lower with the split-phase than with the direct current locomotive system. Nor is this statement modified to any extent in the event that power supply is obtained from a 25 cycle three-phase source, as it will be the exception rather than the rule that any power company will be found willing to furnish single-phase power from its balanced three-phase circuit when the pernicious effect upon the general distribution system of a violently fluctuating low power-factor single-phase load is fully understood. Some corrective device like a phase converter must be introduced and its first cost and efficiency are both comparable to the rotary converters which are permissible with 25 cycle supply to secure direct current. It would seem therefore that the complication of the split-phase locomotive system renders it inherently more expensive to install and less efficient to operate. This is due largely to the fact that substations containing moving machinery are required both on the ground and also in the locomotive cab itself.

The single-phase trolley circuit, irrespective of the type of locomotive it may supply, constitutes in itself a most serious handicap to the adoption of any type of alternating current locomotive. Neighboring circuits of all kinds are practically put out of commission by static and inductive disturbances unless adequate protective measures are introduced. No method of complete protection has as yet been perfected although many schemes have been proposed that are partially successful. The elaborate and expensive apparatus now being installed upon one of our most important single-phase railways will soon be in operation and it is expected to give relief from the present serious condition obtaining. As the inductive interference of the single-phase trolley is proportional to the intensity of the current and distance it is transmitted, it is to be expected that a maximum disturbance will result in the case of mountain grade divisions where the current input to trains approaching 3000 tons gross weight is several times that thus far met with in any single-phase trolley installation now operating. No cost estimate of single-phase trolley systems is therefore complete without including a liberal allowance for telephone and telegraph protective devices. This cost will probably not be less than $2500.00 per mile of route and may even greatly exceed this figure. Even with such an expenditure, no assurance is at hand that hazard to employees and interference with service will be entirely eliminated, and until more exact knowledge of this whole situation is available, single-phase trolley interference constitutes a most serious handicap to the adoption of any alternating current locomotive system of operation.

This paper is largely devoted to a comparison of alternating and direct current motor locomotives, as lack of appreciation of the fundamental facts involved has perhaps been the basis of the false hopes raised as to the possible advantages resulting from the installation of the single-phase trolley. It surely does look attractive to install a system employing 15,000 volts on the trolley, no feeder copper and no rotating substation apparatus. But investigation and experience discloses the fact that the single-phase trolley is a decided menace to neighboring circuits, feeder copper is required for return circuit, substations are comparable as to first cost and efficiency with direct current substations and finally, the alternating current locomotive of the most promising type, the so-called split-phase combination of induction motors, transformer and phase converter is heavy, expensive, complicated and inefficient to a degree that would not be tolerated in direct current construction. Assuming that the favorable results of factory experiments are borne out in the success of later commercial operation, there appear to be no controlling advantages of alternating current locomotive traction which cannot be secured at less expense and with greater reliability in operation with direct current motive power.

Until the adoption of the inter-pole motor construction made it entirely practicable to build direct current motors for high potentials, there was some justification for considering alternating trolley systems as offering the best means of changing from steam to electric motive power at a reasonable first cost. The high voltage direct current motor has now been developed, built and proven completely successful under the most exacting service conditions. The trolley potential has been raised to 2400 volts which seems sufficiently high to ensure a distribution system of reasonable first cost and not too high to handicap the locomotive as regards its first cost, reliability and operating efficiency. Experimental results already obtained with direct current apparatus tested at potentials higher than 2400 volts indicate that no constructive difficulties apparently exist and the installation of a higher voltage becomes an economic question rather than an engineering problem.

With 2400 volts direct current both protected third rail construction and multiple unit car operation are feasible. The third rail offers advantages in accessibility and low cost of maintenance on single track roads and multiple unit car operation is without question the proper way to take care of local traffic. Furthermore, 2400 volt equipments can be successfully operated upon the lower voltage terminal zone that local restrictions may make necessary.

It is popularly supposed among electrical engineers that the cause of electric traction is retarded by an openly expressed divergence of views as to the relative merits of different systems of electrification. The opinion is advanced on the contrary that a free presentation of the facts available, but not always made public, will do much to clarify the situation. No one contributing cause has done more to hurt the electric railway industry than the failure of the single-phase system to make good the too optimistic claims of its early advocates, and no such open presentation of installation and operating costs has ever been made public on any alternating current installation in operation in this country or abroad, as has been published by Mr. B. F. Wood in a paper before the A.I.E.E. on the West Jersey & Seashore Railway.

This paper has been purposely restricted to a discussion of engineering questions entering into the electrification problem as having a fundamental bearing upon the all important matter of first cost and cost of operation. Such estimates are readily prepared for any local conditions obtaining provided there is no serious conflict of engineering opinion regarding engineering details as exist today. The direct current motor is fully able to meet all the requirements of the heaviest passenger and freight train operation as proved by the entirely successful installations now running and which afford the convincing facts upon which statements of cost and operation are based. No such condition exists with any alternating locomotive system and such operating facts as are obtainable are not of such a nature as to inspire confidence in selecting such a system to meet the exacting requirements of heavy electric railroading. The engineering facts presented herewith are offered with the purpose in view of clearing the engineering atmosphere preparatory to the serious work that seems to lie immediately before us, that is the problem of where and to what extent it will pay to replace the steam engine by the electric locomotive.

# THE ELECTRIFICATION OF CANE SUGAR FACTORIES

By A. I. M. Winetraub

Engineer, Zaldo & Martinez, Havana

In the August, 1913, issue of the Review we published an article, "Electricity Applied to the Manufacture of Sugar," by Mr. P. S. Smith, which presented an interesting description of the principal features in sugar manufacture and gave the reasons for the growing tendency to equip or re-equip all machines requiring mechanical drives with electric motors. The present article is an excellent continuation of the former, in that it constitutes a conclusive mathematical proof of the savings to be made by electric drive over steam drive. The author confines himself entirely to those improvements that may be made in fuel economy, and only names some of the other benefits which are co-incident with the installation of an electric drive.—**Editor.**

The extensive application of electricity in sugar factories during the last three or four years has given complete satisfaction, and present indications point to the belief that its use in this industry will become so general that the lack of complete electric drive will be a proof of a sugar factory's inefficiency. Its absence may even contribute toward the exclusion from the competitive field of those factories not so equipped.

The promiscuous adaptation of electric motors for pumping and general mechanical drive without a systematic study of the individual requirements for each factory may, however, not result in ultimate fuel economy. The engineer entrusted with the problem of electrifying a sugar factory must be therefore extremely careful in analyzing the particular requirements of that factory, that he may suitably devise for it such an equipment as will give the desired economy.

Until a very short time ago the problem of sugar making was strictly a problem of industrial chemistry and the installation of machinery was looked at from the chemist's point of view. He needed steam for a certain evaporation; he wanted enough of it, and there was nothing that so fully answered his requirements as the old pump working with steam unexpansively. At that time and before the mechanical engineer had devoted his attention to this industry, the juice extraction from the sugar cane was as low as 50 or 60 per cent, and it is reasonable to expect that under such prevailing conditions the bagasse should have given all the steam required and that the amount of steam exhausted to the atmosphere need not have been given any concern.

With the advent of ingenious machines, however, extracting as much as 80 or 85 per cent of the cane juice, the bagasse did not prove in practice to be sufficient, and additional fuel had to be purchased to generate the steam needed for cooking, for this greater extraction now meant much greater evaporation and much larger pumping and driving machinery. The exhaust steam from such machines was greatly in excess of that needed for cooking, with the result that exhaust steam with its contained heat was allowed to go to waste. The logical sequence of such conditions was the seeking of machinery, the exhaust steam from which would balance the cooking requirements, and therefore the most efficient known method of applying power, the electric motor, was called into service.

An actual example will best serve to show the fuel economy obtainable from a proper electrification outside of other adjunct advantages consequent to electric drive, such as reduced labor and maintenance, elimination of shut-downs, increased output, etc. These are all apparent and are productive of ultimate economy in the cost of production. The calculations in the following example do not include all the refinements in the art of sugar making, but such assumptions as have been made approach very nearly to actual practice. The example is worked out mainly with the idea of showing how important it is for the electrical engineer to make his calculations intelligently, and at the same time illustrates the manner in which they are to be made.

Assume a mill of 70 tons per hour grinding capacity, or roughly 100,000 bags of sugar of 325 lb. each per season of 100 days, operating 23 hours per day with a sugar yield of $10\frac{1}{2}$ per cent from the cane. The dry bagasse being 13 per cent of the weight of the cane, and the extraction 80 per cent of the weight of the cane we have:

| | |
|---|---|
| Dry bagasse per hour . . . . . | 9.1 tons |
| Juice . . . . . . . . . . | 56.0 tons |
| Loss in moisture of bagasse . . . | 4.9 tons |
| Total . | 70.0 tons |

The gross thermal value of the moist bagasse has been determined and given as 3767 B.t.u. by Geerlings and as 3920 B.t.u. by Deerr. To be conservative in our deductions, let us assume the latter value to hold good for the bagasse obtained.

The thermal efficiency of boilers, having the high flue temperature of those used in an ordinary mill, being only 55 per cent, we have the result that each pound of bagasse actually delivers in the shape of steam $3920 \times 0.55$ or 2156 B.t.u. (Deerr). For 14 tons of bagasse we have

$14 \times 2000 \times 2156 = 60.5 \times 10^6$ B.t.u. in steam available from the bagasse.

The approximate amount of heat required to cook the juice after dilution can be calculated as follows: The average density of the raw juice, before dilution water is added, is 20 degrees Brix. This is generally reduced to 17 deg. Brix before it is defecated, and, therefore, the added water is $\frac{20}{17} - 1$ or 18 per cent of the weight of the juice which was assumed to be 56 tons. The added water being 10 tons we have the total weight of the juice to be defecated, cooked, and reduced to sugar equal to 66 tons at 17 deg. Brix.

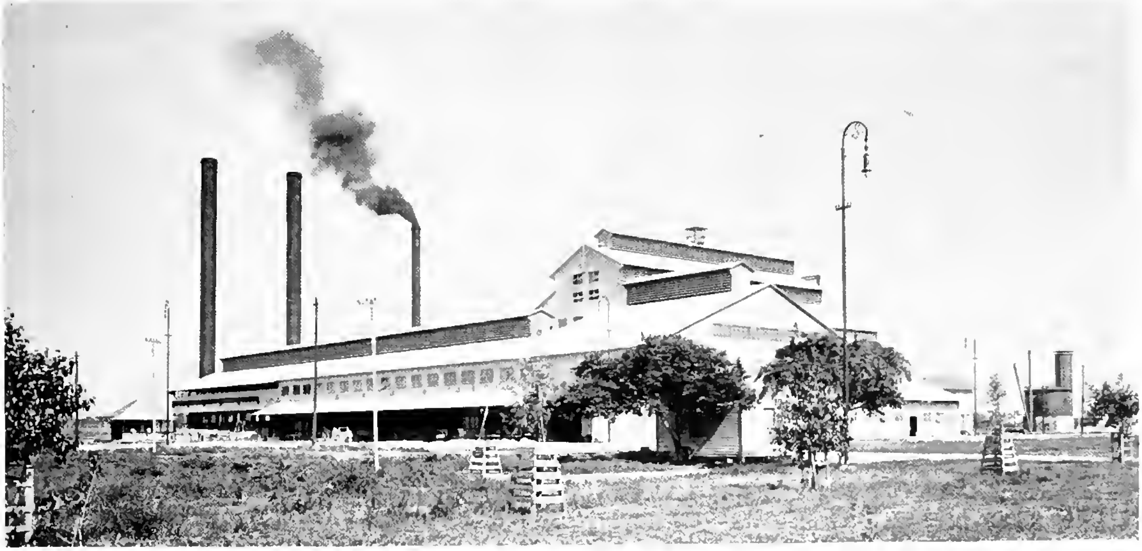

Fig. 1. The Ingenio Las Delicias San Manuel Sugar Co., Cuba, which is equipped with nearly 1500 h.p. in electric motors

The temperature of the juice is raised to 100 deg. F. from the original 70 deg. F. by the B.t.u. contained in the water of condensation, and this heat is therefore not to be considered as there are sufficient B.t.u. contained in the condenser water to do this work.

The juice is then heated from 100 deg. F. to 208 deg. F. in heaters, and the heat required is

$66 \times 2000 \times (208 - 100) = 14.2 \times 10^6$ effective B.t.u. This heat is supplied by exhaust steam at 6 to 8 lb. per sq. in. pressure, but as the steam in cooling gives up only its latent heat or 952 B.t.u. while the heat in the admitted steam is 1152 B.t.u. this work requires

$$\frac{1152 \times 14.2 \times 10^6}{952} = 17.2 \times 10^6 \text{ actual B.t.u.}$$

which is 28.5 per cent of the heat in the steam evolved by burning the bagasse.

In the quadruple-effect evaporator, the density of the defecated juice is changed from 17 to 55 deg. Brix, and the water to be evaporated for this concentration is

$$2000\left[0.90 \times 66 - \left(0.90 \times 66 \times \frac{17}{55}\right)\right]$$

or 82,000 lb.

In practice 3.7 lb. of water are evaporated by one pound of steam at 6 to 8 lb. pressure in a quadruple-effect evaporator. Therefore, 22,700 lb. of steam are required, which at 1152 B.t.u. represents $25.6 \times 10^6$ B.t.u. or $42\frac{1}{2}$ per cent of the steam generated by the bagasse. The remaining substance termed "meladura" $\left(0.90 \times 66 \times \frac{17}{55} \times 2000 \text{ lb. or } 36{,}800 \text{ lb.}\right)$ is to be reduced ultimately from 55 to 95 deg. Brix, and the water to be evaporated is therefore

$$\left(36{,}800 - 36{,}800 \times \frac{55}{95}\right) \text{or } 15{,}500 \text{ lb.}$$

Assuming this operation to be done in a vacuum pan under high vacuum and with exhaust steam, the steam required is proportional to that of the multiple-effect evaporator or

$$\frac{3.7}{4}\times 15{,}500\times 1152 = 16.5\times 10^6 \text{ B.t.u. or } 27.3$$

per cent of the steam generated by the bagasse.

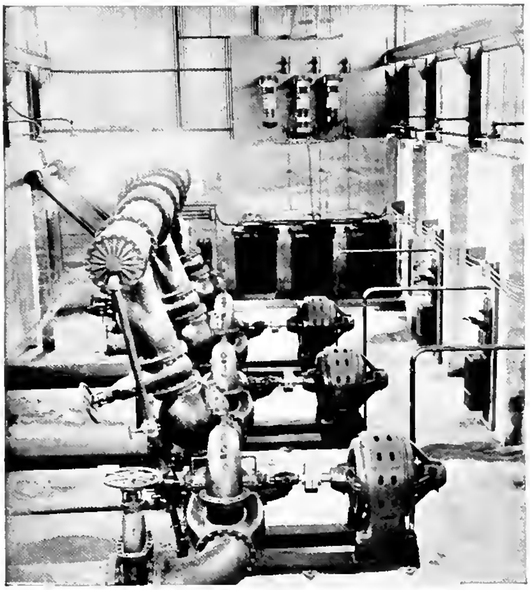

Fig. 2. Direct-connected, Motor-driven Centrifugal Pumps Providing Injection Water for Vacuum Pans and Multiple-Effect Evaporators

Assume now that the extraction gives a first yield amounting to 9 per cent of the cane or 12,600 lb. per hour when the "massecuite" as above is $36{,}800\times\frac{55}{95}$. We then have as molasses

$21{,}400-12{,}600$ or 8,800 lb. per hour.

This molasses is to be diluted say from 88 deg. Brix to 50 deg. Brix, and then further concentrated to 92 deg. Brix in the vacuum pan. The dilution water is $\frac{88}{50}-1$ or 76 per cent water by weight. Therefore, there are 15,500 lb. of liquor to be concentrated to 92 deg. Brix and the water to be evaporated is

$$15{,}500-15{,}500\times\frac{50}{92} \text{ or } 7050 \text{ lb.}$$

The heat required is, calculating as above,

$$\frac{3.7}{4}\times 7050\times 1152 = 7.5\times 10^6 \text{ B.t.u. or } 12.4 \text{ per}$$

cent of the steam generated by the bagasse. The total heat required for heating and evaporation, in terms of heat evolved from the burning of the bagasse is, therefore:

| | | Per Cent |
|---|---|---|
| Heating and defecating . | $17.2\times 10^6$ B.t.u. = | 28.5 |
| Evaporating in effect . . | $25.6\times 10^6$ B.t.u. = | 42.5 |
| Evaporating in vacuum pan . . . . . . . | $16.5\times 10^6$ B.t.u. = | 27.3 |
| Evaporating of molasses . | $7.5\times 10^6$ B.t.u. = | 12.4 |
| Assumed losses in condensation . . . . . . | $6.1\times 10^6$ B.t.u. = | 10.0 |
| Total . . . . . . | $72.9\times 10^6$ B.t.u. = | 120.7 |

or 20.7 per cent more than the actual steam generated by the bagasse. Analyzing this in dollars and cents, we have for the case under consideration the following result. 20.7 per cent × 14 tons = 2.9 tons of extra bagasse required per hour for cooking the "dilute" obtained from grinding 70 tons of cane per hour.

The average pound of coal contains 14,000 B.t.u., so that if bagasse possesses 3920 B.t.u. the ratio between coal and bagasse is 3.6, and the extra coal required per hour is, therefore,

$$\frac{2.9}{3.6} = 0.81 \text{ tons of coal per hour.}$$

Where wood is used as fuel, the ratio is obtained on the basis of the heat contained in the variety of wood used.

Operating the mill 100 days per season, 23 hours per day, and assuming that 14,000 B.t.u. in wood cost $7.00 per ton, the mill would spend per season for extra fuel needed to evaporate the water from the dilute,

$$0.81\times 100\times 23\times 7 = \$13{,}000.$$

Fig. 3. Back-geared Motors Driving Crystallizer Countershafts by a Chain Drive

This sum is greatly exceeded in mills of this size and extraction, indicating that money is spent for steam other than that required for cooking purposes, and it is probable that the most of this steam is freely exhausted into the atmosphere.

By the proper use of an electrical equipment, the difference can actually be saved.

Remembering now that the thermal efficiency of the steam engine, or that the percentage of actual B.t.u. required for the transformation of heat units into mechanical units is very low, and that nearly all the heat units put into the engine at the higher pressure are still contained in the low-pressure exhaust and therefore available for cooking, and assuming 8 or 9 per cent of the B.t.u. required for actual mechanical drive, which has been shown by practice to be a reasonable value, we would have the total heat required to be generated in the shape of steam to run the plant. This amounts to $79 \times 10^6$ B.t.u. or 130.7 per cent of the heat generated by the bagasse.

Each boiler horse power delivers 33,300 B.t.u. per hour. Therefore, the boiler capacity in this case, a 70-ton-per-hour mill, should be 2360 boiler horse power, or 34 boiler horse power per ton of cane ground per hour. As a matter of fact, the boilers installed and operating are nearer 45 and 50 boiler horse power per ton of cane per hour, which is a figure that has been found in actual practice to be in excess of the requirements of a factory equipped with a suitable electric drive.

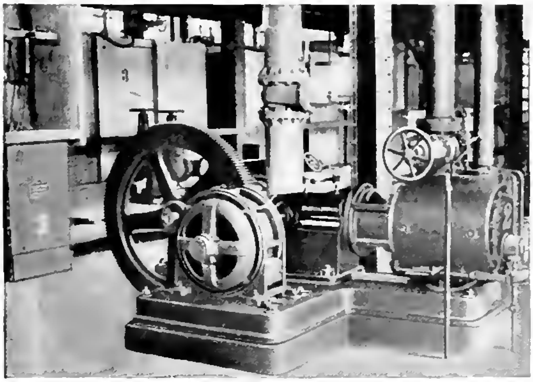

Fig. 4. One of Five Motor-driven Vacuum Pumps Installed in a Sugar Factory

In the electrifying of a sugar factory, i.e., changing its drive from steam to electric, it is apparent therefore that this excess boiler capacity can be used as a spare, with a consequent more efficient boiler operation which will also reduce the cost of repairs and increase the life of the boilers. The problem of electrification, from the modern mechanical or electrical engineer's point of view, is not to diminish the cost of steam required for cooking but to install such machinery as will not give an exhaust in excess of that needed for cooking. If additional machinery is required for mechanical drive or other purposes, it should be of such a type as to consume the least amount of steam and to waste the least or give no exhaust to the atmosphere.

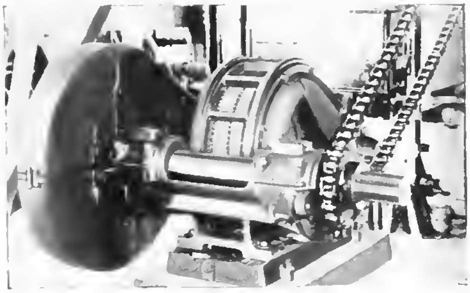

Fig. 5. Back-geared Motor and Chain Drive for a Countershaft Belted to Two Massecuite Pumps, Four Molasses Pumps and a Screw Conveyor

The mechanical power installation for the plant under consideration must, therefore, be proportioned in such a manner that its exhaust will be capable of furnishing the required $72.9 \times 10^6$ B.t.u. per hour. Any exhaust in excess of this represents wasted money; and the mill which shows a continuous stream of exhaust gives an indication of being operated uneconomically. Many a mill owner claims he has steam to spare, that he requires no improvements, and as a proof of it he points to the free exhaust, forgetting that he paid good money to obtain the 1152 B.t.u. contained in the exhaust steam at 6 lb. pressure, or that his extraction is so poor that he cannot use all the heat contained in the bagasse.

Now let us suppose that we have carefully analyzed the power requirements of each mechanical drive in terms of input, and that after considering the proportionate time of operation of each machine, i.e., the load-factor, the power requirements, in engines for crushers, mills, pumps, mechanical drive, electric lighting and power, tool shops, etc., are 28 brake horse power* per ton of cane ground per hour or a total of 1960 brake horse power for a 70-ton-per-hour sugar house. The steam consumption of the various steam engines must now be considered

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* This figure is in agreement with the 8 or 9 per cent of the heat required for cooking, as previously mentioned.

as guaranteed by the manufacturers, and the equipment must be proportioned accordingly. An average steam engine of the Corliss type in a sugar house, running non-condensing and with 6 to 8 lb. back pressure, consumes approximately 28 lb. steam per indicated horse power hour, and with a general gross efficiency of brake to indicated horse power of 85 per cent the actual steam required would be $\frac{28}{0.85}$ or 33 lb. per brake horse power hour. As the heat contained in the exhaust is 1152 B.t.u. the heat of the steam exhausted by each brake horse power is

$$1152 \times 33 = 38{,}000 \text{ B.t.u.}$$

Fig. 6. Inclined Track at Ingenio San Manuel Sugar Co., Cuba, to take care of the wood fuel needed to help the bagasse in the process of evaporation, and for which the bagasse alone is insufficient

Therefore, the necessary capacity of steam engine equipment for the needed exhaust is as follows:

$$\frac{72.9 \times 10^6}{38{,}000} = 1{,}920 \text{ brake h.p.}$$

With an equipment of 1960 brake h.p. in engines consuming 33 lb. of steam per brake h.p. hour, we see that we would have in this case very nearly only the actual amount of exhaust necessary for evaporation and thus no steam would be wasted. This, therefore, constitutes as near an ideal arrangement as is possible for this particular installation because the only fuel expense is that necessary for obtaining the heat required in concentrating the liquor and for which work the bagasse is not sufficient.

Assume now that instead of having 1960 brake h.p. in engines all consuming 33 lb. of steam per brake horse power hour, we had say 30 per cent of the total brake horse power requirements in pumps, hydraulic machinery, etc., using in the neighborhood of 100 lb. of steam per actual brake horse power hour, which consumption is by no means high in non-expanding steam engines.

With this latter arrangement we would have

$$0.70 \times 1960 \times 1152 \times 33 = 52.1 \times 10^6 \text{ B.t.u.}$$
$$0.30 \times 1960 \times 1152 \times 100 = 67.7 \times 10^6 \text{ B.t.u.}$$

Total heat available in the exhaust $119.8 \times 10^6$ B.t.u.

As we only require $72.9 \times 10^6$ B.t.u. the extra fuel is spent for obtaining

$$(119.8 - 72.9) \times 10^6 = 46.9 \times 10^6 \text{ B.t.u.}$$

By the installation of a suitable and duly proportioned electrical equipment, it is entirely feasible to save these $46.9 \times 10^6$ B.t.u., the value of which can be estimated as follows.

One pound of bagasse contains 3920 B.t.u.; the coal equivalent compared with bagasse is 3.6, as has been shown; the cost of coal equivalent is assumed at $7.00 per ton. Assume a 23-hour-per-day operation and a 100-day season.

Then:

$$\frac{46.9 \times 10^6 \times 23 \times 100 \times 7}{3920 \times 3.6 \times 2000} = \$27{,}000 \text{ can be}$$

saved in a mill of 70 tons per hour grinding capacity. A newly built factory of this size, without the use of a suitable electric drive, will then actually lose at the rate of $27,000 per season of 100 days.

Assuming now that for electrifying an old sugar house the interest on the investment for the change-over would represent yearly the sum of $7000, the sugar mill owner would actually have a yearly profit of approximately $20,000. This is apart from the interest on the electric motor investment, and is exclusive of the other very important coincident advantages which will save, as will be demonstrated in a later article, as much as and even more than the value of economized fuel.

Analyzing this result from another point of view, it will be apparent that from the value of the saved fuel alone and without considering the other advantages, the change-over from steam to electricity, in an old mill, would pay for itself in three or four years.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## MAGNESIUM METAL

The value of magnesium as an alloy with copper and zinc has been known for some time. Recently the extremely light construction desirable for airships and other machines has brought aluminum-magnesium alloys into prominence, and it has been found that for castings an alloy of aluminum with 10 per cent magnesium is preferable to pure aluminum for practically all purposes, as it is harder, stiffer, casts better, takes a better polish and is materially stronger, so that lighter constructions are permissible. Aluminum-magnesium alloys, with magnesium contents varying from a few per cent to 50 per cent have been introduced some time ago under the trade name "magnalium," but were limited by the high price of magnesium.

Magnesium metal is now on the market at approximately $1.40 per pound, which is quite reasonable considering the bulk of the material, due to the low specific gravity which is 1.75. This renders it practical to consider magnesium-aluminum alloy for various electric machines.

Magnesium metal, as now offered on the market, analyzes 99.8 per cent magnesium and 0.2 per cent iron. The properties of this metal have been found as follows, which is practically what has been previously found for pure magnesium:

Resistivity at 22 deg. C....... 4.55 microhms
Conductivity at 22 deg. C. . . 38.1 per cent
Temperature coefficient at 22 deg. C., 0.00380
Temperature coefficient at 0 deg. C., 0.00412
Tensile strength, lb. per sq. in........30,000
Elastic limit, lb. per sq. in......below 10,000
Shearing strength.....................15,600

J. D. B.

## CHARACTERISTICS OF NON-ARCING METALS

The purpose of this investigation was to determine the a-c. voltage necessary to establish an arc between two clean metal cylinders, after the intervening gap has been broken down by a static spark. The results, at first, did not seem to be at all consistent and finally it was found that the data taken depended to a marked extent on the particular reactance used to limit the short circuit current when the dynamic arc held. This lead to the suspicion that power-factor had an important relation to the holding a-c. voltage, and that all reactances used must not be saturated.

The nearer the voltage and current are in phase, the higher the voltage required to establish the arc. Unit power-factor curves are irregular, as should be expected. Theoretically, the voltage and current should be zero at the same time and the arc should break, but a finite curve is obtained, due probably to a time displacement between the current and the vapor stream of the metal and also to the slight reactance of the transformers and resistance circuit.

At the very small gaps, say from 0.01 in. to 0.1 in., the dielectric strength of the air is a predominating factor, while for the larger gaps the condition of the arc stream and the formation of more vapor is more effective. Hence, the increase and decrease of voltage, as shown by the curves.

From the data it seems that, for copper, brass and wrought iron, the minimum voltage required depends more on the angle of lag of the current than it does on the material under test. However, the curves for carbon and graphite seem to give much lower average values.

These results partly explain why titanium lamps would not operate on some circuits until the maximum reactance of the lamp was used. For example, on one 50 lamp system standard connections were wholly inadequate; that is, the power-factor of the system was too high and, under those conditions, the available voltage was not high enough to maintain the arc.

The same seems to hold for a system of magnetite lamps; that is, if the stability gained by station reactance is partly balanced by the capacity of a section of cable, the operation of the lamps is generally unsatisfactory. Perhaps some have noticed this on our local lighting circuits.

H. D. B.

## QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial person in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

### INSTALLATION OF A CURVE-DRAWING WATTMETER

**(75) It is desired to install, in a system already in operation, a curve-drawing wattmeter connected according to the accompanying wiring diagram (Fig. 1). There is at present one curve-drawing wattmeter, one watthour meter, and one voltmeter. The potential for these is taken from two 200-watt potential transformers and it is intended to use the same source for the added curve-drawing wattmeter. The current coils are intended to be connected to another set of current transformers, as shown in the diagram.**

We would say that the proposed arrangement would seem to be permissible. However, an accurate estimate of the errors involved can not be given without the ratio and specification numbers of the potential transformers, the ratio and specifition numbers of the current transformers, the specifications or serial numbers of the relays, their type, form, etc., the frequency of the circuit, and the power-factor limits of the output power from the 2000 kv-a. transformers into the 2300-volt busses.

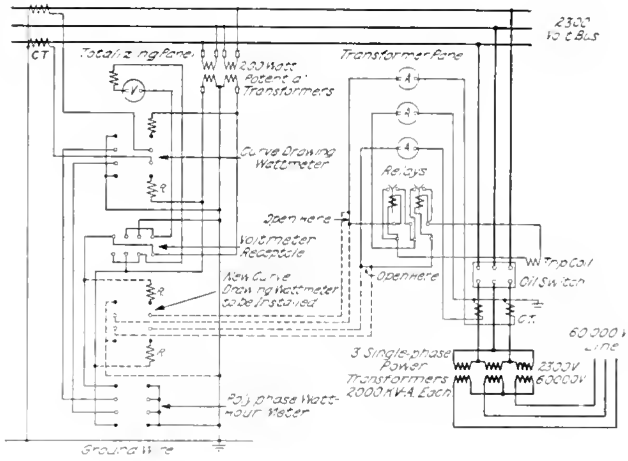


Fig. 1

L.T.R.

### POWER-FACTOR OF TRANSFORMER ON SHORT CIRCUIT

**(76) What are the internal characteristics affecting the power-factor of a transformer on short circuit; and what would be the value of the power-factor for, say, full-load current and also 150 per cent full-load current, both of course, at reduced voltage?**

The power-factor of a transformer on short circuit depends upon the ratio of its resistance to its impedance; and would be the same at full-load current and at 150 per cent full-load current. The actual value for this is subject to such wide variation that it would hardly be safe to answer by giving one definite figure, because it varies with the size, voltage, frequency, and type of the transformer. For instance, in one type it may be as low as 0.10 and in another type it may be as high as 0.75.

R.K.W.

### STARTING UP COMMUTATING-POLE ROTARY CONVERTERS

**(77) Why is it necessary to raise the direct-current brushes on a compound-wound commutating-pole rotary converter when starting from the alternating-current side?**

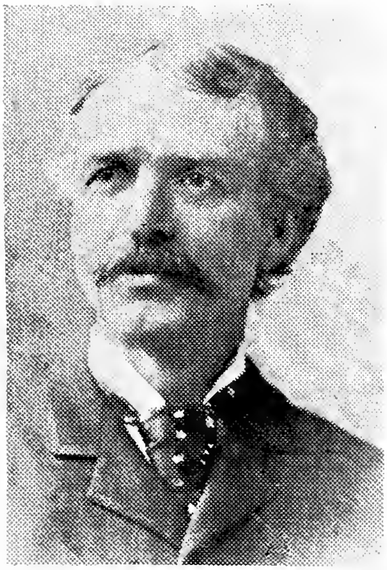
As is well known, there is at the starting of a rotary converter not equipped with commutating poles more or less sparking at the brushes due to the alternating field which induces voltage in the coils short circuited by the brushes. When commutating poles are added, a certain amount of magnetic material is thereby placed over the coils which are short circuited by brushes. This decreases the magnetic reluctance, and the induced voltage due to the alternating flux is increased. This induced voltage becomes effective between those adjacent commutator bars short circuited by the brushes with the consequent result of burning the brushes and commutator. The brushes are raised, therefore, to avoid the short circuit and burning. Incidentally also this operation decreases the starting current. When starting all the brushes are raised except two narrow ones, one positive and one negative, which remain down for excitation. The main field circuit is opened to give higher starting torque and less starting current.

J.L.B.

# IN MEMORIAM

## DANIEL MOODY BARTON

The sudden death of Daniel M. Barton, which occurred Monday, December 8, 1913, at his residence in Schenectady, N. Y., after an illness of only five days, removes a prominent employee from the organization of the General Electric Company. He is survived by his wife, who was Miss Lucinda Hill; a daughter, Mrs. Robert E. Nivison, and three grandchildren. He also leaves a brother, Silas A. Barton of Waltham, Mass., and a sister, Miss Vila Barton of Northampton, Mass.



D. M. BARTON

Daniel Moody Barton was born in the town of Ware, Hampshire County, Mass., in the year 1843, the son of Silas D. and Eliza Johnson Barton. There he spent most of his youth up to the age of nineteen, when together with his brothers, Henry and Silas A., he enlisted in the army. He served through the Civil War in the 10th Regiment of Massachusetts Volunteers, which fought at Fredericksburg and Gettysburg. After his return from the war, he became a dry goods merchant in Meriden, Conn., and Fall River, Mass., following which he removed to Lynn, Mass., where he pursued the occupations of bookkeeper and newsdealer.

In 1883 the Thomson-Houston Electric Company was formed by citizens of Lynn, one of the leading spirits being Silas A. Barton. Three years later Daniel M. Barton entered the employ of that company and became its first Production Manager, under E. W. Rice, Jr., Superintendent. During his administration of that office, inspired by the first large railway contract secured by the company, for electrifying the West End Street Railway, Boston, he devised and inaugurated some novel and successful systems of scheduling, regulating and expediting production, which attracted wide attention.

In 1891, the purchasing for the company, including that of its allied companies, was centralized in what was termed a Purchasing Bureau, located at Boston, with Silas A. Barton, Manager; F. W. Webster, Purchasing Agent; E. D. Floyd, Assistant Purchasing Agent. In 1893, D. M. Barton became Assistant Purchasing Agent of the General Electric Company, which was formed the previous year. With the removal of the offices to Schenectady, after it was decided early in 1894 to make that city the headquarters of the company, Mr. Barton was appointed Purchasing Agent, this title being changed to General Purchasing Agent some years later, which position he filled ably and loyally up to the time of his death.

Daniel M. Barton was a true christian gentleman, exceptionally devoted to his home and family; endowed by nature with deep human sympathies, which he extended to all, his kind hearted impulses and sunny disposition, coupled with a stern integrity and a scrupulous sense of justice, made his character a respected and lovable one. His death will cause a keen sense of personal loss, not only to his business associates, but also to his many friends in the industrial world.

## MATTHEW MAURY CORBIN

Matthew Maury Corbin, who died suddenly on August 24th at Charlestown, W. Va., was born near Fredericksburg, Va., in 1873. At the age of 21 he was graduated from the Virginia Military Institute in Civil Engineering, class of 1894, immediately following which he successfully completed a two years' special course in applied electricity at Johns Hopkins University. He taught school for a year in Southern Maryland and was later employed by the Bailey Switch and Signalling Company to assist in laying out their electric signalling system.

M. M. CORBIN

At the age of 25 he was commissioned Second Lieutenant, 1st Regiment, U. S. Volunteer Engineers, which was organized on the outbreak of the Spanish-American War in 1898 by the late General Eugene Griffin under the direction of President McKinley. He was promoted in the field to First Lieutenant and was at one time commanding officer of the Island of Ponce, Porto Rico, when that island was put under military jurisdiction.

At the end of the war, Lieutenant Corbin was given an opportunity to remain in the Government service, but he resigned and entered the General Electric Company's testing department, from which he was subsequently transferred to the Railway and Traction Engineering Department, under Mr. W. B. Potter. He served the Company in Schenectady, Cincinnati, Philadelphia and San Francisco, being a specialist in the electrification of steam railways.

J. C. CALISCH

Mr. Corbin was married in 1906 to Mary Anderson Rinehart of Plainfield, N. J. He is survived by his wife and two children.

### J. C. CALISCH

J. C. Calisch, special agent of the railway department of the General Electric Company, died in New York on November 28th from septic pneumonia.

Mr. Calisch entered the New York office of the Edison General Electric Company in 1890 and remained with this company when it was merged with the General Electric Company in 1892. In 1895, Mr. Calisch was appointed manager of the Pittsburgh office, and in 1899 manager of the Buffalo office. In 1906 he resigned to become vice-president and general manager of the Buffalo & Lake Erie Traction Company. In 1912 he returned to the General Electric Company, and since then has been located in New York as a special agent to look after certain large assigned customers.

### J. H. RYAN

J. H. Ryan, special sales agent for the Chicago office of the General Electric Company, died in one of the hospitals of that city on October 22nd.

Mr. Ryan was graduated from Cornell University in 1909, and after spending some time in the testing department of the General Electric Company, was transferred to the Chicago district in November, 1910, where he was employed as salesman's assistant. In February, 1912, Mr. Ryan was put in charge of sales to certain large interests in Chicago, which position he ably filled up to the time of his death.

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# GENERAL ELECTRIC REVIEW

*A MONTHLY MAGAZINE FOR ENGINEERS*

Manager, M. P. RICE
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FEBRUARY, 1914

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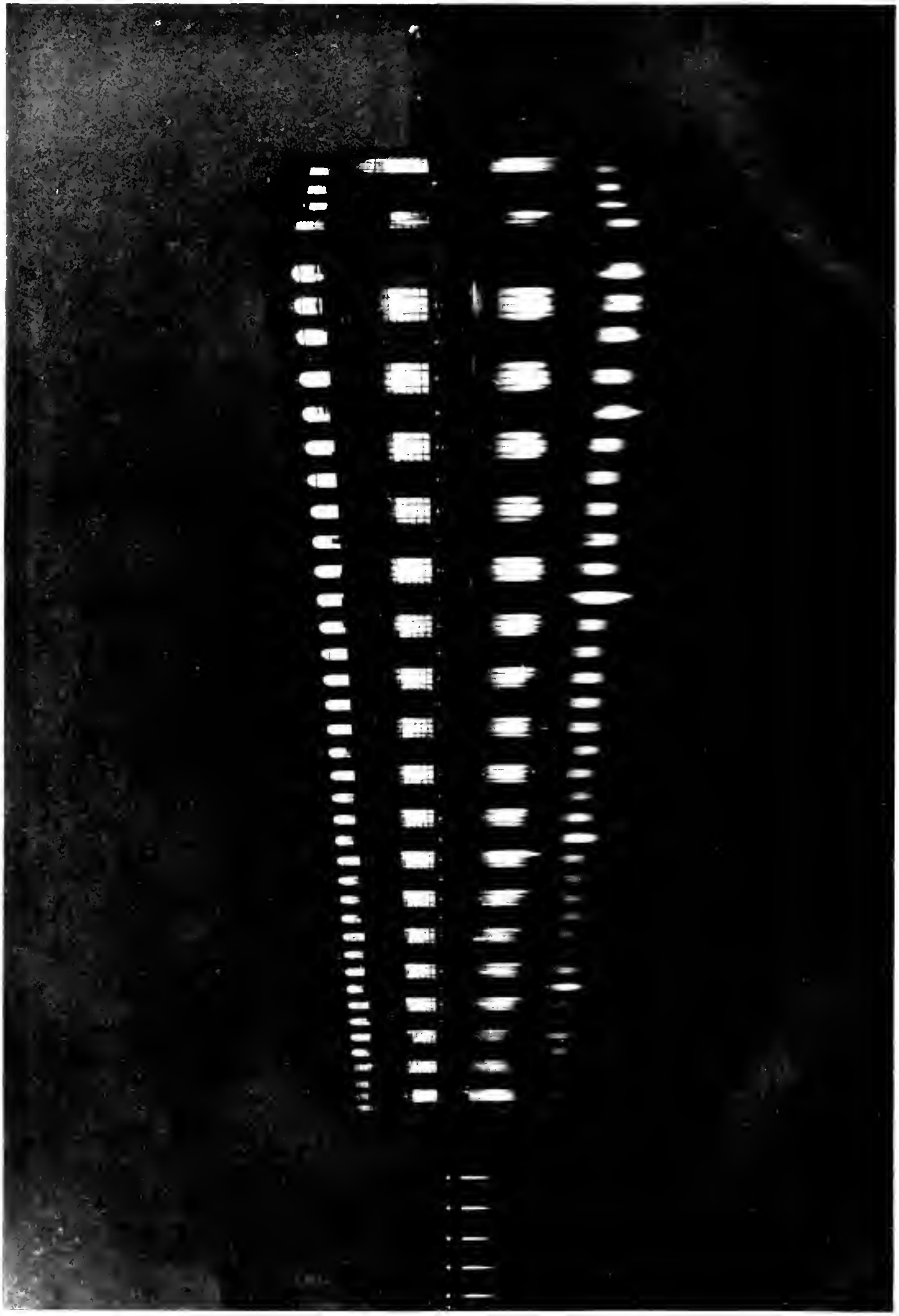


THE POWER HOUSE AT KEOKUK BY NIGHT

GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

With the beginning of a new year it is not uncommon to review the progress made during the last twelve months, but this is not always easy, and even when well done is seldom satisfactory. At best we touch those achievements which are the most apparent, and as size alone makes some developments so conspicuous, we are apt to lay too much stress on the large and to pay too little attention to the apparently small. It is often these small developments that lead to future progress and upon which the larger achievements are built, although it takes some time for their influence to be felt. However, the building of a power station larger than any yet constructed, and the manufacture of generating and transforming apparatus of immense proportions are notable steps taken along the paths of progress, as one of the chief objects of increased size in this direction is the securing of increased efficiency. The steady decrease in the number of pounds of material used in producing a kilowatt of energy is alone ample evidence that we are advancing. The article which we publish in this number, entitled "Some Notable Electrical Developments in 1913" cites numerous instances of progress in several different directions.

If time and space were available to thoroughly analyze the advances made during the last twelve months, there is little doubt but that the foundations which led to them could, in a very great number of instances, be traced to the research, testing, and other laboratories, where pioneer work is being done all the time, and here again the pioneer work which counts for so much eventually is often apparently insignificant at the time the work is being actually done. The choice of suitable materials and the development of new materials and ways and means of working them are among the important undertakings in this direction. There are so many notable things done today that could not have been done a few years ago, owing to the lack of suitable material and a lack of knowledge in the way to handle them, that the work constantly going on along these lines must be regarded as most important.

The strides made during 1913 in increasing the efficiency of the incandescent lamp will make the year notable for some time to come, and it would take a bold mind to predict the final result that the introduction of the use of gases in incandescent lamps may lead to.

In this issue we publish a paper by Dr. Coolidge on a new and more powerful form of X-ray tube. This work again is the product of the research laboratory of a large manufacturing firm, and bears an eloquent tribute to the nature of work undertaken. It would seem that this particular development may pave the way for further progress along these lines, and it is not unreasonable to believe that it may lead to some spectacular discoveries in that region of the spectrum lying between the X-rays and the gamma rays from radium. The work already accomplished with these rays, especially the discovery of radium, forms one of the most fascinating chapters in scientific research; and if Dr. Coolidge's work should lead to the writing of "known" on that portion of the spectrum hitherto marked unknown, it would indeed be a most notable achievement and a matter for the most whole-hearted congratulation. Such work will be heralded with great joy all over the world and it is not unreasonable to suppose that it may be the foundation stone for future work and future progress along lines that the whole scientific world, and especially the medical contingent, are deeply interested in.

Hydro-Electric Development at Keokuk on the Mississippi River, Showing Dam, Power House and Ship Lock

# THE MISSISSIPPI RIVER HYDRO-ELECTRIC DEVELOPMENT AT KEOKUK, IOWA

## PART I

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The completion of this immense hydro-electric development was one of the notable achievements of the year 1913. The construction of the dam and the foundation for the power house was fraught with difficulties, principal of which were the heavy spring floods with their destructive ice jams, that all but defeated the project. The success of the undertaking is as much a credit to the courage and progressiveness of the civil engineer as it is a record of accomplishment for his fellow workman in the electrical field. In this article the author has given us a very satisfying description of the entire development; the present instalment including a historical sketch of the project, and full and well illustrated descriptions of the dam, power house, ship canal, and hydro-electric and electrical equipments (the latter only in part). The concluding instalment, which will appear in our April issue, will deal with the power-limiting reactances, switching arrangements (including control boards), transmission lines, and the St. Louis substation.—Editor.

The huge hydro-electric development of the Mississippi River Power Company at Keokuk, Iowa, is one of the largest that has ever been undertaken in this country and unquestionably ranks highest among the plants of its kind in the world. It is located at the foot of the Des Moines Rapids, a dam having been constructed across the river between the cities of Keokuk, Iowa and Hamilton, Illinois, and the power house erected on the Iowa side.

### Historical Review of Development

The history of the project of developing power from the Des Moines Rapids dates back as far as 1848, but no success attended the various attempts until in 1899, when a final effort was made by the citizens of Keokuk and Hamilton. The Keokuk and Hamilton Water Power Company was organized with a capital of about $2500, which was raised by the sale of stock. The city councils of Keokuk and Hamilton were applied to for help, and by unanimous consent of the citizens $7500 was appropriated and turned over to the promoting company, every cent of which has been paid back to the city treasuries. With these funds at their disposal further investigations were carried on, and Congress was applied to for a franchise, which was granted early in 1905 after a thorough investigation to safeguard the rights of the people. In the early part of 1910 sufficient capital had been assured, and the actual work on the construction was started on January 5, 1910, just thirty days before the franchise expired. The Mississippi River Power Company was formed in the spring of 1911 to succeed the old Keokuk and Hamilton Water Power Company, and is now the owner of the entire plant and equipment. Current was delivered to St. Louis on July 1, 1913, as provided by contract made long before this water-power development was even an assured project. The total cost of the development was approximately $25,000,000.

"Sacred to the Memory of Keokuk, Distinguished Sue Chief, Born at Rock Island in 1788, Died in April, 1848"

### General Features of the Plant

The ultimate capacity of this development will be 300,000 horse power. The present power house installation comprises only one-half of the ultimate equipment, although the sub-structure of the building is complete for the second section, which will be erected as soon as the demand for additional power warrants it.

The electric power will be used mainly for manufacturing and agricultural purposes. The power zone is expected to cover a territory around Keokuk having a radius of about 200 miles and a population of over five million people according to the latest census report. The cities of Keokuk, Fort Madison, and Burlington in Iowa; Hamilton, Quincy and Alton in Illinois; and Hannibal and St. Louis in Missouri, are in the territory receiving power from this system.

Several transmission lines have been erected, one 110,000 volt line covering the territory along the river as far south as St. Louis, 144 miles from Keokuk; one 66,000 volt line from Meppen to Alton; two 33,000 volt lines, one to Hannibal and one to Quincy; and one 11,000 volt line covering the territory up the river to Burlington. The bulk of the power is at present disposed of in St. Louis, where 60,000 horse power is contracted for on a 99-year lease. All the power will be disposed of wholesale to large consumers, independent distributing companies, who may tap the main transmission lines through conveniently located substations.

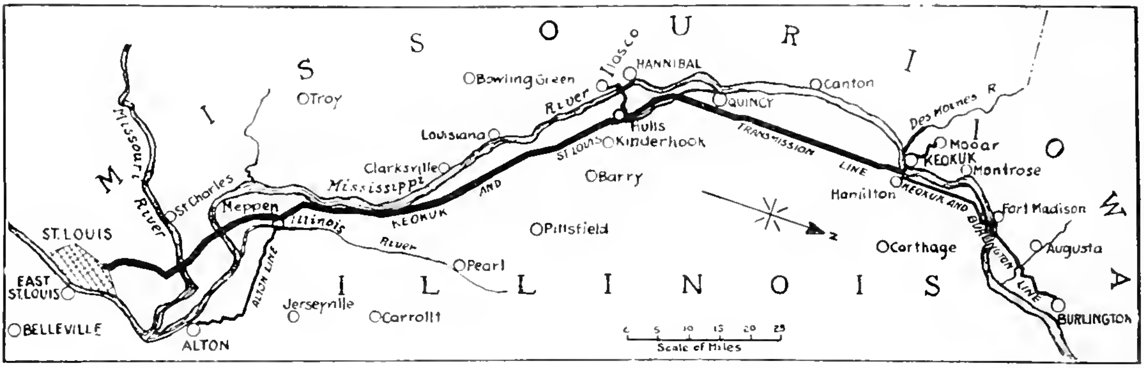


Fig. 1. Map of Country Served by Keokuk Development

The plant consists of the dam across the river, the power house, a navigation lock and dry dock, a retaining wall for protecting the railroad tracks, and an ice fender—all one concrete mass with a total linear length of 2½ miles.

One of the restrictions made by the Government when granting the franchise was that a deep waterway must be maintained, the old locks, dry dock and canal being submerged under many feet of water with the new development. A lock and dry dock had therefore to be built by the water power company and ceded free of cost to the Government, which will have complete ownership of them. The lock, which is 400 feet long and 110 feet wide, is one of the largest in existence, the width being the same as that of the Panama locks. Power for operating both the lock and dry dock, as well as the machine shops, is also furnished free from a separate turbine-driven air compressor plant built by the Company and turned over to the government.

Fig. 2. Timber Cofferdam for Power House Resisting Ice Jam, March 24, 1912. Cofferdam 25½ feet high

### Dam

The dam is of the gravity type, built of mass concrete without reinforcement and keyed down into the limestone bottom of the river about five feet. The structure, including the east and west abutments, has a total length of 4649 feet, a width of 29 feet at the top and 42 feet at the bottom, and a height from the bottom averaging about 53 feet. It comprises 119 equal spans, consisting of arches supported on piers between which the spillway sections are placed. The structure therefore acts both as a bridge and dam, with the water flowing over the spillways beneath the arches. The piers are 6 feet wide and the spillway sections 30 feet long and about 32 feet high.

In designing this dam the extreme variations in the stream flow of the river had naturally to be provided for, this varying from a minimum of 20,000 cubic feet per second to a maximum of 372,500 cubic feet, according to records taken during the last twenty years. While the normal operating head is 32 feet, this will vary from 21 to 39 feet from high to low water.

Fig. 3. View of Dam and Gate Crane

It was also necessary to limit the water level above the dam to prevent flooding of such land as had not been included in the flowage lands. The height of the spillway has therefore been designed to take care of the limit of the upper level. Furthermore, in order to keep the water above the dam at a constant level with smaller flow, steel gates have been provided on top of all the spillways. In extreme high water periods these gates will all be open, while at lower stages a suffi-

Fig. 4. Downstream Side of Dam

cient number will be closed to maintain the pool above the dam at the proper level.

The spillway gates are built of steel truss framework faced with steel plates, and they are raised or lowered by means of two electrically operated derricks, traveling on a track on top of the dam. Two standard gauge railroad tracks previously used for construction are also located on the dam and serve the above mentioned gates.

Fig. 5. First Boats to go Through New Lock. June 12, 1913

The erection of this dam across the Mississippi River at Keokuk has formed a lake which covers an area of approximately 43,000 acres. It extends 65 miles upstream to Burlington, Iowa, and varies in width from one to three miles. Navigation for this distance, which formerly was very difficult during low water periods, has therefore been greatly benefited.

### Power House

The power house is located some distance from the Iowa shore, the intervening space forming the forebay. It lies almost parallel with the river, and the water runs through the intakes and draft tubes nearly at right angles to the river flow, resuming its normal direction in the tail race, which is excavated in the river bed from the upper end of the power house along its entire length and for some distance beyond the downstream end.

The total length of the power house will be 1708 feet, of which the portion normally submerged is now completed. It consists essentially of two distinct parts, the substructure and the super-structure. The former not only serves as a foundation for the present part of the power house superstructure, but is in reality the hydraulic structure of the building. It has been completed to its full height on the forebay side for the entire plant, including the future extension, while on the river side the downstream half has been built above high water. It includes, however, the draft tube openings for the future units.

The width of the building is 132 ft. 10 in., and the total height 177 ft. 6 in., of which the height of the substructure to the generator floor is 70 feet and to the transformer floor 78 feet. The height of the generator room is 68 feet, which gives ample head-room for the traveling cranes, and makes it possible to take out the turbine runners with their shafts and carry them to the repair shop at the end of the generator room.

To gain head, and in order that the draft tubes might always be covered with water, the power house foundation has been extended down in the bed-rock of the river about 25 feet below the limestone bottom. The substructure is built entirely of concrete, the intake, scroll chambers and draft tubes being moulded in. It contains 211,400 cubic yards of concrete, or 13,400 cubic yards more than was used for the dam.

The superstructure is a reinforced concrete building of imposing design, containing four floors. The generator room is located on the main floor along the river side. The exciter sets and transformers are installed in compartments in the center of the building, while the gateroom occupies the shore side of the building. The floor level for the exciter, transformer and gaterooms is 8 feet higher than the floor of the generator room.

For the low tension switches, busbars and reactances, there are provided two narrow mezzanine floors in the center of the building.

Except at the ends, where additions are built out over the generator room to accommodate offices and store rooms, the fourth floor extends for the entire length of the building on the shoreward side only. This floor contains the switchboard control room, the 110,000 volt switches, busbars and lightning arresters.

The floors are supported partly on steel trusses and partly on concrete beams, interconnecting four rows of columns which rest on the sub-structure and extend to the roof. The floors and roof are of reinforced concrete slabs, a large portion of the floors being covered with red tile, while the roof is covered with tar and gravel. Window sashes and frames are all of steel, the windows being electrically operated. The lower part of the interior walls are painted dark green, while the finish of the upper part is white or cream. The entire exterior surface of the building is finished with white cement wash.

## HYDRAULIC EQUIPMENT

### Intakes and Scroll Chambers

From the forebay the water enters each turbine through four intakes converging into a scroll chamber moulded in the concrete around the turbine. The design of this spiral-formed scroll chamber and the intakes has been made very carefully in order to insure an equal velocity and force of the water all around the circumference of the wheel and thus obtain the highest efficiency possible. Three of the intakes for each turbine are entirely separate from the fourth, uniting in a common passage, some distance from the scroll chamber for passing the water to the further side of the wheel, while the fourth intake supplies the water to the nearest side. The scroll chamber has an average diameter of 39 feet and a height of 22 feet.

The outer openings of the intakes, which are 7½ feet wide by 22 feet high, are provided with steel gates sliding in cast iron guides. For raising these gates, as well as the screens, a 75-ton traveling crane is provided, running the full length of the gate house. For lowering the gates, however, there are separate brake mechanisms for each gate.

### Draft Tubes

The water from the turbines is discharged to the tail race through concrete draft tubes. These are about 60 feet long, gradually curved from a vertical to a horizontal direction. The foundations at their outlets are about 25 feet below the normal river bed. The draft tubes have a diameter of 18 feet at the wheels, but their cross section changes from a circular section at this point to an oval shape at the outlet; the tail race openings measuring 22 feet 8 inches in height by 40 feet 2 inches in width. This enlargement and change in shape is calculated to reduce the discharge velocity of the water

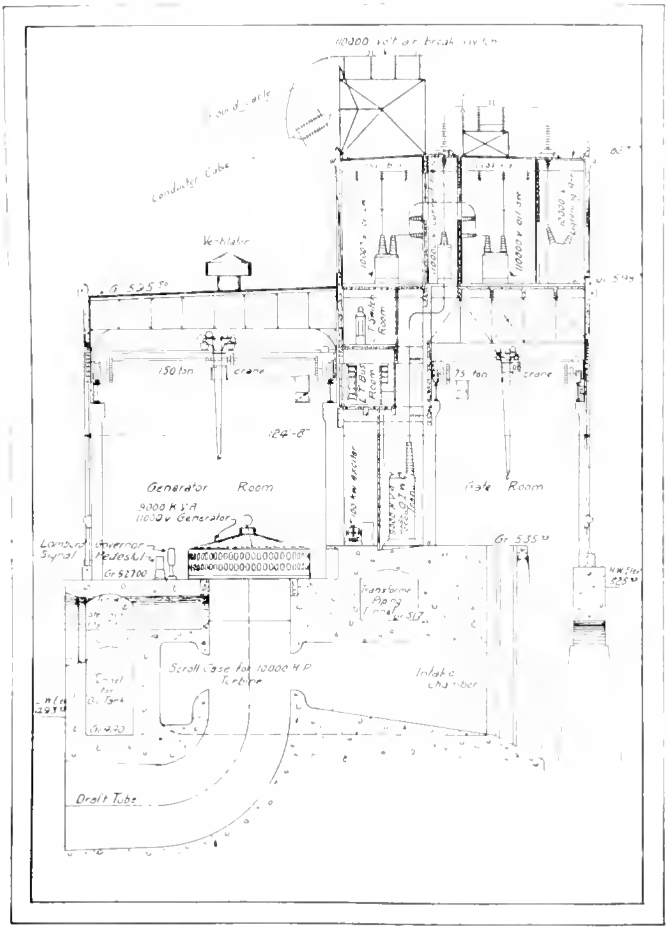


Fig. 6. Sectional Elevation of Power House

to four feet per second at the outlet into the tail race.

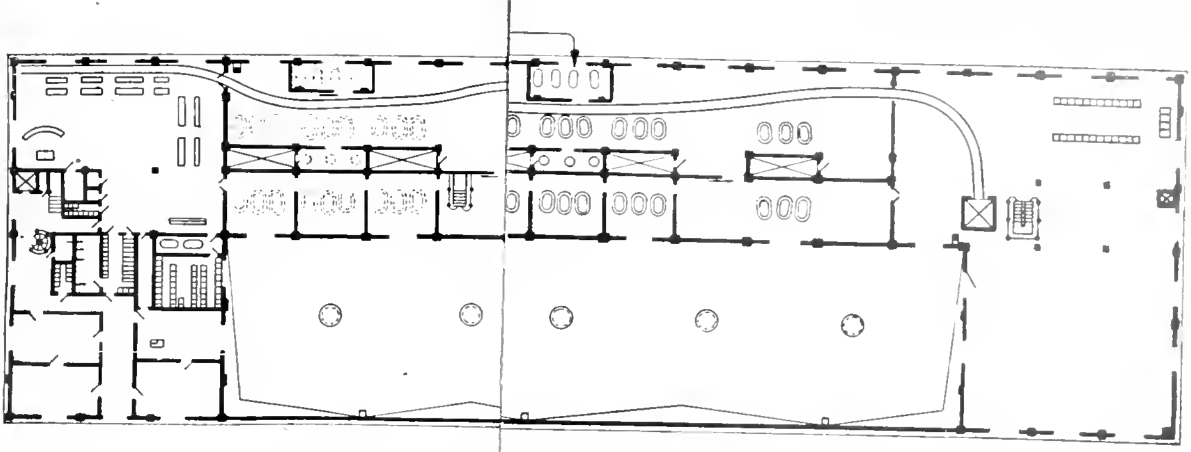
Fig. 7. Looking South Through Gate Room, Showing Gate Mechanisms in Place August 4, 1913

### Main Turbines

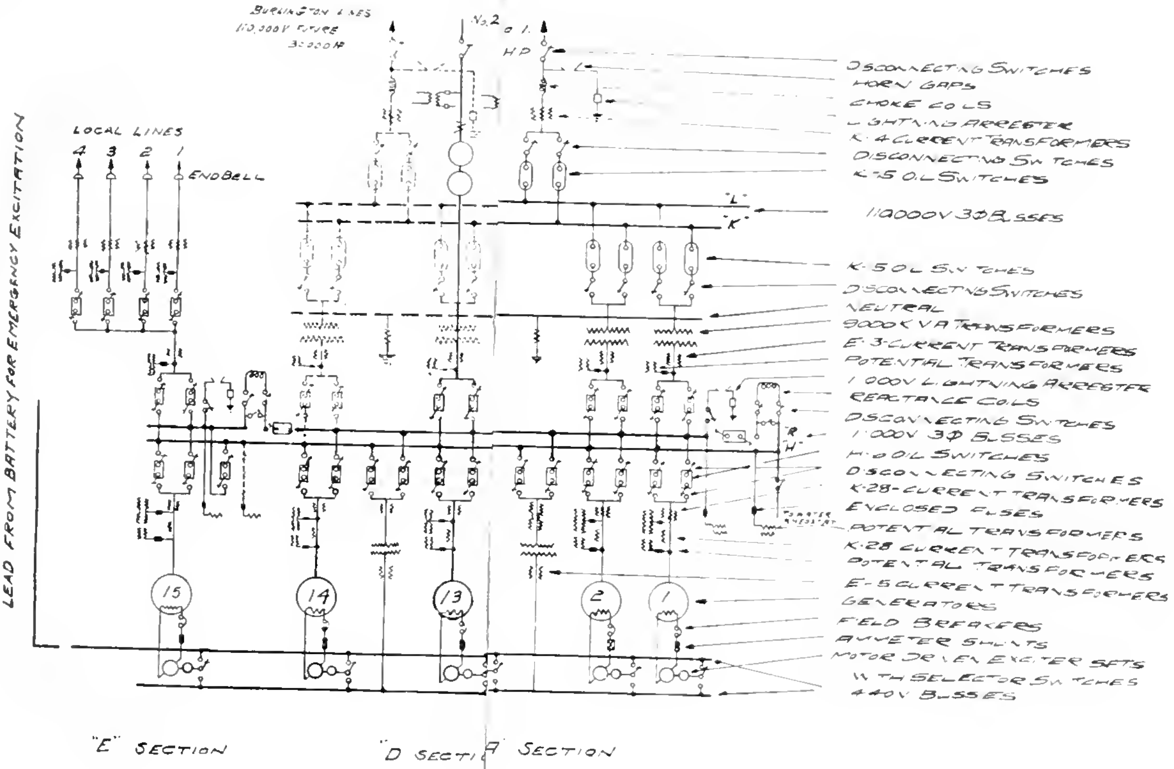
The initial installation comprises fifteen main turbines of the vertical single runner Francis type. They have a normal rating of 10,000 h.p. based on a head of 32 feet. Their design is, however, such that they will operate efficiently with a head varying from 21 to 39 feet. The actual speed is 57.7 r.p.m., the specific speed 338, and the maximum efficiency at normal head about 88 per cent.

The turbine itself is placed at the bottom of a large concrete-encased steel cylinder called the pit liner. Bolted to the upper and lower ends of this steel shell are large cast iron rings, weighing 30 to 40 tons each, which support the entire weight of the unit, or approximately one million pounds. Each turbine has twenty cast steel guide vanes, which are placed just below the pit

Fig. 8. Generator Room



Fi uture Installations



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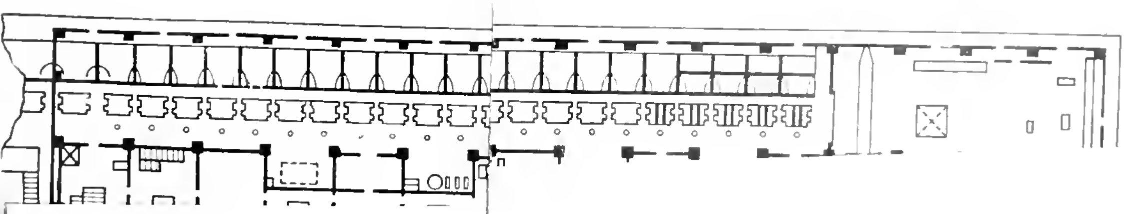


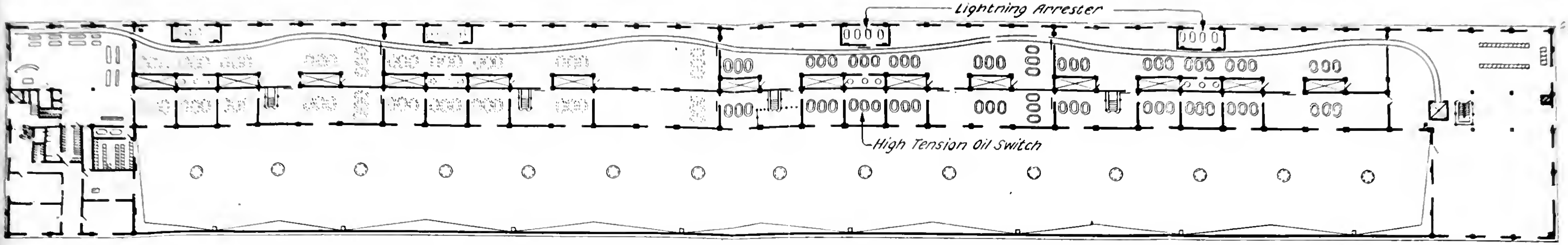


Fig. 6a. Plan of Fourth Floor of Power House, Showing Location of High Tension Switches and Lightning Arresters. Dotted Units Indicate Future Installations

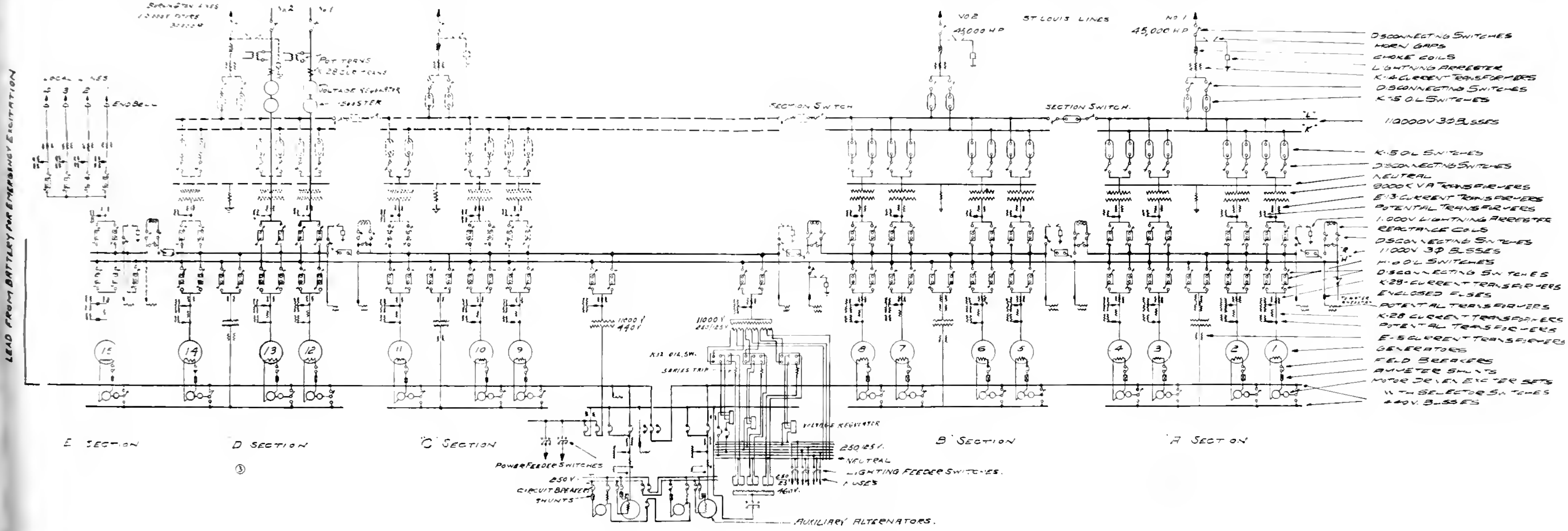


Fig. 6b. Diagram of Connections. Dotted Portions Indicate Future Extensions

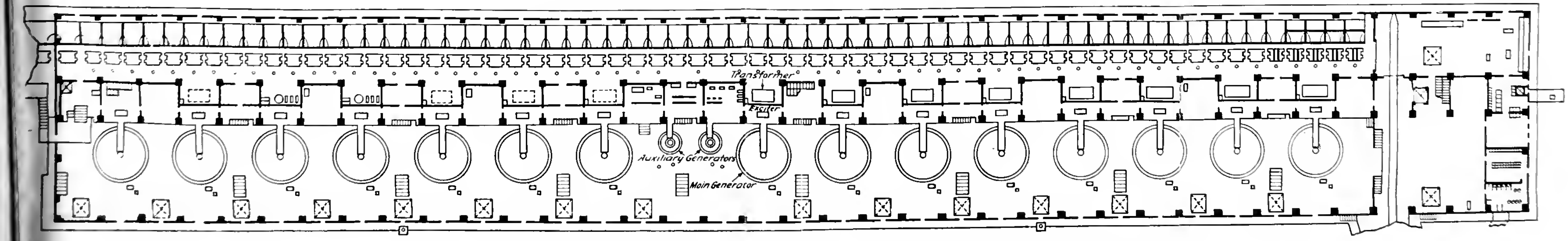


Fig. 6c. Plan of Generator Floor, and Elevated Floor on which are Mounted the Exciters, Transformers and Gate Mechanisms

liner cylinder between two heavy cast iron foundation rings, which are separated by 8-inch bolts.

Each runner has 16 vanes, the outside diameter at the bottom being approximately 17 ft. and at the top 12½ ft., the length being 11 ft. The runner is mounted on a forged steel shaft, which has a diameter of 25 inches and is coupled to the generator shaft above. The weight of each runner alone is 64 tons, while the weight of the total revolving element, including the water thrust and the generator field, is 275 tons. This weight is carried by a thrust bearing at the top of the wheel and below the generator, the bearing being supported from the upper foundation ring. Two guide bearings are also provided for each turbine unit.

Two different kinds of thrust bearings are used. Twelve of the units are equipped with the Standard Roller Bearing Company's combination oil-pressure and roller bearing. Under normal operation oil is forced between the two bearing faces at a 225 pound pressure, separating these by a thin film of oil, on which the revolving element is supported. However, if for any reason the oil pressure or supply should fail, the upper bearing plate will settle down on a set of oil-immersed steel rollers, which will then carry the weight of the rotating element without interrupting the operation. The three remaining thrust bearings are of the Kingsbury type, and require lubrication at only atmospheric pressure.

For lubricating the pressure type thrust bearings, each unit is provided with a separate triplex oil pump, chain driven from the governor shafts and having a capacity of 150 gallons per minute at 225 lb. pressure. A central oil supply system for the thrust bearings is also installed to be used in case of emergency. This consists of two motor-driven triplex oil pressure pumps, located in the main pump room and piped to the different bearings.

The lubricating oil for the guide bearings is furnished either by two waterwheel-driven or two motor-driven pumps. The oil is pumped to large tanks, whence it flows by gravity to the bearings and thence to reservoirs under the lower bearings. From the reservoirs it is pumped to the filtering and central supply tanks. Provisions are also made so that the oil can be simultaneously pumped directly to the bearings and the gravity tanks.

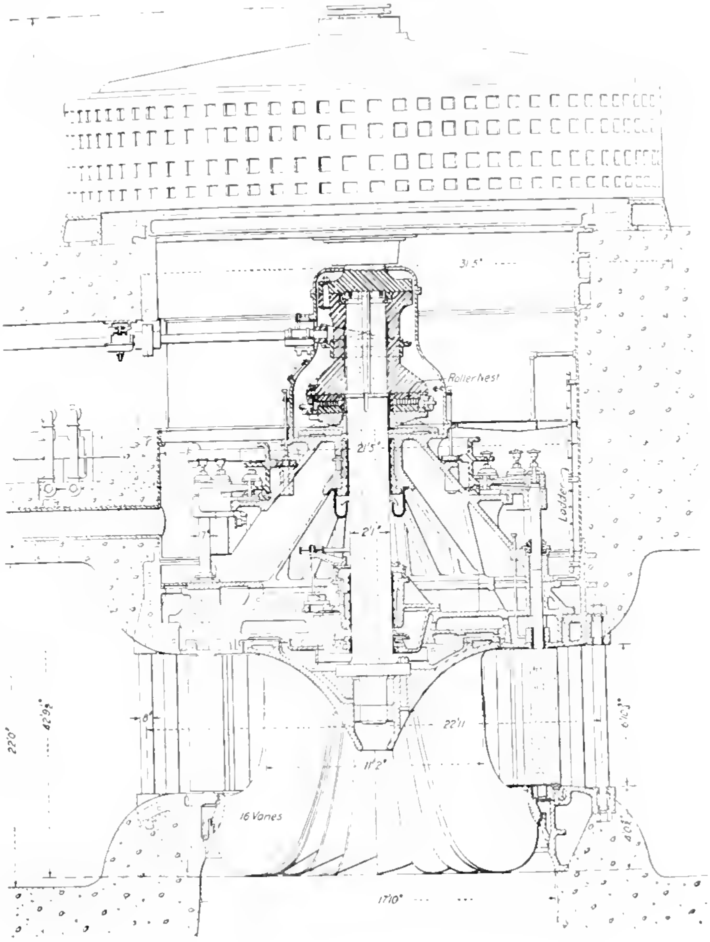


Fig. 9. Sectional Elevation of Turbine Showing Thrust Bearing and Connection to Generator Shaft

Revolving indicators, designed on the principle of water meters, are inserted in the piping leading to the guide bearings of each unit. These indicators are so adjusted that a certain number of revolutions correspond to a certain quantity of oil. Thermometers are also inserted in the in and outgoing oil supply pipes for each unit.

### Auxiliary Turbines

In addition to the main units there are two smaller turbines for driving the auxiliary generators furnishing power to the motor-driven exciters. These turbines, which are also of the vertical type, have a capacity of 2200 h.p. and a speed of 125 r.p.m.

**Governors**

The regulation of each turbine is accomplished by a specially designed Lombard oil-pressure governor, the balanced guide vanes being controlled through an exposed operating mechanism from the actuators, which are located on the generator floor in front of each unit. The operating mechanism consists of a rocker ring, which is carried on ball bearings and which is connected by links to the cranks on the guide vane stems. The rocker ring is operated by means of piston rods from two high-pressure regulating cylinders, which, together with the relay valves, are located on the thrust bearing floor. Under 200 lb. oil pressure these cylinders will develop 250,000 ft. lb., and the oil pressure is furnished by a separate induction motor-driven triplex pump for each unit. This pump and motor, as well as the accumulator and receiving tanks are also installed on the thrust bearing floor. By means of an automatic control arrangement the pump is started up if the pressure falls below 140 lb., and continues to run until it has reached 180 lb. The speed control element and the anti-racing devices are installed in the governor pedestals on the main floor, and the governor fly balls are driven mechanically from a counter shaft which is geared direct to the turbine shaft. On the governor pedestals are further mounted various gauges indicating the oil pressure, the gate opening, and the speed, while provisions are made so that the automatic regulation can be changed over to hand control if desired. The governor mechanism is also equipped with a motor connected electrically to the control switchboard, in order that the switchboard operator shall be

Fig. 10. Looking South Through Machinery Tunnel

able to control the speed of any unit when synchronizing.

The governors are guaranteed to maintain the speed steady within one-half of one per cent, and on decrease to load to bring the speed to normal within five seconds.

## ELECTRICAL EQUIPMENT

### System of Connections

The system of connections has been laid out with a view of securing the greatest flexibility and reliability, and double sets of busbars are therefore installed on both the high and low tension sides. As seen from the wiring diagram, one of the low tension buses runs continuous for the full length of the station, and this set will normally be used for forming a ring-connection or for transfer purposes in case of emergency. The generators will be normally connected to the other bus, which is divided into five sections, with current-limiting reactances and sectionalizing switches inserted between sections.

Both high-tension buses are divided into two sections, the operating bus being provided with sectionalizing switches; and while these will be open under normal operation, they afford means of paralleling the sections if desired. The other set is intended for transfer of the transformers within the respective sections only.

The two 110,000 volt outgoing St. Louis circuits are connected to sections "A" and "B," while the two 11,000 volt Burlington circuits are fed from section "D." The station and local service is taken from sections "C" and "E." However, when the demand for power increases, it is the intention to run two 110,000 volt lines from sections "C" and "D." In this manner the generators and transformers feeding each outgoing line will be on a separate section, insuring against trouble caused by short circuits or surges spreading from one section to the other.

### Arrangement of Apparatus

The fifteen main generators are located directly above the turbines and are spaced along the generator room 48 feet apart, measured between the center lines of the units. The two auxiliary generators are installed between main units Nos. 8 and 9. These auxiliary generators are equipped with direct-connected exciters mounted on top of the units, while the individual exciters for the main generators are motor-driven; the sets being installed in compartments on the same floor level as the gate house floor, eight feet above the generator room floor. These exciter compartments are entirely open towards the generator room, and openings are furthermore provided in the partitions between the compartments, thus affording a continuous passage through the whole length of what may be termed the exciter gallery. The auxiliary exciter, lighting and power transformers, as well as the auxiliary switchboards, are also located in compartments on this gallery, facing the generator room.

The large main transformers are installed on the same floor level and back of the exciter sets in compartments opening towards the gate house. The low-tension busbars and oil switches are located above these compartments, as shown in the cross-section.

Fig. 11. Step Bearing for Unit No. 1

The high-tension room occupies almost the entire top floor of the gate room section of the building. Its floor is at the same elevation as the roof of the generator room, and it is divided into a number of compartments, or rather rooms, for separating the various high tension switches, lightning arresters, connections, etc. The outgoing lines run through roof bushings to the roof structure to which the long river spans are anchored. These roof structures also support the line disconnecting switches and the lightning arrester horn gaps, while the arrester tanks are installed on the high-tension switch room floor.

The control switchboards are located in a large room at the south end of the high-tension switch room floor—a position which ultimately will be in the center of the building when this has been extended to its full length. This room is entirely shut off from the generator room; but, by descending a short flight of stairs to an inspection gallery, a view of the entire generator floor is obtained. All the pumps for water, vacuum and air compressor systems, are located in tunnel below the transformers.

**Main Generators**

As previously mentioned, the present installation comprises fifteen main units. They are of the three-phase, twenty-five cycle, vertical revolving field type, having 52 poles and operating at a normal speed of 57.7 revolutions per minute. They have a maximum continuous rating of 9000 kv-a. at 11,000 volts, and when operating at 80 per cent power-factor the temperature rise will not exceed 50 deg. C. on the armature winding measured by resistance or temperature coils placed in the armature slots between the top and bottom coils; 50 deg. C. on the field winding measured by resistance; or 50 deg. C. on all other parts measured by thermometer.

The machines are designed for a high internal reactance, limiting the instantaneous short circuit current to about five times the normal value. At the same time they have an inherent regulation of approximately 8 per cent at unity power-factor and 20 per cent at 80 per cent power-factor.

The guaranteed efficiencies were as given in the following table, while actual tests after installation indicated even somewhat higher values:

| | Full Load | 3/4 Load | 1/2 Load |
|---|---|---|---|
| 9000 kv-a., 1.0 power-factor | 96.3 | 95.9 | 94.6 |
| 7200 kw., 0.8 power-factor | 95 | 94.5 | 93 |

The required maximum excitation is 85 kw. at 250 volts.

The armature winding consists of form-wound interchangeable coils of the barrel type, heavily insulated with both mica and varnished cambric. They are Y-connected, but the neutral is not brought out to the terminal board.

The field spider is made of cast iron with the field rim of cast steel. The pole pieces are securely bolted to the rim and the whole construction is designed to withstand a 100 per cent over speed. The flywheel effect ($WR^2$) of the revolving field is approximately 20,000,000 pound-feet.

The two collector rings are mounted on the shaft extension above the top brackets. Bridges with handrails are built to the exciter gallery, thus facilitating the inspection and adjustment of the collector ring brushes. These bridges also serve as a support for the field leads, which run in conduit underneath the bridge directly from the exciters to the collector rings.

Two guide bearings are provided for each generator, one above and one below the rotating field. The shaft is a hollow steel forging 27 inches in diameter, with a forged coupling, 57 inches in diameter, on the lower end for bolting to the combined coupling and thrust block on the waterwheel shaft.

For ventilating the machine, the movement of the air is brought about by the natural fanning action of the revolving field, holes being provided in the field spider rim between the poles to secure a uniform ventilation of the field coils. The air is drawn through the openings in the top cover of the frame and from the pit below, and is discharged through holes in the sides of the frame after having been forced through the ventilating ducts in the core.

Each generator is equipped with a pneumatically operated brake, consisting of eight sets of brake cylinders with shoes which work against the lower surface of the revolving field rim. These brakes are designed to bring the whole rotating element to rest in from five to ten minutes, against the water leakage which may be expected to leak through the gates. The piping to the cylinders has been laid out so that a failure to any of the sets will not affect and cripple the others.

The outside diameter of the generator frame is 31 ft. 5 in., and of the revolving field 25 ft. 5 in., while the height of the unit at the center is 11 ft. 3 in. The net weight of the stator is 221,000 lb., of the base 165,000 lb., and of the rotor and shaft 228,000 lb., the total being 614,000 lb.

### System of Excitation

The system of excitation is of unusual interest, being quite out of the ordinary. In order to obtain the greatest flexibility, each generating unit is provided with a separate exciter. These are motor-driven and operate at a much higher speed than would have been possible with direct connected units, which results in a more economical arrangement. The exciter sets receive their driving power normally from an entirely independent source, consisting of two auxiliary waterwheel-driven alternators feeding into a set of busbars which run the full length of the station; sectionalizing switches being provided only in the middle so that if desired the bus can be divided into two sections with one auxiliary alternator connected to each. Provisions are also made so that the exciter sets can be fed from the main bus, four step-down transformers being provided for this purpose. They connect the main bus with a second auxiliary exciter bus, which is sectionalized in four groups with one transformer for each group. Connections can also be established, in case of emergency, with one of the duplicate storage batteries which ordinarily are used for the operation of the oil switches.

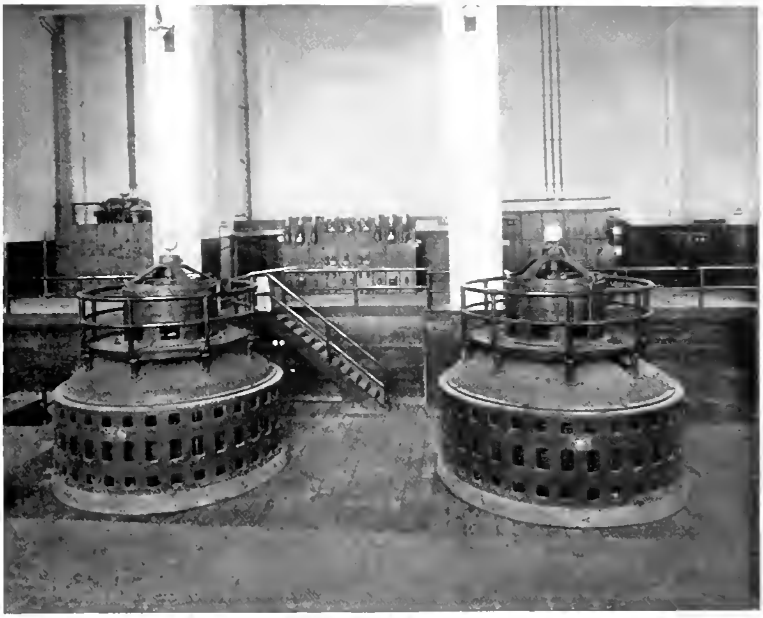


Fig. 12. Auxiliary Alternators Nos. 1 and 2. June 10, 1913

The two auxiliary alternators are equipped with individual direct connected exciters, and TA regulators serve to keep the auxiliary bus voltage constant. Besides supplying the exciter sets, energy is also normally taken from this bus for the power and lighting required for the station service, although provisions are made so that it can also be taken from the main bus.

The field current is conducted directly from the motor-driven exciters to their respective generators, the commutator brushes of the former simply being connected to the collector ring brushes of the latter, with solenoid operated field switches inserted in one of the leads. The regulation is accomplished by adjusting the fields of the individual exciters, thus eliminating large field rheostats and energy losses in the main field circuits. Each exciter is provided with its own TA regulator, and parallel operation with compensation for cross currents is obtained by means of current and potential transformers which are installed in the generator leads and connected 90 degrees out of phase with each other. If cross-currents tend to flow between the generators, the regulators will reduce these by strengthening or weakening the field of the affected generators.

The two auxiliary alternators are of the vertical type direct connected to waterwheels. They have a maximum continuous rating of 2000 kv-a. at 460 volts and operate normally at 125 r.p.m. Their general design is the same as for the main units, with the exception that each is equipped with a direct connected exciter mounted on the upper bearing bracket so that the machines can be started as self-contained units. The upper bearing bracket also supports a Standard roller thrust bearing which carries the weight of the total revolving element, including the waterwheel runner and the water thrust.

Under test these auxiliary generators showed a temperature rise well within 50 deg. C. and an efficiency of 95.1 per cent, both based on the full load of 1600 kw. at 80 per cent power-factor. At full load, with unity power-factor, the inherent regulation is approximately 8 per cent. Each unit requires a maximum excitation of about 30 kw. at 250 volts, and motor-driven field rheostats are provided so that the voltage may be adjusted from the control switchboard.

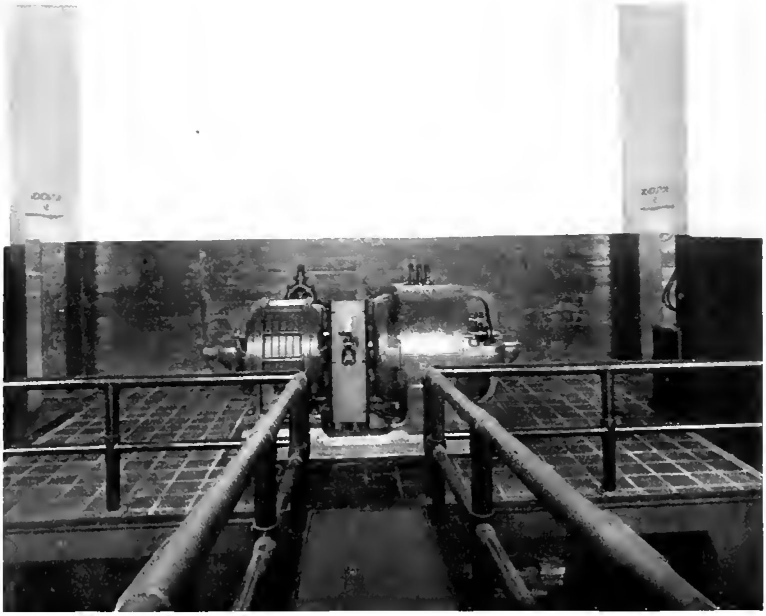


Fig. 13. Exciter Set for Unit No. 12. June 19, 1913

The direct connected exciters for these units are of the compound-wound, commutating pole type. They have a normal rating of 60 kw. at 250 volts, and each exciter is therefore capable of exciting both the machines in case one of the exciters should be disabled. Connections and switching arrangement are provided to accomplish this, and also to make it possible to operate the two exciters in parallel if desired.

The total weight of each auxiliary generator is 127,000 lb. and of each exciter 15,000 lb.; the combined weight of the rotating elements being 42,500 lb. The diameter is 13 ft. 8 in. and the over-all height from the floor to the top of the exciter, 13 ft. 3 in.

Each of the exciter sets for the main units consists of a six-pole 100 kw., 250 volt-shunt-wound commutating pole generator mounted on the same base with and driven by a four-pole 25 cycle, 3-phase, 440 volt squirrel-cage induction motor, the set operating at a synchronous speed of 750 revolutions per minute.

The sets are designed to operate at 25 per cent overload for 2 hours, and with a full-load efficiency of 84.2 per cent. The starting is accomplished through a starting compensator. Provision is made for overload or low-voltage tripping, although not used at present. The total weight of each set is approximately 11,500 lb.

The four transformers for supplying power for the exciter sets from the main bus are of the three-phase, oil insulated and water-cooled shell type construction. They have a continuous rating of 600 kv-a. with a temperature rise not exceeding 40 deg. C., based on a cooling water supply of 6 gallons per minute at 15 deg. C. They also have a 2-hour overload capacity of 750 kv-a. with a rise of 55 deg. C. based on a water supply of 7.5 gallons per minute.

The high-tension winding consists of five coil groups, five in series for 11,000 volts, and five in parallel for 2200 volts. Similarly, the low-tension winding consists of four groups to be connected in series for 440 volts, in series-parallel for 220 volts, and in parallel for 110 volts. No other taps are provided and both the high and low tension windings are connected in delta. The high tension winding has been submitted to a one-minute test of 22,000 volts from primary to secondary and core, and across the full winding, while the low tension winding has been tested at 4000 volts for one minute between the secondary winding and core.

The full load efficiency is 97 per cent and the regulation at 100 per cent power-factor 2.3 per cent.

The cooling coils are of wrought iron, and the connections to oil piping and vacuum system are provided for these units as for the main transformers. Each unit occupies a floor space of 7 ft. by 4 ft. 2 in. and an over-all height of 12 ft. 10 in. The total weight including the oil is 25,200 lb.

Fig. 14. 9000 Kv-a. Transformer. June 3, 1913

**Main Transformers**

There are nine three-phase oil-insulated water-cooled transformers of the shell type construction, one of which is for spare. They have a maximum continuous rating of 9000 kv-a. with a temperature rise not exceeding 50 deg. C. This rise is based on an ingoing water quantity of 46 gallons per minute at a temperature of 27 deg. C.

The low-tension 11,000 volt winding is delta-connected and the high-tension 110,000 volt winding Y-connected, with the neutral brought out and dead-grounded. For bringing out the leads four high-tension and three low-tension bushings are therefore provided in the cover. No taps are provided in either winding.

The high voltage winding is very heavily insulated and has been submitted to a one-minute high potential test of 250,000 volts from primary to secondary and core, and across the full winding, while the high-tension bushings have been tested at 450,000 volts. A similar test at 22,000 volts has been applied between the low tension winding and the core.

The efficiency of the transformers at normal load is approximately 98.5 per cent. The regulation at unity power-factor, 1.3 per cent and the reactance 5.7 per cent.

The supporting framework which holds the core and coils together, is built of structural I-beams, channels and angles. The tanks are made of boiler plate reinforced by numerous ribs and designed to withstand atmospheric pressure. On account of their large size they had to be made in two sections, an upper and a lower, which were riveted together after their arrival at the plant. The top covers are provided with gaskets, making the transformers practically air-tight. However, a four inch overflow pipe is provided and sealed with oil paper gaskets. In general, the design is such that the cover, core and leads can be lifted out of the tanks without detaching any parts, while the whole unit rests on a wheeled truck which permits moving of the transformer from its compartment out into the gate house where it may be handled by the crane.

Fig. 15. Exciter Transformer

The cooling coils are of the $1\frac{1}{2}$ inch wrought iron pipe, each coil being made up in three sections, the total length being 1834 feet.

They are designed to withstand a water pressure of 500 lb. per sq. in. The water for cooling purposes is pumped from the gate house by motor-driven centrifugal pumps, after which it is filtered and led to the cooling coils. A duplicate system of piping is provided, the valves and visible discharge nozzles being mounted back of the transformer compartments on the walls facing the generator room.

Each transformer requires about 10,000 gallons of insulating oil, and a complete piping system with pumping equipments has been installed for handling this between the cars, tanks and the various transformers. Large storage tanks for both filtered and unfiltered oil are installed in separate compartments in the lower tunnel below high tail race water level, the tanks being imbedded in sand as a fire protection.

There are 12 storage tanks for transformer oil, six for the good and six for the bad oil. Two oil treating outfits with the necessary pumps, filters, drying ovens, etc., are provided for filtering the oil. These are at present of the portable type, but piping arrangements are made so that permanent equipments can be installed. Connections are provided at the bottom of the transformers for filling or emptying the oil. At the bottom of the tank is also a quick acting valve accessible from the generator room, which allows the transformer oil to be quickly discharged either into the storage tanks in the sub-structure or directly into the tail race in case of emergency.

Each transformer is provided with an oil gauge and a thermometer of the capillary tube type.

Each transformer occupies a floor space of approximately 9 ft. by 16 ft. The height to the top of the cover is 18 ft. 6 in. and to the top of the high-tension leads 24 ft. 3 in. The weight of the complete unit including the oil is 246,000 lb.

(*To be Concluded in April* REVIEW)

Fig. 16. Power House

# POWER FROM MERCURY VAPOR

## Part II

### By W. L. R. Emmet

Consulting Engineer, General Electric Company

This paper relates to a process by which it is expected to accomplish a very large saving of fuel in the practical production of power. In our January issue Mr. Emmet gave a general outline of the theoretical considerations governing the application of mercury vapor as a means of generating power. In his present article he deals with the practical aspects of this development. He cites some of the first experiments made and tells of the later designs of apparatus that give promise of success. Some of the mechanical details described are of very great interest and much ingenuity has been displayed in solving such problems as guarding against leaky joints. The article is concluded by a brief resumé of the proposed methods of commercial application. The paper was presented before the Schenectady Section of the A.I.E.E. at its December meeting.—Editor.

With a view to developing a design for a mercury boiler which would produce the vapor with practicable methods of firing, without destructive temperatures in the steel and with a small total amount of mercury in use, much experimenting was done to determine the behavior of mercury under boiler conditions.

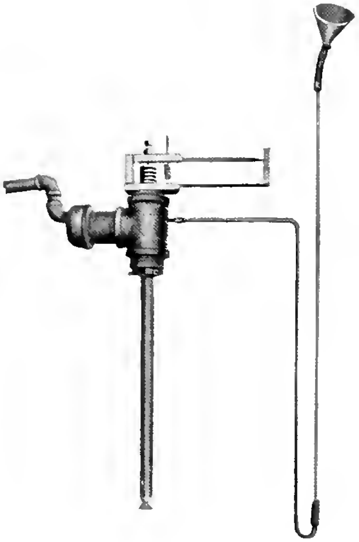


Fig. 1. First Experimental Mercury Boiler Tube

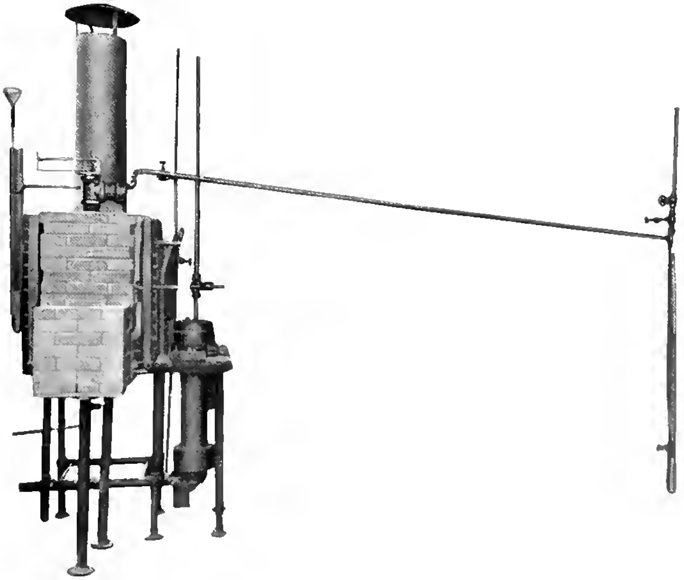


Fig 1a. Mercury Boiler Tube of Fig. 1 Encased in Brick Setting

The first experiments made were with tubes containing solid cores, with a small clearance between the core and the tube and a central hole in the core provided for circulation of the liquid. The apparatus used in this experiment is shown by Fig. 1. A rod was carried downward through the central duct and projected out through a packing as shown. The relative expansion of this rod and of the outer walls of the tube was indicated by a multiplying lever as shown, which afforded an accurate measure of the average temperature difference between the outer walls, which constitute the heating surface, and the liquid which was flowing in contact with the rod. This tube was subjected to various heating conditions and curves were plotted which compared rates of vapor flow with temperature difference. Some unexpected results were encountered and the nature of the action was investigated by boiling mercury between concentric glass tubes having an annular clearance about equivalent to that used in the steel tubes. These experiments showed that to absorb a large amount of heat with a small temperature difference between the heated surface and the liquid, it was necessary to provide for a very free circulation of the liquid so that a large amount of liquid could flow. The size of the central hole had a very positive effect upon the vapor capacity of the tube.

Since the mercury does not wet the heating surfaces, the tendency is for the vapor to fill a space between the liquid and the heating surface and thus to prevent heat removal. The way to get effective action in a mercury boiler is to create conditions by which so much liquid will circulate in hot parts that very little vapor will be formed until the heated liquid reaches the upper parts of the tubes, where the pressure is relieved and where the heat stored begins to be released in vapor.

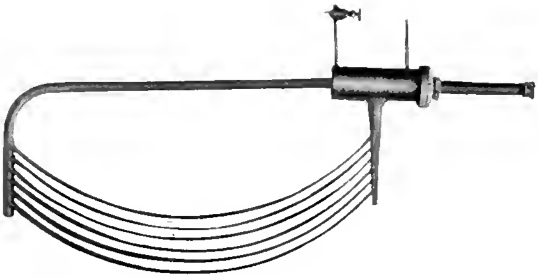


Fig. 2. Second Experimental Mercury Boiler Tube

Difficulties with temperature differences are only encountered in the hottest parts of the boiler where radiation plays an important part. With the low rates of heat transference which prevail through a greater part of the surface, extremely narrow spaces can be provided for the circulation of liquid and for the release of the vapor which is formed.

Having obtained by experiments data concerning possible rates of heat transference, a boiler was built in which the heating surface was made up of round tubes with concentric cores. The tubes were expanded into a horizontal sheet which formed the bottom of a box, and arrangements were made by which the central ducts in the cores always received a supply of liquid. The tubes in this boiler were rather thin, and in experimenting with it, it was found that at the hot end the expanded joints in the tube sheet became loose, the temperature differences imposing

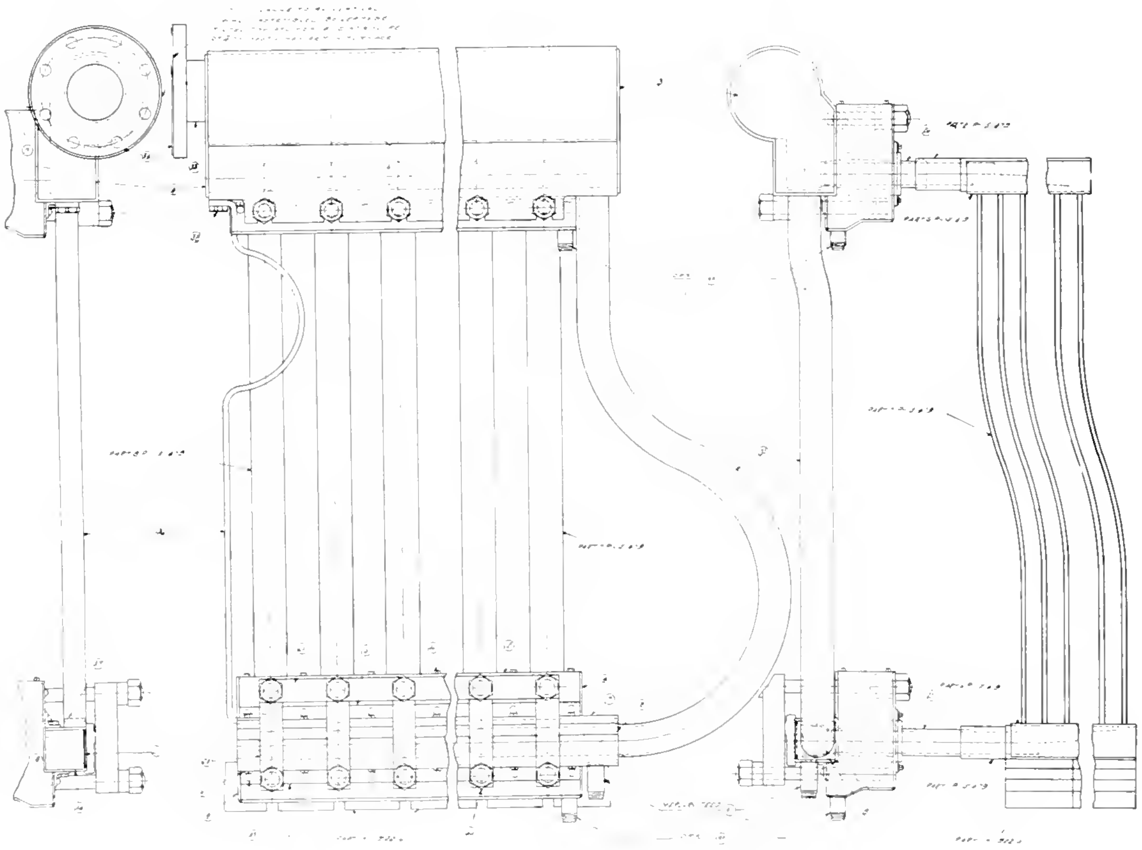


Fig. 3. Assembly of Experimental Mercury Boiler

strains which exceeded the elastic limit of the metal. This trouble could have been corrected by acetylene welding these joints; but this would have involved various changes and difficulties, and since trouble was also encountered in making the bolted joints of the box vacuum tight, it was decided to abandon this boiler and build another on an entirely different principle, which had been in the meantime devised and experimented with. The construction of this new boiler is shown by Fig. 3, and the experimental unit used to determine its characteristics is shown by Fig. 2.

This boiler is made up of a number of heating units each consisting of an upper and a lower header which are connected together by curved flattened tubes. The flattening is to reduce the space which must be filled with liquid mercury, without diminishing the

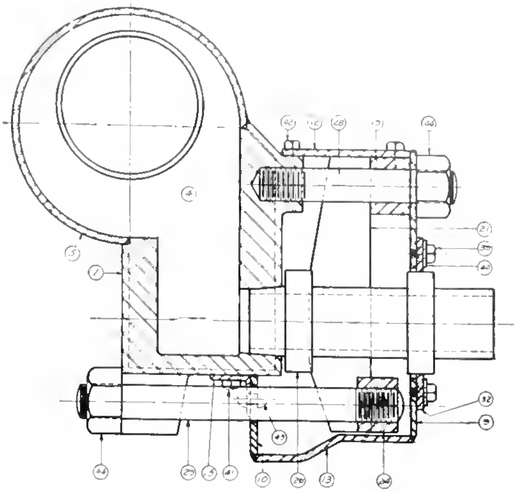
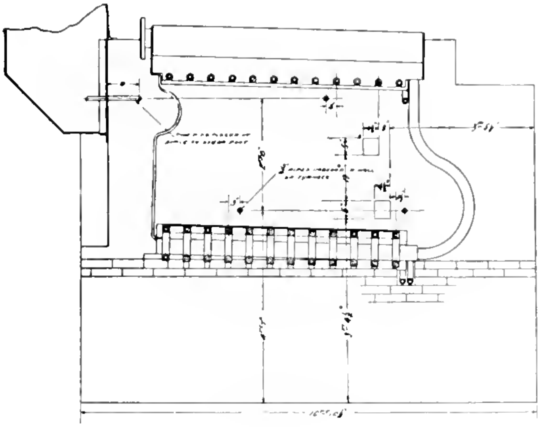


Fig. 5. Sectional View of Upper Main Header, Mercury Boiler



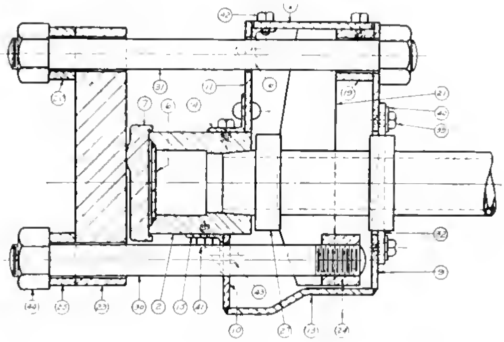


Fig. 6. Sectional View of Lower Main Header, Mercury Boiler

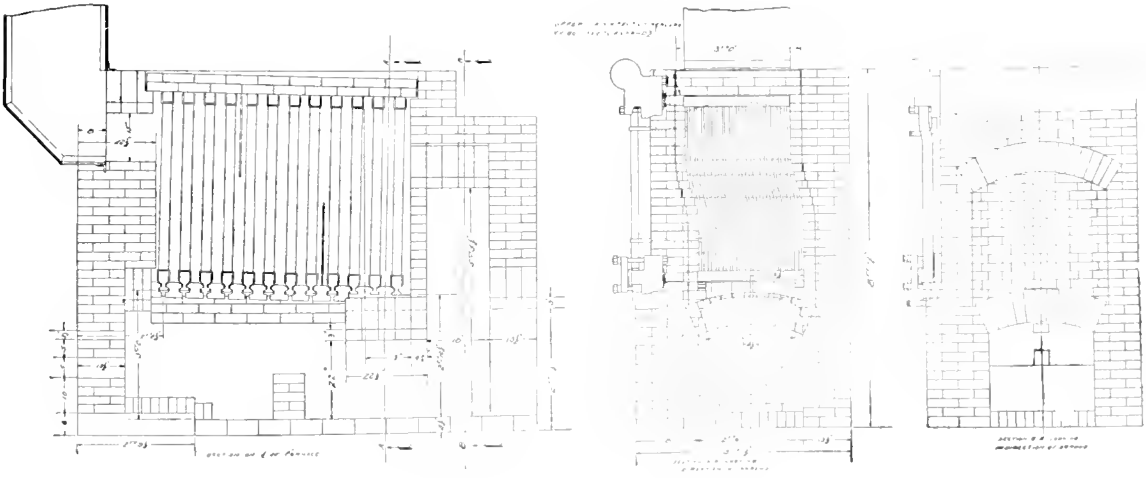


Fig. 4. Mercury Boiler Setting

surface. The curvature is to prevent mechanical strains through unequal expansion caused by irregular heating. These flattened tubes are connected into the headers by acetylene welded joints. The tubes are first welded from the inside into channel-shaped pieces; these channels, with the set of tubes connecting them, are then annealed so as to release all strains incident to the welding. After annealing, they are tested with high pressure air, suitable clamps being used to confine the air in the channels. If the welded sheets will stand the anneal and the subsequent pressure test, it is assumed that they will be reliable for service, since in service they will be subject to uniform temperature conditions and will be practically free from mechanical strains. These channel pieces are then welded to steel headers so that the whole unit becomes perfectly tight and capable of standing a high pressure. The headers of these units terminate in taper nozzles, which fit into taper holes in the bus header at the bottom and into a vapor chest at the top. A curved liquid duct connects the vapor chest to the bottom header at the hot end, so that the heating units which are exposed to the greatest heat receive the most direct supply of liquid. In these hot units, a larger internal space will be allowed than in the units which occupy the cold part of the boiler, so that the colder part will not carry an unnecessary amount of liquid.

Fig. 7. Mercury Boiler and Turbine as Erected in Power House

If these heating units will remain tight, and the success of experiments indicate that they will, it will be impossible for liquid mercury or vapor to escape except at the joints where these headers connect to the bus headers and to the vapor chest, or at the joints through which the vapor is conveyed to the turbine. To guard against loss through leakage in such places, arrangements have been made by which the sets of joints at the top and bottom of the boiler are enclosed in boxes which are practically air tight, the bolts used in tightening these joints extending outside of the boxes in such a manner that a leaky joint can be drawn up. These boxes are connected by ducts to a condensing cooler in which a low pressure is maintained by the suction from the base of the stack or from any other sufficiently exhausted place. This suction will maintain within the boxes a pressure lower than any of the pressures which surround them, so that there will be a constant indraft of air through such leaks as may exist and a flow of all the liquid or vapor which may escape into the cooler. In this cooler it will be carried through passages over water pipes until all the vapor is condensed and nothing but cool air and gas is discharged. In a similar manner, any joints in the system which might possibly be subject to leakage can be enclosed by boxes and connected to this same cooler. By this means, all possible leakage except that which may occur in heating units will be effectively caught.

In case there should be loss of mercury in any of the heating units, means are provided by which such loss can be quickly discovered before any large amount has escaped. The feed of each boiler is so arranged that it is governed automatically by the difference of pressure between the lower header from which liquid circulates and the pressure in the vapor chest, this being the force necessary to produce sufficient circulation. At the back of the valve which admits the feed there is a reserve chamber, to which connections are provided so that the level of liquid in this reserve chamber is visible to the fireman.

In case loss of this liquid is apparent, the doors will be opened, the fire drawn, and the liquid drained out of the boiler into a receiving tank. The boiler can then be tested with air pressure and the leaky elements replaced, the construction being such that any one of these elements can be taken out without disturbing the others.

The arrangements of the turbine have also been improved as the result of experience. The first turbine arranged was made from an old experimental steam turbine and had many joints which were difficult to keep vacuum tight. The new experimental turbine has only one joint, arranged in a manner which has been experimented with and which will avoid leakage.

The condensing boiler used in the experiment now in preparation is made from a standard high pressure feed heater having a water space at the top and bottom connected by tubes in the manner customarily used in such devices. This boiler has apparently worked satisfactorily and produced steam from mercury vapor in the manner expected. It is not, however, considered a suitable design for the purpose, since the temperature differences impose a strain on the expanded tube sheets. It is thought that tubes attached at one end with concentric circulation after the manner of the Nicholaus boiler will afford the most satisfactory method for such condensers. Since no violent temperature differences will exist, it is believed that these condensing boilers can be made practically free from deterioration and entirely free from leakage.

As has been said, the turbine is provided with a centrifugal packing and is kept sealed by a constant admission of liquid mercury from a suitable level in the condensing boiler. The turbine is also provided with a throttle valve which can be used in governing, and with a by-pass valve which allows the vapor to pass directly to the condensing boiler in case the admission to the turbine is shut off.

### Proposed Method of Commercial Application

The plan which has been considered for commercially applying this process is to produce a simple type of unit suitable for installation in the same floor space occupied by a standard 500 h.p. steam boiler. This unit would be so proportioned that the steam output of the condensing boiler would equal that obtainable from the standard 500 h.p. boiler. For each of these boiler units, a separate turbine and generator would be provided, the nature of this process being such that there is no loss of efficiency involved in such multiplication of generating units.

Since it would never be desirable to operate these mercury-driven generating units alone, the generators could be made either of the induction or synchronous type, completely enclosed, with an air supply from some clean outside source. Their circuits would run to the main switchboard, they would need no attendance, and the space around them would not have to be kept either cool or clean, although it would generally be possible to get them within an enclosure which would not be exposed to the fire room dirt. By such means a single set of parts or combinations of a few standard parts could be made to cover a very wide demand, and this would greatly simplify the commercial introduction of such a process.

Without the acetylene welding process, a satisfactory mercury boiler design would be very much more difficult to arrive at. The manufacture of such boilers as are here described would involve a very large amount of acetylene welding, requiring great care and a considerable expense.

The possible cost of the commercial application of such a process has not been carefully studied. It has, however, been roughly estimated that if existing stations were converted to this method, the cost per kilowatt of added power would not exceed the present cost per kilowatt of well designed steam stations, not including the cost of real estate. Thus this process, if successful, would greatly extend the capacity of existing stations and postpone the building of new stations; the saving would about cover the real estate values, and the gain in fuel economy over that of the best existing plants should be about 45 per cent.

Such a process, with the most efficient oil firing of boilers, ought to give a fuel economy very near to that which is commercially obtainable by Diesel engines, and its mechanical simplicity and freedom from the probability of deterioration should give it a very decided advantage over the Diesel engine. While it is not wise to make definite predictions about anything so radically new, it certainly appears to the writer that this process is worthy of very careful study.

# A POWERFUL RÖNTGEN RAY TUBE WITH A PURE ELECTRON DISCHARGE

By W. D. Coolidge

Research Laboratory, General Electric Company

This article relates to the development of a new tube for the production of Röntgen rays. Briefly, the device consists of a tube exhausted of all gases to the extreme possible limit, in which is supported the cathode so arranged that it may be heated electrically; an electrically conducting cylinder or ring connected to the heated cathode, and so located with reference to it as to focus the cathode rays on the target; and the anti-cathode, or target. The advantages of the tube are complete and immediate control of the intensity and the penetrating power of the Röntgen rays; continuous operation without change in the intensity or character of the rays; absence of fluorescence of the glass; and the realization of homogeneous primary Röntgen rays of any desired penetrating power. This article was abstracted for the Review by the author from his paper in the December number of the *Physical Review*.—Editor.

## § 1. INTRODUCTION

A consideration of the limitations of a Röntgen tube of the ordinary type showed that they were for the most part incident to the use of gas and that they could, therefore, be made to disappear if a tube could be operated with a very much higher vacuum. In this case, of course, the electrons constituting the cathode ray stream would have to be supplied in some other way than by bombardment of the cathode by positive ions.

The work of Richardson and others on the emission of electrons from hot bodies suggested that the electrons might be produced by simply heating the cathode. But the values of the thermionic currents obtained by different observers had varied between wide limits, so much so as to suggest that a Röntgen tube based upon this principle might be as unstable in resistance as is the standard tube. Moreover, the fact that the substances usually worked with, platinum and carbon, are so difficult to completely free from gas, suggested strongly that with the cleaner conditions (greater freedom from gas) that could be realized by the use of tungsten, the thermionic currents might cease altogether. Some experiments by Dr. Irving Langmuir, however, on the thermionic currents between two tungsten filaments in a highly evacuated space were very reassuring. According to his observations, after a certain high degree of exhaustion had been reached the thermionic currents increased, up to a certain limiting value, as the tube became freer and freer from gas.

The idea of using a hot cathode in a Röntgen tube was not new, but, so far as the writer could learn, the principle had never been successfully applied in a vacuum good enough so that positive ions did not play an essential role.

Wehnelt & Trenkle had used a hot lime cathode for the production of very soft Röntgen rays, working with voltages from 400 to 1000. Wehnelt, in another article, describes the use of his lime cathode in a Braun tube, and here he says that it is not advisable to employ more than 1000 volts, as otherwise cathode rays come off from that part of the platinum which is bare, giving bad disintegration. As the platinum is heated only to dull redness, this obviously means that there is sufficient gas in the tube to furnish positive ions which bombard the platinum and so cause it to emit electrons. For it has been shown that platinum, unless heated almost to its melting-point, will not yield an appreciable thermionic current*. Apart from this fact, of course, the Röntgen rays produced by voltages as low as 1000 are too "soft" for the ordinary applications.

Lilienfeld & Rosenthal had described a Röntgen tube whose penetrating power is, they say, independent of vacuum. The main aluminum cathode and the platinum anti-cathode are shaped and located like the electrodes in the ordinary Röntgen tube. Besides these, it has an anode and an auxiliary hot cathode. Current from a low voltage source passes from the hot cathode to the anode, and this current furnishes the positive ions which by their bombardment of the main cathode liberate electrons from it. Their tube is dependent for its operation on the presence of positive ions, for without these there is no means provided for getting electrons out from the main, or aluminum cathode. Lilienfeld concludes, from his extended experiments in tube exhaustion, that

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* H. A. Wilson concluded a paper upon this subject, in 1903, with the following statement: "It is probable that a pure platinum wire heated in a perfect vacuum would not discharge any electricity at all, either positive or negative, to an extent appreciable on a galvanometer."

the complete removal of all gas from tube and electrodes would not do away with positive ions. There would, according to this view, be no such thing as a pure electron discharge. Lilienfeld's work in exhausting the gas from the tube itself and from the glass seems to have been excellent, but according to the experience of the writer, none of his electrodes were sufficiently freed from gas to justify the conclusions drawn. Working even with tungsten electrodes in a tube so designed that the electrodes could be heated in place to very high temperatures, the writer has had the positive ion effects persist for hours, disappearing completely, however, as the electrodes become sufficiently freed from gas.

The work of Dr. Langmuir had shown that a hot tungsten cathode in a very high vacuum could be made to continuously yield a supply of electrons at a rate determined by the temperature.

Further work showed that very high voltages, up to at least 100,000, in no wise affect this rate of emission. For application to the fields of radiography and fluoroscopy, it was necessary to develop a satisfactory method of focusing. And, finally, the large amounts of energy transformed into heat in a Röntgen tube render imperative the use of a very heavy target, and this made it necessary to develop methods for sufficiently freeing large masses of metal from gas.

The result of efforts in this direction has been entirely successful, and tubes have been made, based upon this principle, which are free from most of the limitations of tubes of the ordinary type.

## § 2. GENERAL DESCRIPTION

The structural features of the new tube which differ from those of a tube of the ordinary type are the following:

The pressure, instead of being, as in the ordinary tube, a few microns†, is as low as it has been possible to make it; that is, not more than a few hundredths of a micron.

The cathode consists of a body which can be electrically heated (such as a tungsten or tantalum filament) and, suitably located with reference to this portion, an electrically conducting ring or cylinder, consisting preferably of molybdenum, tungsten or other refractory metal. The ring or cylinder is connected either to the heated portion of the cathode, or to an external source of current by means of which its potential may be brought to any desired value with respect to the heated portion. The heated portion of the cathode serves as the source of electrons, while the ring or cylinder assists in so shaping the electrical field in the neighborhood of the cathode that the desired degree of focusing of the cathode-ray stream upon the target shall result.

The anti-cathode, or target, functions at the same time as anode.

## § 3. THEORY OF OPERATION

As will be seen from the characteristics of the tube (in §5) it gives no evidence of positive ions. This makes the theory of its operation exceedingly simple.

The discharge appears to be purely thermionic in character.

The rate of emission of electrons from the filament appears to be in accord with Richardson's Law, which says that the maximum thermionic current which can be drawn from a hot filament is

$$i=a\sqrt{T}\quad e^{-\frac{b}{T}}$$

where $T$ is the absolute temperature, $e$ is the base of the natural system of logarithms, and $a$ and $b$ are constants.

In the particular tube described in detail in this paper, over the range of temperatures and voltages included in the curves shown in Figs. 4, 5 and 6, this simple law accounts perfectly for the conductivity of the tube.

## § 4. DETAILED DESCRIPTION OF TUBE NO. 147

This description relates to tube No. 147, which was used in getting the data for the following curves. Fig. 1 shows a complete assembly, while Fig. 2 shows an enlarged detail of the cathode and of the front end of the target.

### The Cathode

In the diagram, 25 is a tungsten filament in the shape of a flat, closely wound spiral. It consists of a wire 0.216 mm. in diameter and 33.4 mm. long, with 5½ convolutions, the outermost of which has a diameter of 3.5 mm. It is electrically welded to the ends of two heavy molybdenum wires 14 and 15, to the other extremities of which are welded the two copper wires 16 and 17. These in turn are welded to the platinum wires 18 and 19. The molybdenum wires are sealed directly into a piece of special glass, 12, which

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† A micron is 0.001 mm.

has essentially the same temperature coefficient of expansion as molybdenum. This first seal is simply to insure a rigid support for the hot filament, the outer seal being the one relied upon for vacuum tightness. The outer end, 13, of the support tube, is of German glass like the bulb itself, and it is therefore necessary to interpose at *S* a series of intermediate glasses to take care of the difference in expansion coefficients between 12 and 13. The small glass tube, 20, prevents short-circuiting of the copper wires, 16 and 17.

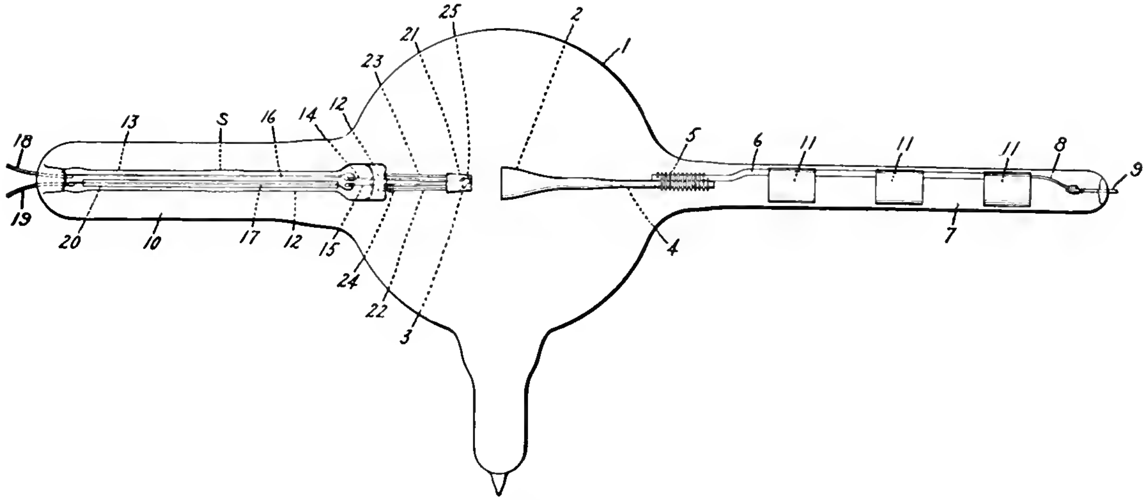

Fig. 1. Experimental Röntgen Ray Tube

The filament is heated by current from a small storage battery which is well insulated electrically from the ground. In the circuit are placed an ammeter and an adjustable rheostat, and by means of the latter the filament current can be regulated, by very fine steps, from 3 to 5 amperes. Over this current range the potential drop through the filament varies from 1.8 to 4.6 volts and the filament temperature from 1890 to 2540 degrees absolute.

### The Focusing Device

This consists of a cylindrical tube of molybdenum, 21. It is 6.3 mm. inside diameter and is mounted so as to be concentric with the tungsten filament, and so that its inner end projects about 0.5 mm. beyond the plane of the latter. It is supported by the two stout molybdenum wires, 22 and 23, which are sealed into the end of the glass tube, 12. It is metallically connected to one of the filament leads, at 24.

Besides acting as a focusing device, it also prevents any discharge from the back of the heated portion of the cathode.

### The Anti-cathode or Target

The anti-cathode, or target, 2, which also serves as anode, consists of a single piece of wrought tungsten, having at the end facing the cathode a diameter of 1.9 cms. (Its weight is about 100 gms.) By means of a molybdenum wire, 5, it is firmly bound to the molybdenum support, 6. This support is made up of a rectangular strip, and riveted to this are three split rings, 11, 11, 11, all of molybdenum. The split rings fit snugly in the glass anode arm, 7. They serve the double purpose of properly supporting the anode and of conducting heat away from the rectangular strip, and so preventing too much heat flow to the seal of the lead-in wire, 9.

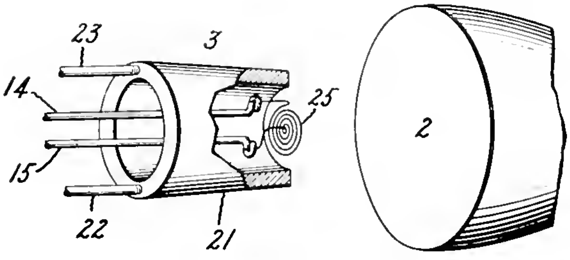

Fig. 2. Enlarged View of Cathode and Front End of Target

### The Bulb

This is of German glass and is about 18 cm. in diameter.

**The Exhaust**

This is as thorough as possible.

For the earlier tubes, mercury pumps were used, with a liquid air-trap between the tube and pump to eliminate mercury vapor. The whole tube, while connected to the pump, was in an oven and was heated at intervals to 470 deg. C. Between heating operations the tube was operated with as heavy discharge currents as the condition of its vacuum would permit. For hours the tube would show the characteristics of an ordinary Röntgen tube, and in many cases a several days application of the above treatment was required to entirely eliminate these characteristics and to realize an essentially pure electron discharge.

The exhaust time has been greatly reduced in two ways. The massive tungsten anode is given a preliminary firing to a very high temperature in a tungsten-tube vacuum furnace*. The molybdenum support is also fired, to a somewhat lower temperature, in the same manner. In the second place, a Gaede molecular pump has been substituted for the mercury pumps and, at the same time, a very large and short connection has been adopted between the tube and pump.

In the later stages of the exhaust a very heavy discharge current is maintained continuously on the tube for perhaps an hour, the temperature of the bulb being kept from rising too high by the use of a fan.

The pressure in the finished tube is very low, certainly not more than a few hundredths of a micron and probably much less than this.

**Connections and Method of Operating**

The tube was connected as shown in the diagram, Fig. 3, in which *T* is the tube; *B* is a small storage battery; *A* is an ammeter; *R* is an adjustable rheostat which can be controlled from behind the lead screen which shields the operator from the Röntgen rays; *S* is an adjustable spark gap with pointed electrodes, which can also be operated from behind the lead screen; and *M* is a milli-ampere-meter which can be read from behind the screen.

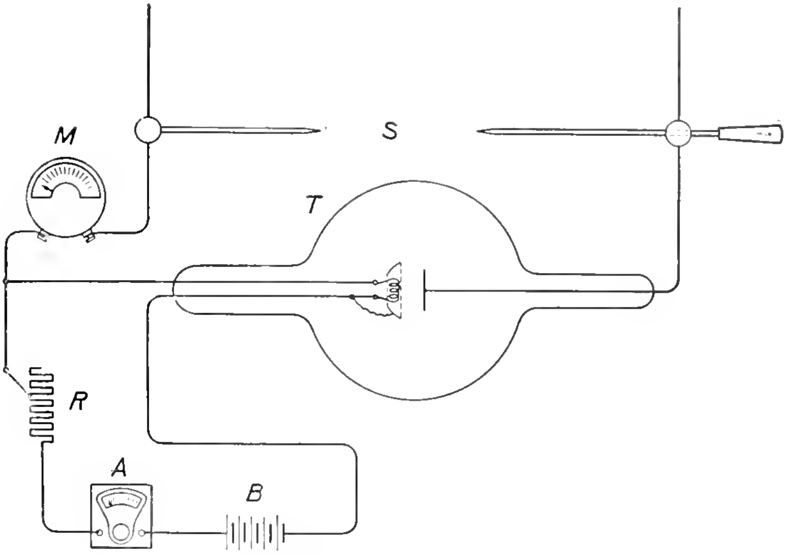

Fig. 3. Diagram of Connections

As the high potential is connected to the battery circuit it is necessary that the latter shall be thoroughly insulated from the ground.

As a high potential source, a 10 kw. Snook machine, made by the Röntgen Apparatus Co., was used. This consists of a rotary converter driven from the direct-current end and delivering alternating current at 150 volts and 60 cycles per second to a closed magnetic circuit step-up transformer with oil insulation. From the secondary of this transformer the high-voltage current is passed through a mechanical rectifying switch (which is direct connected to the shaft of the rotary) and the milli-ampere-meter, *M*, to the tube. The output of the transformer is controlled by a variable resistance in the primary circuit.

## § 5. CHARACTERISTICS OF THE TUBE

*A. No Discharge Current Unless Filament is Heated.*

Unless the filament is heated, the tube shows no conductivity in either direction, even with voltages as high as 100,000.

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* A description of this furnace will be published in the near future. The heating element consists of a tungsten tube 2.5 cm. inside diameter and 30 cm. long. This is fastened in an upright position and, by means of suitable terminals, is connected to a 100 kw. transformer. The heating element is placed in a water-cooled metal cylinder, and the space within connected to a pump which maintains, with the furnace at its highest temperature, a vacuum of a few microns.

*B. Tube Allows Current to Pass in Only One Direction.*

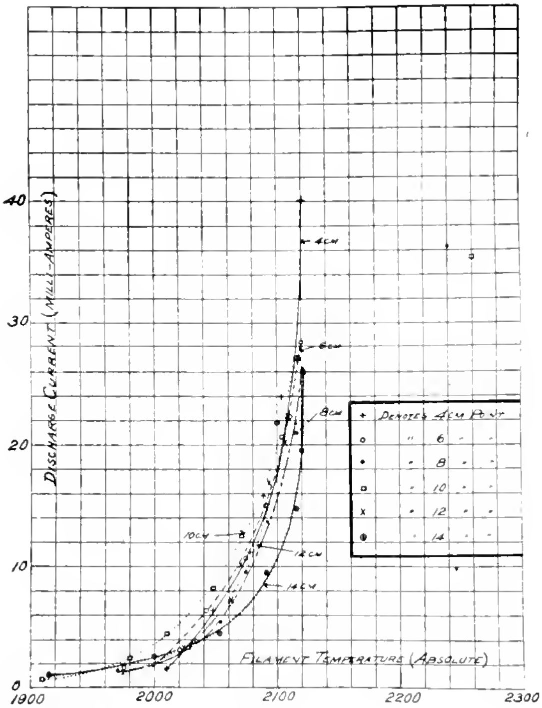

Fig. 4

The tube suppresses any current in the direction which does not make the hot filament cathode. It is therefore capable of rectifying its own current when supplied from an alternating source.

In the case of a focusing tube, however, the use of alternating current will very considerably lower the maximum allowable energy input, for as soon as the target becomes heated at the focal spot to a temperature approximating that of the filament, the tube will cease to completely rectify as the temperature of the focal spot rises, and will allow more and more current to pass in the wrong direction. This, to be sure, will not cause either a harmful vacuum change or a metallic deposit on the bulb, as it would in the case of the ordinary tube, but it will give rise to needless heating of the bulb where it is bombarded by the cathode rays from the target, and to disturbing Röntgen rays emanating from the glass at this point. In the case of a tube which does not focus, but in which the cathode rays bombard the entire surface of the anode, the allowable energy input which the tube will completely rectify can be increased to any desired amount by simply increasing the surface of the anode.

*C. Discharge Current Determined Primarily by Filament Temperature.*

With a given design, the amount of discharge current which can be passed through the tube is determined primarily by the temperature of the filament, and responds instantly to changes in the same in either direction.

The effect of both temperature and voltage on the discharge current, in the case of the tube illustrated in Fig. 1, may be seen by referring to Fig. 4. The different curves obtained for different voltages, expressed in terms of the equivalent parallel spark gap, are seen to lie very close together, showing that over the range of voltages employed, the magnitude of the discharge current is practically independent of voltage. This shows that the current in these experiments was always the saturation value.

Richardson's Law, stated in §3, may also be written in the following form:

$$log_{10} \frac{i}{T} = b \frac{.434}{T} - log_{10}\, a$$

which is the equation of a straight line.

If then the values of log $\frac{i}{T}$ and $\frac{.434}{T}$, corresponding to the curves in Fig. 4, are plotted, they should lie along straight lines, provided the conduction in the tube, between the voltage limits used, follows Richardson's Law.

Reference to the plots, Figs. 5 and 6, will show that the points are clearly represented by straight lines.

If the temperature of the filament is low, only a small number of electrons escape from it and, consequently, only a small discharge current (the saturation current) can be sent through the tube. Increasing the impressed voltage above that needed for this current value causes no further increase in current. It simply increases the velocity of the cathode rays and hence the penetrating power of the Röntgen rays.

*D. Penetrating Power of Rontgen Rays Determined by Voltage Across Tube Terminals.*

The penetrating power of the Röntgen rays coming from the tube increases with the potential-difference between tube terminals.

With the tube excited from a variable potential source, such as the transformer, it did not seem safe to predict that, with the same equivalent spark gap, the rays would show, photographically, the same penetrating power as those from a standard tube. But upon making the experiment, using a Benoist penetrometer, it was found that they did.

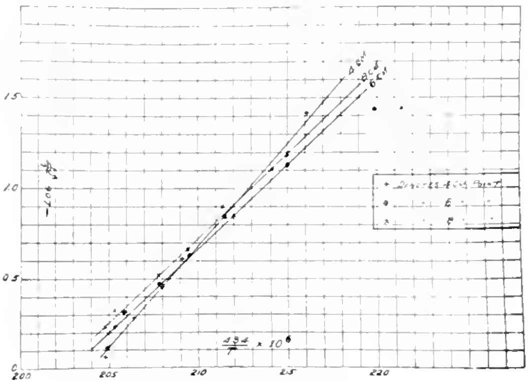

FIG. 5

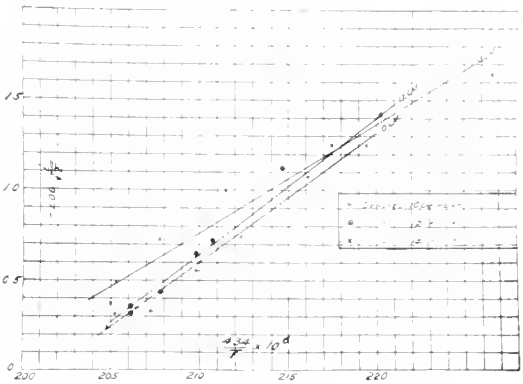

FIG 6.

*E. Capable of Continuous Operation Without Change of Characteristics.*

That the tube may be operated continuously without exhibiting an appreciable change in characteristics, is shown by the following experiment on Tube No. 147, illustrated in Fig. 1.

The filament current was set at 4.1 amperes. This gave a discharge current of 25 milliamperes. The impressed voltage was then set at a point where the tube showed a 7 cm. equivalent spark gap.

The tube was then run continuously, with no adjustment of any kind, for 50 minutes. The readings of discharge current and equivalent spark gap, taken every two minutes, are given in Table II.

TABLE II

| Time | Discharge Current (Milli-Amperes) | Equivalent Spark Gap (Cm.) |
|---|---|---|
| 11:48 A.M. | 25 | 7.0 |
| :50 | 25 | 7.0 |
| :52 | 25 | 6.9 |
| :54 | 25 | 6.5 |
| :56 | 25 | 6.5 |
| 12:00 P.M. | 25 | 6.7 |
| :02 | 25 | 6.9 |
| :04 | 25 | 6.5 |
| :06 | 24 | 6.4 |
| :08 | 24 | 6.5 |
| :10 | 24 | 6.5 |
| :12 | 23 | 6.6 |
| :14 | 25 | 7.0 |
| :16 | 25 | 6.8 |
| :18 | 24 | 6.8 |
| :20 | 25 | 6.9 |
| :23½ | 23 | 6.7 |
| :26 | 23 | 6.9 |
| :28 | 25 | 6.9 |
| :30 | 25 | 6.9 |
| :32 | 25 | 7.0 |
| :34 | 24 | 6.9 |
| :36 | 25 | 7.0 |
| :38 | 24 | 7.1 |

*F. Sharpness of Focus.*

Other conditions remaining the same, the greater the distance between the filament and the front (end facing the target) of the molybdenum tube, the sharper will be the focus.

*G. Fixity of Position of Focal Spot.*

The focal spot on the anode does not wander, but remains perfectly fixed in position. This is in sharp contrast to the ordinary Röntgen tube in which the focal spot does move about, and often so rapidly as to be noticeable even during the shortest radiographic exposures. The effect of movement of the focal spot is, of course, to cause in the radiograph or on the screen, a blurring of all lines except those parallel to the direction of motion. In the earlier stages of exhaustion, while the new tube is being operated with a relatively poor vacuum, the focal spot may dance about, but as the electrodes and the glass become freer from gas the motility of the focal spot decreases and finally disappears completely. Its disappearance goes hand in hand with the disappearance of fluorescence of the glass, discussed in section J. Movement of the focal spot appears to be due to the action of positive ions in disturbing the distribution of static charge on the glass walls of the tube.

*H. Tube not Sensitive to Considerable Changes in Gas Pressure.*

The gas pressure within the tube is so low that it can increase several-fold, and apparently decrease without limit, without appreciably affecting the other characteristics.

*I. Capable of Continuous Operation With High Energy Input.*

Owing to the fact that the tungsten target can run at such a high temperature, large amounts of energy can be continuously radiated.

*J. No Fluorescence of Glass.*

When operating properly the tube shows no fluorescence of the glass at any point. Corresponding to this, there is an absence of the usual strong local heating of the anterior hemisphere. The absence of fluorescence and of local heating seem to point to the fact that there is no bombardment of the glass by secondary cathode rays sent out from the target. This is in striking contradistinction to what takes place in an ordinary Röntgen tube, where, in the case of a platinum target, it has been found that there are about three-fourths as many electrons leaving the target, and going to the glass as secondary cathode rays, as there are bombarding it, in the form of primary cathode rays. This elimination of secondary cathode ray bombardment prevents the production of a large part of the useless and disturbing Röntgen rays which emanate from the glass in the case of the ordinary tube.

The simple explanation appears to be based upon the fact that the large number of positive ions present in an ordinary Röntgen tube is here lacking. The inner surface of the glass becomes strongly negatively charged, when the tube is first operated, and, not being able to attract an appreciable number of positive ions, remains so. The presence of this negative charge upon the glass prevents further electrons, either in the shape of primary or secondary cathode rays, from going there.

*K. Identity of Starting and Running Voltage.*

The starting or break-down voltage of the tube is the same as the running voltage. This is very different from the state of affairs in the ordinary tube in which the break-down voltage is much the higher of the two. The explanation of this difference is as follows: In the ordinary tube the number of ions present when the circuit is closed is exceedingly small, being only that due to natural ionization causes, such as radio-active matter in the surroundings. After the discharge circuit is closed, the number of ions increases, by collision, very rapidly, and the voltage across the tube terminals falls in consequence. In the case of the new tube, on the other hand, the full supply of electrons is there the instant the discharge circuit is closed, and even before this, and the available number is not changed by the discharge current.

*L. Permits of Realization of Homogeneous Bundle of Primary Rontgen Rays.*

The tube must permit of the realization of a strong homogeneous bundle of primary Röntgen rays of any desired penetrating power. For this purpose it should clearly be excited from a source of constant potential. The result should be attained even though the discharge is intermittent.

*M. No Heating of Cathode by Discharge Current and no Evidence of Cathodic Disintegration.*

At the high vacuum and with the relatively gas-free electrodes of the new tube there is no evidence of any bombardment of the cathode. On the pump, in the earlier stages of gas removal, when a discharge can be made to pass through the tube without the heating current in the filament, the latter is seen to be strongly locally heated by the discharge current, as from bombardment by positive ions. But when the exhaustion has been completed and the tube is operated with the cathode hot, a voltmeter and ammeter in the filament circuit show no change even when a very heavy discharge is sent through the tube. Positive ion bombardment, if it existed to an appreciable extent, would raise the temperature, and hence the resistance of the tungsten filament, and would therefore be indicated by the instruments. If it were very local and considerable, it would be further indicated by a melting through of the filament at the point in question. The resistance change and local disintegration of the filament have been observed in only those cases where the vacuum, as shown by other effects such as fluorescence of the glass, has been poor.

Disintegration of the cathode would also manifest itself in blackening of the bulb. Even after running for several hours, the deposit on the bulb is very slight, and what there is may well be entirely accounted for by vaporization of tungsten at the focal spot on the target.

*N. The Size of Focal Spot on the Target the Factor Limiting Allowable Energy Input.*

Of the many factors limiting the allowable energy input in the ordinary tube, but one remains in the case of the new tube. With sharp focusing and above a certain energy input the tube resistance is unstable, dropping suddenly to perhaps a small fraction of its original value returning instantly to the old value, however, upon stopping the discharge or upon lowering it to the limiting value. The cause of this phenomenon appears to be as follows:

With a very high energy input and sharp focusing, the surface of the target melts at the focal spot and volatilizes. Owing to the fact that this tungsten vapor is produced at the focal spot, all of the primary cathode rays pass through it and, by collision, ionize it. This, of course, decreases the tube resistance. The larger the focal spot the greater is the allowable current. The design of the target also has a great deal to do with the allowable current value, as the face of a thin target is vaporized with a much lower energy input than a relatively thick one. For very short excitation of the tube, the allowable energy input is somewhat larger than for longer periods; but an input which can be carried for a few seconds can be carried indefinitely.

## § 6. DANGER CONNECTED WITH USE OF TUBE

There has been in the old tube a certain element of safety in that it could not be run continuously with a very heavy energy input. The new tube, even when focusing sharply, can be operated, for example, on a 7 cm. parallel spark gap with currents as high as 25 milli-amperes for hours at a time, and without the slightest attention.

For most purposes, other than fluoroscopic or radiographic work, there is no advantage in having the tube focused. In case it is not, the above mentioned energy input limitation falls away and the tube can apparently be designed for any energy input whatsoever. This permits, in this field, of the use of much greater Röntgen ray intensities than have heretofore been realized.

In the light of the above, it will be seen that the precautions which have been shown by years of experience to be sufficient for work with the old tube are not necessarily sufficient for the user of the new one.

## § 7. SUMMARY

In the foregoing, a new and powerful Röntgen-ray tube has been described. It differs in principle from the ordinary type in that the discharge current is purely thermionic in character. Both the tube and the electrodes are as thoroughly freed from gas as possible, and all of the characteristics seem to indicate that positive ions play no appreciable role.

The tube allows current to pass in only one direction and can, therefore, be operated from either direct or alternating current.

The intensity and the penetrating power of the Röntgen rays produced are both under the complete control of the operator, and each can be instantly increased or decreased independently of the other.

The tube can be operated continuously for hours, with either high or low-discharge currents, without showing an appreciable change in either the intensity or the penetrating power of the resulting radiations.

The tube in operation shows no fluorescence of the glass and no local heating of the anterior hemisphere.

The tube permits of the realization of intense homogeneous primary Röntgen rays of any desired penetrating power.

It is a pleasure to the author in closing, to express his appreciation of the services of Mr. Leonard Dempster, who has assisted him throughout this work.

# ELECTRIC RAILWAY SYSTEMS

By C. E. Eveleth

Railway and Traction Engineering Department, General Electric Company

The introduction of this article (based on a lecture delivered in New York City) acquaints one with the rapid growth which has been made in the application of electricity to traction, its present surprising magnitude, and some of the reasons which have brought about the extensive electrifications. At this point, the author makes a novel distinction between the "Science" and the "Art" of electric railroading, devoting the remainder of his article to the latter division of the subject. Starting with the power supply, he traces through to the rolling stock the different features and items which influence the choice and affect the maintenance of the systems that are to be considered.—Editor.

When considering the subject of electric railway systems it is well to bear in mind that only twenty-six years have passed since the first electric motors propelling street cars in Richmond startled the people by the terrifying flashes at the overhead collector and from the motor brushes. As in any radically new enterprise the pioneers were called upon to bear the brunt of development and to overcome what appeared to be almost insurmountable difficulties. The improvements made in the various elements were so rapid that soon the electric motors not only displaced horses as motive power but also lead to the extension of the field of city transportation. Then there followed the development of many thousands of miles of interurban electric lines, which have brought the outlying farms close to the cities in almost every locality east of the Mississippi river. This network is being steadily extended and will eventually cover the entire country as the density of population increases. The effect of the inter-communication so afforded is incalculable, both from an economic and sociological standpoint.

It is interesting to know, in these days when so much is heard about the increased cost of living, that such elements in our daily lives as are served by electricity have steadily decreased in cost, and today we ride farther for a nickel and have more electric light illumination for less money than ever before. Is it not significant to learn that the only divisions of one of our large eastern steam railroads where the net earnings per passenger car mile are holding their own are on the portions operated electrically, while on those divisions not so operated the net earnings are only a fraction of what they were seven or eight years ago and are decreasing at an alarming rate?

We sometimes ask: when will our railroads be operated electrically? In a recent lecture by Steinmetz, the statement was made that there is more aggregate horse power in electric motors operating cars and locomotives today than the aggregate horse power capacity of all of the steam passenger locomotives used for transportation in this country. Based upon this, we can fairly say that electrification is here now. The day has not yet arrived when the universal electrification of our steam railroads can be economically accomplished, but the decreasing cost of power and the lower cost of electric equipment for rolling stock is gradually extending the field where the application of electricity to transportation is justified and will eventually permit electricity to replace steam on all important railroad divisions.

At present we are using electricity to accomplish results unattainable with steam engines, notwithstanding the magnificent accomplishments which the steam engine designer has achieved with the Mallet locomotive, oil-fired boilers and the use of super-heated steam. Of all known agents, electricity is the most convenient means of distributing power and its application to transportation successfully overcomes widely different limiting conditions. On some railroad divisions about one twentieth of the gross ton mileage is used for hauling the coal to supply the steam locomotives with fuel: on other sections, the speed on going up grade is limited by the boiler capacity of the engines. The operation in descending these same grades is frequently hazardous, owing to the possibility of the loss of air for the air brakes, or danger from over-heated brake shoes and wheel tires. Applying electric locomotives to these conditions, in many instances, eliminates entirely the freight tonnage required to haul fuel. We are able to increase the speed of freight trains up grade to the maximum safe or economic limit, and by the use of regeneration we not only lessen the danger from failure of air for the brakes and the heating of tires and brake shoes, but are able to actually recover a material portion of the energy given up by a train descending a mountain and utilize this power for ascending trains. We are able to overcome the difficulties incident to bad water found in desert regions on one hand, and to more quickly transport the suburbanite on the other. Other limiting conditions which can only be met by electric traction are the elimination of smoke, the better utilization of space in city terminals by the use of different track levels, the elimination of round houses, turn tables and the saving of time required by steam locomotives while going for water and cleaning fires.

There are two broad divisions of the subject under consideration; one might be called the "Science of Electric Railroading," and the other the "Art of Electric Railroading."

The "Science" has to do with all the fundamental details which enter into the present development and includes the work of improvements and invention, which are necessary to broaden the field of electric traction. This includes developments in insulation, designs of generating, transmission, conversion and rolling stock equipment parts, the solution of problems of current collection, the mechanical structure of locomotives for high speeds, and the many elements which go to make up a successful and economical system of control for the electric power from the prime movers to the train wheels. There are thousands of men employed in the development of the science of electric railroading, and it is to these men that we shall be indebted for the final victories of the electrification.

The "Art" of electric railroading includes the analysis of conditions and the selection and application of the available elements to a specific problem as well as the operation and maintenance of the finished system.

It is the problem of the electrical engineer to so select and balance all the elements of power generation, transmission, and consumption in such a manner as to deliver the desired quality and quantity of transportation with the greatest reliability and the lowest cost.

As set forth, the problem seems simple, but experience has indicated that very different conclusions are reached, both as to the methods which should be applied and the anticipated results. The problem is, in fact, extremely complex; so much so that it is almost impossible to retain in mind the many elements which must be simultaneously considered to reach a justifiable conclusion. Frequently one sees results cited, which, on analysis, are found to disregard entirely elements of the greatest importance.

A better comprehension of the situation can be obtained by outlining some of the elements which must be equated. We will assume that the problem as to schedules, train capacities, grades, etc., both for the present and future, has been accurately set forth. For conditions requiring the use of motor-car trains and locomotive operation, there are available for consideration direct current and single-phase equipments or possibly single-phase for the motor cars and split phase for the locomotives, with a further possibility of three-phase, if the problem involves the use of locomotives only. To reach the proper conclusion every element from the prime movers to the train wheels must be considered.

### Power Supply

In some sections of the country, in the Carolinas, Michigan, Montana, Washington, Oregon and California, for instance, we find networks of power distribution which range from five hundred to two or three thousand miles of transmission circuits in each system. Generally in such localities, it is more economical for a railroad to buy than to manufacture its own power, since this requires less capital expenditure, and the power companies which have the benefit of diversified load factor, can, generally, manufacture power for less cost. Where such conditions exist the frequency of the primary distribution is established by these systems. Where it is necessary for the railway to build its own power house, the question of frequency with its bearing on the power already available in the territory to be served and the demands of the particular rolling stock selected must be carefully investigated. Comparisons must be made between single-phase and three-phase power generation, due weight being given to the elements of initial cost, efficiency, power-factor and protective appliances. Some of the problems such as the desirable size of power house units, their overload capacity, etc., is common to all systems.

### Distribution System

This is the simplest element in the chain and can generally be worked out on its economic merits as regards the selection of voltage, size of conductors and the character of installation to conform to the distance of transmissions and permissible line regulations for the various systems.

### Secondary Distribution and Substations

The location and capacity of substations must be considered jointly with the secondary power distributions to the trains. This involves the selection of voltage; the determination of the permissible potential drops; provisions for the mitigation of inductive interference with telephones and telegraphs for the single-phase and three-phase systems, or the consideration of the possibility of electrolytic difficulties in case of the direct current, both for normal operation and for conditions of short circuits; the selection of third rail or overhead trolley; the affect of atmospheric conditions such as lightning, snow and sleet; examination of the reliability of the elements chosen and decisions regarding the amount of line to be incapacitated when local repairs must be made. The selection of substation apparatus will be different for each system and will further vary with the frequency of power supply. The advisability of using transformers or auto-transformers with questions of capacity and regulation must be considered for the alternating-current systems; and with direct current, there are questions of the relative merits of motor-generator sets, rotary converters or motor converters with the determination of their normal and overload capacities and regulation. To make these different elements comparable, the selection of apparatus must be so balanced as to yield the same degree of insurance in case of the failure of individual elements or abnormal congestion of traffic, due to any cause.

### Rolling Stock

This item is by far the most important, as the proper selection of these elements is vital to the success of the system. Here we are at once confronted with the consideration of the inherent features and costs of the various kinds of apparatus available and due consideration must be given the relative values of constant versus variable speed, features involving the starting characteristics, efficiency of motors, conversion devices, control and driving mechanisms, effects of inherent characteristics on power load factors, electrical power-factors, etc.; in addition, the desirability of regeneration and emergency braking require consideration, if mountain work is involved.

After having determined the first costs and rates of depreciation of each of the above elements, there remain two important items for consideration. The first is the analysis of power consumption, which can be carried through with reasonable accuracy for the particular conditions under consideration. The second is the problem of the determination of the operating and maintenance costs, which is more difficult. It is in these elements that the results of practice are most often lacking, and the value of an individual's judgment will depend on his general experience, and on his ability to deduce from available data information which can be applied, when properly modified, to meet the specific problem in hand.

### General

The assembly of these elements in the order of their relative merits is the problem before the engineer who is called upon to select a system for a particular application. It is not surprising that different results are reached by different investigators, due to the different weights assigned to the elements or difference in the degree of optimism towards some of the unproved features. Very often it is surprising to find how little difference there is in the initial costs of the various systems, as some of the elements tend to offset each other. For example: the high cost of single-phase rolling stock equipment frequently offsets the greater cost of direct-current substations, while the additional weight of the single-phase equipments offsets the greater conversion losses of the direct-current substations, resulting in both the cost and power consumptions of the two systems being almost identical. Consequently with a greater quantity of rolling stock, the tendency is for the moderate voltage direct-current systems to be lowest in cost and cheapest to operate, while with few rolling stock elements the tendency is to relatively favor the higher voltage systems. For suburban electrifications a moderate direct-current voltage is generally the most economical, while for single track infrequent service, higher voltages are desirable.

A discussion of electric railway systems would not be complete without consideration of the Standardization of Systems. There is no doubt but that standard third rail and overhead trolley clearances are necessary to avoid serious interference with bridge girders, station platforms and various structures existing along main railway rights of way. About seven years ago, the Germanic countries headed by Prussia, adopted certain arbitrary standards that all main railways should be equipped with fifteen thousand volt single-phase trolleys operated at sixteen and two-thirds cycles. At that time there was no experience available to justify such a selection, but it was believed by those in power to be desirable to have all efforts expended in one direction, and, furthermore, it was deemed necessary for military reasons. Since then, it has developed that the limitations imposed are very adverse to economical motor car operation, that inductive interference with telephones and telegraphs under certain conditions are extremely serious, and the low frequency involves difficult mechanical problems and practically bars out forever an economical design of induction motor for certain classes of service. These limitations are arousing some dissatisfaction in Germany; the Italian engineers have decided that three-phase is better suited to their conditions and the majority of engineers in England, Australia, Canada, France and Russia seem to favor direct current.

In this country we have done well to avoid a limitation such as an arbitrary standard system of electrification would impose, since it leaves us free to work in every direction whether it be single-phase, three-phase, split phase, moderate or high voltage direct current, the mercury rectifier systems, or in any other direction which may be entirely unknown to us today. Arbitrary standardization of a system would mean limited development or stagnation.

Electrification of railways is desirable, not only from the standpoint of superior transportation, but on account of improvement in land values and the comfort and safety of travel. Although electrification is economically justified for many conditions there are to-day no known systems sufficiently low in cost to permit universal use of electricity for railroads and we must, therefore, have a free hand in order to achieve the ultimate general application which we believe will come.

# SOME SALIENT FEATURES OF RECENT 60-CYCLE SYNCHRONOUS CONVERTERS

By J. L. Burnham

Direct Current Engineering Department, General Electric Company

When the first sixty-cycle synchronous converters were brought out, they were regarded as rather sensitive pieces of apparatus. The improvements which have been made in recent designs have, however, placed them on a par with their twenty-five-cycle prototypes. What these changes are, how they came to be made, and their effects on the characteristics of the machines constitute the principal points covered in this article.—Editor.

The confidence that has been gained for the 60-cycle converter as a reliable piece of apparatus is due principally to improvements in mechanical details which permit of higher surface speeds. The adoption of commutating poles has also aided materially in its satisfactory operation, particularly in the larger sizes. Aside from improvements in the converter itself, the generally better present conditions for operation, such as larger transmission lines, more uniform frequency of power supply, and better and more complete protection, have an important influence on the increase of reliability of service. Those more important factors in the design and manufacture of synchronous converters that contribute to its present success will be here considered.

Safety against flashing at the commutator has been increased by providing more distance between brushes of opposite polarity. This is particularly true when this distance is as small as is obtained for 60-cycle converters, if heretofore considered allowable commutator speeds are employed. For instance, a speed of 4500 ft. per minute gives a distance of 7½ in. between centers of brushes of opposite polarity. The distance between the nearest points of brush-holders is less than 7½ in., which is admittedly small for 600 volts. To add 1½ in. to this distance would increase the commutator speed proportionately and would give a speed of 5500 ft. per minute (which is now considered conservative). Nine inches between brushes would increase the safety against flashing in a much greater proportion than the 22 per cent increase in speed, as the distance between brush-holders is increased in a much greater proportion.

With the improved design of commutator to stand higher speeds, the sequence of operations of manufacture and assembly of bars and the treatment of mica has received much attention, so that the finished commutator requires much less seasoning to fix the bars permanently. It is now quite generally recognized that commutators for 60-cycle converters must hold perfectly true and smooth to secure successful operation.

The proper proportioning of thickness of mica between commutator segments to voltage per bar has been proven in practice to give operation at higher voltage between bars equal in reliability to that obtained with lower voltage between bars. With 20 per cent greater voltage and 30 per cent more mica between bars than was formerly used (with also the same size and speed of commutator) there is practically no difference in the tendency to flash under adverse conditions. The tendency to spark is less with the smaller number of segments and the commutator is easier to build, therefore, usually better.

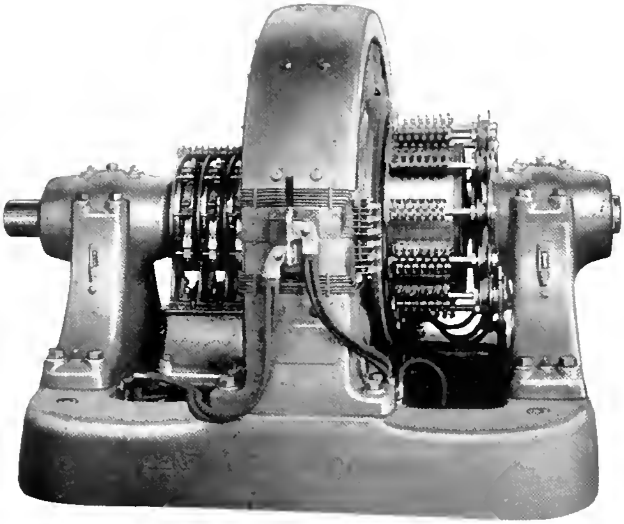

Fig. 1. 12 Pole, 500 Kw., 600 R.P.M., 575 Volt Rotary Converter without Commutating Poles

With the ability to build longer high-speed commutators, it became possible to increase the output per pole, that is, to increase the r.p.m. for a given size of unit. In recent machines the output per pole has been increased beyond the inherent commutating ability, so that commutating poles are necessary.

An interesting comparison to show the development in the past ten years is given in Figs. 1, 2 and 3. These machines all have 12 poles and run at 600 r.p.m. The one in Fig. 2 is capable of delivering twice the output of the machine in Fig. 1, and represents about the maximum output per pole as limited by commutation without commutating poles. The converter in Fig. 3 is able to carry three times as much load as the converter in Fig. 1, and represents present good practice in regard to the limiting features, namely: commutator length and speed, and commutating ability with commutating poles. The converter in Fig. 1 has 95 per cent more pounds of material per kilowatt than the commutating pole machine in Fig. 3. The one in Fig. 2 has 50 per cent more material per kilowatt than the one in Fig. 3.

This comparison also shows how armature surface speeds have been made greater with proportionately greater pole pitch, or spacing. The more recent designs in Figs. 2 and 3 have approximately 40 per cent higher surface speeds than the older one in Fig. 1. This allows of a 40 per cent greater distance between adjacent pole tips, without changing the ratio of pole arc to pole pitch, which reduces the amount of magnetic fringe flux cutting the armature conductors in the neutral space undergoing commutation. The resulting smaller voltage between commutator segments, under and near the brushes, allows of more latitude in brush position with less cause for sparking, due to the short-circuit current from the armature coils passing through the brushes during commutation. Also there will be a less possibility of flashing over in the event of heavy sparking due to excessive load, or

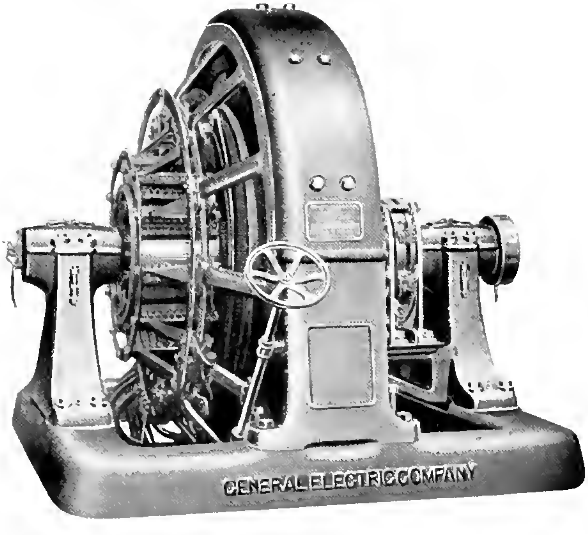

Fig. 2. 12 Pole, 1000 Kw., 600 R.P.M., 600 Volt Rotary Converter without Commutating poles

unusual disturbances for the lower voltage between the commutator bars, near the brushes, would have less ability to maintain the incipient arcs. Since the ratio of pole arc to pole pitch is unchanged, the ratio of maximum volts per bar to average volts per bar is also unchanged.

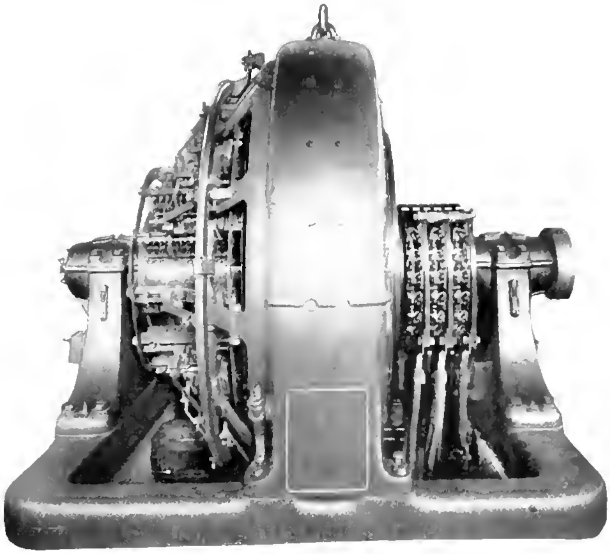
Fig. 3. 12 Pole, 1500 Kw., 600 R.P.M., 600 Volt Rotary Converter with Commutating Poles

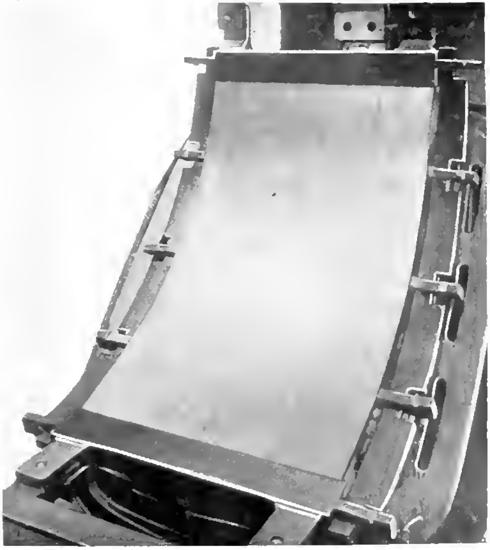
Fig. 5. A Welded-Joint Pole Damper

This comparison is based on 600-volt converters. The same comparison might be made with the 300-volt converters showing the even greater increase in output per pole, which has been made possible by the use of ventilating vanes fastened to the commutator bars. With the lower voltages, the possibility of flashing is so much less that the vanes do not add any material risk of damage in the case of a short-circuit or other disturbance that might cause flashing. The danger to the attendant is eliminated by enclosing the vanes, as shown in Fig. 4, by a circular trough, which also serves to direct the cooling air more effectively past the vanes.

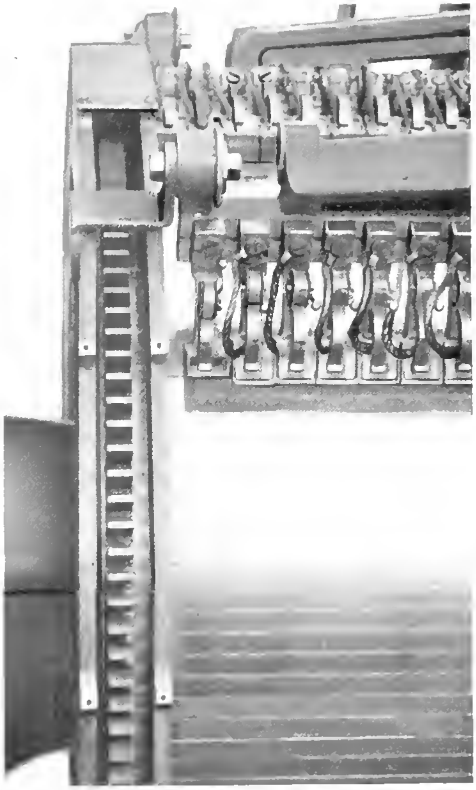
Fig 4 Partial View of a Commutator Equipped with Ventilating Vanes and Protecting Trough, latter partially removed

An average example of the gain in cooling surface by the addition of vanes to a commutator would be about as follows:

Commutator bar 0.4 in. wide, 25 in. long, cooling surface 10 sq. in. A vane $4\frac{1}{4}$ in. wide by 2 in. high by $\frac{1}{8}$ in. thick would add about 5.6 sq. in. of radiating surface. The cooling surface of the commutator would be increased over 50 per cent by the vanes which, with their protecting cover, occupy about 8 per cent of the commutator length.

With commutating poles, it is necessary to raise the direct-current brushes in order to avoid sparking when starting a converter with alternating current. The rigging for raising all of the brushes by the movement of one lever is shown in Fig. 8. The current required to start a commutating-pole converter with brushes raised is less than required by converters without commutating poles with brushes down, and all sparking is of course eliminated.

To obtain quick changes in field strength, to correspond with changes of load for good commutation with commutating poles, the polepiece dampers have been modified so that they will not enclose the commutating pole. To compensate for the omission of the connection of the bridges between adjacent poles, the dampers are made of lower resistance and much attention has been given to the making of all joints so they will remain permanent. There are three methods of making the joints in pole dampers, now in use: (1) by welding, Fig. 5; (2) by casting, Fig. 6; and (3) by a slight taper, Fig. 7, carefully fitting and drawing them sufficiently together by a nut to expand the copper, or brass.

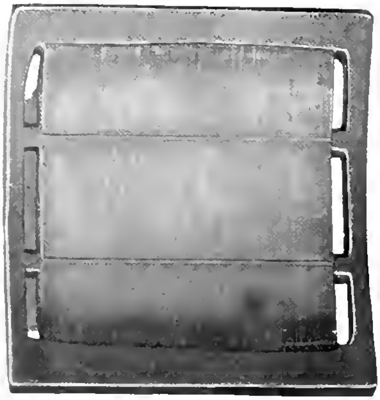

Fig. 6. A Cast Pole Damper

To avoid overloading some of the brushes, greater care is now taken to insure uniform resistance from the commutator to the bus-ring through each brush, when the greater number of brushes per arm are required. A busbar, to which all of the brush leads are connected, is mounted on each bracket and is connected to the main bus-ring. This construction is shown in Fig. 3. For a similar reason, it is also specially desirable to have the armature windings thoroughly equalized, Fig. 8, to insure uniform commutation and equal distribution of heating.

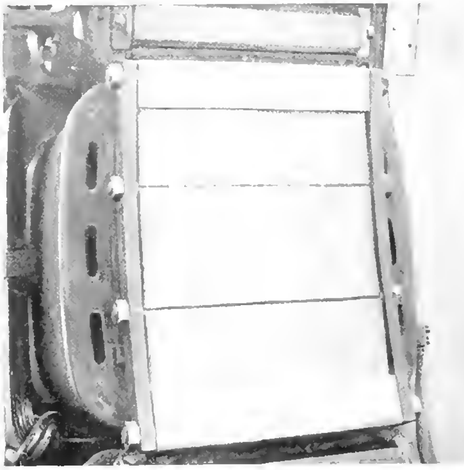

Fig. 7. A Taper-Joint Pole Damper

The machine illustrated in Figs. 3 and 8 is operating very successfully under unusually severe conditions. It transforms power received at the end of a 100,000-volt, 153-mile line, which is subject to direct strokes of lightning and other interruptions usual to such long-distance, high-voltage transmissions.

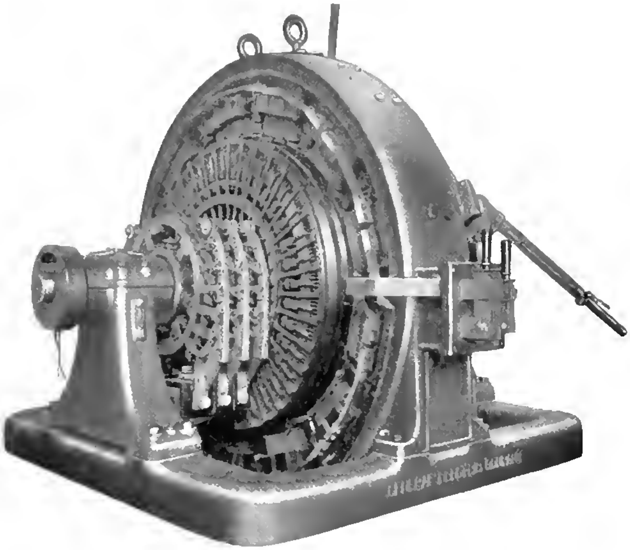

Fig. 8. Another View of the Machine Shown in Fig. 3. Lever at Right Raises and Lowers D-C. Brushes

# ELECTRIC PROPULSION ON THE U.S.S. JUPITER

By W. L. R. Emmet

Consulting Engineer, General Electric Company

The author gives some interesting data comparing the Cyclops, Neptune and Jupiter, which are equipped respectively with reciprocating engines, turbines with helical gearing, and turbines in conjunction with two induction motors. The trials referred to were not the official trials, but only preliminary trials. We hope to be able to give our readers the results of the official trials when these have been run. This paper was read before the Society of Naval Architects and Marine Engineers in New York on December 11, 1913. Editor.

The contract for propelling machinery of the U. S. Collier Jupiter was awarded by the Government to the General Electric Company in June, 1911. The designs had been made during the previous year when it was expected that the ship would be built in a private yard. The ship was built at the Mare Island Navy Yard, and was put in commission September 15, 1913. Since that time she has made a number of trial runs in San Francisco Bay and at sea, but she has not yet had her official trials.

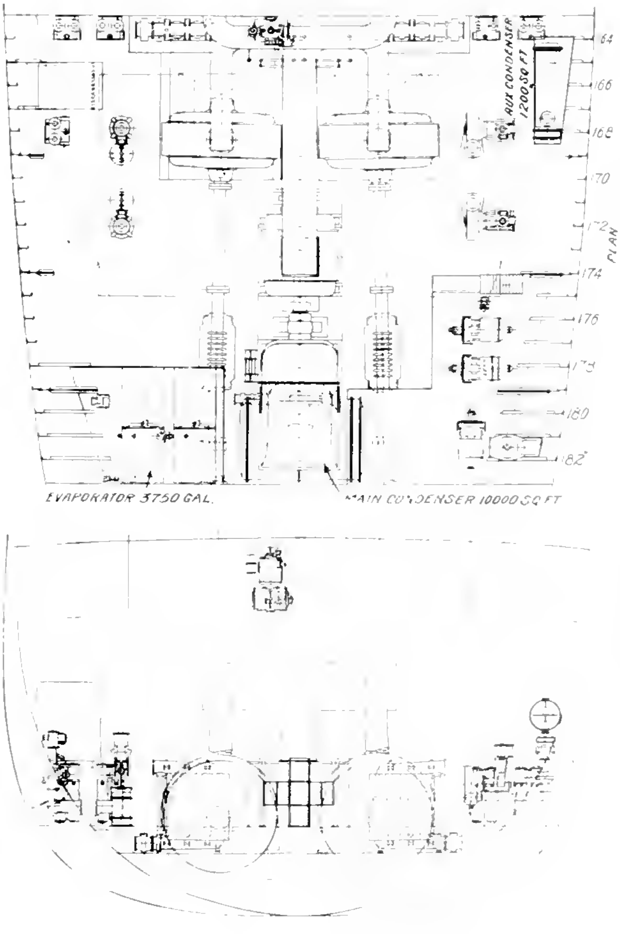

Fig. 1. Arrangement of Machinery

The Jupiter is a very large vessel of about 20,000 tons displacement, and is designed to carry about 12,000 tons of coal and oil. The length of her deck over her cargo space is occupied by a line of derricks, which must add considerably to the weight and wind resistance of the ship.

She is a sister ship of the colliers Cyclops and Neptune. The Cyclops was equipped with reciprocating engines and has been in operation for some years. The Neptune was equipped with turbines connected to the propellers by helical gearing.

The Jupiter is equipped with one turbine generating unit and two induction motors, one driving each of the propeller shafts. There is also a board carrying switches and instruments.

A comparison of the equipment of these three vessels is given by Table I on page 123.

The character of the apparatus installed in the Jupiter is shown by the accompanying cuts. It is all of a type commonly used in the electrical industry and need not be described in detail here. There is only one feature about the generating unit which is different from the type of units ordinarily used for electrical purposes; that is, that the governor is so designed that it can be set to hold any desired speed through a wide range, the adjustment of the governor being the normal method of speed variation used in this vessel. The ship can also, if desired, be controlled by the throttle, so that the governor is simply a convenience and in no sense a limitation.

The windings of the generator, which carry the alternating current, are on the stationary part and are insulated with non-combustible material. The generator drives its own ventilating air by powerful impellers attached to the ends of the rotor. This air is delivered from the top of the generator through a duct which connects to the space from which the fire room blowers take their air supply. The heated air from the motors also passes out of the engine room through similar ducts. The revolving parts of motors are connected to water-cooled resistances through collector rings, and means are provided by which these collector rings can be short circuited so that the rotor circuits are closed upon themselves. Such a condition, with the resistances cut out, is the normal state of efficient operation, the resistances being used only for the purpose of giving a large torque in reversing. The vessel can be operated with the resistances continuously in circuit. With this connection, the immediate movement of either motor in either direction is very convenient, and this method of operation is normally used in maneuvering in narrow waters or about wharves. The ship can, however, be maneuvered and reversed without the use of the resistance; and while this method has not yet been fully experimented with, it is thought that her reversal, even without the resistance, will be about as effective as that of vessels having existing types of equipment.

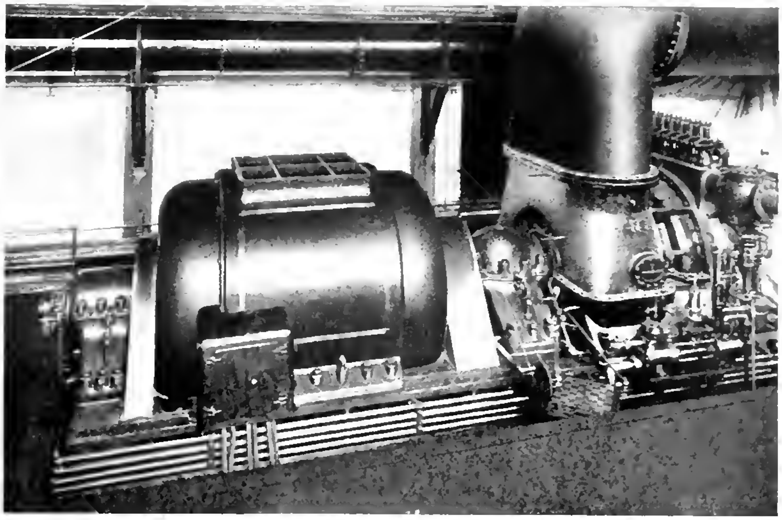

Fig. 2. Generating Unit

Since the Jupiter apparatus was designed, a method of designing induction motors has been developed which will give all the desired characteristics for reversal without the use of external resistance. Such motors will have squirrel-cage rotors, which are of a simpler character than the definite wound rotors now used. While the method of control and operation of the Jupiter is extremely quick and simple, the operations necessary with this new type of motor will be simpler still. With this new method it will be extremely easy to accomplish all the operations of speed control or reversal of either propeller from the bridge if desired.

When the first tests of the Jupiter operation were made she had been lying at the Navy Yard dock for four months, so that her bottom was in a very foul condition. Her speed in that condition was something like 25 per cent below normal. This produced abnormal electrical conditions, since the low frequency made necessary the use of higher magnetic densities than are desirable. Many of the conditions of these runs were very unfavorable. A large proportion of the crew were green men; in one fireroom watch a large proportion of the fireroom force were seasick. A great deal of boiler compound was used in the boilers, and the priming was excessive. The condensed water was much discolored by boiler compound, and water was at frequent intervals forced from the valve packings.

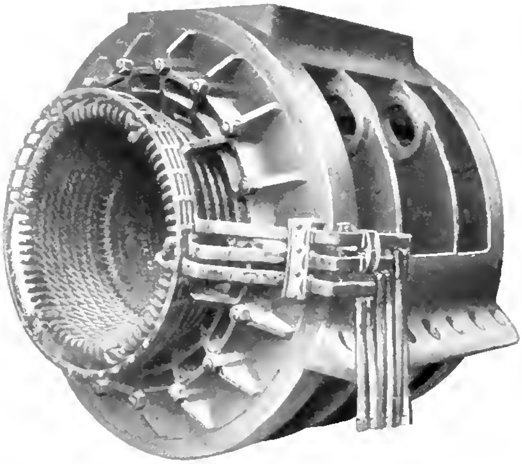

Fig. 3. Stator Frame and Windings of Generator

The operation of the apparatus during these runs was exactly in accordance with expectations. The turbine ran with a very perfect

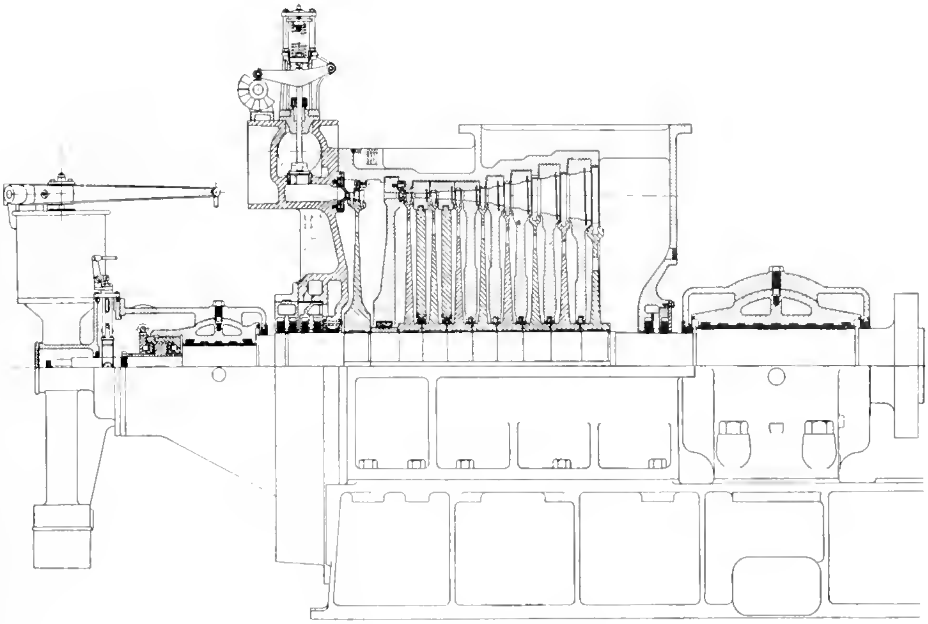

Fig. 4 Cross-Section of Turbine

balance, and ran just as steadily in rough water as in smooth. The governor held its speed perfectly. The lifting of propellers to the surface at no time caused any perceptible speed variation. The only effect of such lifting of propellers was a fall of current on the instruments showing a diminution of power delivered to the propellers. Examination of the turbine after several such runs had been made showed it to be in perfect condition, and free from rust, scale or dirt.

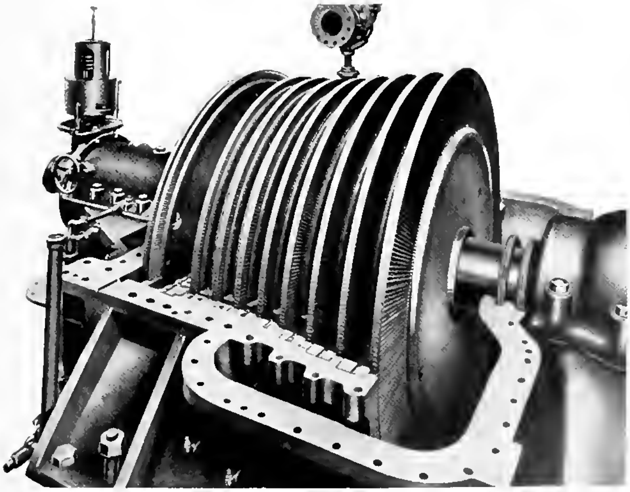

Fig. 5. Turbine for U. S. Collier "Jupiter" Mid-Bearing Cap and Top Intermediate Holder. Intermediates and Nozzles Removed

After this period of preliminary trials, the ship was docked, and since that time she has made a set of standardization runs and a 48-hour unofficial trial with a clean bottom. On this 48-hour trial the ship averaged 14.78 knots, the average power delivered by the generator was 5000 kw., corresponding to about 6300 h.p. The average revolutions of the propeller were 115. The Cyclops in her official 48-hour run made 14.61 knots with an average of 6705 i.h.p.

The power required by the Jupiter in this 48-hour run is somewhat less than would be expected from the Cyclops performances, and the slip of the propellers is also less than was expected. It has been suggested that this difference might, in some degree, be attributable to the fact that in the Jupiter the torque delivered to the propellers is continuous, while with the reciprocating engines the impulses are intermittent. Careful investigation would be necessary to ascertain whether there could be anything in such a theory. It has also been suggested that there would be some advantage in the fact that the

Jupiter's propellers were entirely free from racing, but since some of these tests were made in quite smooth water, this could hardly have had any effect. If no advantage is gained through these causes, it would certainly seem that the performance of the Jupiter's propellers is very creditable to Captain Dyson, who designed them.

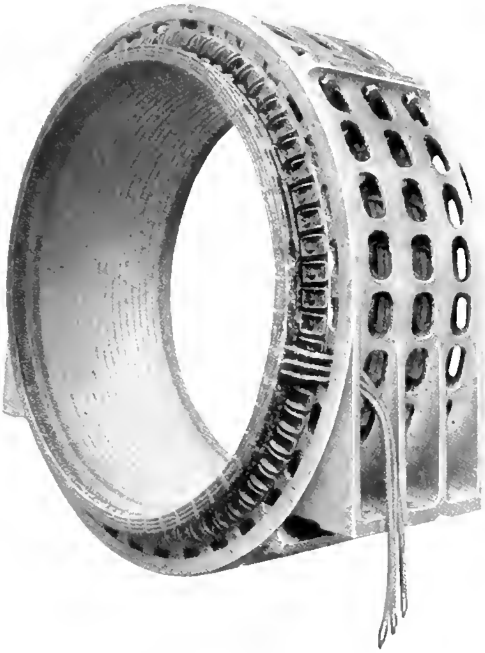

Fig. 6. Stator for Motor

Through a misunderstanding, the steam pipe on board the Jupiter was made much too small, so that the normal pressure at the turbine cannot be attained. The vessel will not give her best performances until this is corrected, and until an effective separator is put between the boilers and the turbine so that the efficiency of the turbine will not be affected by priming. It is believed that when these changes are made, the Jupiter can, if desired, be operated at a much higher speed than that which has been attained, and that her economy will prove to be far better than that of any vessel afloat.

The steam consumption of the Jupiter turbine and the efficiency of all of her apparatus has been determined by exhaustive tests at Schenectady, and is also accurately known through knowledge of the performances of other similar apparatus. These results are shown by the accompanying curve, and they cannot fail to be accomplished in the ship herself when all conditions are normal.

Since the preliminary trials above mentioned, the Jupiter turbine has been injured through the breaking of a half-inch tap bolt, which held the section of stationary buckets used in the first stage of this machine. On account of this trouble her official trial has been postponed, and it is hoped that the steam pipe will be changed and a separator put in before the official trial is made. A section of stationary buckets held by these bolts is the only detachable part in this turbine. Tap bolts are subject to the danger of breaking under such conditions, and we have had trouble with such method of attachment in other turbines. The matter in this case was, however, unfortunately overlooked. The trouble is easily corrected, and the accident has no significant bearing upon the demonstration which this ship has made. While this bolt destroyed all the buckets in the first stage, the turbine was still capable of operation. The turbine was taken apart because it was seen that the economy was not normal. By taking out the bolt which was adrift and clearing the damaged parts which might interfere, the ship could still have been operated indefinitely at normal speed with a very fair economy. Such arrangements could be made in a few hours.

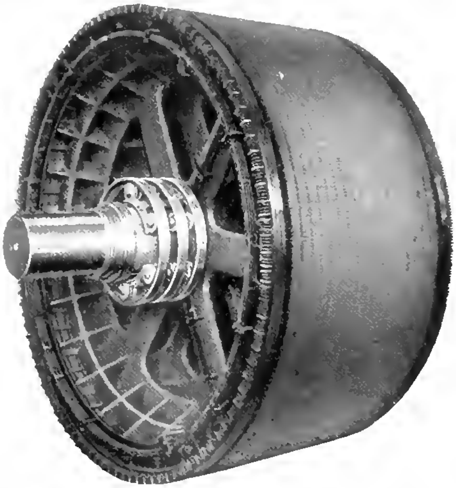

Fig. 7. Rotor for Motor

Four years ago I presented my first paper on Electric Ship Propulsion to this Society.

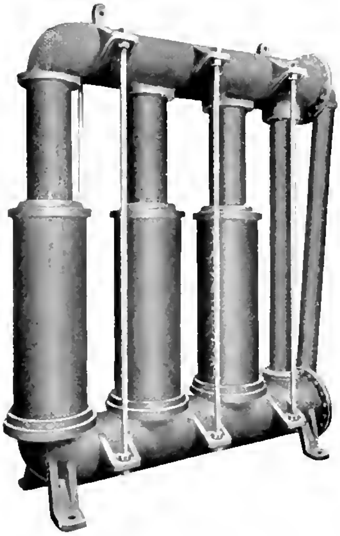

Fig. 8. Water-Cooled Rheostat

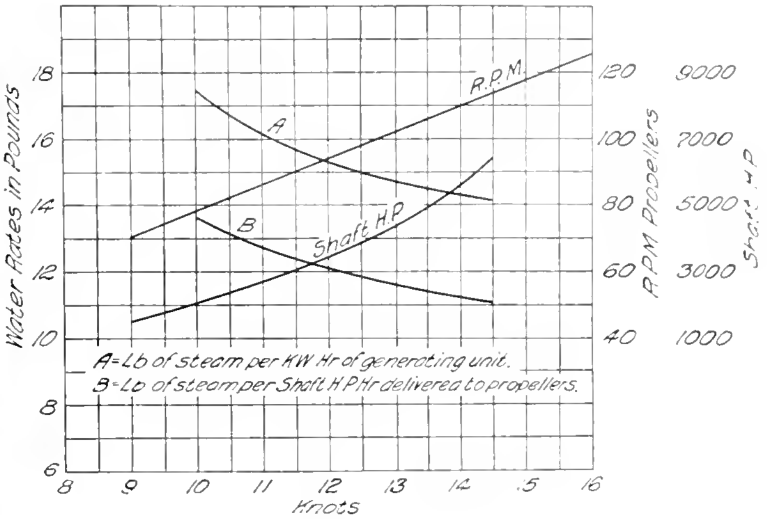

Fig. 9. Water Rates U. S. S. "Jupiter"—Conditions 190 Lb. Gauge, 28.5 In. Vacuum, No Superheat

A year before that I had designed an equipment for the battleship Wyoming, and a proposal had been made to the Government in which my designs were embodied. Since that time I have submitted several designs to the Government relating to equipments of battleships which have been built. My last design applied to a case like that of the Pennsylvania, and was submitted last spring. My estimates as to the results of this equipment as compared with those which will be accomplished by the equipment which is being put into the battleship Pennsylvania are shown by Table II.

With reasonable allowances for steam required outside of the main turbines, it would appear that this ship, which is provided with 12 boilers, could, with the turbo-electric

## TABLE I

| | Cyclops | Jupiter | Neptune |
|---|---|---|---|
| Displacement, tons | 20,000 | 20,000 | 20,000 |
| I.h.p. at 14 knots | 5600 | . . | . . . . |
| Engine or turbine speed at 14 knots | 88 r.p.m. | 2000 r.p.m. | 1250 r.p.m. |
| Propeller r.p.m. at 14 knots | 88 | 110 | 135 |
| Weight driving machinery, tons | 280 | 156 | |
| Character driving machinery | 2 triple expansion engines | 1 turbo-generator and 2 motors | 2 turbines each with gearing |
| Steam consumption in lb. per s.p.h. hr. | 14 (estimated) | 11.2 (tested) | |
| Speed maintained on 48 hr. trial | 14.6 knots | | 13.9 knots |

## TABLE II

| | R.P.M. 21 Knots | H.P. Required 21 Knots | Pounds of Steam per Hr. Turbines Alone 21 Knots | Pounds of Steam per Hr. Turbines Alone 15 Knots | Weight of Driving Machinery in Tons |
|---|---|---|---|---|---|
| Turbine drive with geared cruising turbines as adopted | 222 | 31,700 | 374,000 | 106,000 | 749 |
| Turbo-electric drive | 160 | 29,200 | 305,000 | 91,000 | 598 |

equipment, operate equally well with 10 boilers. If two boilers were omitted, the whole weight saving would be 266 tons.

If my first design for a warship made over four years ago had been accepted by the Navy Department, the vessel produced would have been very greatly superior in respect to economy, reliability, weight, simplicity, and cruising radius to any ship now afloat, and ever since that time my case has been steadily strengthening through the great improvements which have been made in high-speed turbines.

Since the Jupiter has been put in operation, much interest has been aroused among ship owners and ship builders, and it is probable that equipments for several large vessels will, within a short time be contracted for. If such a beginning can be made, the practical results accomplished will soon develop great activities.

# DIAGRAMS OF THE POLYPHASE COMMUTATOR MOTOR

By Dr. H. Meyer-Delius

Induction Motor Department, General Electric Company

In this article, the theory of the polyphase commutator motor is developed. First the theory of the d-c. motor is outlined, and it is shown that the same principles apply to the polyphase motor, with the only difference that due to the alternating nature of the current a reactance drop has to be added to the ohmic drop. Making use of elementary geometrical relations of vectors, the author develops a diagram for the polyphase series motor, by means of which the current, power-factor, speed, torque and efficiency can be determined for different values of load. It is shown how this diagram can be drawn after the reactance and the resistance of the motor have been determined either by test or calculation. The diagram is finally applied to the brush-shifting series motor invented by Prof. Goerges of Germany, the commercial application of which has only recently become possible, as a result of a better understanding of alternating current commutation.—Editor.

The torque of any electric motor is produced by the reaction of the magnetic field on the current flowing in the armature conductors. Fig. 1 shows diagrammatically the connections of a normal d-c. motor. The field winding, *F*, excites the field. The main current, passing through the brushes and commutator into the rotor winding, produces with the action of the field the mechanical torque which drives the motor. When the rotor revolves, the rotor conductors cut the field and a counter e.m.f. is induced between the brushes which is proportional to the number of revolutions. The counter e.m.f. times the current represents the electrical energy taken from the line equivalent to the mechanical energy delivered at the shaft. (Losses neglected.)

This same principle holds exactly with a-c. commutator machines. The only difference is that, due to the pulsation of the currents, reactance voltages appear, which cause phase displacements of currents and voltages, rendering the phenomena more complicated than with d-c. machines. In order to avoid too large phase displacements, the reactance voltage should be kept as small as possible. In d-c. machines the armature field is steady and does little harm outside the commutation zones; in a-c. commutator machines the armature field must be neutralized, because the reactance voltage induced by this strong field would be prohibitively large. This could be effected by a compensating winding on the stator connected in series with the rotor. The compensating winding is a true duplicate of the armature winding, completely neutralizing the armature ampere turns along the whole circumference. This arrangement is shown in Fig. 2, drawn for quarter phase current. Besides the second phase we

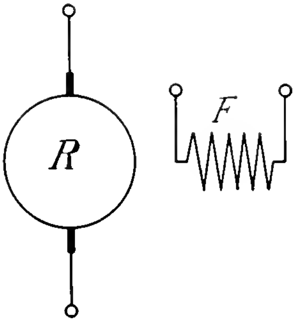

Fig. 1. Connection Diagram of a D-C. Motor

have added to the d-c. diagram of Fig. 1, only the compensating winding $C_1$ and $C_2$. The rotor is the unchanged d-c. armature. Since the stator field is excited by a-c. current, the stator iron must be laminated. The compensating winding, like the rotor winding, is distributed over the whole circumference in small slots, so that the stator of the a-c. commutator motor has generally the appearance of that of a normal induction motor. The field windings $F_1$ and $F_2$ may be placed in special big slots producing distinct poles as in a d-c. machine, or they may be distributed in the same small slots with the compensating winding. In the latter case a distributed field of more or less sine shape is produced, as in normal induction motors, In this case the field and compensating winding are of the same type and may also be converted into one winding. But in order to separate the actions of the field and compensating winding more clearly, we will assume a separate field winding, as shown in Fig. 2.

We will now study the actions of the different windings. Fig. 3 shows in a simplified manner the windings and magnetic paths of the commutator motor of Fig. 2 in the axis of one phase. $S$ indicates the stator and $R$ the rotor iron. Between the main terminals $T_1$ lie the compensating winding $C_1$ on the stator and the rotor winding $D$ on the rotor, which are connected in series over the brushes $B$ on the commutator. The compensating winding is wound with the same number of turns as the rotor winding, but in the inverted sense, so that a current flowing through both windings does not produce any flux in the magnetic circuit $SR$. The compensating winding neutralizes the armature field completely.

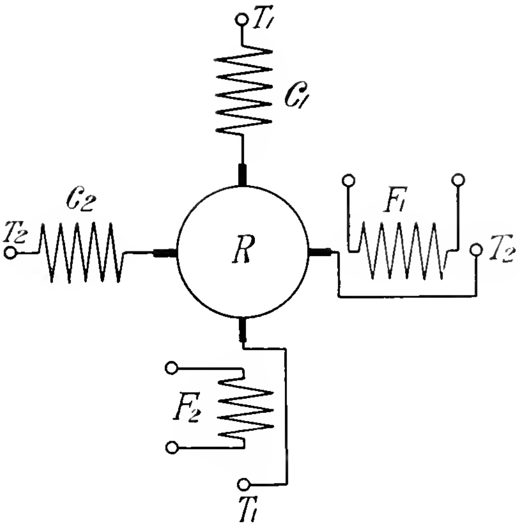

Fig. 2. Connection Diagram of a Polyphase Commutator Motor

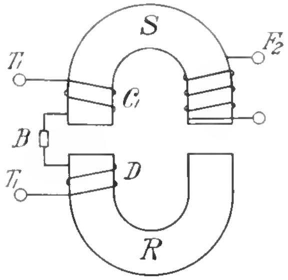

Fig. 3. Simplified Connection Diagram of a Polyphase Commutator Motor

The field winding $F_2$ is wound separately on the stator. If we connect $F_2$ to an a-c. voltage, a field is excited in $SR$. This field induces equal and opposed voltages in the compensating and rotor windings, so that no voltage appears between the main terminals $T_1$. For the motor this means that at standstill a field excited by the field winding produces no difference of potential between the main terminals, since the transformation voltages induced by the main field in compensating and rotor windings necessarily balance each other at the main terminals. Thus we do not at all need to introduce these transformation voltages in the diagrams or calculations. Now if we turn the rotor, a rotation voltage is produced by the main field in the rotor winding, which does not appear in the steady compensating winding and which therefore shows up at the main terminals. Just as in d-c. machines, this rotation voltage is at each instant proportional to the number of revolutions and the strength of the field. It is therefore in phase with and of the same frequency as the main field. The intensity of this voltage is entirely independent of the frequency of the applied current and is proportional to only the speed of the rotor and the intensity of the main field. This is the characteristic difference between the commutator motor and the induction motor. In the latter the rotor voltage is dependent upon the line frequency as well as upon the speed.

The only other voltage appearing at the main terminals is the impedance drop in the compensating and rotor winding. Fig. 4 shows the voltage diagram of the motor. The following voltages appear at the terminals:

1. $e_r$: the rotation voltage. It has the same phase and frequency as the field. Its intensity is proportional to the intensity of the field and the number of revolutions, and is independent of the line frequency.

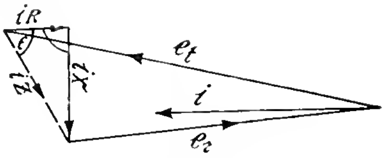

Fig. 4. Voltage Diagram of a Polyphase Commutator Motor

2. $i\times R$: the ohmic drop in the conductors carrying the main current. Its phase is opposed to that of the current and its intensity proportional to the current.

3. $i\times X$: The leakage reactance drop in the conductors carrying the main current. Its phase is 90 deg. behind the current. Its intensity is proportional to the current and the impressed line frequency and independent of the speed of the motor, correct commutation being assumed for the sake of simplicity. (See article, "The Commutator as Frequency Changer," GENERAL ELECTRIC REVIEW, Dec., 1913.)

These three voltages must balance the impressed line tension $e_t$. The resultant of the latter two voltages, the ohmic and reactance drop, is the impedance drop $i\times Z$. With the line frequency constant, the reactance drop is proportional to only the current, as is the ohmic drop. The impedance triangle therefore has a constant shape, and the third side—the impedance drop, $iZ$—is proportional to the current and has a constant phase displacement from it. Let the constant angle between the impedance and ohmic drop be $\epsilon\left(tan\ \epsilon=\frac{X}{R}\right)$.

Compare with the above diagram the voltage diagram of a d-c. motor as shown in Fig. 5. $e_r$ represents the rotation voltage and $i\times R$ the ohmic drop. These two voltages must balance the line tension $e_t$. All tensions are in phase and all possible operating conditions are covered by the plain algebraic equation:

$$e_r+i\times R=e_t$$

The difference between the terminal voltage and the rotation voltage drives the current over the resistance $R$. With increasing speed the current becomes smaller and smaller, because the rotation voltage grows, until the developed torque, which is proportional to current times field, is the same as the counter torque of the driven machine.

The only new voltage in the a-c. diagram is the leakage reactance drop $i\times X$, which throws the total drop $i\times Z$ considerably ($\epsilon°$) out of phase with the ohmic drop of the d-c. diagram. The algebraic d-c. equation becomes with a-c. a geometrical vector equation:

$$\overline{e_r}+\overline{i\times Z}=\overline{e_t},$$

because the three voltages are no longer necessarily in phase with each other. But the general character of the equation is unchanged. The difference between the terminal voltage and the rotation voltage drives the current over the impedance $Z$. With increasing speed the current becomes smaller and smaller until the developed torque is the same as the counter torque of the driven machine. The motor torque is now proportional to the current times field times the cosine of the angle of phase displacement between current and field.

Just as in a d-c. motor we obtain a series motor if the field is excited by the main current, a shunt motor if the field is excited by the terminal voltage, and a compound motor if the field is excited by both at the same time, so in an a-c. motor we obtain the same characteristics with the same connections. For each type of motor we will study the electrical relations between the three voltages of the diagram regarding phase and intensity for different loads. These electrical relations will give geometrical relations between the corresponding vectors in the diagram. These geometrical relations will show that the end of the impedance vector, $Q$, must move on a geometrical locus with varying load. This locus will enable us to find for each load the line current in intensity and phase, the torque at the shaft, the speed, the input and output, and the efficiency of the motor.

Fig. 5. Voltage Diagram of a D-C. Motor

## THE SERIES MOTOR

The connections are shown in Fig. 6. The field $F_1$ is excited by the main current $i_1$ and is therefore in phase with and proportional to it (no saturation of the iron assumed). But we can use as well the current $i_2$ or any combination of the currents $i_1$ and $i_2$ for the excitation of the field $F_1$, as is shown in Fig. 7. The phase of the resultant field $F_1$ is shifted from the phase of the main current $i_1$ over an angle which is determined by the relation of the number of turns of the two exciting windings. This angle, which we will call $\beta$, is constant for all loads. Since the rotation voltage is in phase with the field, it has a constant phase displacement $\beta$ from the main current. We found before that the impedance vector, which includes the impedance of the field winding in the series motor, has also a constant phase shift ($\epsilon^\circ$) from the current. Thus the impedance drop and the rotation voltage have also a constant phase displacement from each other. Therefore in the diagram of Fig. 8 the angle $\delta$ between $i \times Z$ and $e_r$ is constant ($\delta = 180 - \epsilon - \beta$). The end of the impedance vector $Q$ must move therefore on a circle, in which the terminal tension $OE$ as chord subtends the angle $\delta$. This is the desired locus for the end point of the impedance vector.

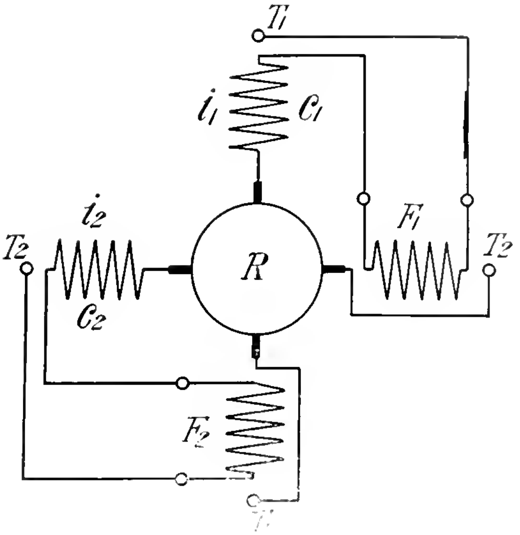

Fig. 6. Connection Diagram of a Polyphase Series Motor

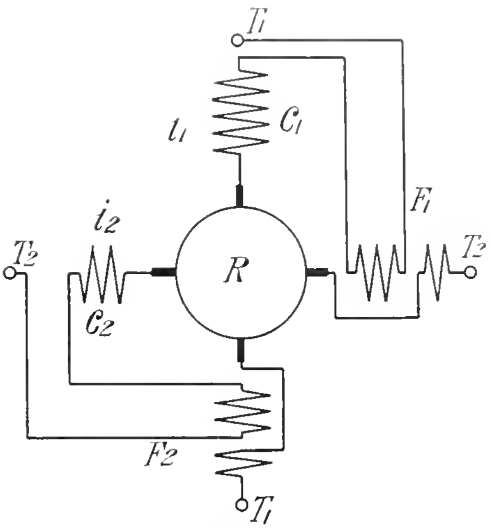

Fig. 7. Connection Diagram of a Series Motor with Phase Combination on the Exciting Winding

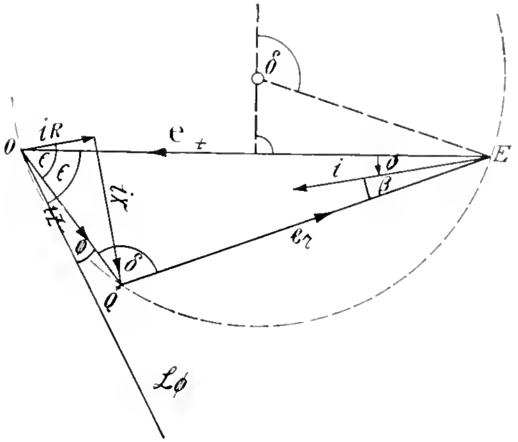

Fig. 8. Circular Diagram of a Series Motor Showing Current and Power-Factor

### Current and Power-factor

Since the impedance drop is proportional to the current, we measure the current by the same vector $OQ$. This vector is lagging $(180 - \epsilon)$ degrees behind the current. If we draw a line $L\phi$ through $O$, which forms the same angle with the terminal voltage (see Fig. 8), we can measure the phase shift $\phi$ of the current from the terminal voltage by the angle between this line $L\phi$ and the impedance vector $OQ$.

### The Speed

The rotation voltage is proportional to the speed times the field, which is again proportional to the current.

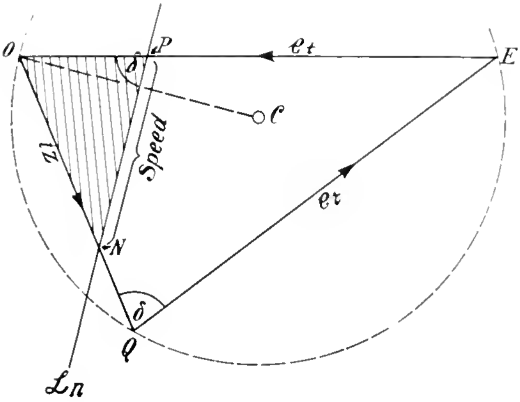

Fig. 9. The Speed in the Diagram of a Series Motor

$e_r = QE = n \times i$, where $n$ indicates the number of revolutions. The impedance drop, $OQ$, is proportional to the current;

$$\underline{i \times Z} = OQ = i$$

thus $$\frac{e_r}{i \times Z} = \frac{QE}{OQ} = n \qquad \text{(See Fig. 9)}$$

Draw a line $L_n$ through an arbitrary point $P$ on $OE$ under the angle $\delta$. This line $L_n$ may cut $OQ$ in $N$. $\Delta OPN$ is similar to $\Delta OQE$, because two angles are equal.

$$\frac{QE}{OQ} = \frac{NP}{OP} = n$$

If $Q$ moves on the circle, the vector $OQ$ cuts off from the line $L_n$ a portion $PN$, which is proportional to the speed, the denominator $OP$ of the above ratio $\frac{NP}{OP}$ remaining constant. The point $P$ may be chosen so that the number of revolutions appear on $L_n$ in a convenient scale.

### Input and Output

The input is proportional to the watt component of the current. If we draw a line $L_1$ through $O$ at right angles to the power-factor line $L\phi$ (see Fig. 10), we could measure the input by a line $QW$ through $Q$ perpendicular to $L_1$, which would represent the watt component of the current.

To obtain the output, we have to deduct the losses in the motor from the input. There are the $I^2R$, core and friction losses. The core loss is nearly proportional to the square of the field, or in this case to the square of the current, so that we may unite the $I^2R$ and core losses and take both proportional to the square of the current.

Draw the line $OCT$ through the center $C$ of the circle. $\Delta OQT$ is a rectangular triangle. Draw the perpendicular to $OT$ through $Q$, which cuts $OT$ in $S$. We find

$$\frac{OS}{OQ} = \frac{OQ}{OT} \text{ or}$$

$$(OQ)^2 = OS \times OT = I^2$$

If $Q$ moves on the circle, $OS$ is always proportional to the square of the current or to the $I^2R$ and core losses.

Prolong $QS$ until it cuts $L_1$ in $U$. If $Q$ moves on the circle, the triangle $QWU$ is always of the same shape and therefore $\frac{QU}{QW}$ is a constant relation. $QW$ represented the input, and $QU$ is therefore also proportional to the input. The triangle $OSU$ is always of the same shape, $\frac{US}{OS}$ is therefore a constant relation, and $SU$ is also proportional to the losses. If we draw an arbitrary line through $O$, which may cut $QU$ in $V^1$, $UV^1$ is also proportional to the losses. If $QU$ (= the input) and $UV^1$ (= the losses) are drawn to the same scale, $QV^1$ will represent the output. We find the right scale at standstill, where the output is zero and the input equals the losses. $QE$ represents the rotation voltage, which is zero at standstill. $Q$ falls in $E$. The input is $EU_s$, which at the same time must represent the losses. $OE$ is therefore the output line. For our former load point, $Q$, the input is pro-

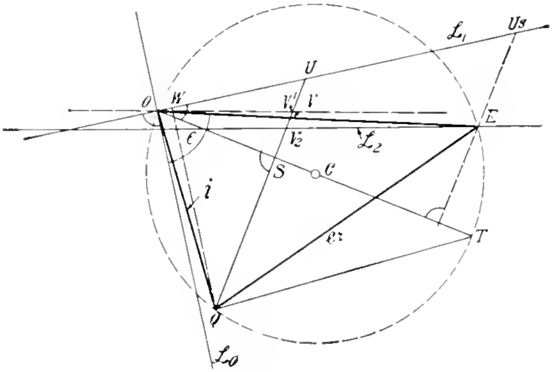

Fig. 10. Input and Output in the Diagram of a Series Motor

portional to $QU$ and the output to $QV$ in the same scale.

So far we have neglected the friction and windage loss. This loss has a complicated relation to the speed, which makes it impossible to introduce it exactly in a diagram. Since it is a small part of the losses a rough approximation will do, at least in the normal speed range. At standstill this loss is zero, so the output line must go through point $E$. We draw a straight line $L_2$ through $E$, which gives at normal speed the right friction loss, $VV_2$ and measure the output only up to this line $L_2$.

### The Torque

The torque is proportional to the current times the field times the cosine of the angle of phase shift between them. This angle is $\beta$, which we found is a constant angle. The field is proportional to the current. The torque therefore varies with the square of the current, just as in a d-c. series motor. It could be represented in the diagram by the same line $UV$, as the losses varying with the square of the current. This distance being rather small for the normal speed range, we had better take the distance $OU$ on $L_1$, which is proportional to $UV$, to indicate the torque.

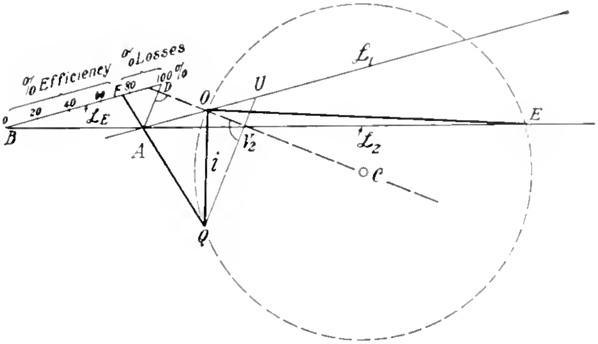

Fig. 11. The Efficiency in the Diagram of a Series Motor

### The Efficiency

$$\text{The efficiency} = \frac{\text{output}}{\text{input}} = \frac{QV_2}{QU}$$

See Fig. 11. Prolong the output line $L_2$ beyond the intersection $VA$ with the input line $L_1$. In an arbitrary point $B$ on $L_2$ draw a line $L_e$ parallel to $L_1$ and through $A$ a parallel to $QU$. The two parallels cut themselves in $D$. Further prolong $QA$, until it cuts $L_e$ in $F$.

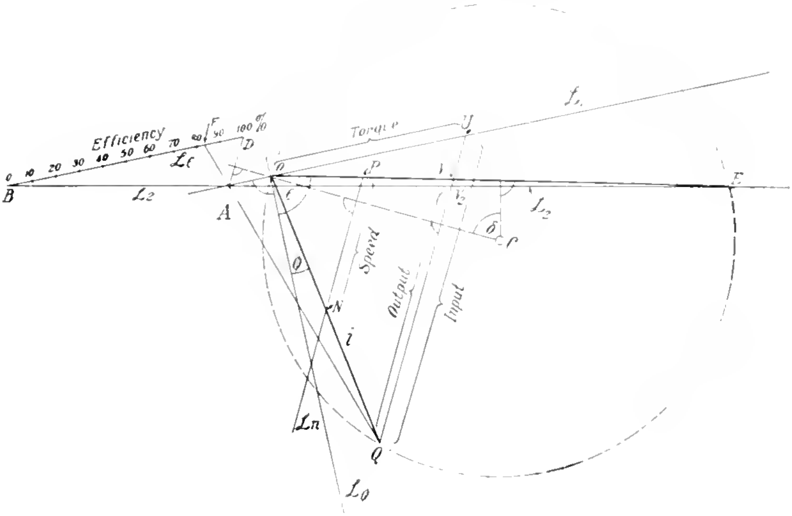

Fig. 12. The Complete Diagram for a Series Motor

It is

1. $\Delta\, AQU$ similar to $\Delta\, FAD$
2. $\Delta\, AV_2U$ similar to $\Delta\, BAD$

$$\text{from 1 we have } \frac{QU}{AU} = \frac{AD}{FD}$$

$$\text{from 2 we have } \frac{V_2U}{AU} = \frac{AD}{BD}$$

Equation 2 divided by 1:

$$\frac{V_2U}{QU} = \frac{FD}{BD} = \frac{\text{losses}}{\text{input}}$$

Therefore

$$\frac{BF}{BD} = \frac{\text{output}}{\text{input}} = \text{efficiency}$$

For $Q$ moving on the circle, the point $F$ moves on the line $L_e$. $BF$ represents the efficiency, because the denominator $BD$ of the relation $\frac{BF}{BD}$ remains constant.

$B$ may be be chosen on $L_2$ so that the efficiency appears to a convenient scale. *

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* An analytic derivation of similar loss and efficiency lines may be found in the book of E. Arnold, die Wechselstromtachnik, volume 1, page 118 ff.

### The Complete Diagram

For the construction of the diagram the following data are required:

*1.* The impedance as obtained, for instance, by a standstill test. The standstill current $i_{st}=\frac{e_t}{Z}$. The power-factor = cos $\epsilon$ at standstill gives angle $\epsilon$. It is also $\tan\epsilon=\frac{X}{R}$.

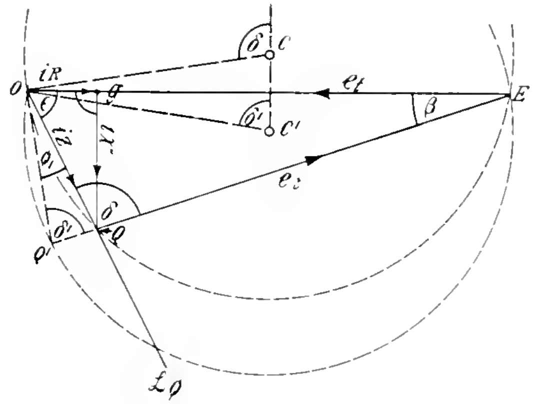

Fig. 13. Influence of the Angle $\delta$ on the Power-Factor of a Series Motor

Make $OE=i_{st}$ (Fig. 12) and draw $L\phi$, the power-factor line, through $O$ under angle $\epsilon$ and at right angles to $L\phi$, the input line $L_1$.

*2.* The phase displacement between the field and current, angle $\beta$. This gives $\delta=180-\epsilon-\beta$. Draw the circle, in which $OE$ as chord subtends angle $\delta$. Draw $OQ$, the current for normal load.

*Speed:* At a convenient point $P$ on $OE$ draw $L_n$, the speed line, perpendicular to $\overline{OC}$. $PN$, representing the normal speed, gives the speed scale.

*Output:* Draw $QU$ perpendicular to $OC$. $QU$, representing the input, gives the watt scale. Make $VV_2$ equal to the friction and windage losses and draw the output line $L_2$ by connecting $E$ with $V_2$.

*Torque:* $OU$ gives the torque scale.

*Efficiency:* $L_1$ and $L_2$ intersect in $A$. Draw $AD$ perpendicular to $OC$, choose $B$ on $L_2$ at a convenient point and draw $L_e$ parallel to $L_1$. Divide $BD$ in 100 parts, to indicate the efficiency at the intersection $F$ of $QA$ and $L_e$.

We are now able to look over the operating conditions of the motor completely and we shall see how similar they are to those of the d-c. series motor. In Fig. 13 just that load point $Q$ is shown at which the power-factor is unity, $Q$ falls on the power-factor line $L\phi$. The reactance voltage is balanced by a component of the rotation voltage $e_r$. Resolve $e_r=QE$ into the watt component $GE$ and the wattless component $QG$. The latter balances the reactance tension $iX$ completely, and we have the plain d-c. diagram, $OGEO$.

But the balancing rotation tension $QG$ is proportional not only to the current as the reactance voltage, but also to the speed. Therefore for lower speeds it is too small and the power-factor becomes lagging. For higher speeds it is too large and the power-factor becomes leading. In the neighborhood of the unity power-factor point the differences are small and the power-factor is nearly unity, and current, speed, torque and efficiency are exactly the same as in a corresponding d-c. machine.

For a given current the speed is determined by the strength of the watt field or the number of turns of the field winding. The power-factor is given by the strength of the wattless field, or by the angle $\beta$. For larger $\beta$ the power-factor becomes better; $\delta=180-\epsilon-\beta$ becomes smaller and the circle bulges higher, as shown in the dotted circle of Fig. 13. For a properly chosen $\beta$, the power-factor is approximately unity over a rather large speed range.

Though the reactance voltage produces a lagging current at lower speeds, it gives the a-c. motor a decided advantage over the d-c. motor at starting. At standstill the rotation voltage is zero and the full reactance voltage throttles away the main part of the terminal tension. The standstill current is therefore still moderate, and no starting resistances or transformers are necessary.

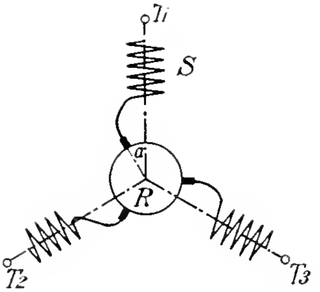

Fig. 14. Connection Diagram of a Brush Shifting Series Motor

In a d-c. motor the standstill current would be prohibitively large and starting resistances are always required. This fact makes the controlling apparatus for a-c. motors very simple.

We will apply the above diagram to a special practical type invented by Prof. Goerges, of Germany. The motor was exhibited in 1891 in Frankfurt a/M, Germany. But only recently have the conditions at the a-c. commutator been sufficiently cleared so that such a motor could be designed to operate with sparkless commutation; which was, of course, necessary before a market could be opened for it.

The connections for three-phase current are shown in Fig. 14. The stator is an entirely normal induction motor stator with one three-phase winding distributed in small slots and connected in Y. The Y point is formed by the rotor winding, which is connected in series with the stator winding over three equally spaced brushes sliding on the commutator. The rotor is an entirely normal d-c. rotor. The brushes are mounted on a movable brush yoke so that any brush position may be obtained.

Just as in a normal induction motor the stator winding excites a nearly uniform sine shaped field, and so does the similar rotor winding. Therefore the field resultant from the stator and rotor ampere turns is also of sine shape, whatever the brush position may be, so that practically no disturbing local fields appear.

Let us suppose the ampere turns of stator and rotor to be exactly equal in strength, and let us put the brushes in the same axis as the corresponding stator winding. The stator winding completely neutralizes the rotor winding over the whole circumference; no field is excited, and the stator winding acts as a plain compensating winding.

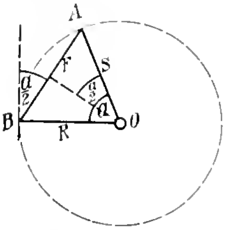

Fig. 15. Vector Diagram for Rotor and Stator Ampere Turns of a Brush Shifting Series Motor

Let us now shift the brushes over a certain angle $\alpha$, as shown in Fig. 14. Stator and rotor ampere turns no longer balance each other and the resultant ampere turns excite a field of sine shape, as we have seen before, proportional to the current and the angle of brush shift. A torque is developed by the field reacting on the current in the rotor winding. The motor is a plain series motor. A constant current assumed, the field increases with larger brush shifts. As in a d-c. motor the speed varies nearly inversely proportional to the field. The brush shift therefore controls the speed in a very simple manner without any auxiliary controlling apparatus.

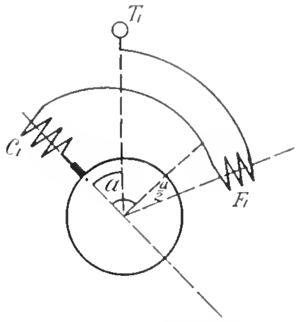

Fig. 16. Separation of Compensating and Field Winding in a Brush Shifting Series Motor

If the brushes are shifted over 180 deg., stator and rotor ampere turns are again in the same axis; instead of bucking, they act in the same sense. The torque is zero and the motor takes only a very small current from the line, since the impedance of the two windings in series is very large. This position is therefore well suited for connecting the motor to the line. By shifting the brushes forward, torque gradually develops until the motor starts and comes to the desired speed.

To develop the circle diagram for this motor we resolve the stator winding into two components, the compensating and the exciting winding. Since the stator and rotor ampere turns have uniform sine shape, they may be represented by vectors, as in Fig. 15. $S$ is the stator ampere turns, $R$ those of the rotor, shifted from the former by the brush shift angle $\alpha$. We resolve the stator vector $AO$ into the compensating ampere turns $BO$, equal and opposed to the rotor ampere turns, and into the field winding $AB$. Fig. 16 shows the two corresponding windings on the stator for one phase, $C_1$ the compensating, $F_1$ the field winding. We see that the field winding has a shift of $\frac{\alpha}{2}$ degrees. In our diagram we have called this angle $\beta$; therefore

$$\beta = \frac{\alpha}{2}$$

An impedance test at standstill gives the standstill current, and angle $\epsilon$ for this brush position. By finding $\delta = 180 - \epsilon - \beta = 180 - \epsilon - \frac{\alpha}{2}$ and constructing the circle diagram in the above indicated way, all desired data can be obtained from the diagram for all speeds. This method, repeated for several brush shifts, will show the features of the motor in all possible operating conditions.

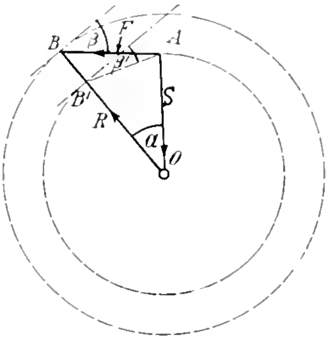

Fig. 17. Influence of the Strength of the Rotor Ampere Turns on the Angle $\beta$

It will be found that a motor designed in this way has not a very good power-factor for normal load and speed. We have seen above that to improve the power-factor the angle $\beta$ must be increased. This can easily be effected in the following way.

We see from Fig. 15 that the strength of the field winding is proportional to the angle of brush shift, at least for smaller angles, where the sine is approximately proportional to the angle itself. To increase $\beta$, the phase of the field winding $AB$ must be shifted without changing the brush shift or angle $\alpha$. This can be effected by increasing the rotor ampere turns with unchanged stator ampere turns, as shown in Fig. 17.

For the lower speeds the power-factor must drop, because we would need too large a wattless field to balance the reactance drop at the low speed. The necessary increase of the rotor ampere turns would be incomparatively large, and the size and cost of the motor would grow too much and the efficiency would drop. For smaller brush shifts or angles $\alpha$, which give the higher torques at higher speeds, the above method is very effective and only a small increase of the rotor ampere turns is necessary to obtain a high power-factor over a rather large speed range without affecting the size and cost of the motor.

The brush shifting series motor is only an example, to show how the diagram developed above may be applied to practical motors. Other polyphase series motors may be dealt with in the same way. The separation of the compensating winding and the field winding simplifies the electrical conditions in imagination and calculation, because all transformation voltages disappear. The remaining rotation voltage and impedance drop bring the a-c. motor near the d-c. motor in character, the principles of the latter having long been well known.

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# SOME NOTABLE ELECTRICAL DEVELOPMENTS OF 1913

By John Liston

Publication Bureau, General Electric Company

The electrical manufacturing industry is one of extreme mutability and in no other line has there been required such continuous variation in design and construction methods. This is clearly shown in the following article, although a majority of the installations referred to do not indicate fundamental changes, but rather a logical and progressive development of apparatus already in successful operation.—Editor.

Owing to the vast extent of the developments which have characterized the electrical industry during the past year, it is difficult to select for special reference apparatus or installations which will serve as typical instances of recent advancement in the electrical art.

The following review will, therefore, be limited to brief reference to certain examples of 1913 apparatus and installations which are notable either for size or unique design, and indicate the achievements and tendencies of electrical manufacture for the year.

### Water Power Development

Pre-eminent among the notable hydroelectrical installations of the year is the huge power station at Keokuk, Iowa, which is the largest plant of its kind in the world, both on account of the extent of the engineering work involved during its construction and the volume of electrical energy which it is designed ultimately to develop. Its construction work included the building of a dam, power house, lock, dry-dock and ice fender, which combined constitute a concrete monolith with a total linear measurement of about 2½ miles. The power house itself is over 1700 ft. in length, and will, when completed, have 30 vertical shaft turbo-generators, the driving wheels of which under the normal head of about 32 ft. will develop an aggregate of 300,000 horse-power. A full description of this development is given in an article by Mr. E. A. Lof, beginning on page 85.

A water power plant which indicates the trend of electrical development for the year 1913 in a more striking manner than that of the equipment at Keokuk, is found in the hydro-electric development of the Pacific Light and Power Corporation of Los Angeles, Cal., on the Big Creek River, at a distance of about 200 miles northeast from Los Angeles. The two power stations are practically identical in their system of operation and the amount of their output, and a brief outline of the equipment of No. 1 station will serve to indicate the advance in the construction of electrical apparatus which this development involves.

The main equipment represents an increase in the size of units over all previous hydro-electric installations. The waterwheels are the largest impulse type turbines ever constructed, and they drive generators which have in turn a greater output than any hydraulically operated generators yet placed in service. At a speed of 375 r.p.m. these generators deliver an output of 17,500 kv-a. at 6600 volts, 50 cycles. The transformers, which are rated at 4500 kv-a. and operate at 150,000 volts, are also the largest units that have so far been produced for this voltage.

This development is essentially a high head plant, the water drop between the intake and the waterwheels being 2146 ft. The water is projected against the waterwheel buckets in a stream of 5½ in. diameter, at a velocity of about 300 ft. per second.

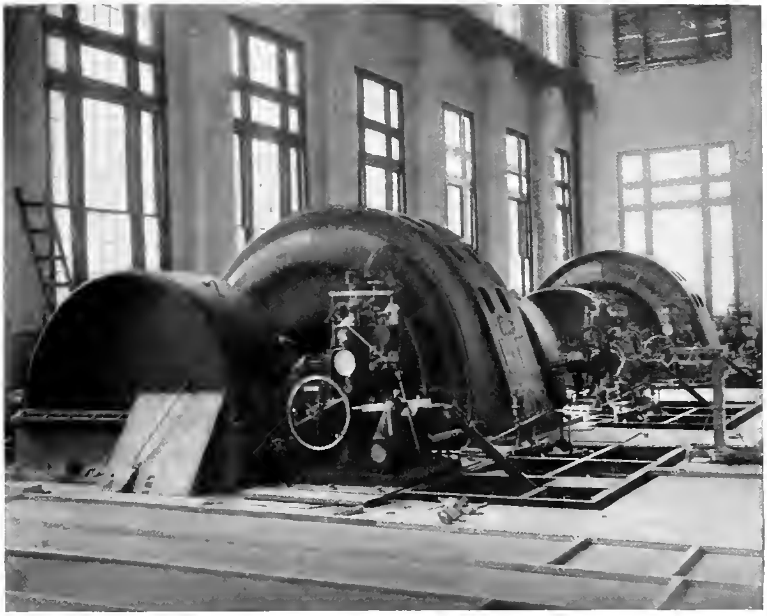

Fig. 1. 17,500 Kv-a. Generator Sets, Pacific Light and Power Corporation

This installation is also notable for the length of the transmission line, which consists of two sets of conductors carried on separate steel towers, the two lines running parallel (spaced 80 ft. apart) for 241 miles. The lines terminate at the Eagle Rock substation near Los Angeles, where the current is again transformed and utilized for lighting and railway service.

This power station has still another feature of unusual interest, necessitated by the high potential and extreme length of the transmission circuits. In order to compensate for line fluctuations and to insure proper regulation at the distribution point, the substation has been equipped with two 15,000 kv-a. synchronous condensers, which are the largest machines of this type ever used.

### Transformers

Since transformers were first manufactured for commercial service, each succeeding year has seen an increase in the physical size and electrical capacity of power transformers. This increase, which has been most notable during the past decade, was the result of, and coincident with, the development of enormous water power plants and central stations. With the consequent increase in voltage, necessitated by continual efforts to secure economical current transmission over great distances, there arose the imperative demand for transformer improvement. Of all the problems presented in transmission, that of the transformer is the most complex, and yet that problem has been successfully solved by the manufacturers in ample time to keep well ahead of the ever advancing demand. The year 1913 has witnessed the successful installation of numerous transformers which represent a distinct advance over previous practice. During that period the unit capacity has reached 15,000 kv-a. and the maximum potential 150,000 volts.

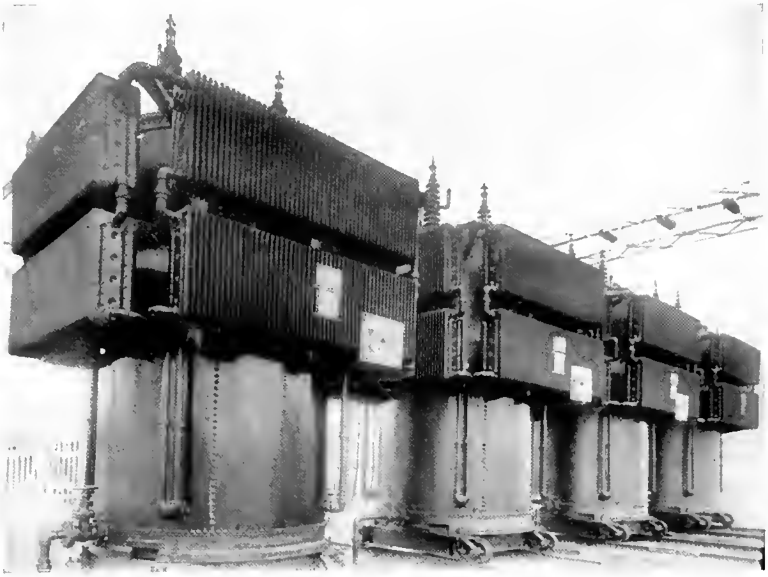

Fig. 2. High-Voltage, Self-Cooling Transformers, Out-of-Doors Type

One of the most radical designs consists of a relatively large self-cooled oil-insulated transformer, a number of units of this type, in capacities up to 3000 kv-a., having been constructed for use on a 100,000 volt transmission line. These units are entirely self-contained and are equipped with external pressed steel radiators, which are designed for automatic circulation and cooling of the oil; the internal arrangements being practically the same as those of the water-cooled type. By this means the benefits of the small self-cooled type have been incorporated with practically all the advantages heretofore available only in the large water-cooled type. A number of these transformers equipped with pressed steel radiators are at present being built for the Isthmian Canal Commission for use on the Panama Canal power system.

The use of transformers for out-of-door service has been given a strong impetus during the past year by the performance of various units of this type, which have withstood all sorts of climatic conditions. Several units of 3000 kv-a. for 140,000 volt lines, as well as others of 7500 kv-a. for 120,000 volt lines, have been installed. Experience has demonstrated that neither size nor voltage, nor climate is a bar to the successful operation of properly designed transformers out-of-doors.

### Electric Mine Hoists

One of the most important developments of the year in the application of electricity to mining service consists of the electrically driven automatic hoist recently designed for the Inspiration Consolidated Copper Mining Company of Miami, Ariz. This

Fig. 3. 4500 Kw., 150,000 Volt Transformer

electrical equipment is designed for the relatively low hoisting speed of 750 ft. per minute, and for automatic operation, although an emergency equipment for hand operation is also provided. The hoisting will be done at the rate of 1000 tons per hour from each of two shafts having a depth of 630 feet. The two balanced hoists are each independently driven by a 750 h.p., 575 volt direct current motor, to which current is supplied from a flywheel motor-generator set consisting of two 500 kw. generators driven by a 750 h.p. induction motor. The arrangement of this hoisting set represents a distinct advance in mining service, due to the immense tonnage which can be brought to the surface by the set, and the saving effected in the operation of large skips, which are automatically filled at the bottom of the shaft from storage bins and automatically dumped at the surface. This set is the largest automatic hoisting outfit in the United States, and the attendance actually required is limited to the starting and stopping of the motors at the beginning and ending of the operating periods, which will average about 14 hours per day, and an occasional inspection and renewal of the lubricant.

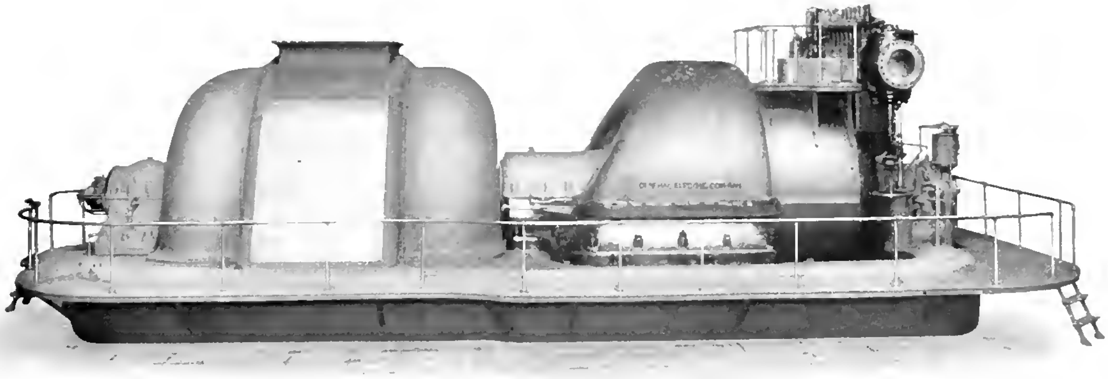

Fig. 4. 12,500 Kw. Horizontal Curtis Steam Turbine

These hoisting equipments are, however, dwarfed by the mammoth duplicate hoisting sets recently shipped to the gold mines of the Rand in South Africa, one for the Crown Mines, Ltd., and the other for the Modderfontein Gold Mining Co., Ltd. These are the largest mining hoists in the world, each set consisting of two 2000 h.p. motors installed one at each end of the hoist and direct connected to the hoist shaft. Each motor is over 16 ft. in diameter, and operates at 53½ r.p.m. Current is supplied to each set at 1000 volts, and the motors are connected in series. Current for their operation is received from the Victoria Falls and Transvaal Power Company's lines at 2000 volts, and is transmitted to the hoist motors through a motor-generator set consisting of two 1650 kw. generators driven by a 5000 h.p. motor. No flywheel is used.

An idea of the service conditions under which these motors operate may be gained from the fact that they hoist 8 tons per trip from a maximum depth of 3540 ft., at a speed of 3500 ft. per minute, which is equivalent to about 40 miles per hour; and during the hoisting cycle the load varies as much as 12,500 h.p. in a period of 30 seconds, the maximum positive load reaching 9000 h.p.

In view of their unusual size (the total weight aggregating 90 tons), it was necessary to ship these equipments in sections, and to reassemble them at the mines.

### Curtis Turbines

During the past year the development of the Curtis steam turbine has not been marked by any change of type or any radical departure from previous practice. Considerable advance has been made in the efficiencies obtained in the improvement of details, and in the size of units constructed and contracted for.

In general, the tendency has been in the direction of higher rotative speeds, and improvements in nozzles and buckets, both in arrangement and material. The earliest Curtis turbines generally consisted of a small number of stages, each containing several rows of moving and stationary buckets; subsequently, the number of stages was increased and the number of rotating rows of buckets in each decreased. This tendency has continued.

The design of the buckets and nozzles has not changed except in regard to detail. Various metals are employed, depending on the stresses and other requirements in each case. Curtis turbines that have been completed during the year and accurately tested show an efficiency superior to anything heretofore produced.

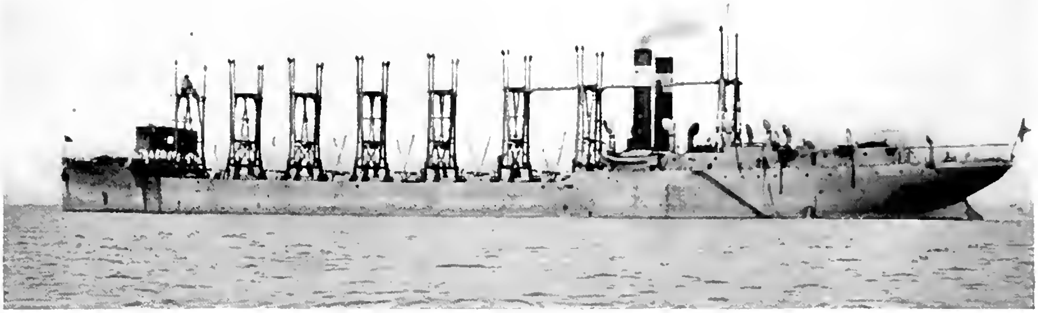

Fig. 5. U. S. S. Jupiter

A number of large horizontal units, ranging from 10,000 kw. to 20,000 kw. in capacity, have been completed and shipped, while other machines of 30,000 kw. and 35,000 kw. output are at present under construction. These latter are the largest turbine sets ever contracted for by any manufacturer, and consist of single self-contained units, the steam end and generator in each case being direct-connected and mounted on a common bed plate.

### Electric Ship Propulsion

The advantages of the electric propulsion of ships is exemplified in the equipment of the United States collier *Jupiter*, the power plant of which includes a Curtis steam turbo-generator, and two induction motors for driving the twin screws. The *Jupiter* has a displacement of 20,000 tons and is the first large vessel to be so equipped.

In comparison with her sister ship *Cyclops*, which is provided with reciprocating engines, the *Jupiter* showed a notable improvement in steam economy. By operating the turbine at about 2000 r.p.m., and the driving motors at 110 r.p.m., economical and efficient speeds were obtained for both prime movers and propellers. For a speed of 14.8 knots a turbine output of 6800 h.p. was required.

The adoption of electric drive has not only simplified the maneuvering and speed control of the ship, but has also materially reduced the weight of the power plant hitherto required for the development of corresponding energy by means of marine engines.

### Generators

During the year 1913 there has been developed a complete line of engine-driven generators with commutating poles for lighting and power service, this type of generator being the last to receive the benefits of the commutating pole feature. There has also been developed a new and original design of

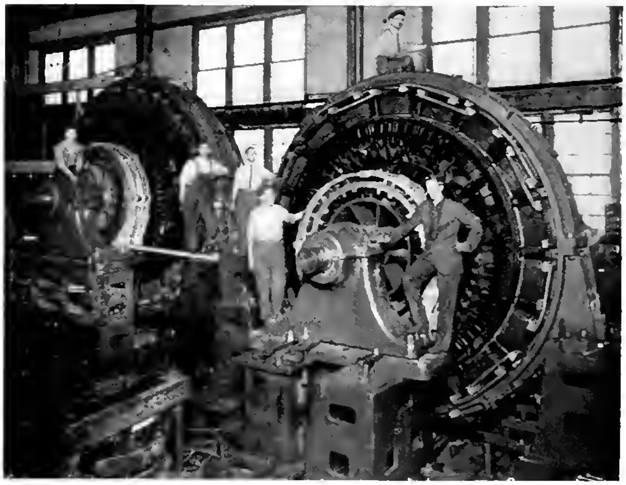

Fig. 6. Two 4000 Kw., 600 Volt Synchronous Converters for Commonwealth Edison Company in Test

revolving compensator for producing the neutral for three-wire service. This compensator is self-contained with the armature, and requires the use of but one collector ring for obtaining the neutral. It will supersede the oil type of separate oil-cooled compensator.

During the past year work was started on eleven 5200 kw. direct current generators for the Southern Aluminum Company, to be used for the refinement of aluminum. These machines are 26-pole, 170 r.p.m., 520 volt units, designed for waterwheel drive and capable of withstanding 75 per cent over speed. They are probably the largest d-c. machines that have been constructed.

### Motor-Generators

For supplying current to the 1200 and 2400 volt railway installations, special motor-generator sets have been required, and it is probable that in the near future higher voltages will be used for this apparatus which will involve the development of direct current generators for potentials up to 5000 volts.

### Synchronous Converters

In the design of synchronous converters, the year 1913 witnessed a steady reduction in the amount of space required for a given capacity in this type of machine; and for lighting service there have recently been constructed units having an output of 3000 kw. which occupy the same space as former units rated at 2000 kw. For railway work 4000 kw. converters have recently been successfully mounted on foundations originally provided for 2000 kw. units. These improvements have been rendered possible by the utilization of commutating poles, combined with an increase in speed; and in the case of the machines for lighting service, in a special arrangement for cooling the commutators, consisting of projections on the ends of the commutator bars which provide additional surface for heat radiation and augment the cooling effect by increased air circulation. The 4000 kw., 600 volt commutating pole rotary converters built in 1913 for the Commonwealth Edison Company of Chicago are of greater capacity than any previously built. For electrolytic work there was constructed a 2500 kw., 500 volt, 50 cycle machine, which is the largest of its type.

The reliability of the modern rotary converter, even when operating under extremely adverse conditions, is indicated by the success with which a 1500 kw., 60 cycle, 600 volt unit, installed at the end of a long 110,000 volt transmission line passing over mountain ranges at a high altitude and subjected to frequent and severe disturbances from lightning, has operated during the past year. Notwithstanding these operating conditions, this machine was run successfully for a large part of the year without a single breakdown.

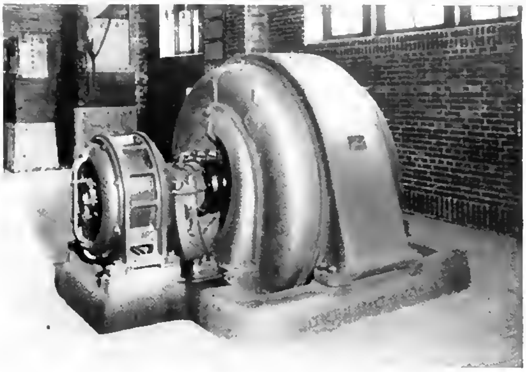

Fig. 7. 1000 Kv-a. Synchronous Condenser with 35 H.P. Starting Motor, United Electric Light and Power Company, 187th Street Substation

### Synchronous Condensers

Interesting as an example of special construction is a totally enclosed 1000 kv-a. synchronous condenser set which was designed to secure noiseless operation. The set is installed in a small substation located between two apartment houses in New York City, where any appreciable noise would be objectionable; but by the use of solid end shields and forced ventilation from below the floor line, the set has been entirely successful in meeting the requirements of noiseless operation.

### High Voltage D-C. Railway Electrification

The most conspicuous advance in railway engineering during 1913 has undoubtedly been the rapid development of the high voltage direct current system. Four steam railroads have now adopted 2400 volt direct current in the United States and Canada, one of which is already in operation; namely, the Butte, Anaconda & Pacific Railway. The others are the Michigan United Traction Company, which is contemplating the operation of 92 miles of 2400 volt interurban railway, part of which is now operated by steam. This road will see the first installation of 2400 volts collected from third rail, and also the first use of 2400 volts on multiple unit motor cars. The third road is the Canadian Northern Railway, which has ordered seven 2400 volt locomotives for hauling transcontinental trains into the Montreal terminal. The present electrification includes about nine route miles from the Montreal terminal through the tunnel under Mt. Royal to outlying suburbs. Eight multiple unit motor cars for interurban traffic are also to be equipped for this road. The fourth 2400 volt road is the Canadian Pacific Railway, which is preparing to electrify about 22 miles of mountain grade section between Castlegar and Rossman in western Canada.

Fig. 8. 2400 Volt Locomotive Hauling Ore Train, Butte, Anaconda and Pacific R. R.

All of these electrifications will employ high tension a-c. for distribution to substations, where the energy will be converted to 2400 volts d-c. by two 1200 volt generators connected in series.

Among the railways which have recently adopted high voltage direct current service are the Victorian Railways, Melbourne, Australia, and South Manchurian Railways, Manchuria, China. The Victorian Railways include about 325 miles of track, over which the traffic is now handled by steam trains. The potential to be employed on the trolley in this installation is 1500 volts d-c. The electrical equipment will require 400 motor cars. This electrification is by far the most extensive steam road conversion ever attempted.

It should be noted that the trend towards high voltage direct current railways is not considered to be a new system, but the natural development of the standard 600 volt system which has given satisfaction in practically every city in the country. The requirements for long interurban railways, however, require a higher trolley voltage, and for these systems 1200 and 1500 volts are commonly used. The heavy freight and passenger roads now operated by steam require a still higher voltage on account of the great distances and the heavy power requirements.

The 1200 volt system was adopted by a large majority of the newly built interurban systems in 1913, and by many other roads formerly operated on single-phase or 600 volt direct current. At the close of the year there were thirty railways in the United States and Canada which had standardized on high voltage direct current operation, the additions during 1913 totaling fourteen railways with an aggregate trackage of about 2000 miles.

One of the notable accomplishments of the year is the supplying of 16 new high speed

Fig. 9. Looking West from Flinders Street, Melbourne. Victorian Government Railways

passenger locomotives to the New York Central & Hudson River Railroad. These locomotives anticipate the extension of the system to Albany.

### Storage Battery Locomotive

For some time past the storage battery type of locomotive has been used for internal transportation in commercial and manufacturing plants, and a considerable number were used with notable success in the tunnel construction work of the Catskill aqueduct. But it was not until 1913 that the advantages of this type of locomotive were fully recognized for mine haulage. The first equipment so used consisted of a 4-ton haulage locomotive which was placed in service in the Glendower Colliery of the Philadelphia & Reading Coal & Iron Company of Pottsville, Pa. Its success in coal mine haulage resulted in other installations for similar work, and the size of the locomotives was increased until at the end of the year ten ton units were being manufactured.

### Locomotives

In the trolley type of locomotive there has been no notable increase in size during the past year, and the improvements which have been made are along the lines of perfection of details. The most important features in recent types are the use of commutating poles on all sizes of driving motors and the use of ball bearings for the motor shafts.

The most striking development in locomotives of this general type is found in the 40-ton units which are being constructed for hauling ships through the locks of the Panama Canal. These are solid body 4-wheel units, arranged for control from either end, and are driven by alternating current, three-phase, 220 volt, 25 cycle motors. The hauling speed is two miles per hour, the returning speed five miles per hour, and the draw-bar pull 34,000 pounds. For the hauling operation the locomotives are provided with pinions which run in mesh with a rack located in the center of the haulage track. Four locomotives will be utilized for handling a ship, but only two of these do the actual hauling. These two are located on the lock walls, one on each side of the fore part of the ship, while the remaining two locomotives are similarly placed at some distance to the rear, where they serve to steady the ship during its progress through the lock.

Fig. 11. New York Central Locomotive, 600 Volts, Hauling 12-Car Train

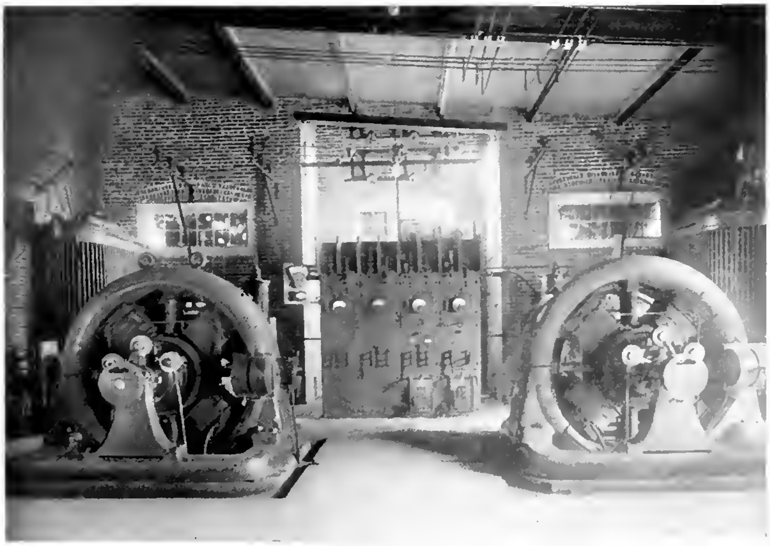

Fig. 10. Pittsburgh and Butler Street Railway, 1200 Volt Substation at Mars. Two 300 Kv-a. 1200 Volt Synchronous Converters, Transformers and Switchboards

The towing cables are wound on a friction drum mounted on the locomotives and independently motor-operated. These drums are so adjusted that sudden excessive strains, which might serve to break or injure the cable, are avoided by an automatic compensation of the drum friction.

Fig. 12. 835 Kv-a. 2300 Volt Sine Wave Generator, and 450 H.P., 440 Volt Motor. United Electric Light and Power Company, New York City

### Motors

For the operation of the Panama locks and concomitant machinery, about 1500 motors are required, and a large percentage of these were completed during the year. They are not notable for size, but the climatic conditions imposed insulation guarantees which involved radical departures from standard detail construction.

### Testing Set

Another relatively small machine may be cited as an instance of special work for the year. It consists of a motor-generator testing set for the United Electric Light & Power Company of New York City, in which a 450 h.p., 440 volt, 750 r.p.m. induction motor drives an 835 kv-a., 2200 volt sine wave generator.

### Switchboards

The development of switchboard apparatus kept pace with the demands imposed by the increasing transmission potentials and capacities which characterized the hydro-electric developments of the year. In the manufacture of switching apparatus the principal improvements consist of changes in design and construction details, which will render the switching equipment more accessible for inspection and repair. This matter is one which has become of considerable importance, due to the increasing size of the switching units.

The 100 amp., 130,000 volt solenoid-operated, triple-pole, single-throw oil switches supplied for outdoor service on the transmission system of the Utah Light & Power Company may be cited as an indication of this tendency. They are among the largest switching units developed during the year, and, except for the heavy casings which are required to insure safety for the moving elements in outdoor service, they are similar in construction and operation to the 150,000 volt units which were provided during the year for indoor use.

Conspicuous among the switchboard installations for the past year are the control boards for the Panama Canal Locks which have operating and indicating features which are unique in switchboard construction. There are three of these boards, all of which have been completed and which will be installed respectively at the locks at Gatun, Miraflores, and Pedro Miguel. These boards are arranged practically as miniatures of the locks themselves, and the various indicating devices are designed to operate in synchronism with the main machinery so that every change in the water level, the movements of the valves, lock gates, guard chains, etc., are simultaneously shown on the control board. The switches on these boards are so interlocked that an improper sequence of operations is impossible.

### Arc Lamps

No fundamental changes in arc lamps were made during 1913, but there was a steady increase in efficiencies obtained and improvements in mechanical detail. In the case of the flame arc lamp there were numerous new installations, the most important being the addition of 6000 lamps to the street lighting system of Chicago, which now has 10,000 flame arc lamps in service. This is the largest single flame arc lamp installation.

Early in the year there was completed at Cincinnati, Ohio, an equipment which indicates the extent to which combined unit series arc rectifiers are being used for supplying arc lighting circuits. There are 118 75-

light, 4-ampere double-tube sets in this installation, serving 6800 luminous arc lamps.

The ornamental luminous arc lamp, which first came into prominence in 1912, became increasingly popular during the past year, and among the numerous cities which utilized them for street illumination are: Boston and Cambridge, Mass., Buffalo and Schenectady, N. Y., Dubuque, Iowa; Toledo, Ohio; Chattanooga, Tenn.; Washington, D. C. and a number of cities in Canada. The largest installation is found in Providence, R. I., where 1500 lamps of this type are used.

**Incandescent Lamps**

Perhaps the most radical improvement in electric lighting during the year 1913 is represented by that type of mazda incandescent lamp, in which the filament is surrounded by a gas instead of a vacuum. In this lamp the previous effective candle-power possible with a given energy consumption has been more than doubled. Lamps of this type which have so far been developed commercially are largely high candle-power units. It cannot be doubted that the general introduction of this lamp will have a far-reaching influence on the problem of effective and economical lighting of streets and large areas, for which its evident advantages render it especially available.

Fig. 13. Solenoid-Operated Triple-Pole, Single-Throw, 130,000 Volt, 100 Amp. Oil Switch

Fig. 14. Train Load of Switchboard Material for Tata Hydro-Electric Power Company, Bombay, India

# CHURCH LIGHTING

By A. L. Powell

Edison Lamp Works, Harrison, N. J.

The matter that is the subject of this article is one which is only just beginning to receive the attention it deserves and, of course, there has been but very little material published upon this type of illumination. As the author points out, the lack of activity in improving church lighting is due, without doubt, to the fact that of the total hours comprising the week but a very few of them are spent at church and still fewer there during the evening when artificial illumination is necessary. This condition has been used to a great extent as an excuse to condone the lack of progressiveness along these lines. Poorly lighted architecture and strained vision demand an improvement. The following article gives directions as to how these changes should be made in churches varying from the Gothic to the modern type, furnishes the reasons governing the selection of the units and their location, and presents photographs showing the resulting lighting effects.—Editor.

From a lighting standpoint, our churches and our homes are very closely related, for in this class of illumination the artistic element is far above the consideration of efficiency. When the term *artistic* is used in its broadest sense, eye protection is assured, for nothing can be artistic that is not thoroughly comfortable. This leads to another thought, which involves a very broad statement. If our homes were as poorly lighted as many of our churches, it would soon have a serious effect on our vision; but as we are in the church for only two or three hours each week, the matter is not given sufficient thought.

In a great number of churches very little attention has been paid to the proper protection of the eye; the fixtures used are very rarely in architectural unity with the building and the efficiency of light utilization is entirely neglected. For these reasons, and the fact that there is so much work to be done, church lighting is one of the most interesting problems now confronting the illuminating engineer. He must, however, cooperate with the architect and bear out the latter's ideas with respect to location of units, type of fixture, and relative distribution of light in the various portions of the structure.

### Necessity for Good Illumination

It is true that the Gothic churches of the middle ages had a very low intensity of illumination, but in those days little light was needed, for most of the worshippers were unable to read or else knew the services by heart. These masterpieces of architecture were, however, well lighted to bring out the beauties of the building. By day, light filtered through immense stained glass windows and the beams of colored light, in vivid contrast to the dark woodwork, presented an impressive picture. Very little light was effective in the upper part of the room and the lofty vaulted ceilings seemed still higher. At night, although the light sources—candles or oil lamps—were not far from the floor, and hence often in the line of vision, the brilliancy was so low as to make them relatively unobjectionable. The flickering shadows cast by these units increased the majesty and solemnity of the structure.

Now, however, practically everyone reads, and a light suitable for reading is required. In the church, in contrast to the theater or assembly hall, the lights are turned on the entire time that the congregation is present, and particular attention must be paid to the arrangement of lighting units, concealing the lamps from view or equipping them with diffusing glassware. Frequently it is quite difficult to conceal the light sources on account of the construction of the church, but in any event glare must be avoided.

The light must come from an angle such that the eyebrows shade the eye, else headache and drowsiness will result. It is often wondered why the men are affected with drowsiness so much more than are the ladies at church services. This can be easily explained by remembering that the ladies usually wear their hats in church, the projecting brims of which furnish an eye-shade.

We must make the churches comfortable to everyone, and if care is taken in selecting and locating the lighting fixtures these edifices can be very satisfactorily lighted, for they seldom have brilliant interior finishes to cause glaring reflections, while the ceilings are usually high, thus permitting hanging the lamps above the angle of vision.

### Requirements for a Church Illuminant

The light, first of all, must be easy to maintain, for as a rule the sexton, who has charge of the entire building, is not of a mechanical turn of mind; second, it must not be too large, i.e., too high candle-power, for frequently architectural considerations demand a number of small units; third, its color quality must approach that of daylight, for millinery and gowns of many colors will be lighted; and lastly, it must be easy to control, as quite often it is desired to use the church in the absence of the caretaker.

These facts seem to indicate that the incandescent lamp is the logical illuminant, for it fulfills the demands outlined, and as the mazda lamp is the most efficient of the incandescent sources, the following discussion will be based on the use of this unit.

### Methods to Avoid in Designing a Church Layout

Most chandeliers are bad for two reasons—(a) they have no architectural significance, and (b) they are usually loaded with clusters of bare lamps, sending the light directly into the eyes.

Studded lights around the capitals of the pillars, along the beams and on the corbels are also objectionable, for it is almost impossible to avoid annoying images. While this system sometimes brings out the architectural beauties of the building, one very strong objection is that a lamp will burn out now and then, and, as there are so many sources, the decrease in illumination due to the few outages will not be noticed, and the lamps will not be replaced until a considerable number are out. Each burned out or black lamp will make a break in the continuity and spoil the effect sought. The use of this system will occasionally produce freak effects; for instance, a row of small lamps around the capital of a pillar may give the appearance of an open space and leave the roof and its arches without visible means of support. The efficiency of this system is low and renewal cost high. Decorative lighting around the pulpit and organ is particularly serious, for anyone giving attention to the speaker must look at these bright spots.

### Classes of Churches

Churches may be divided into two main groups: ritualistic and evangelical. In general this applies to both the architecture and the lighting arrangements.

The ritualistic church is usually Gothic in construction, while the evangelical, though a great number are Gothic, modified or pure, has a tendency toward the Renaissance or some more recent period.

In the first class, the amount of reading required is relatively little, as a large percentage of the congregation is familiar with the responses, prayers, etc., while in the latter the form of worship is more varied, and text which is not so familiar is used. It is a well known psychological fact that the most brightly lighted portion of any area attracts the attention, and as the service in the ritualistic church is centered about the altar, this must be put in prominence by a relatively high illumination. In the other group, the minister or speaker symbolically demands the highest intensity of light.

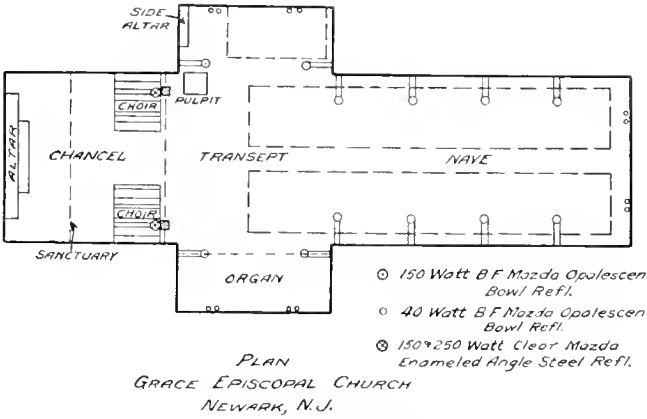

Fig. 1. Floor Plan of a Lighting Layout for a Church Built on Gothic Lines

### Ritualistic Churches

The characteristic arrangement of a Gothic church without side aisles is shown in Fig. 1. The nave contains the pews, while the transept at one side has the organ (in the church under discussion, mounted on a balcony) and at the other side a small altar which is used as a chapel for even-song and the like. The chancel is divided into the choir and the sanctuary.

The nave and transept can usually be lighted by direct overhead units, either concealed from the eyes of the congregation, or on lines conforming with the architecture. The ritualistic churches of the Basilica type present a slightly different problem for illumination, and can be treated by the methods described under evangelical churches.

On account of the elaborate ritual held in the sanctuary, this must be the most brightly lighted portion of the church, and yet no lights should be visible, for the congregation faces in that direction. In the Gothic structure, there is usually an excellent opportunity for locating the units behind the chancel arch. Angle steel or mirrored glass individual, or glass trough reflectors and clear lamps are applicable. The various distributions afforded by the large holophane D'Olier asymmetrical reflectors, simplify the problem remarkably.

The sanctuary should have plenty of light to bring out its decorative value, and yet the altar should not be uniformly bright, for shadow effects are then lost and the elaborately carved portions appear flat and dull, with consequent absence of detail. It is usually better to light the altar from the sides, simulating the daylight values, rather than from the top. Light coming from both sides can be made to avoid deep shadows, without entirely annuling them.

Fig. 2. Night Photograph Showing Lighting Effect in the Church Whose Plan is Given in Fig. 1

The lamps should be so arranged that the choir stalls are well illuminated, and it is often desirable to have the units on several switches, so that various intensities of light can be secured to meet the demands of the different portions of the services.

In a number of churches, the candles have been replaced with imitation candlesticks and all frosted candelabra lamps. In most services, however, the candle has a symbolistic value and it is sometimes a question whether the substitution is in good taste.

Having roughly outlined the principles to be observed in lighting this class of church, an example of their application is of interest. Fig. 2 is a night photograph of the interior of Grace Church (Episcopal), Newark, N. J. The floor plan is shown in Fig. 1.

The building is of the early English period of the Gothic, and being without the side aisles the hammer-beams offer a logical place from which to suspend lighting fixtures. Bowl frosted mazda lamps are used with "Alba" bowl reflectors, hung sixteen feet from the floor by a simple brush brass chain suspension.

The appearance by day is very pleasing, and when lighted the diffusion is excellent and the distribution satisfactory. The lines of the unit are quite severe, bearing out the Gothic idea, and the placement of the lights does not violate the architectural continuity.

An illumination test gave the following results: Average intensity in nave, approximately 1.3 foot-candles with a power consumption of 0.4 watt per square foot. It is true that the illuminating efficiency is not so very high, but it must be remembered that a large part of the light flux is transmitted by the reflector and serves to illuminate, to a low intensity, the rather darkly decorated ceiling which has low reflective power. This slight illumination of the ceiling is an essential point, for no matter how brightly the reading or working plane is illuminated, if the ceiling is dark the room presents a gloomy appearance.

The unit used here would also be applicable in a Gothic structure with side aisles, the lamps being hung from the apex of the arches between the supporting pillars. A proportionally larger lamp should be used on account of the greater area per outlet to be illuminated.

A white leaded glass shade of the "Monolux" type with trefoil decoration could have been used in place of the pressed opalescent bowl with equally good results.

Still another method might have been employed in this particular building, namely, focusing prismatic reflectors and clear mazda lamps on short brackets on the sides of the hammer-beams toward the altar. The illuminating efficiency would have been greater and the lights concealed from the congregation; but the ceiling would have been rather dull and no decorative value added.

A glance at the illustration will show that the sanctuary is the most brightly lighted portion of the church. Behind the chancel arch and on each side at the points "X" are two D'Olier enameled steel angle reflectors, hung pendant; the lower lamps being 150 watt and the upper 250 watt clear mazdas. The choir stalls are well lighted (average intensity 3.0 foot-candles), and the vertical illumination on the rear wall, about three feet to the left of the altar, varied as follows:

3 feet above the floor, 1.1 foot-candles
6 feet above the floor, 1.2 foot-candles
9 feet above the floor, 1.25 foot-candles
12 feet above the floor, 1.3 foot-candles

The horizontal illumination at the base of the altar was 1.2 foot-candles.

### Evangelical Churches

Since the ceilings of many of these buildings are light in color and not as steep as those which have just been discussed, there is much more latitude in the choice of lighting equipment. In the pure Gothic church, indirect systems of illumination are quite out of the question, but in the modified Gothic structure with a smooth ceiling, light in color, or in the Basilica, the scheme is often quite feasible. Again, the non-ritualistic church is often in the form of a large hall, and to light these the problem is quite simple, as the location of units is not fixed by the architecture.

Gorgeous lighting is particularly out of place, for any attempt at pageantry is to be deplored. While the light units should be in architectural conformity, utility of the lighting should be given consideration. By this is meant: 1st. Use every precaution to prevent eye strain, which leads to drowsiness and attendant discomfort. We do not go to church to be annoyed and yet the writer's experience has been that in most churches unprotected lamps are continually in the line of vision, distracting attention and irritating the congregation.

2nd. Ocular comfort having been secured, enough light should be provided in all parts of the room for easy reading. Experience has shown that if there is no annoying glare or bad contrast, an intensity of from 0.75 to 1.5 foot-candles is sufficient for reading at short intervals, as for instance during the singing of a hymn or psalter responses.

Fig. 3 shows a night view of a church which infringes all the rules laid down for good church lighting, and, yet, while this is an extreme case, the installation is characteristic of many others. The first criticism is that there seems to be absolutely no place in partial shadow on which the eye can momentarily rest; a uniform brightness prevails and gives one the impression of entering into a flood of light. This is aggravated by the fact that there is really a greater wattage used than is necessary, namely, 1.1 watts per square foot, with no diffusing enclosing globes. Second, medium size (60 watt, large bulb) clear lamps are used with a very flat milk glass shade, which does not protect the eye in the least. These are used at the groins and bases of the main arches, one at each cross beam, making it almost impossible to avoid being in the line of vision. Third, so-called decorative brackets are used at each side of the pulpit and choir loft, which, although equipped with diffusing shades, are in a direct line with the speaker and anyone sitting slightly to the side of the room. Fourth, a rather hideous chandelier of brass and mirrored glass is suspended from the crossing. This is a relic of the days of kerosene lamps and was converted to electricity when the church was wired. As there are usually a few of its lamps burned out, it detracts from rather than adds to the general appearance of the building.

Contrast this picture with a few of the installations which are in accord with the requirements mentioned above. These may suggest some new ideas which will aid in the advancement of the art of good illumination.

Fig. 4 is a night view of the interior of the Methodist Episcopal Church of North Adams. The building is of modified Gothic construction with light colored wall and ceiling. The mazda monolux semi-indirect fixture is used. This is of spectro-white glass, leaded together, and is of Gothic design. It is forty inches in diameter, with a brass

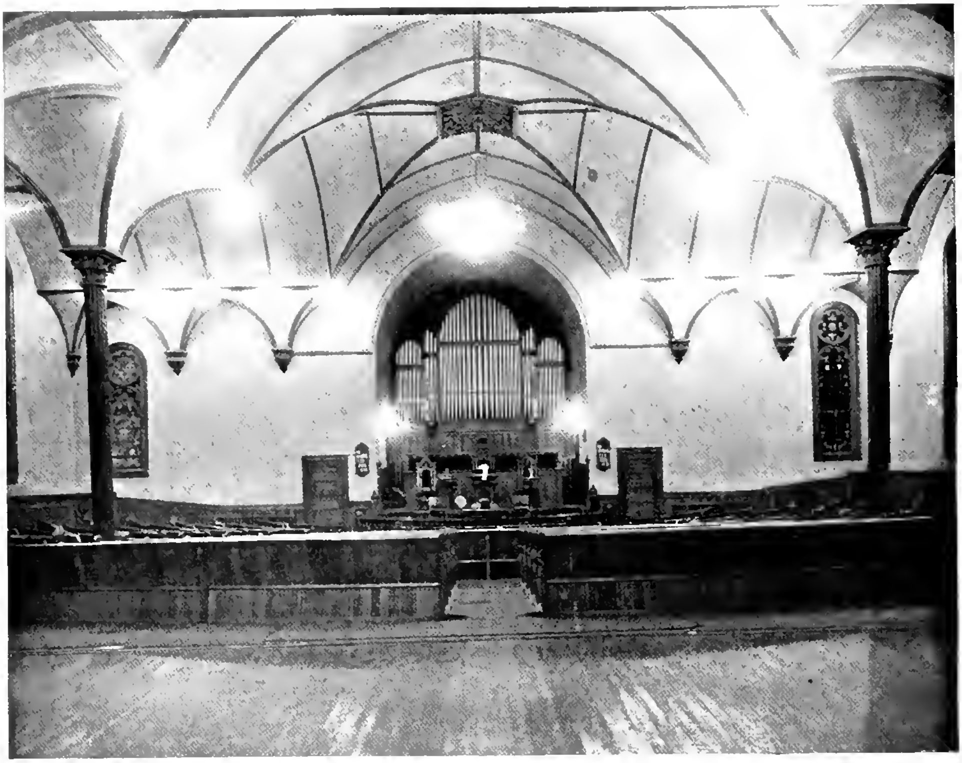

Fig. 3. An Example of Poor Lighting. The Lamps are in the Line of Vision and Produce a Uniform Brilliancy

Fig. 4. A Church of Modified Gothic Design Lighted by Semi-Indirect Units

Fig. 5. A Church Lighted by Totally Indirect Lighting Units

Fig. 6. An Example of Good Lighting in a Church of Colonial Design

chain suspension 15 feet in length which brings the lamps 28 feet above the floor. Five units are used with three 250 and three 150 watt clear mazda lamps in each. Considering the total floor area, the power consumption is 0.8 watt per square foot. An illumination test (corrected for voltage variation) showed the average intensity to be about 1.5 foot-candles with the units clean. The depreciation, due to the collection of dust in seven months' service without cleaning, was 14 per cent.

Fig 5 is an interior night view of the Delaware Avenue M. E. Church, Buffalo, New York. Totally indirect lighting units are used. Silvered one-piece glass reflectors and clear mazda lamps are used, and are concealed within large composition fixtures of Gothic type. The system is effective and the writer found the character of the lighting pleasant, with no discomfort such as is often experienced while at services.

The data on this particular installation is as follows: ceiling height to peak, 45 feet; at sides, 32 feet; auditorium, exclusive of balcony, 39 by 97 feet; three units with five 250 watt mazda each. Two balconies 15 by 97 feet each. Above these, six units with five 100 watt mazda each, and below ten units with one 150 watt mazda each. One watt per square foot, considering large units only. Designing engineer estimated an average intensity of illumination in the center of the church of three foot-candles.

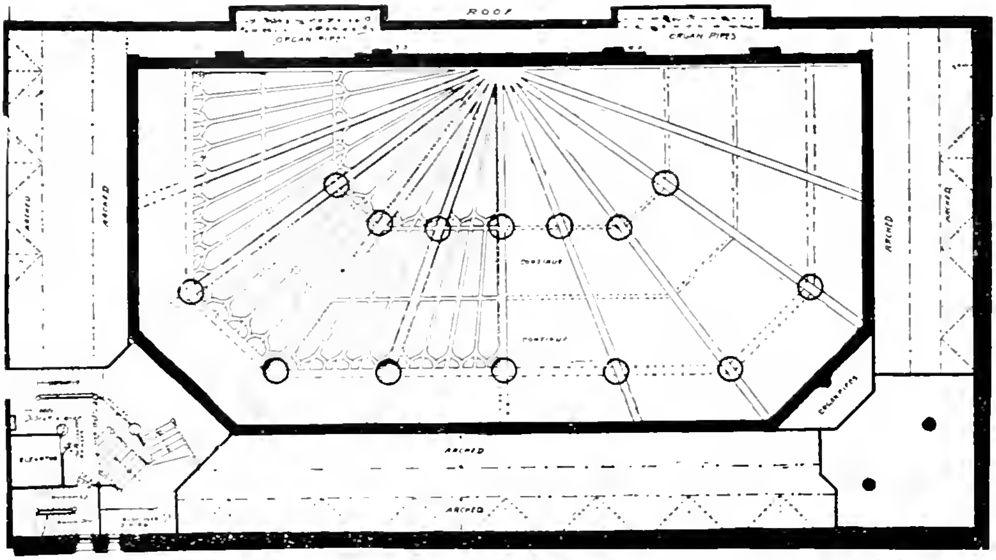

Fig. 7. Floor Plan of the Church Shown in Fig. 9. Location of Lighting Units Marked by Circles

The First Reformed Church, Port Richmond, S. I., N. Y., has recently installed a new lighting system. Fig. 6 shows a night view of the installation. The building is of the Colonial type of architecture, the church proper being a rectangular room with a flat ceiling and a relatively low balcony at the sides and rear. The ceiling decoration was such that there was a rosette at each of the four corners, at the approximate location of the outlets, for a symmetrical five-lamp arrangement. At the center was a ventilating hood, from which was suspended a chandelier. The ceiling is papered white with a bronze decoration. At each of the four rosettes and the center outlet was installed a 500 watt clear mazda lamp with a hemispherically shaped opalescent glass dish suspended by chains, the arrangement thus furnishing semi-indirect illumination. Watts per square foot = 0.9.

From the ceiling below the balcony were suspended bowl shaped opalescent glass reflectors and 60 watt bowl frosted mazda lamps, these being equally spaced. The church was formerly lighted with carbon lamps, and the installation of the combination of semi-indirect and direct lighting with mazda lamps showed a considerable saving of power, at the same time increasing the illumination remarkably and presenting a very attractive appearance as well as avoiding glare. The light is very evenly distributed and shadow is minimized. The old kerosene brackets were retained, although never used, for the congregation feels that these fixtures are in excellent conformity with the architecture, and also that they are of considerable historic interest, being a part of the original equipment.

A church in New York state, now under construction, is planning to install a rather novel, yet logical and efficient system of direct illumination. The auditorium ceiling is shaped somewhat like an open fan, as indicated roughly in Fig. 7, rising from the rear toward the front. From equally spaced points on this roof will be suspended 400 watt mazda lamps, with angle type fixtures, such as shown in Fig. 8. This is of leaded opalescent glass, and gives an asymmetrical distribution of light. Arranged as shown in Fig. 9, most of the light is directed toward the pulpit, and yet through the white diffusing glass there will be sufficient transmitted light for the portion of the balcony under the units, and the rear portion of the main floor. The lines of maximum light flux are such that there will be no glare effect, and the lamps will be well out of the angle of vision. The fixture will have a hinged stem to permit easy re-lamping, for sections of the glass ceiling above the church are to be made removable. To clean and renew lamps it will be a simple matter to reach through the opening with a hook, pull up the unit and turn it about the joint mentioned.

### Other Requirements

Having briefly discussed the general illumination of the auditorium, chancel, etc., it might be well to give a little attention to the other factors which often are to be considered. In many respects the demands of a church are similar to those of a theater, and it is advisable, if the cost is not prohibitive, to install dimmers both on the main and chancel circuits. During the sermon the dimming of the lights produces an effect which is very desirable.

Another similarity is the necessity for pocket outlets. In many churches entertainments are given, some of which require the use of a stereopticon. A pocket should be provided for this purpose with sufficient capacity for the lantern. At other times decorative lighting is called into play, as for instance at Christmas, when a tree might be illuminated by small lamps. A receptacle on the rostrum or stage is very convenient on such occasions. Many pastors use notes, and a floor plug with reading lamp answers the demand for a strong localized light.

### Windows

Most churches have at least one elaborate stained art glass memorial window. By day this is a thing of beauty, but at night, when viewed by reflected rather than transmitted light, it appears as a dark, dull space. In most cases it is not difficult to illuminate the window. Weatherproof type, enamel steel, angle reflectors with clear lamps, or tubular lamps with cylindrical reflectors, have proven of use. In most cases it is necessary to make a point by point illumination calculation to determine the type of unit and its location for the even distribution of light, and this can often be supplemented by some slight experimentation to determine the final result.

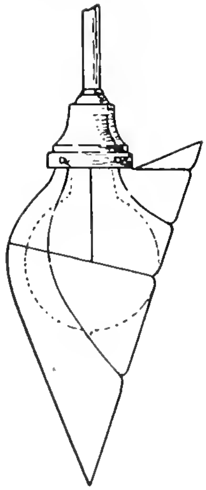

Fig. 8. Holder and Shade for the 400-watt Lamps in the Church Shown in Fig. 9

As a general rule, the window should be evenly illuminated, and it is bad practice to have the position of the light source visible through the glass. Sometimes, however, there is a point in the design which logically demands a higher intensity of light, as, for example, the sky in a landscape scene, and these features must be given attention.

Light of a color approximately daylight must be used, to prevent distortion of the colors of the glass.

### Choir

In the Evangelical church, this occasionally presents a problem. It is often located at the front, and the light from the main auditorium units is both low in intensity and from the wrong direction.

The practice has been to a great extent to place a few brackets on the organ and shield the lamps with some sort of diffusing shade. These units are continually in the vision of the congregation and are extremely annoying. One solution is to place the lamps in recessed boxes in the overhanging portion of the organ, and diffuse the light through glass plates. If the organ structure will not permit of this, recourse has been made to bowl shaped steel reflectors painted on the outside to harmonize with the organ finish, and used on brackets. While these are not especially decorative, a strong light is provided on the books of the choir, and as the reflectors are opaque, the eyes of the audience are protected. Reading lamps on music racks, as in the orchestra pit of a theater, are also applicable and possess many advantages.

A local lamp is, of course, provided for the organist, and in many instances it is advisable to have a low candle-power lamp below the keyboard to illuminate the pedals. These lamps should be readily controlled for use during rehearsals.

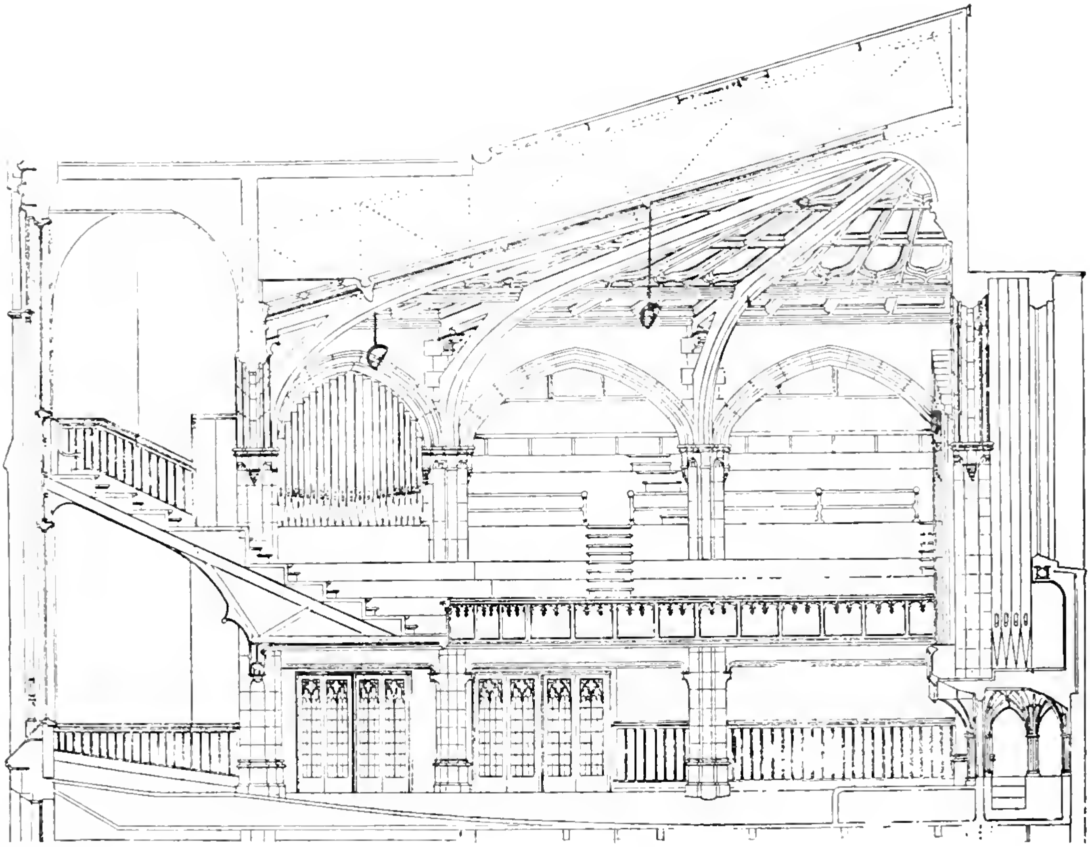

Fig. 9. Sectional Elevation of a Church having an Inclined Floor and Ceiling Suspended Lighting Units

**Exterior**

In conclusion, it might be well to mention some of the recent innovations along this phase of church lighting—illuminated signs, crosses, and bulletin boards are becoming quite widely used. Installations of ornamental street lighting are often made directly about the church, which have the effect of attracting attention, with the result that the chance pedestrian is often induced to attend the service.

# PUBLIC SERVICE AND PUBLIC OPINION

By William McClellan

Consulting Engineer, New York

Mr. McClellan, who was for some years Engineer of the Public Service Commission of New York, has had such broad experience in the relationship between the public service corporation and the public that his views on this important subject are of much value. He points out very frankly the sins of the past, and states that though a Public Service Corporation should have no objection in dealing with the public through a commission, this condition ought to be unnecessary, for frankness and honesty on both sides is the real desideratum. The author looks to a better understanding in the future than there has been in the past. This paper was read by Mr. McClellan before the Eastern New York Section of the N.E.L.A. at their annual meeting at Lake George last fall.—Editor.

Every business needs the support of public opinion. Where there is competition, the need is quickly perceived and the support is striven for. Merchants of commodities know another kind of competition, that of disuse. The overcoming of this type of competition they call "creating a market." This is our kind of competition, and we, the public utilities, need the support of public opinion to overcome it. It has taken most of us a long time to realize this, but, with a few exceptions, we recognize it now. Our obtuseness in the past, however, has left us with a sorry burden, for we do not simply lack the support of public opinion but find that that which does exist is adverse to our welfare. We are in the class which the community does not trust, along with the ice man and the watering milkman, and the short-weight coal man. How can we change our condition and get the support of public opinion?

When I consider our circumstances, I am not at all hopeless. I simply try to recognize a problem and then seek the solution. And the problem must be solved if the business is to become entirely satisfactory. Merely dodging an answer never removes a really vital question.

Distrust and consequent regulation did not arise out of vindictiveness. By forgetting or ignoring the force of public opinion, we brought it all upon ourselves. I prefer to think of the public not as wanting to "get us," not as consciously unfair, but as simply insisting on certain rights which have so frequently been denied it in the past. The public must deal with us, and if it prefers to deal through Commissions, there can be no reasonable objection on our part. Fortunately, there is little objection; and education with patience will remove whatever difficulties loom up great at the time.

How shall we gain the much needed support of public opinion? Naturally, it must be gained in such a way that we may keep it. It is the foundation of our business. Unless we build on it, the results may be very disastrous. There are examples enough now to show what is sure to happen in the way of repudiation, virtual confiscation, and even total loss, if public opinion is continually flaunted. There are also examples to prove that in times of stress public opinion is the inner line of fortification which secures a company against annihilation by political and other opportunists.

We may put this differently. Public opinion will support us only on the basis of an enduring confidence. It must have faith in us, which means we must keep faith with it. This involves a sincerity which is not merely a business policy but a state of being. For many of us, it means a complete change of mental attitude, a decided shift of position. Mere promise or protestation will not do. Every action, every statement, every interview, every contract, every negotiation, not only by the chiefs but also by every employee, must be based on a confidence-begetting sincerity. A simple slip, a single case of double-dealing, too much shrewdness, or one attempt to "put something over," can easily undermine a confidence which has been built up by years of effort and thousands of dollars of expense. How shall we start? What are some of the cardinal points?

In the first place, if we have not already done so, we must clean house. We cannot be sincere if we have anything to hide. We ought to know how much property we have, and what it is worth on some basis. We ought to know the cost of doing business, and whether it is as low as our circumstances will permit. We ought to know the condition of our property, and whether it is being handled so as to be continuously in a state of 100 per cent operating efficiency. We know better than anyone else that rate-making is not a matter of scientific accuracy; but, nevertheless, it should not be a matter of grape-vine growth. We ought, therefore, to make sure that each particular group of rates is internally consistent on some basis. We ought to be able to give some explanation of their peculiar forms. If we are accumulating various funds and accounts, we ought to be able to give an adequate reason for them. We ought to know just what profit we are making, and whether we could square this with public opinion. We have no business to be criminally prosperous.

Such a house-cleaning will be dictated by enlightened self-interest. Public regulation ought not to be able to do more than we can do ourselves. In a few cases, it is demagogic; usually, it is prompted by honest intentions but is accomplished in an ignorant and inexperienced manner. Unfortunately, in the past, it has been too frequently found, on the examination of many companies, to be a mess of greater ignorance and planless operation. Information was not available until it was dug out by the regulators. After many a regulation, in spite of some unpalatable orders perhaps, the company has hardly recognized itself in the light of the information given to it by the investigation. Moreover, there are not many examples of ruin caused by regulation.

Having cleaned house, and with nothing to hide, we ought to be accessible. The prepared-food people have shown us the way. They cleaned house, and then invited the public to come and see how clean it was. Their business is something like ours. Both of us are in a business which the public can do for itself, if it wants to, though in different ways. As a matter of fact, the public went into business with us when it gave us a franchise. We thought it was a free gift, but we were somewhat blind and misled. Again enlightened self-interest would want the public to be acquainted with us. Our officers, therefore, high and low, should be easily accessible. Offices should be arranged so that there is an atmosphere of ease and welcome. The limit of authority of under officials and employees to make adjustments in accordance with well-established principles should be set as wide as possible. Information and explanation should be given with great freedom. The public has the right to understand the basis on which it is paying for service, and it is to our interest that they should. It is easy for a merchant who has one price for a particular article to get the confidence of his patrons. It will be just as easy for us, if we can make our customers understand that we really have one price for each particular kind of service.

Proper relations with, and fair treatment of, our employees are powerful aids to the good-will of the public. It is often forgotten that employees are part of the public, that they live in all sections of our territory, that they are frequently asked questions about this and that feature of our often perplexing methods; and that, therefore, they have much opportunity to mold public opinion. The sincerity of the company can be impressed on them in several ways, not with the idea of buying their loyalty and good-will but of inducing these valuable assets. They should never be asked to do anything which could not be justified publicly if necessary. They should understand that nothing is going on in any part of the company that need be concealed, and that their own work is to be carried on in the same manner. They should be taught the ideals of the company, and that they are expected to have a large part in the realization of these ideals. All questions of hours, remuneration, and other working conditions should be open for discussion at any time between the persons involved. Whatever the outcome, it should be capable of explanation from the standpoint of the business as a whole. They should be dignified by being treated as freely contracting parties with the company, and not as a species of valuable beast of burden which must be controlled and cared for. A certain amount of welfare work is desirable, insofar as it does not replace a proper increase in remuneration. This question of the employee has received too much attention of one kind and not enough of the right kind. They are our outposts in the public and have tremendous force in specific cases and in general influence.

A constructive policy in relation to social and community progress is essential in gaining public opinion. I believe that a public service company is the most important factor in the development of a community. To believe this and act accordingly is to realize the responsibility of our franchises. Have you ever thought about this "free gift" of franchises? The community wanted to give them to us and hoped that we would take them. They thought that we were going to make a lot of money through them; but that was not the reason that we got them. The community also expected to benefit greatly from the gift. Therefore, in proportion as it benefits, so will we gain their good opinion. This means adequate and satisfactory service, and extension of lines promptly so as to aid the growth of the community in area and development. Under such a policy, I believe rates will adjust themselves on account of the enlightened self-interest of the company. High rates and largest profits seldom go together.

This constructive policy will show itself in some broader phases of community life. Legislation of various kinds will not be opposed unless it is inherently wrong. When opposition is necessary, it will be done publicly; and in the hope of enlisting the intelligent sympathy of the community. The company, regarding itself as a good citizen, will be in active sympathy with all uplift movements, such as hospitals, and safety plans for the public and its employees. It will contribute from its funds, but especially by its knowledge and intelligent effort, so far as sound business and social policy will permit. The presentation of a pulmotor to a hospital, or of expenses to an injured employee are good actions in themselves. How they will affect public opinion depends upon whether or not the actions flow from a consistent business policy.

In our own state, perhaps the most shining example of a lack of constructive policy is shown by our treatment of the conservation of water power. Public opinion regards the water powers of the state as great and valuable resources. Attempts are made to develop these resources and the public service companies of the state are found in opposition. There is some indication that this opposition is organized in the sense that it proceeds from national and state committees representing the companies. In the resentment which is called forth, it is not perceived by public opinion that the opposition is almost entirely against the method and not against the principle. This must be charged, however, to the lack of constructive effort on our part. Surely as business men, we know that the easiest method to beat a bad scheme is to provide a good one. In times past, when public opinion was quite inattentive to such matters, other methods were available, but not now. Opposition to such projects as these has a far reaching influence in our local business relations. Why should not the public service men of this state stand out in the broad light and acknowledge that the state has valuable water powers which could be developed? Why should these men not offer their wide experience in devising proper plans by which the developments could be made so as to give the state as a whole the benefits and profits to which it is justly entitled, and, at the same time, protect investments of all kinds already made? Why should not a bill be offered which the public service men could work for openly, in the light of day? I know that there would be much misunderstanding by the public. They have never been accustomed to seeing us play such a part. But, if it is right, we ought to have the courage to attempt it. A dozen public service men, known in as many communities as men of probity, ability and experience, standing as directors of a campaign of education, going directly to the public of their own communities, hiding nothing, using no subterfuges, might have a long pull to the finish, but would discount failure at the start. And the collateral benefits from such a campaign would be very great. Public opinion is now active and thinking about our affairs. We must reckon with it; or, finally, lose out.

Advertising, I have put last where I think it should be. After we have done everything else which is necessary, we can talk about it. I believe in advertising and plenty of it. This is not the place to discuss methods, where there are so many. As a matter of fact, everything that we do should be advertising, that is, turning the people to us. Advertising which is mere protestation or exaggerated promise is ruinous, in the end; and is likely to result in nothing but a cynical smile. Simplicity, truthfulness, and sincerity count here as elsewhere.

After all, does not our whole argument mean that we must take the public into a real partnership? In a peculiar sense, they have been contributors to our enterprise. A franchise is a necessity in order to have a public service business and yet there has been little disposition to allow a company to value it. May this not be regarded as the equity of the public in the business? Are not all the attempts made by the public to regulate our business to be regarded as an attempt to assert this partnership? May it not be that its very obstinacy arises from our past stubbornness in regarding our business as entirely private, to be operated as we saw fit. The total disregard by the public, in the past, of its interest in our business is as much responsible for the present condition as our misunderstanding of the relations which should exist. While the change is taking place, there is great danger that the dominance of capital will be exchanged for the dominance of the public. Both are bad, because they are both naturally self-seeking.

The hope of a proper balance is in the operating man, from President to common laborer. His part is to teach each of his partners to respect the rights of the other. The "Company" can no longer be synonymous with "Capital" but must mean the three-strand partnership of capital, labor and the public.

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# THE DESIGN OF AN OSCILLATION TRANSFORMER

By S. Thomson

Consulting Engineering Department, General Electric Company

The following is a direct quotation from the conclusion of this article: "Oscillation transformers have recently come into use for testing insulators, as they offer a cheap means of obtaining a very high voltage. Experience shows that the high frequency discharge can find defects in insulators which have passed the standard 60 cycle tests." Thus we are acquainted with the fact that there is a new commercial field for the oscillation transformer in which it bids fair to supplant the apparatus used at present. The article furnishes a description of the various parts of such a transformer, the explanation of the electrical factors entering into its design, information relating to the materials to be used, and a liberal amount of data for its calculation.—Editor.

An oscillation transformer, sometimes called a Tesla coil, is an apparatus for obtaining very high electrical potentials by means of the well known phenomena of resonance. There are two windings which are coupled inductively, as in the ordinary transformer, but the step-up in voltage is not obtained by adjusting the ratio of primary to secondary turns, but by the free oscillation of the secondary under the influence of high frequency impulses inductively communicated from the primary, which build up in this manner a standing wave of high potential. The frequency supplied by the primary winding is adjusted to correspond to the natural period of free oscillation of the secondary. By such means very high potentials are obtained at the terminals of the secondary or high tension coil. As will be readily seen, these have nothing to do with the ratio of turns. An air core is always used, as at the high frequencies employed the eddy current losses and screening effect would be excessive, even in a finely laminated iron core.

Fig. 1 gives the essential parts of an oscillation transformer circuit. $A$ is a coil of fine wire wound on an insulating cylinder or frame work, with its ends brought out to spark-gap terminals; $B$ a coil of a few turns of heavy wire wound, on a wooden frame, concentrically with coil $A$, which constitutes with $A$ the oscillation transformer proper; $C$ a condenser of proper voltage and capacity; $D$ a ball gap; $E$ an iron core transformer, preferably of high reactance, supplying a voltage of 10,000 to 20,000; $F$ an air or open iron cored reactance; and $G$ the alternating current supply.

### I. The Oscillating Circuit

In designing an oscillation transformer the first thing which we must consider is the oscillating circuit $BCD$. Here originates the high frequency discharge which operates the coil. Let us assume that we are going to build an apparatus to supply a high potential discharge at a certain frequency. We must then arrange to produce this frequency in the circuit $BCD$ by the discharge of condenser $C$ through the coil $B$ and the ball gap $D$. The frequency of discharge of such a circuit, when it is of negligible resistance, is determined by the product of its inductance and capacity according to the well known formula:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The inductance and resistance of the circuit, including that of coil $B$, must be comparatively low if we wish to obtain the best results and have it free from arcing in the ball gap, which occurs when the circuit has too much inductance. Coil $B$ is therefore usually made of a few turns (5 to 10) of heavy wire, and the remainder of the circuit also of heavy wire and as short as possible. For a large apparatus it is advisable to use an air blast on the ball gap, or some form of rotary gap to prevent overheating by the discharge, and a dynamic arc instead of the desired interrupted discharge. Thus, as we are confined within rather narrow limits as to the amount of inductance in the circuit, we must obtain the frequency desired by regulating the capacity of the condenser.

In order to obtain maximum power with a given frequency the condenser should be operated at as high a voltage as possible. In all cases we must have enough power to overcome the losses in the coil $A$ when operating at a voltage sufficient to break down the maximum spark gap which we wish to use.

To summarize: high power coupled with high frequency means the use of a high voltage on our condenser $C$. If, however, we are not particular about the frequency, but wish simply high power, the condenser should be of the largest possible capacity, and be operated at 10,000 to 20,000 volts. Higher voltages make the condenser undesirably bulky, and with voltages below 10,000 the ball gap must be set so small that it does not get good ventilation and has a tendency to overheat and arc. However, as low a voltage as 5000 can be used with small coils.

### II. The High Tension Coil

Since the frequency has already been determined by the constants of our low tension circuit, we must make the high tension coil of such dimensions that its natural period of free oscillation will correspond to this impressed frequency. Here we are dealing largely with distributed inductance and capacity, and therefore the frequency of such a coil is:

$$\frac{1}{4\sqrt{LC}}$$

The capacity of the terminals themselves must, of course, be taken into account. It is a difficult matter to calculate beforehand just what the natural period of such a coil will be, as it depends not only upon the constants of the coil itself, but upon the degree of coupling with the low tension coil and the inductance of this coil. The best plan, therefore, is either to wind a coil which previous data shows to be a little too large and then adjust it by testing and removing the few turns that are unnecessary, or to provide an adjustable condenser in the low tension circuit.

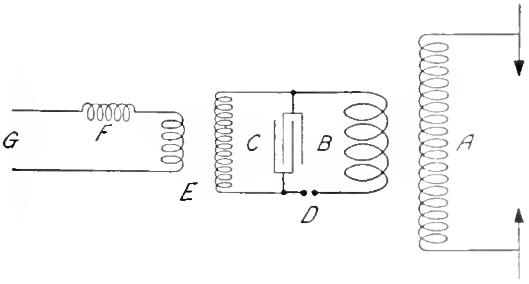

**Fig. 1. Diagram of Connections of Oscillation Transformer**

The greatest problem in winding the high tension coil is that of insulation, especially in the larger coils. Hard rubber has proved to be the best material of which to build the frame work which supports the coil. The following table gives the creepage distance between small wires over the surface of several materials immersed in number six oil as compared with the corresponding jump in air between needle points of a 150,000 cycle discharge.

| | Creepage under oil | Spark in air |
|---|---|---|
| Oiled pressboard | 6 in. | 15½ in. |
| Porcelain | 6 in. | 17½ in. |
| Hard rubber | 6 in. | 21 in. |

Paraffined wood, stressed with the grain under oil, in time breaks down below the surface, and there are formed small charred paths under stresses with as low as 8 inches air needle gap for a 6 inch creepage path. The coil should therefore be wound in a single layer and the supporting frame work built of hard rubber, allowing a creepage distance between ends under oil equal to the desired spark between needle points in air. This provides a factor of safety of more than three which is ample.

The next thing that interests us is the spacing between the high tension and the low tension coils. It has been found by experience that the diameter of the high tension coil should be from one-half to one-third of its length, although this is simply an arbitrary rule. The low tension coil is usually placed outside of the high tension coil, concentric and co-axial with it. This arrangement combines in one the insulation between primary and secondary, and the insulation to ground. The spacing between high and low tension coils depends upon the dielectric strength of oil, and on whether we wish to connect the coils together at one end, in the middle or keep them entirely isolated.

In the case of end connection, the low tension coil is built in the conical form, the total stress coming across the insulation at the opposite end. With the middle connection, or the isolated condition (which is the most common), the low tension coil takes a cylindrical form, and the voltage stress is distributed one-half at each end. The choice between these connections depends upon the way the coil is to be used and the available space, etc.

Having chosen the connection to be used, we must know the dielectric strength of transil oil against a high frequency discharge.

A number of tests have shown that the relative jumping distances, between needle points in air and in number six oil of a high frequency discharge, is 25 or 30 to one. Choosing a factor of safety of somewhat more than two,* a good rule to follow is to allow an inch spacing in oil for every foot of spark in air. This may be all at one end or distributed between the ends as described above, according to the connection used.†

The copper wire used in the high tension coil should be from 0.016 to 0.032 inch in diameter. This is of low enough resistance not to damp unduly the oscillating discharge, and yet is small enough so that we can wind 15 to 30 turns to the inch, according to the insulation used. It may even be used bare and wound in a spiral groove turned in the surface of the supporting frame, which is, perhaps, the best method; or it may be heavily insulated and wound as closely as possible. The latter method is the easiest to carry out, but does not give quite so good a coil, owing to the fact that the insulation losses are somewhat greater in the fibrous insulation than in clear oil. A double cotton covering is not sufficient, except for coils of the smallest size, as the stresses between adjacent turns may reach thousands of volts in the larger coils.

Triple cotton covered enameled wire has been used very successfully on coils giving sparks up to 24 inches. For larger coils we may use sextuple or octuple cotton covered wire. An enamel coating is approximately equal to two cotton coverings. The cotton covering becomes saturated with oil and provides essentially an oil insulation. It is advisable to separate the 15 or 20 turns at each end of the coil by two or three times the normal spacing, as abnormal stresses are liable to occur here.

### III. Tank and Terminals

The two co-axial coils of the oscillation transformer should be immersed in an oil-tight wooden tank under a sufficient depth of well dried oil. The form of the tank will depend upon the size and placing of the coils (vertical or horizontal). A metal or metal lined tank introduces a much more difficult insulation problem but is much more easily made oil tight.

The terminals of the high tension coil are usually brought out beyond the ends of the low tension coil by means of flexible wires through suitable porcelain, hard rubber, or oil filled bushings in the wooden tank cover. If we use the arrangement with one terminal grounded, one bushing only is required, and a vertical position of the coils is probably the best. This arrangement is most suitable for very large coils.

All the metal parts of the terminals which are exposed to the air should be made with surfaces having as large a radius of curvature as possible to keep the losses by corona at a minimum.

### IV. The Transformer

The transformer which is used to supply the low tension circuit should be made preferably of the open core construction for two reasons:

1st. The high magnetizing current of such a transformer would supply the heavy leading current taken by the condenser, thus reducing the current drawn from the power source and greatly improving the power-factor.

2nd. The high reactance limits the short circuit current when the ball gap discharges. If we wish to use an ordinary low reactance transformer to charge the condenser, an open core or air cored reactance coil must be inserted in series with the low tension side of the transformer. The reactance should be adjusted to give maximum power-factor, in order to take minimum current from the power source when the coil is operating.

Experience with wireless apparatus has shown that the best frequency of alternating current with which to operate a high frequency oscillating circuit is in the vicinity of 500 cycles per second. With this we get 1000 discharges across the ball gap in a second, which is about as high as it can be run without excessive heating and arcing. The larger the number of condenser discharges in a given time, the more powerful is the high tension discharge. We see, therefore, that it is advisable to use the highest available frequency up to 500 cycles, although 60 cycles will be very satisfactory for most uses.

The high tension winding of the supply transformer should always be grounded at one end to fix its potential with respect to ground, and thus eliminate breakdowns to ground caused by the grounding of one terminal of the high tension coil of the oscillation transformer, and a resulting breakdown from the other terminal to the low tension coil, and thence to ground.

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* This is purposely made low to act as a relief gap.

† Full spacing at both ends should be allowed when the coils are isolated.

### General

Below are given the characteristics of a number of coils which have been built.

| | No. 1 | No. 2 | No. 3 |
|---|---|---|---|
| Spark length | 14 in. | 24 in. | 48 in. |
| Frequency (approx.) | 200,000 cycles | 150,000 cycles | 100,000 cycles |
| Condenser volts | 13,000 | 13,000 | 20,000 |
| Supply volts | 110 | 110 | 220 |
| Supply amp. | 18 | 70 | 100 |
| Supply kw. | ¾ | 3 | 12 |

Oscillation transformers have recently come into use for testing insulators, as they offer a cheap means of obtaining a very high voltage. Experience shows that the high frequency discharge can find defects in insulators which have passed the standard 60 cycle tests.

When a high potential test of an insulator is made with this apparatus, the natural period of oscillation of the high tension coil is lowered by introducing at its terminals an extra capacity—the insulator. This, therefore, throws it somewhat out of resonance with the impressed frequency, the more so as the size or number of insulators in parallel is increased. In such a case means should be provided for increasing the capacity of the operating condenser in order to bring the circuits back into resonance. With most coils, however, one or two insulators can be tested in parallel without any condenser adjustment.

A means has been found of regulating the voltage by adjusting the primary spark gap.

## INTERNATIONAL ELECTRICAL CONGRESS

San Francisco, 1915

The International *Electrical* Congress is to be held at San Francisco, September 13 to 18, 1915, under the auspices of the American Institute of Electrical Engineers by authority of the International Electrotechnical Commission, and during the Panama-Pacific International Exposition. Dr. C. P. Steinmetz has accepted the Honorary Presidency of the Congress. The deliberations of the Congress will be divided among twelve sections which will deal exclusively with electricity and electrical practice. There will probably be about 250 papers. The first membership invitations will be issued in February or March, 1914.

Attention is drawn to the distinction between this Electrical Congress and the International *Engineering* Congress which will be held at San Francisco during the week immediately following the electrical congress. The engineering congress is supported by the Societies of Civil, Mechanical and Marine Engineers and by the Institutes of Mining and Electrical Engineers, as well as by prominent Pacific Coast engineers who are actively engaged in organizing it. This Congress will deal with engineering in a general sense, electrical engineering subjects being limited to one of the eleven sections and including about twelve papers treating more particularly applications of electricity in engineering work.

The meeting of the International Electrotechnical Commission will be held during the week preceding that of Electrical Congress.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## PERMEABILITY OF LIQUID AIR

It frequently happens that various schemes are proposed to utilize the magnetic properties of liquid air, including its use as the magnetic circuit of a transformer core. These suggestions doubtless grow out of the statement that liquid oxygen $O_2$ is strongly magnetic. This statement is perfectly true but is correct from the standpoint of the physicist, rather than that of the engineer, as liquid $O_2$ is strongly paramagnetic only as opposite to diamagnetic.

The permeability of liquid $O_2$ is about 1.004, or 0.4 per cent more magnetic than air and is, therefore, not to be considered as a substitute for the ferromagnetic metals. There is no reason to suppose that the magnetic values of liquid $O_2$ and $O_2$ gas are the same for equal weights, as between the two there exists wide differences of temperatures and physical conditions in general.

J.D.B.

## IRON CONDUCTORS AS A PROTECTION AGAINST HIGH FREQUENCY DISTURBANCES

Although skin effect and other high frequency phenomena in iron conductors is pretty thoroughly understood, there seems to be a general misconception as to the value of iron in affording protection to apparatus from line disturbances. A partial acquaintance with the phenomena that takes place in iron conductors at high frequencies leads to the false conclusion that such a conductor affords considerable protection from line disturbances. After a careful perusal of all the available data, the question arises as to whether it affords appreciable protection or not.

A discussion of the relative merits of an ordinary copper choke coil and one made of soft iron conductor will perhaps throw some light on the subject. It is assumed that the coil is to be placed in the high tension side of a transmission line, in series with the station apparatus, for the purpose of choking back high frequency disturbances and forcing them through the protective apparatus.

There is a certain critical frequency between $10^4$ and $10^5$ cycles which is destructive to station apparatus, and this article deals only with frequencies between these limits. Chapters VI, VII, VIII and IX of Dr. Steinmetz's "Transient Phenomena" cover the entire field thoroughly in a theoretical way, and if actual research data is desired, a reference to Mr. E. F. W. Alexanderson's "Magnetic Properties of Iron at Frequencies up to 200,000" A.I.E.E., 1911, Part III, page 2433, would be of benefit.

It is well known that a copper choke coil does not give a sufficient degree of protection to station apparatus. Although it may choke back the greater part of the high frequency energy, enough seeps through before the protective apparatus is brought into play to start up destructive oscillations. To prevent this seeping an iron coil must have an appreciable increase in effective resistance and internal reactance at high frequencies over one of copper, and the high frequency hysteresis losses should be much more than at the commercial frequencies. Even at low frequencies there is considerable skin effect in iron conductors; that is, the current flows only in the outer shell of the conductor and thus only a small volume of a solid conductor would have hysteresis loss. It must be remembered that in most cases the high frequency current is superimposed upon the commercial current in the form of a path in the outermost shell of the conductor, its depth of penetration being much less than that of the lower frequency. There would thus be a very small volume of iron to produce hysteresis loss, and for this reason the loss is not so pronounced as would be supposed. This is shown in Mr. Alexanderson's article. There is, however, a considerable increase in effective resistance and internal reactance at high frequency. These factors vary as the square root of the frequency, but the coil reactance varies directly as the frequency, and thus at high frequencies is much greater than the internal resistance and reactance.

It seems then, that an ordinary copper coil with an increased number of turns would be more effective in holding back disturbances than would one made of iron.

J.D.B.

## QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial person in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

### THREE-PHASE CONNECTIONS

(78) How many correct but different combinations are there of connecting the leads of a three-phase generator to the bus?

Six. Assuming the generator to be represented by the symbol (a), the bus by (b), and their leads by the numbers 1, 2, and 3, the various ways follow:

First:
1 on (a) to 1 on (b)
2 on (a) to 2 on (b)
3 on (a) to 3 on (b)

Second:
1 on (a) to 2 on (b)
2 on (a) to 3 on (b)
3 on (a) to 1 on (b)

Third:
1 on (a) to 3 on (b)
2 on (a) to 1 on (b)
3 on (a) to 2 on (b)

Fourth:
1 on (a) to 3 on (b)
2 on (a) to 2 on (b)
3 on (a) to 1 on (b)

Fifth:
1 on (a) to 2 on (b)
2 on (a) to 1 on (b)
3 on (a) to 3 on (b)

Sixth:
1 on (a) to 1 on (b)
2 on (a) to 3 on (b)
3 on (a) to 2 on (b)

The phase rotation in the first three methods is opposite to that in the last three.

R.E.D.

### LIGHTNING ARRESTER CHARGING

(79) A certain aluminum lightning-arrester equipment for a 17,000-volt ungrounded system has the usual four tank connections, with the exception that there is no transfer device for charging, and the ground tank never becomes a line tank. The arresters are charged by merely inserting a conductor between each horn gap, taken one at a time. Will this method of charging keep the arresters in good operating condition?

This method of charging is absolutely wrong and will probably result in damage before long. It has been tried, but has failed to keep the films in good condition. (Closing one gap at a time when the films are in poor condition and when there is any disturbance on the system is somewhat like an arcing ground.) The method is to be condemned from every standpoint.

E.E.F.C.

### STEEL MILL, RUNNING LOAD

(80) What is considered good practice when figuring motor loads in steel mills? Assume 1000 h.p. of motors (name-plate rating), varying in size from 10 to 75 h.p., located around a mill on roll tables, cranes, shears, etc. They in no case carry full horse-power and are not all working at the same time. What would be an average horse-power load to use in figuring generator or transformer capacity?

An average horse-power load for figuring the generator or transformer capacity for motors operating roll tables, cranes, shears, etc., may be obtained by taking from 25 to 33 per cent of the total horse-power of the motors.

G.M.B.

### PROPER SIZE OF CABLE

(81) What would be the proper size of cable to carry current to the following?

1600 h.p. a-c. 2200-volt motor (roll-drive), 80 per cent p-f., 500 ft. distant from generator.

1200 h.p. under the same conditions.

200 h.p., 70 ft. distant; otherwise under the same conditions.

The generator voltage is in all cases 2300 volts.

1600 h.p., 2200 volts, 80 per cent p-f., 500 feet from 2300-volt generator,—750,000 circular mils.

1200 h.p., under the same conditions,—400,000 circular mils.

200 h.p., 70 ft., otherwise under the same conditions,—No. 4 B.&S.

In each of the above cases the cables are capable of carrying 50 per cent overload for 2 hours.

G.M.B.

### STORAGE BATTERY AUXILIARY *versus* OVERLOADED GENERATOR

(82) Is it considered good practice to use storage batteries to aid direct-current generators in carrying a peak load, or, if the excess load is not too great, to allow the generators to supply the peak load alone?

The only statement that can be made in answer to this question is the general one that if the overloads are not too great and are not of too long duration the generator should be allowed to supply the demand. It would be necessary to know, however, the magnitude and time-characteristics of the load and the size of the generators before the values of the limits "too great" and "too long" can be set.

G.M.B.

### EFFICIENCY OF CARBON AND TUNGSTEN LAMPS

**(83) What is the actual measured efficiency in watts per horizontal candle-power of 16 and 32 candle-power carbon and tungsten filament lamps of 110 and 220 volts?**

On account of the present rating, neither the carbon filament nor the tungsten filament lamps give exactly 16 or 32 candle-power, but those which give the nearest to these figures have been selected and following is a table showing the results of measurements made on these lamps.

| | Hor. C-P. | Watts | W.P.C. | Rated Life |
|---|---|---|---|---|
| *Carbon Filament* | | | | |
| 110 volts.... | 16.83 | 50 | 2.97 | 700 |
| | 33.66 | 100 | 2.97 | 600 |
| 220 volts.... | 16.26 | 60 | 3.69 | 750 |
| | 32.52 | 120 | 3.69 | 750 |
| *Tungsten Filament* | | | | |
| 110 volts.... | 16.0 | 20 | 1.25 | 1000 |
| | 34.2 | 40 | 1.17 | 1000 |
| 220 volts.... | 18.0 | 25 | 1.40 | 1000 |
| | 30.5 | 40 | 1.31 | 1000 |

S.L.E.R.

### IRON CORE *versus* AIR CORE CHOKE COILS

**(84) Some discussion recently brought out the fact that low-voltage coils such as are used in telephone work are provided with an iron core. Choke coils, however, on higher voltages are not provided with an iron core, probably due to the transformer action if this were done.**

**A certain installation has a choke coil in a protection panel operating in series with a lightning arrester. This coil has 50 turns of No. 5 wire and is caring for approximately 10 h.p. on 500 volts direct current. Considerable trouble has been experienced, however, due to line surging when a lightning storm is in the vicinity.**

**I would be pleased to have you explain in detail why a choke coil with an iron core would not be allowable on 500 volts direct current, and why the same is permissible on a lower voltage, and also give us some remedy for preventing this surging.**

Iron cores are not used in lightning choke coils because the thickness of lamination of the ordinary iron is great enough to permit serious eddy currents to flow in the iron. As a result of the eddy currents the use of iron is worse than none at all, due to the fact that a counter-magnetomotive force is set up. Placing iron in the lightning choke coil is almost equivalent to diminishing the area of the cross-section of the choke coil by the area of the cross-section of the iron used. If very thin laminated iron is used the high frequency eddy currents can be diminished and the iron becomes useful. It is difficult, however, to insulate the turns from the iron and the lightning is liable to jump from the end turn to the iron and back again to the coil, thus shunting out the turns of the choke coil.

Iron is not used in a current-limiting reactance for the simple reason that the iron saturates on short-circuit current and thus becomes ineffective at the time when it is most needed to limit the current. On the other hand, when the permeability is least needed, viz., at normal or low loads, it is high and produces poor regulation on the line.

Choke coils in telephone circuits are used in different ways, and the writer cannot decide what is the function of the choke coil, as mentioned in this question. Where continuous induction is to be guarded against, drainage coils are used, in which the inductance from line to line is very high but the inductance from line to ground is very low.

Complete protection for 500-volt direct-current circuits can be obtained by using d-c. aluminum arresters. These arresters will shunt out high-frequency surges of lightning and will also take the electromagnetic kick which comes from opening an accidental short-circuit.

E.E.F.C.

### A-C. INSTALLATIONS WITH STORAGE BATTERIES

**(85) Will you please publish some information regarding the following use of storage batteries in connection with alternating-current installations? The purpose of the batteries is to deliver at peak-load hours the energy which they have stored up during the night and at other periods of light load.**

We do not believe that there are many such installations. Storage batteries are, of course, widely used in hotel plants and other isolated plants for the purposes mentioned, but such installations are nearly all direct-current. The storage batteries as used by central stations in modern practice are not generally discharged at peak load, but are kept floating on the line almost fully charged as a reserve, being discharged only in case of an emergency. This practice obtains on account of the fact that the efficiency of the storage battery is only 60 to 65 per cent, i.e., output divided by input.

When used in connection with alternating-current installations and charged and discharged by a motor-generator, the losses in the motor-generator are, say, 12 to 15 per cent during charging and 12 to 15 per cent during discharging, i.e., a total of 25 to 30 per cent is involved in addition to the loss in the storage battery itself, so that such a system is not generally employed in large plants. There are some cases, viz., steel mill drives, mine hoists, etc., where extremely high peak loads of very short duration are frequently encountered. A few such installations employ alternating current: one at the U.S. steel mills at Gary, where a split-pole rotary converter is used to transform the alternating current to direct current and vice versa. Another installation is at the Kolar gold fields, Mysore, India, where 25-cycle alternating current from a transmission line is fed through small motor-generators into a storage battery which supplies larger motor-generators, that in turn generate 50-cycle alternating current. In this form the power is transmitted to a number of electrically operated mine hoists. This plant is regulated so that the storage batteries take a constant load for the 24 hours in spite of the very widely varying load on the hoisting circuit.

The Boston Edison Company has recently made an installation of storage batteries in connection with alternating-current lighting distribution, but here the storage battery is used largely as a reserve and it is not intended to be discharged very much at peak loads.

H.R.S.

# GENERAL ELECTRIC REVIEW

MARCH, 1914

## A Special Number

on

## Electric Lighting

# GENERAL ELECTRIC REVIEW

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# GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

A history of artificial illumination would make a most interesting study. If such a history were written it would reveal the fact that the industry of lighting, and especially that of electric lighting, like most of our modern industries, has developed more during the last two or three decades than during an equal number of centuries previous to this period. During the last century, and especially during the latter part, our modes of living have changed enormously, and the changes have been brought about in the main by the work of the scientist and the engineer. We believe that amid all the advances and development made in this most progressive period of man's history, no industry has been so progressive as the electric lighting industry It was born scarcely thirty years ago, and has grown to such proportions that it is hard for the human mind to comprehend the vastness of the industry as it stands to-day. We might take our readers through a bewildering mass of figures to show this growth. The number of incandescent lamps in use, the number made every day, the number of towns and the number of people using electric light are all figures that could be compiled with a greater or less degree of accuracy by the patient statistician; but such figures would in reality mean very little to the average mind. Some would be so enormous that we might either multiply or divide them by ten or even a hundred, and the difference would mean little to most of us. If we want a real comparison in this matter, we must compare "what was" with "what is." A careful comparison of this sort is hard to make, as written histories mostly deal with kings and queens, the rise and fall of governments, of battles, of conquests and defeats, and most, at least, make little mention of the conquests made by the gentler men of science; but Macauley in his "History of England" does devote a most interesting chapter to "The state of England in 1685," in which the following paragraph concerning the lighting of London occurs.

"It ought to be noticed that, in the last year of the reign of Charles the Second began a great change in the police of London, a change which has, perhaps, added as much to the happiness of the body of the people as revolutions of much greater fame. An ingenious projector, named Edward Heming, obtained letters patent conveying to him, for a term of years, the exclusive right of lighting up London. He undertook, for a moderate consideration, to place a light before every tenth door, on moonless nights, from Michaelmas to Lady Day, and from six to twelve of the clock. Those who now see the capital all the year around, from dusk to dawn, blazing with a splendor besides which the illuminations of LaHogue and Blenheim would have looked pale, may perhaps smile to think of Heming's lanterns, which glimmered feebly before one house in ten during a small part of one night in three. But such was not the feeling of his contemporaries. His scheme was enthusiastically applauded, and furiously attacked. The friends of improvement extolled him as the greatest of all the benefactors of his city. What, they asked, were the boasted inventions of Archimedes, when compared with the achievement of the man who had turned the nocturnal shades into noon-day? In spite of these eloquent eulogies the cause of darkness was not left undefended. There were fools in that age who opposed the introduction of what was called the new light as strenuously as fools in our age have opposed the introduction of vaccination and railroads, as strenuously as the fools of an age anterior to the dawn of history, doubtless, opposed the introduction of the plough and of alphabetical writing. Many years after the date of Heming's patent there were extensive districts in which no lamp was seen."

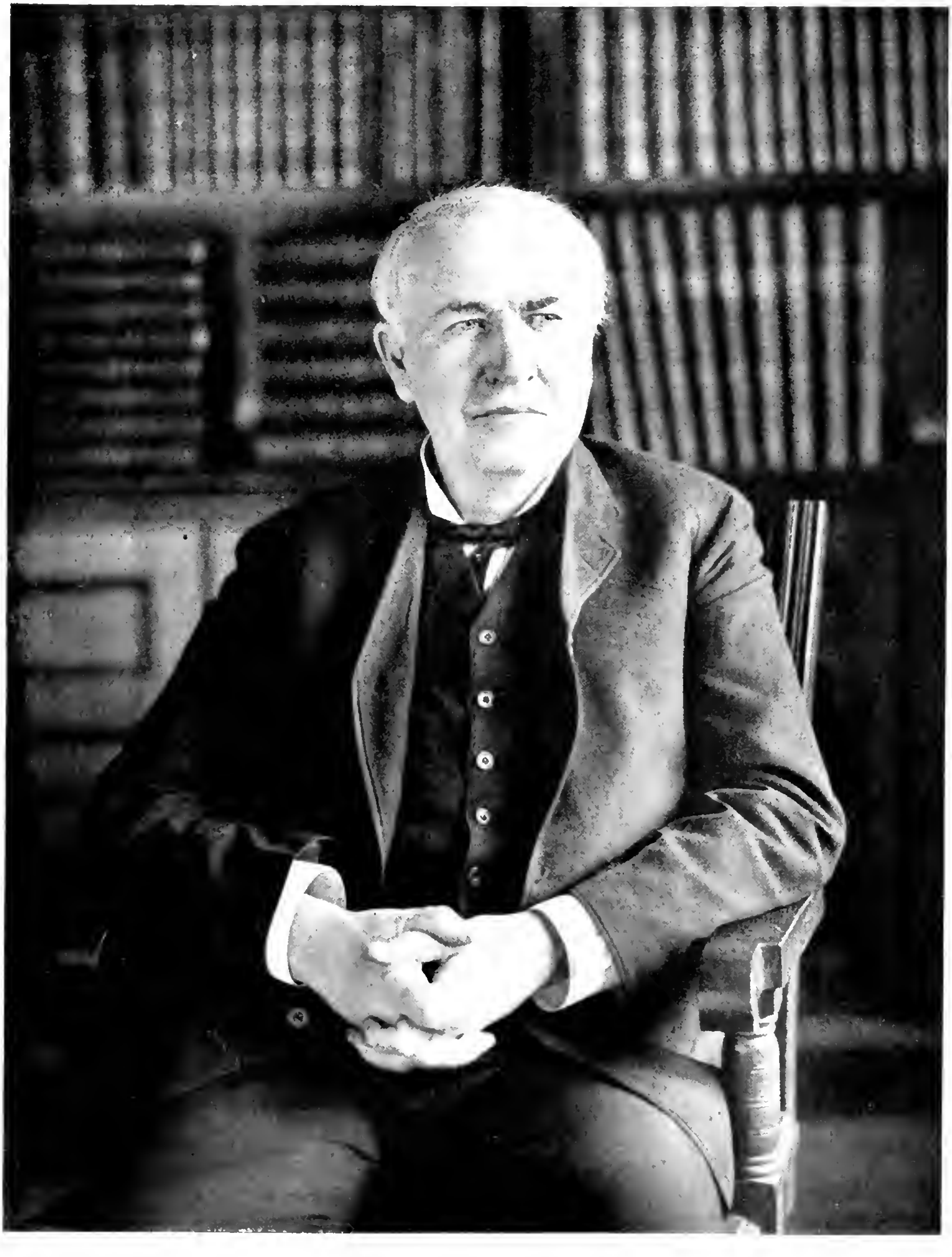
If the reader, after perusing this paragraph concerning the conditions as they existed some 229 years ago, walks down any of the main streets of any large modern city, he can form a good mental picture of the progress made. We should naturally expect great progress in so long a period, but if a similar paragraph were written describing accurately the state of things a hundred years or even only 30 years ago, the picture would be hardly less impressive, as it is in the last quarter of a century that the greatest strides in the lighting industry have been made.

It is interesting to spend some time in considering the word "light" itself. It is used so commonly, but what does it mean? It may be used in so broad a way as to make it meaningless and confusing to the lay mind, or it may be used in so narrow a sense as to limit its meaning beyond the point of usefulness to the scientific mind. The limits to its meaning have not yet been defined. If the word light is to include only that bare octave of energy vibrations in ether that affect the human eye, then the ultra violet light used in photography is not light but something else; and similarly the infra red just beyond the wave length to which the eye is sensitive is not light but something else, and the exact limit would vary with different eyes. There is no excuse for confining the word light to these narrow limits unless our definition of the word is to state that it is only to include those vibrations to which the average eye is sensitive. Should this be done, then what would be light to some eyes would not be light to others, as our range of perception differs; so this is hardly satisfactory. On the other hand, if no such limit is set, the meaning of the word light is extended indefinitely, perhaps too indefinitely, and light includes both visible and invisible energy radiations extending in both ways to the extreme limits of the spectrum, and the term light then includes all the energy radiation of the spectrum, embracing hertzian rays, radiant heat, visible light, ultra violet and x-rays, and so on up to the highest limits of the spectrum including the gamma rays from radium. As no definition of "light" seems quite clear, perhaps the best way is to be paradoxical and talk of "visible light" and "invisible light." It is some years ago now that Professor Sylvanus Thomson published his most interesting lectures, entitled "Light, Visible and Invisible," and there seems even now little ground for quarreling with this title.

If space permitted, we should like to deal with some of the problems, both scientific and commercial, of the lighting industry, but the subject is so vast that an attempt to cover even a small part of it in so short an editorial would be futile; but it is interesting to note in passing that these problems are so many and so varied that the progress made in the past, great as it has been, is small when compared with the work that is left to be done. Our most efficient illuminant, although a vast improvement on our best of a few years ago, is still woefully inefficient when compared with theoretical possibilities.

The science of light is perhaps the broadest of all the sciences; it includes so much, embracing as it does so many of the physical phenomena. We have learned much in the past, but still the study of light seems almost like a groping in the dark. It is true that our modern scientific conceptions occasionally give a glimmer of hope, and that such conceptions as our modern views on the nature of matter and the properties of the electron seem bound to broaden our scope of scientific research and achievements; but at the same time there is a tremendous field left as yet untrodden, and much building to be done right down on the foundations of the science of light that were laid by the immortal Newton. Such brilliant minds as Sir Thomas Young, Clerk Maxwell and Helmholtz, including such men of modern times as Lord Kelvin and J. J. Thomson, have broadened these foundations, but we have yet to learn the answer to that question which seems well nigh like the riddle of the universe: What is ether?

Fortunately, the scientific mind seems to be fed and stimulated on difficulties to be overcome, so it is rather an encouragement than otherwise to know that in spite of the brilliant work done in the past there is still more to be done; and that of the problems, both scientific and commercial, facing the electric lighting industry of to-day, it might be said, as of the charms of Cleopatra, that "age cannot wither" nor custom stale their "infinite variety."



Thomas A. Edison

Whose reminiscences form a contribution to this issue

# MR. EDISON'S REMINISCENCES

The Editor went to see Mr. Edison at his famous laboratory at Orange, N. J., for the purpose of [illegible] his reminiscences in regard to the beginning of the electric light business. The following is the substance of the interview. Mr. Edison kindly read and personally corrected the manuscript. It may interest our readers to know that Mr. Edison corrected this manuscript on February 11th, 1914, the sixty-seventh anniversary of his birth.—EDITOR.

Electric lighting is a broad subject and it is no easy task to furnish an article to preface so large a special issue of the REVIEW devoted to it. As this issue contains many articles covering widely different phases of the present day industry, and as prophecy is difficult and often dangerous I shall, in the main, confine myself to some of the earlier phases of the industry around the time that it was born.

Those of us that were actively interested in this great industry at the time of its birth are very few now compared with the number of younger men that have entered this field since the industry has been on a commercial basis. It is hard for the later comers to realize the conditions that existed then, as practically speaking, nothing was known of the electric circuit as we know it today. Everything had to be learned.

After a great deal of work had been done, the arc lamp was put on a more or less commercial basis, and this was the first commercially successful system of electric lighting, but it was suitable for exterior illumination only. I realized at the outset that the arc lamp could not be made suitable for general interior illumination. It was too large a source of light for ordinary house illumination and it was too bright, having a bad effect upon the eyes. I could see at this early date that the big field for electric lighting was the interior illumination of houses and that for every arc lamp burning in the streets there would, some day, be a thousand smaller electric lights burning in dwellings, office buildings, and factories. For this interior illumination it was necessary to obtain smaller units which could be used in exactly the same way as the gas lamps to which the people in general had become thoroughly accustomed at this time. The problem that faced me was how to obtain a small electric unit.

The younger men of today can't possibly realize the situation as it was then. We were literally working in a new unknown continent of thought. In these early days around 1877 and 1878, everyone who was working on the electric lighting problem had thoroughly made up their minds that the subdivision of the electric current was an impossibility. Men talked about it and wrote about it as an impossibility, and eminent scientists proved it to be impossible by mathematics and by logic, and indeed with our knowledge of electrical matters as it stood at that date it did seem an impossibility; but in July, 1878, I conceived my first idea of the low tension multiple arc system for the distribution of electricity for light, heat and power purposes.

I fully realized at this time that the problem was a gigantic one and that its solution would involve an immense amount of study, experimental work and commercial figuring. I started my task by reading an enormous amount of literature and studied everything I could find on the subject, investigating all systems of lighting, including gas, and taking into special consideration the commercial features. I made up my mind that the whole thing had to be done in one certain way or not at all, and then I started experimenting to discover and perfect the devices for this pre-determined system.

The problem was a broad and fundamental one, requiring the development of a complete system which I realized from the first must be analogous to the gas system of illumination then in use.

There was no previous work to serve as a guide. Everything had to be done first hand, so I settled down to take the gas system as a model and to make a system of electric light that could compete with it on a commercial basis.

The lamp was the key to the whole situation. I must invent an electric lamp about the same candle-power as the gas lamp then in use, which must be reasonably cheap and the cost of copper to feed it must be small. It must be durable and capable of burning at full incandescence and at full candle-power for a great number of hours; and over and above this, it must be made independent of all other lamps on the system.

A complete system of distribution for electricity had to be evolved, and as I had to compete with the gas system this must be commercially efficient and economical, and the net-work of conductors must be capable of being fed from many different points. A commercially sound net-work of distribution had to permit of being placed under or above ground and must be accessible at all points and be capable of being tapped anywhere.

I had to devise a system of metering electricity in the same way as gas was metered, so that I could measure the amount of electricity used by each consumer. These meters must be accurate so that we could charge correctly for the current used, and also they must be cheap to make and easy to read and keep in working order.

Means and ways had also to be devised for maintaining an even voltage everywhere on the system. The lamps nearest the dynamo had to take the same current as the lamps farthest away. The burning out or breaking of lamps must not affect those remaining in the circuit, and means had to be provided to prevent violent fluctuations of current.

One of the largest problems of all was that I had to build dynamos more efficient and larger than any then made. Many electrical people stated that the internal resistance of the armature should be equal to the external resistance, and said that that was Ohm's law; but I made up my mind that I wanted to sell all the electricity I made and not waste half in the machine, so I made my internal resistance small and got out 90 per cent salable energy, and these electrical people found that Ohm's law still held good. There were so many other improvements to be made in the dynamo to suit my system of electric lighting that I cannot enter into a description of them in so short an article.

Over and above all these things, many other devices had to be invented and perfected, such as devices to prevent excessive currents, proper switching gear, lamp holders, chandeliers, and all manner of details that were necessary to make a complete system of electric lighting that could compete successfully with the gas system. Such was the work to be done in the early part of 1878. The task was enormous, but we put our shoulders to the wheel, and in a year and a half we had a system of electric lighting that was a success. During this period, I had upwards of one hundred energetic men working hard on all the details.

One question concerning this early system has often been asked, namely: "Why did I fix 110 volts as a standard pressure for the carbon filament lamp?" The answer to this is that I based my judgment on the best I thought we could do in the way of reducing the cost of copper and the difficulties we had in making filaments stable at high voltage. I thought that 110 volts would be sufficient to insure the commercial introduction of the system, and 110 volts is still the standard.

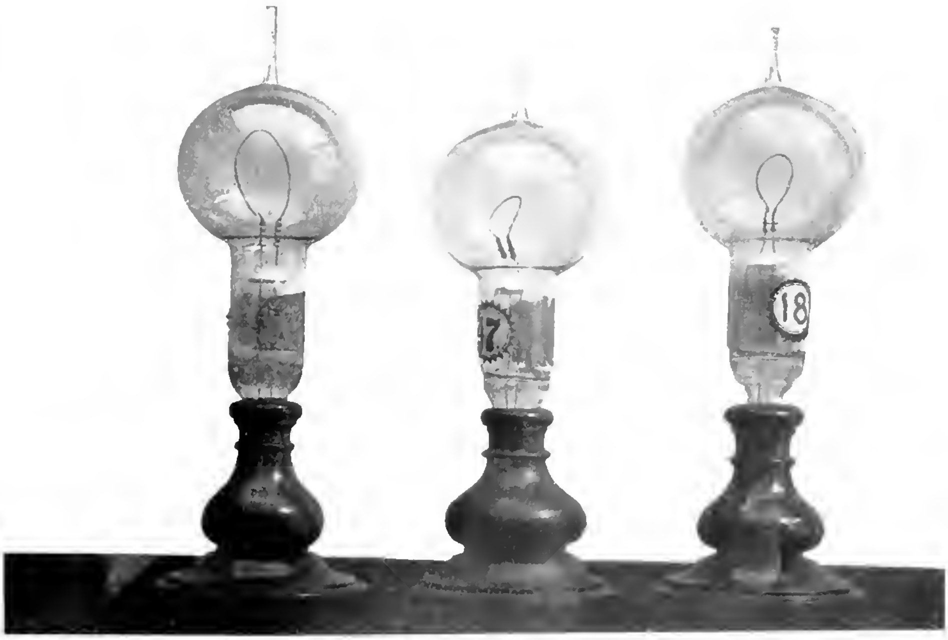
A detailed account of the work done in evolving this first system of incandescent lighting would fill volumes; but as I have already stated, the lamp was the key to the whole situation so a few remarks on this point of the work seems essential. The development of the first practical commercial incandescent lamp involved an enormous amount of experimental work. The first things I tried were filaments of metal, and finally long lengths of metal coiled to get high resistance and small radiating surface with varying degrees of success. Many of these experiments were made both in air and in vacuum. The results of these experiments proved to my entire satisfaction that the successful incandescent lamp must consist of a filament of high resistance, with a small radiating surface, and that such a filament must be contained in as nearly a perfect vacuum as we could make. I therefore proceeded to improve our apparatus for making a good vacuum and when I had accomplished this, success seemed certain. After all our experiments had been made to find the best material for the filament, I came back to carbon on account of the ease of getting a high resistance with a small radiating surface, and after innumerable trials, finally, on October 21, 1879, I carbonized a piece of cotton sewing thread bent into a loop, and this was sealed into a glass globe from which the air had been exhausted up to one millionth part of an atmosphere. This was the birth of the first commercial electric lamp. The sub-division of the electric current was an accomplished fact.

A patent taken out by me on Jan. 27, 1880, numbered 223,898, covered practically all of the salient features of the carbon lamp as made today, and the results that I arrived at were obtained because I had determined that I wanted to compete with gas and I worked all branches of the system to effect the desired result.

Many other people have worked on the incandescent lamp since this date, but I still believe in the great future of the carbon lamp. There are certain phenomena which work against high economy, but I believe that in time these defects will be surmounted and carbon will be the filament par excellence.

In conclusion, I would say that I am often asked to prophesy as to what artificial light may be developed in the future, but I have an objection to prophesies, as none of us knows very much; but it is certain that there are many things as yet untried that may give results as yet unthought of. A great deal of interest has been taken in what is known as cold light, namely, phosphorescence and fluorescence, but the chief objection to this is that it does not seem to suit the eyes of mammals. It is interesting to note here that there are still more streets lighted in New York City with gas than there are with electricity; but I believe that electric light will extend and will gradually supersede all forms of illumination, and that in the future even the country districts will be lighted electrically. If we consider the illumination of any large town, we may divide it into a central or thickly populated business district, with a residential district beyond this, and again a suburban district beyond the residential zone, with highways radiating into the country and leading to other towns. The illumination of all of these sections had to be considered, and it seems to me that all could be illuminated successfully with incandescent lamps, let us say with units of 100 candle-power spaced closely together in the business section and smaller units more widely separated where less light is required, while the country highways might be lighted in the same manner, only with smaller units. All our streets, parks, residences, public buildings, and stores, as well as our factories, will ultimately use electric light. From my own experience, I have found in my factories, where we use 100 candle-power mazda lamps with plenty of them, that we get no shadows and it appears to be the best form of lighting for our works.

There is certainly one good feature about electric light on which we will all agree, that is, that it is about the only thing that has decreased in cost during the last twenty years.



Some of Edison's Early Incandescent Lamps

[illegible]

LIGHT AND LIBERTY

# LIGHT

By Dr. W. R. Whitney

Director of the Research Laboratory, General Electric Company

This article by Dr. Whitney is one of great interest on the general subject of light and its artificial production. He shows that some of our theories and logic are apt to hinder experimentation in profitable directions, and that persistence and optimism are more likely to be rewarded with results than a conservatism born of a knowledge of supposed limitations. The author shows that we are still far from an artificial light for commercial purposes anything like approaching to daylight but he is optimistic as to the future.—Editor.

Dr. W. R. Whitney

My contribution to this symposium on light, I prefer to make general rather than specific. The real work of the research laboratory on the subject is naturally largely confined to the safe and sane applications of what we may call "contiguous reagents" to the problem. By contiguous reagents, I mean such theories of light, of radiation, of conduction, of molecules, of ions, of electrons, etc., as, without too great lapses of time or loan of effort, may be made practically useful, and such materials and principles as seem to promise improvement on present systems. In other words, we do not wander much afield. A theory might be advanced that ultra violet light could be generated more economically than white light and that by suitable yet-to-be-discovered-and-therefore-not-apparently-contiguous reagents, its effects would become visible and therefore useful. But this would not correspond to present methods of study. The research work of the past has been conservative. The incandescent lamp has been repeatedly improved by the application of refined methods, while the general reagents of a glass bulb with an incandescent filament has not been departed from. Practically all promising chemical elements have been tested as filaments in this way and in almost no other way. The arc lamp work has been along the line of continued study of the phenomena which existed in the very first arc that was ever observed. From the charcoal arc of Sir Humphrey Davy to the most recent type of arc lamp, the path has been narrow and the steps small. Substitution of one material for another produced by gradual stages the luminous arcs of today, in which often four or more chemical ingredients are found useful to carry out four or more different physical or chemical processes, all necessary to the lamp.

A general treatment of this research work is unnecessary, and specific treatment can better be given by others.

In this connection, though, there is a point which is always of interest to me: this is the apparent instability of our conclusions when we attempt, as it were, to put limits upon Nature. It seems rather as though Nature rewarded the patient, persistent and optimistic student in marked defiance of what was earlier learned as laws and logic. The trouble is, of course, with us, our laws and our logic. Like our theories, they are strictly useful only when they force us to a trial. All of them are often harmful when they stand in the way of experiment. When Auer von Welsbach made the osmium lamp, he had plenty of laws and logic showing the uselessness of attempting to make a superior incandescent filament of any other metals. Later, when Werner von Bolton, further advancing the art, made the first tantalum filament, he had good reasons to believe that no more promising metal existed. Similar ideas prevailed regarding tungsten when the apparent limit of its efficiency was one watt per candlepower. Alexander Siemens wrote as follows, only last spring, of the one watt lamp: "These results, taken together with the high temperature at which the tungsten lamp works, make it very doubtful whether it will be possible to construct a much more economical glow lamp, so that the consumer will have to look, for further economy, to the improvement and cheapening of the electric supply." The half-watt-per-candle lamp, which was already operating in the laboratory at that time, denied this allegation. Surely the increase of 50 per cent which the nitrogen introduction has effected in the economy of the glow lamp, has come because undue weight was not given to laws, logic and theories which apparently forbade it. There are still plenty of theories pointing onward. The good ones aim towards yet higher efficiencies, longer life, and better color.

Perhaps they ought to be valued more in proportion to their reach than their reason. Maybe this is technical pragmatism.

Therefore, in writing an article like this, I may be permitted to wander from the contiguous reagents and look at artificial light production from a distance.

What relation do our present best lamps bear to the best theoretically obtainable? This is a difficult question. I think it is fair to say that we do not know exactly how much electrical energy is theoretically just sufficient to give us one candle-power. Suppose this were known to be 0.05 w.p.c. We might say that because we are actually using half a watt per candle-power in our best incandescent lamp, our best present lamp would then be about 10 per cent light efficiency, and we might still expect a tenfold improvement. During the past twenty years the value of the ideal (consumption per candle-power) first dropped from 0.22 to 0.11, and then from 0.11 to 0.04 or 0.05, as investigators have continued their work, so that the actual improvements have had to be recalculated on a new basis, leaving us really still far from efficient electric lights. It has often been pointed out that we ought ultimately to expect to reach at least as great an efficiency for practical lamps as we can obtain with any known materials for brief periods of time. We can show for a few minutes, for example, a much greater efficiency than our best lamps exhibit during their much longer lives. It seems as though the difficulties which stand in the way of perpetuating temporary very favorable light efficiencies are more easily overcome than the kind of difficulties we know less about. It is this kind of difficulty that is partly overcome in the nitrogen tungsten lamp where the rate of evaporation of the metal at the temperature of operation is greatly reduced by the simple presence of nitrogen. In accord with this reasoning, one might say that a specific consumption of about 0.25 w.p.c. was in sight. That is, this is about the limits at which a tungsten filament will last at least a short time. This is twice as efficient as our best incandescent lamp and about four times as efficient as the standard mazda vacuum lamp. It is, however, at best not better than 25 per cent ideal efficiency.

An interesting point deserves consideration in this connection. It may well be stated that there are those who believe that there is no great object in making very much more efficient lamps. This condition will doubtless not always exist, but it is quite evident in some places today. Suppose, for example, that all the light needed for a dwelling could be produced at 0.25 w.p.c., and that people were satisfied with 100 c-p. in the house.

Assume, again, that the rate for power were 5c. per kw-hr. and that the lamps were burned 5 hours per night, 30 nights per month. The income to the power station would be 18¾ cents per month. This might mean that the lighting company could not afford to install the meters and read them. What this foreshadows is not that the higher efficiency lamps will be less eagerly sought and introduced, but that electric energy will be more freely used for still other purposes. There is little danger of a limit to power consumption being reached so long as the electric current is not generally used for heating.

While the advances of the past half century in production of light may seem considerable to our worm's-eye view, it is probably really only because of the proximity. No one has produced any considerable light that would be mistaken for daylight. You couldn't fool a half grown pumpkin with it. The energy which comes from the sunlight filtering through our atmosphere on a bright day can be measured as energy, and it amounts to approximately one horse power per square yard. If we arranged our best artificial light so that a horse power of radiant energy fell upon a square yard of earth during the night, would the grass grow at the daylight rate? Certainly not! It would scarcely grow at all. It might grow as much in a whole summer of nights as in one summer's day.

Growing lettuce, when given plenty of electric light, can be kept awake at night and will even grow a little, but tomatoes insist on sleeping and decline to grow under such conditions. It is said in general that "one hour of sunlight will accomplish more in the way of growth than several nights of arc light." In fact, we are still so near the tallow dip and so far from daylight that it is almost inconceivable that an artificial daylight should ever be asked for. We are so accustomed to the changes in color which take place all around us, when we pass from daylight to lamp light, that we seldom even think of it. Our incandescent lamps still give a light that, at its best, would never be mistaken for the feeblest ray of good daylight. A bird's-eye view makes the advance seem slight. A layman might even think we were not trying to imitate daylight at all, but fire light instead. He would be flattering us. I believe the future will be richer in artificial daylight, but the contiguous reagents may seem a little remote. McFarlan Moore, who has perfected a vacuum tube lamp to be used by dyers and color matchers, has produced light which closely resembles daylight, but at a cost and under conditions which seem to make its present use for ordinary illumination prohibitive. By screening the other ordinary light sources with colored screens, a truly white light is available, but thus far the cost also precludes its general use. In other words, there is yet no artificial daylight commercially producible. There can be little doubt that it would be used if obtainable at several times the cost of our present night lights, so that there is some uncultivated field here in artificial light production. While efforts will evidently be continually expended towards cheapening our present lighting methods, it seems also certain that investigation of ways of producing a cheap light which will resemble daylight will receive additional attention. According to the pragmatic doctrine, this is only true when it is made good, and "generalizations in Nature are never strictly true, not even this one."

There is being so much work done in fields not at first apparently closely allied to light, that no little interest is attached to thinking of the inter-relationships. It has been but a short step to follow the investigators who have mapped the spectra of hot bodies or of fire-flies, and those who exposed to our view previously unknown spectral fields even ten times as extensive as our visible spectrum from violet to red. Infra-red and ultra violet rays were to be expected. Prof. Langley practically photographed the sun's spectrum below the red of the ordinarily visible part to wave lengths of 0.005 mm., or over a range ten times as great as the visible portion of light. In this new field were also all sorts of absorption lines and bands like the Frauenhofer lines of the visible spectrum. These are to be looked for in all further extensions of light or ether vibrations. But what an inconceivable field for research must exist in the range where wave lengths pass from 0.0003 mm. of ultra violet light to the 0.000000001 mm., which are now attributed to X-rays; or where the infra red ether vibrations extend upward in the wireless rays to miles in length.

So even if the scientists do not agree in considering the word "light" to cover all radiations in the hypothetical ether, we are still handling a "contiguous reagent" of light when we are operating a wireless station or an X-ray tube. It is certain that the physicist, chemist and electrician are to gain more from the coördination of scientific work in these fields than in any other now known, and this for years to come. I need only, in a layman's way, point for example to the interpretation of spectral lines such as are now found in the mapped regions and as will be found and utilized from X-ray to wireless waves, together with their bearings on the composition of chemical atoms or the unlimited refinement of wireless signalling, to indicate the possibilities.

If one considers light as all radiations of whatever wave length in the ether, he has also a nice way of co-relating all those evidently connected phenomena of "emission" and "convection" while keeping his picture clear. He has a sort of filter which separates all the relevant materials into those which pass and those which are held by the theory. For example, the energy lost from a hot body in air is emitted in part as radiation in ether waves and as convection in the air. In the emanation of radium, polonium, etc., and in all the phenomena of electrical discharges through gases and in X-ray tubes, when we are not dealing with tangible emitted moving masses, as in the case of cathode rays, vaporizing metal, alpha particles, etc., we are dealing with ether vibrations, as in the X-rays proper and the gamma rays. When we know that to the latter may be attributed the velocity of light, and to the former always lower velocities, less penetrability, etc., we have made further steps easier. In going backward in thought from the ether vibration of any kind or color, we find its pedigree shows the chemical atom as its grandparents, with the negative electron its dam and the positive ion its sire. Or, putting it in another way; all the radiations in the ether which I am here wanting to call "light" and which vary from gamma radium rays to wireless waves, are born of the electrons and all are called into being by changes in the velocity of electrons. The family tree of blood relationship helps account for the inherited characteristics in each case.

The absorption of light by a body or material—that is, its opacity—is due to the transfer of the energy of the ether vibrations to something in the body which can transform it into other energy forms. At present we see no good reason, for example, why ordinary light should pass readily through a quantity of lead when this lead is one of the components of a sheet of glass, while it will not pass through the same thickness of lead when in the form of sheet metal.

When we learned that the continuous spectrum, on passing through sodium vapor, lost that part of the yellow light which sodium produces when heated to luminescence, the Frauenhofer dark lines of the solar spectrum were better understood, but the opacity of materials in general was not.

In the case of X-ray light there is greater simplicity. Here the absorption or opacity seems to be determined entirely by the atoms of the material. A substance of high atomic weight is, in general, more opaque to X-rays than one of low atomic weight, and the opacity is proportional to the number of atoms per volume of material. The opacity of an atom is retained in whatever compound it may be found. The lead in lead glass is as opaque as the same lead in white paint or sheet metal. The diamond differs from graphite in opacity to X-rays only slightly and this just as would be expected from the difference in gravity. The heavier diamond is more opaque in the same thickness, because the carbon atoms are more concentrated; the opacity here is proportional to the density. On the other hand, carbon being of low atomic weight, is in all cases more transparent to these rays than most of the other chemical elements. This simplicity, when realized as occurring in all compounds, makes one realize that at present X-rays in this respect are much simpler than ordinary light. The absorption of homogeneous X-rays is an atomic property, and the absorption of a compound, or its opacity, is that of its components for the corresponding concentration. For example, solid sulphur and carbon, when superposed, exhibit the same degree of opacity as the corresponding quantity of carbon bisulphide, though this latter is transparent to ordinary light, and the components are opaque. Something in the atom, and not a property of the molecule itself, nor the material as a whole, takes up the energy of the X light—absorbs it.

It would lead from light to darkness to take up the question of opacity of material to ordinary light, but the recent discoveries of the laws of opacity of X-rays and the gamma rays of radium are encouragingly simple, and they doubtless will greatly aid in the understanding of the relations of ordinary light and light absorbing matters.

# THE PROBLEM OF LIGHT-PRODUCTION

By Dr. Edward P. Hyde

Director of the Physical Laboratory, National Lamp Works of General Electric Co.

The many different aspects from which light can be studied are mentioned, but the author chiefly confines his article to the physical properties of light-giving sources which are important in the production of light. The sensitivity curve of the eye is given and explained. The author then sets out to answer four fundamental questions concerning the problem of light production, viz: (1) What are the extreme values of luminous efficiency possible for monochromatic light, for white light, and for black body radiation? (2) What are the actual values of luminous efficiency for ordinary illuminants in comparison with the values theoretically obtainable, and what are the causes of these relatively low efficiencies? (3) What are the possible ways in which commercial illuminants of higher efficiency may be developed? (4) What other considerations than luminous efficiency enter in determining the most satisfactory illuminant?—Editor.

Dr. E. P. Hyde

LIGHT is a sensation. By extension the term is also applied to the radiant energy emitted by a luminous source, which, transmitted through the ether in electro-magnetic waves and impinging on the retina of the eye, produces those retinal changes which are forwarded through the medium of the optic nerve to the brain cells and call forth the sensation of light. And whether we focus our attention on the last step of the process, and inquire into the phenomena and the mechanism of the phenomena which occur in the cells of the brain and of the nerve fibrils, or investigate the propagation of radiant energy through empty and matter-weighted space, or whether we study these phenomena which are exhibited in the process of emission of radiant energy by luminous sources, the problem is equally interesting.

In the present article we shall center our attention on this last problem—the emission of radiant energy by luminous sources; but in the consideration of this we shall avoid these esoteric questions which have to do with theories and speculations regarding the mechanism of emission and shall concern ourselves principally with those established and measurable physical properties of light-giving sources which are of importance in the problem of lighting. It is, of course, impossible to refrain from traversing the complete circuit from the oscillating electrons to the physiological phenomena involved in vision, for a study of the light-giving properties of luminous sources hangs upon the response in the human eye and brain to those radiations emitted by the source. The problem of light production is indeed the problem of the correspondence between physiological sensibility and physical excitation.

Our first inquiry then, must be into the degree of response of the retina to radiation of varying wave-lengths or color. Complete information on this point under ordinary conditions is given by the curve in Fig. 1, which is ordinarily called the *sensibility curve* of the eye. This curve is obtained from experimental data on the quantities of energy per second in the different portions of the spectrum required to produce the same luminosity, i.e., the same intensity of sensation. The reciprocals of these quantities of energy are thus plotted as the ordinates of the curve of Fig. 1, corresponding to the different wave-lengths, $\lambda$, expressed in thousandths of a millimeter. This curve shows that if a lamp emitted only orange-colored light of wave length 0.00061 mm. (or 0.61 $\mu$) it would have a candle-power of only one-half that of a lamp which emitted the same quantity of energy per second, but which confined its radiation to yellowish-green light of wave-length 0.000545 mm. (0.545 $\mu$). It also expresses the fact that all radiation of longer wave-length than 0.7 $\mu$ and all radiation of shorter wave-length than 0.43 $\mu$ produces little or no visual response, and so this region of the spectrum, taken roughly between 0.43 $\mu$ and 0.7 $\mu$, is defined as the visible region of the spectrum, or more concisely as the visible spectrum. The average eye can see light between the somewhat broader limits of 0.8 $\mu$ and 0.83 $\mu$, but owing to the uncertainty of these limits and to the feebleness of the sensation near these extreme limits the practical limits taken are somewhat narrower. Unfortunately these are not always taken the same by different writers and so I shall define my limits in the following discussion as otherwise inconsistencies may arise.

With these facts regarding the sensibility of the eye before us we are prepared to discuss several questions regarding the radiating properties of matter which are of prime importance in lighting. And perhaps it will be well to confine this limited article to an attempt to answer four fundamental questions in the problem of light production.

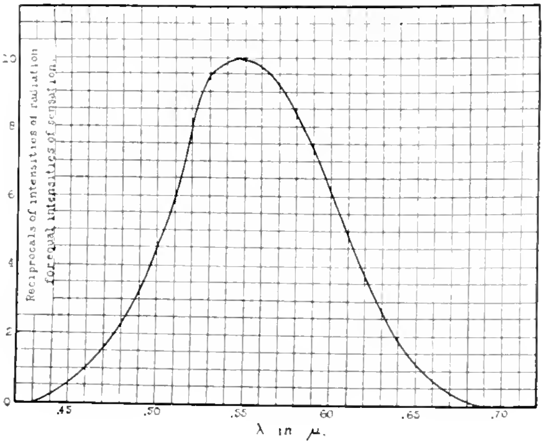


Fig. 1

*a. What are the extreme values of luminous efficiency possible for monochromatic light, for white light, and for black body radiation?* By "luminous efficiency" is here meant the ratio of the rate of luminous radiation measured in lumens, to the rate of energy consumption or transformation, measured in watts supplied to the lamp. From a consideration of Fig. 1 it is seen at once that the highest possible luminous efficiency attainable would be secured if all the energy supplied to a lamp were radiated in yellow-green light of wave-length 0.545 $\mu$. The efficiency of such a lamp would be of the order of magnitude of 800 lumens per watt, or about fifteen times the efficiency of the most efficient light source in current use. It is interesting to note in passing that although we do not know what internal energy reactions are involved in producing the glow of the ordinary fire-fly, looked at merely from the standpoint of radiation the fire-fly has a luminous efficiency of probably more than 95 per cent of the highest attainable efficiency.

If all the energy supplied to a lamp were radiated in the visible spectrum (between $\lambda = 0.76\ \mu$ and $\lambda = 0.38\ \mu$) and if the radiation were distributed throughout the visible spectrum in the way to produce white light the luminous efficiency would be approximately 300 lumens per watt, or about 40 per cent of the efficiency of the monochromatic radiator. In this case it is supposed that all the energy supplied to the lamp is radiated within the visible spectrum, none being radiated in the long infra-red or heat waves.

Finally what would be the highest possible efficiency of a black body radiator at the most favorable temperature? We can think of a black body as represented fairly accurately at ordinary temperatures of operation by a carbon filament. If the carbon filament could have its temperature increased indefinitely without subliming or melting, at what temperature would it attain to the highest possible efficiency and what would be the luminous efficiency at that temperature? It is easy to prove that this temperature would be very closely that of the sun or 5000-6000 deg. C., that the color of the light would be white, and that the luminous efficiency would be approximately 125 lumens per watt, or about 15 per cent of the highest possible efficiency of monochromatic radiation.

*b. What are the actual values of luminous efficiency for ordinary illuminants in comparison with the values theoretically obtainable, and what are the causes of these relatively low efficiencies?* The luminous efficiencies of ordinary illuminants are all far below the maximum luminous efficiency of monochromatic radiation, viz., 800 lumens per watt; moreover, they are all below the maximum luminous efficiency of the black body at 5000-6000 deg. C., which we have just seen to be approximately 125 lumens per watt. It is not the intention in this article to dwell long on the actual values of luminous efficiency of commercial illuminants, but rather to call attention to the relation between these values and the maximum values theoretically possible, and even more particularly to explain some of the phenomena which enter in determining the relatively low efficiencies, and to indicate the possible ways in which commercial illuminants may be developed in efficiency. It may be well, however, before proceeding to this discussion to give approximate values of luminous efficiency for some of the more common illuminants in their relation to the maximum values theoretically obtainable. Such data taken from published investigations are given in Table 1.

The matter of interest in the physics of light-production in connection with the luminous efficiencies of ordinary illuminants is the considerations of the factors which enter to determine these efficiencies. The electric incandescent lamp furnishes an interesting illustration. A definite amount of energy per second is supplied electrically to the terminals of the lamp. A part of this is transformed into heat by the $I^2R$ loss in the leading-in wires and junctions; the remainder is transformed into heat by the passage of the current through the high-resistance filament. That which is transformed into heat by the $I^2R$ loss in the leading-in wires is completely lost, as far as its direct influence on the luminous efficiency of the lamp is concerned. This loss in the ordinary types of lamps manufactured at the present time is negligibly small, amounting in most cases to less than 1 per cent.

**TABLE I.***

**Values of Luminous Efficiency**

| Sources | Values of Luminous Efficiency in Lumens per Watt | Relative Values in Luminous Efficiency in Terms of that of Monochromatic Radiation at Wave-Length 0.545 |
|---|---|---|
| Monochromatic radiation ($\lambda = 0.545\ \mu$) . | 800 | 100 Per cent |
| White light of maximum efficiency . | 300 | 40 Per cent |
| Black body at temperature of maximum efficiency 5000-6000 deg. C. | 125 | 15 Per cent |
| *Quartz mercury arc | 50-60 | 6-7½ Per cent |
| Luminous and flame arcs . . | 40-60 | 5-7½ Per cent |
| Glass mercury arc | 12-24 | 1½-3 Per cent |
| 0.5 Watt-per-candle gas-filled mazda lamp . . | 16 | 2 Per cent |
| D-c. open carbon arc | 16 | 2 Per cent |
| Nernst glower | 5 | 0.6 Per cent |

The energy which is transformed into heat in the filament is dissipated in various ways, only a small part of it ultimately becoming available for the production of light. A part of the energy is dissipated by conduction and convection by the gases in the bulb in cases where the vacuum is not high, but this loss in a good lamp is entirely negligible. Another portion of the energy is dissipated through heat conduction by the leading-in and anchoring wires. Thus, owing to the high temperature of the filament compared with that of the leading-in and supporting wires with which it comes into contact, there is a continual heat conduction away from the filament at these points, thus cooling the filament locally and decreasing its luminous efficiency.

The remainder of the energy transformed in the filament is radiated, the spectral distribution depending upon the temperature of the filament. Only that portion which is radiated in waves within the limits of wave-length of the visible spectrum is productive of light. As stated above, the loss due to conduction and convection by the gas in a normal lamp must be negligibly small. It is quite a simple matter, however, to show what a saving is effected in the case of an ordinary incandescent lamp through the use of an evacuated bulb. If a lamp is constructed having a filament of some material, such as platinum, which can be operated either in air or in a vacuum, the difference in power supplied to the lamp when evacuated and when filled with air (the temperature of the filament being the same in the two cases) is under certain conditions quite large. Thus a platinum filament of 0.1 mm. diameter and 15 cm. length, mounted in a pear-shaped bulb of 8 cm. maximum diameter and 13 cm. length, when operated at a temperature of approximately 1700 deg. abs. (Centigrade+273 deg.), requires 4.75 watts when the bulb is evacuated, and 24.3 watts when filled with air at atmospheric pressure. In other words, the loss by convection and conduction of the gas is 400 per cent of the total power required to operate the filament in a vacuum.

The relative magnitude of this loss, which in the case cited is quite large, must be understood to depend on at least four factors: (1) the diameter of the filament, (2) the temperature of the filament, (3) the emissive power of the filament material, and (4) the nature of the surrounding gas. In the new gas-filled mazda lamp these factors enter in such a way that the relative magnitude of the gaseous conduction losses is small, as otherwise the gain in efficiency owing to the higher temperature of operation of the filament would be largely offset by the loss in efficiency occasioned by the gaseous conduction.

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* This table of values of luminous efficiency needs some explanation to prevent possible misunderstanding. It is to be understood, of course, that the first three values given are for ideal sources never realized in practice, and are, moreover, estimates which may be in error by 25 per cent or even more.

Also the values given for arc lamps are subject to much uncertainty. This is particularly true of the value for the quartz mercury arc. Values of 60 lumens per watt have been recorded for the quartz lamp omitting all consideration of the ballast resistance, etc., but the values obtained in ordinary commercial lamps on ordinary circuits are very much smaller than those given in the table. As our interest in the present article, however, relates rather to the physical explanation of the relatively low efficiencies obtained in the various ordinary methods of light-production at their best than to a practical consideration of lamps in ordinary use it seems advisable to present the highest values obtainable with the quartz arc under the most favorable conditions, and omitting any consideration of losses in ballast resistance, etc.

The losses by conduction at the leading-in and anchoring wires in the ordinary electric incandescent lamps have been variously estimated, the published values ranging from an almost negligible quantity to as high as 25 or 50 per cent in various types of standard lamps. Attempts at direct measurement of the energy radiated seem to indicate comparatively high figures for the thermal conduction losses, whereas the conclusion from practical experience in lamp manufacture points to rather small losses. Measurements by a new direct method gave for these losses for normal carbon, tantalum and tungsten lamps values in all cases of the order of magnitude of 5 per cent, which would seem to be more consistent with the experience of lamp manufacturers than the much larger losses found by other investigators.

If then the losses by convection and conduction amount to but a small percentage of the total energy supplied to the filament, explanation of the relatively low luminous efficiency of the lamp must be sought in the spectral distribution of the radiated energy.

In a similar way the losses in other types of lamps may be analyzed, though not so simply as in the incandescent lamp. In the d-c. open arc the luminous efficiency of the crater, which is at a temperature of 3800-4000 deg. abs. is probably 70 or 80 lumens per watt, but owing to the many losses the net efficiency is only about 16 lumens per watt. Also in the low pressure arc the efficiency of the luminous vapor is quite high but the losses at the terminals are great and so reduce the net efficiency. Except in the case of the electric incandescent lamp there is much energy supplied to the lamps which is not transformed into radiation. But in all the lamps the actual efficiency of the radiant energy is relatively low compared with the maximum efficiency of 800 lumens per watt of monchromatic radiation, though the disparity, especially in the case of such lamps as the quartz mercury arc, would be much less if all the losses except that due to infrared radiation were eliminated.

c. *What are the possible ways in which commercial illuminants of higher efficiency may be developed*? From the preceding consideration it immediately follows that the efficiency of commercial illuminants may be increased theoretically in three possible ways. Thus net efficiency would be increased if the energy losses due to thermal conduction and convection could be eliminated or reduced. It would also be increased if the temperature of operation could be raised without reducing seriously the effective life of the lamp. Finally it would be increased if substances could be found which would radiate relatively more energy in the visible region of the spectrum even at temperatures of operation such as are ordinarily found in similar illuminants in present use.

Regarding the first possibility, there is little to be gained in the electric incandescent lamp in which the efficiency loss owing to the cooling effect at the leading-in and supporting wires amounts only to a few per cent. Much gain has been made in the low pressure arc, such as the Moore nitrogen tube by greatly lengthening the tube and thereby reducing very considerably the relative magnitude of the losses at the electrodes. These losses enter most largely in gas lamps, as in the open gas burner or in the Bunsen flame in conjunction with an incandescent mantle, and though it is impossible to eliminate these losses it is not inconceivable that they might be reduced.

Regarding the second possibility, it is of course very well known that increase in temperature increases the relative amount of energy radiated in the visible region of the spectrum, and also produces a different distribution of energy in the visible spectrum, the two factors combining to increase very materially the luminous efficiency as the result of a relatively small increase in temperature. Thus in the case of the new gas-filled mazda lamp the reduced sublimation owing to the pressure of the gas permits an increase from about 2000 deg. C. to about 2550 deg. C., or approximately 550 deg. in the temperature of operation with a corresponding increase of more than 100 per cent in the luminous efficiency.

Similarly the substitution of quartz or other highly refractive material in the place of glass in the mercury arc has made possible a somewhat higher temperature of operation and a much higher efficiency; and it is not impossible that still further improvement in illuminants may be produced in this way.

The third possibility referred to above is in many ways the most promising. No material substance radiates precisely like the ideal radiator or black body, and the deviations for materials used in commercial illuminants are practically without exception in the direction of increasing the luminous efficiency. Even in metallic filament electric incandescent lamps an appreciable increment to the efficiency is to be ascribed to this cause commonly known as *selective radiation.* The relatively high efficiency of the flame arc is also ascribable to this cause, and the peculiar radiating properties of the ceria-thoria mixture used in the incandescent gas mantle account for the efficiency of this type of lamp.

It has been customary in the past to distinguish between *temperature radiation*, as exhibited ideally in the black body, and illustrated in the carbon and metallic filament lamps, and *luminescence* as exhibited in fluorescence and electro- and chemi-luminescence and illustrated in the flame arcs and the low pressure arcs such as the Cooper-Hewitt lamp and the Moore tube. This distinction is not now so universally insisted upon as in the past, but whether the distinction is real or artificial the practical fact remains that much development in commercial illuminants has proceeded from the utilization of certain radiating substances which under certain conditions of excitation emit radiant energy favorable to high luminous efficiency. With the increasing knowledge which is being acquired regarding the radiating properties of matter I look to the development of lamps based on the principle of highly selective emission as the most promising field in the invention of the illuminants of the future.

*d. What other considerations than luminous efficiency enter in determining the most satisfactory illuminant?* Much has been said regarding the luminous efficiency of illuminants—not from the viewpoint of a comparative study of the efficiencies of lamps and of the variations in these efficiencies under varying conditions, such as that of varying voltage, but rather as a basis for the consideration of the problem of light-production. The first requirement of an illuminant is that it give light, and therefore luminous efficiency enters as a factor of the first importance; but there are other requirements to be demanded of a light source of almost equal if not fully equal importance.

Efficiency has been defined as "the ratio of satisfactoriness to cost, and not the reciprocal of cost." Thus far in considering luminous efficiency we have been dealing only with the denominator of the fraction. We come now to the numerator, but we are restricted to a mere mention of some of the more important properties which an illuminant should possess to be satisfactory. These properties, of course, will in some cases vary with the uses to which the illuminant will be put: such a property is that of *quality* of light. We have seen that the most efficient source would be one radiating all its energy in the yellow-green region of the spectrum, but a yellow-green monochromatic light would be most unsatisfactory for many purposes. The quality of light from an illuminant is a very important element in determining the utility of that illuminant under different conditions, and so the quality of light from an illuminant has come to be looked upon as one of its most important characteristics.

We have seen that the energy radiated in the infra-red and ultra-violet regions of the spectrum is ineffective as regards both the magnitude and the quality of the luminous flux, and yet no one knows positively the bane or blessing that would ensue from the elimination of the radiation in these regions of the spectrum. Infra-red radiation is probably of considerable importance in plant life, and ultra-violet radiation is a well-recognized germicide; it would be difficult to forecast the result of eliminating these radiations from our natural and artificial illuminants.

Brightness of a source, or the candle-power per unit area, is an important characteristic of an illuminant, and there are minor characteristics, such as divisibility into small units, hardiness, convenience of operation, and others, all of which influence the satisfactoriness of an illuminant in practice.

The solution of the problem of light-production must take cognizance of all these desiderata, and the development of improved illuminants must be guided by the requirements which increased knowledge imposes as the result of observation and experiment. The correct evaluation of these requirements comes within the province of the rapidly developing science of illumination.

# EFFICIENCY OF ILLUMINANTS

By Dr. Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

The author begins his article with the statement that efficiency of the light source is the first and most important factor in any problem of illumination; for undesirable qualities, if present, can always be got rid of by a sacrifice of efficiency, and thus efficiency is the dominating factor in economical light production. The only correct comparison of light efficiencies is on the basis of the total light flux of the illuminants, expressed in mean spherical candle-powers or in lumens. Some very interesting data on the efficiencies of the electric illuminants at present available are given in the form of tables; the first table grouping the lamps according to types, and in order from the least efficient to the most efficient units of the several types; the second table giving the relative efficiencies of the illuminants of the first table, also in order from the least efficient to the most efficient, but irrespective of the capacity of the illuminants; while the third, fourth and fifth tables compare respectively the efficiencies of 300 watt and 500 watt illuminants, and the relative efficiencies of the various sizes of illuminants.—Editor.

Dr. C. P. Steinmetz

When considering problems of illumination, whether it be lighting of indoor places, or of the streets of a city, the first and most important question is the efficiency of the source of light, or the illuminant.

Efficiency is not the only factor, but other features come in as essentials of a satisfactory illumination, such as:

The quality or color of the light; that is, how nearly white it is, or whether it is off color towards the yellow or the green.

The size of the lighting unit, as determining uniformity and diffusion of the illumination.

The glare or absence of glare of the illuminant; that is, the intrinsic brilliancy of the light source.

The steadiness of the light, and its sensitivity to fluctuation of voltage or current.

The characteristic of the electric circuit required for the operation, as determining the amount of station apparatus, such as constant current transformers, voltage regulators, etc.

The cost of maintenance and renewal, such as trimming, length of life of the arc lamp electrodes, useful life of the incandescent lamps, etc.

However, all this is secondary to efficiency, because defects in any of the above enumerated features can be overcome by a sacrifice of efficiency:

While a light source which is free of glare would be preferable even if of slightly lower efficiency, its inferiority in efficiency must not be much, as a light source can be freed of glare with a slight decrease of efficiency, by a diffusing globe.

Higher cost of maintenance and renewal balance against lower cost of power in the more efficient illuminant, etc.

Thus, while the other features of a satisfactory economical illuminant must be considered and balanced against light efficiency, the efficiency is economically the dominating factor.

In judging of the efficiency of light sources, two procedures are feasible:

We may secure and photometrically test all the commercially available illuminants, and base our judgment thereon. This would be the proper and only feasible way in solving an illuminating engineering problem, as when designing the illumination for a building, store, streets of a city, etc.

Such procedure would fail, however, when considering the larger problem of the development of the art of illumination, and of the possibilities of the various illuminants, as when dealing with the question whether the new high efficiency incandescent lamp will replace the arc lamp, or whether the arc lamp as well as the incandescent lamp will both find definite fields of usefulness. Questions of this character can not be decided by the comparison of existing types of lamps, as these types merely represent the industrial requirements of the preceding years, and a general judgment on the possibilities of the various illuminants would almost certainly be erroneous and misleading, if based only on existing commercial types. It would for instance not include the effect of the gas-filled mazda lamp or of the titanium lamp, neither of which is yet a standard commercial product.

Thus, in judging on the possibilities of the various types of illuminants, we must go beyond the mere comparison of existing commercial lamps, and must base our judgment on the efficiency characteristics of the light giving radiator—lamp filament or arc stream—as derived from the photometric tests of lamps in commercial existence or in development.

In comparing light efficiencies, only the total light flux given by the source of light can be considered, and will in the following be given in mean spherical candle-powers (msph. c-p.), as the mean spherical candle-power is a more familiar unit than the lumen (one lumen = 4 $\pi$ msph. c-p.).

The candle-power 10 deg. below the horizontal, which is of importance in street lighting, and the mean hemispherical candle-power, which is of importance in indoor lighting, are not measures of the light flux of the illuminant, and have no direct relation to efficiency, but they represent the distribution of the light flux as affected by the type of reflector, globe, etc. Comparisons based on 10 deg. c-p. or mean hemispherical c-p. characterize just as much the efficiency of the design of globe or reflector as the light flux, and thus when used in the efficiency comparison of light production, would be misleading. For instance, a European quartz mercury lamp gives 10 deg. below the horizontal the same c-p. per watt as the mazda lamp, but gives four times the mean hemispherical candle-power of the mazda lamp: its total light flux, however, or its msph. c-p. per watt, are only twice that of the mazda lamp. By a suitable reflector, the mean hemispherical c-p. of the same mazda lamp could be increased by 50 per cent, or by another reflector the 10 deg. c-p. of the mercury lamp made more than twice that of the mazda lamp, etc. Thus, depending on the reflector used, we would get all kinds of comparisons of these two lamps, when using 10 deg. or mean hemispherical c-p. No reflector, however, can change the total light flux, or the msph. c-p. of the light giving source, and with the same light flux and equally good design of reflector, the 10 deg. c-p. and the mean hemispherical c-p. would be closely the same also, so that the total light flux is the characteristic of the illuminant which best determines its efficiency for all uses.

Table I gives a collection of efficiency data of the various available illuminants.

The fourth column gives the msph. c-p. per watt of commercial lamps, as based on photometric tests. Therefrom, and from other tests, are derived in column 1 the specific consumption in watts per msph. c-p., and in column 2 the efficiency in msph. c-p. per watt, of the light source proper, that is, the filament, arc or vapor stream. The values in column 2 usually are higher than those in column 4, by the amount of light which in the commercial lamp is lost in reflectors, obstructed (in the arc lamp) by the operating mechanism, etc. The efficiencies given in column 2 can in general not be realized, since in directing the light flux for the distribution required by the use of illuminants—downwards in indoor lighting, and with a maximum about 10 deg. below the horizontal in street lighting—a loss of light occurs in reflectors, globes, etc. This loss is assumed equal to 20 per cent in the incandescent lamps, and 22 per cent in the arc lamps. These values represent about average conditions met with properly designed light distributors. Column 3 then gives the *available efficiency*, that is, the efficiency of the light flux directed for the contemplated use, or the "useful light flux" available with suitable reflector, etc. Columns 5 and 6 give the mean hemispherical candle-power—indoor lighting—and the candle-power 10 deg. below the horizontal—street lighting—of the lamp per watt, as given by test or estimated as available with suitable reflector, etc.

It is obvious that general efficiency comparisons of the various classes of illuminants must be based on the values in column 3, as these values represent the usefully available light flux in msph. c-p. per watt. All the following tables, except where otherwise stated, are therefore based on the values in column 3 of Table I.

A difficulty exists in comparing flame carbon arcs with each other and with other illuminants, insofar as flame carbons have no typical efficiency, but their efficiency depends on the amount of impregnation. With increasing impregnation, the efficiency increases, but other defects make themselves gradually more and more felt, as slagging and sticking, etching of the glassware, lesser steadiness, etc. In the tables are given the best values found in test, though commercial flame carbons of different types and makes are as a rule lower by from 20 to 50 per cent.

Table II gives the relative efficiency of the various illuminants of Table I, arranged in the order of their efficiency, from the least efficient to the most efficient, irrespective of the size of the illuminant.

The limitation of this table naturally is, that the efficiency of illuminants varies with the size, or watt consumption, in a different manner for different illuminants. Thus the efficiency of incandescent lamps remains approximately constant over a wide range of sizes, while that of arc lamps increases with increasing, and decreases with decreasing watt consumption. A smaller unit of arc lamp would therefore take a lower position, and a larger unit a higher position in the table.

As 300 watts and 500 watts are representative power consumption of medium and of large light units, in Table III and Table IV are given the efficiencies of available 300 and 500 watt illuminants, in order of their efficiency, from the lowest to the highest.

Table V then gives comparison of the watt consumption of the different types of illuminants required to produce respectively 200, 300, 400, 500 and 1000 available msph. c-p. The values in this table are also arranged in order from the lowest efficiency, that is, the highest watt consumption, to the highest efficiency, that is, lowest watt consumption.

Many interesting conclusions can be drawn from these tables.

For instance, in Table V, 400 c-p. seems about the dividing line between high efficiency and low efficiency illuminants: The a-c. and the d-c. arc and the mazda lamp do not go beyond 400 c-p., while the flame carbon arcs, the titanium lamp and the gas-filled mazda lamp do not go below 400 c-p., and can not be produced efficiently in smaller units.

### TABLE I. LIGHT SOURCES

| | RADIATOR | | Available Efficiency; Mean Sph. C-p. per Watt (Inclusive Reflector)* | LAMPS | | |
|---|---|---|---|---|---|---|
| | Specific Consumption Watts per Mean Sph. C-p. | Efficiency; Mean Sph. C-p. per Watt | | Mean Sph. C-p. per Watt | Mean Hemisph. C-p. per Watt | 10° C-p. per Watt |
| INCANDESCENT LAMPS | | | | | | |
| Treated carbon fil., 3.1 watt hor. c-p. | 3.9 | 0.26 | 0.21 | 0.26 | 0.4 | 0.4 |
| Metallized carbon fil. (Gem) 2.5 watt hor. c-p. | 3.1 | 0.32 | 0.26 | 0.32 | 0.5 | 0.5 |
| Mazda, 1 watt p. hor. c-p. | 1.25 | 0.80 | 0.64 | 0.80 | 1.2 | 1.25 |
| Gas-filled mazda, 0.5 watt p. hor. c-p. | 0.625 | 1.60 | 1.28 | (1.60) | 2.4 | 2.5 |
| Melting tungsten in vacuum | 0.28 | 3.6 | 2.88 | | | |
| ENCLOSED CARBON ARC LAMPS | | | | | | |
| 6.6 amp., 450 watt, a-c. series | 2.0 | 0.50 | 0.39 | 0.4 | (0.7) | 0.5 |
| 6.6 amp., 480 watt, d-c. series | 1.25 | 0.80 | 0.62 | 0.6 | (0.9) | 1.0 |
| 500 watt, d-c. "intensified" arc | 1.00 | 1.00 | 0.78 | 0.8 | 1.4 | |
| FLAME CARBON ARC LAMPS | | | | | | |
| Best values of 500 watt yellow flame | 0.25 | 4.0 | 3.1 | 3 | 5.6 | 6.2 |
| Best values of 300 watt yellow flame | 0.4 | 2.5 | 1.95 | 2 | 3.5 | 4 |
| Best values of 500 watt white flame | 0.4 | 2.5 | 1.95 | 2 | 3.5 | 4 |
| MAGNETITE ARC LAMPS, D-C. | | | | | | |
| Standard 4 amp. 300 watt 250 hour | 0.77 | 1.3 | 1.0 | 1.0 | | 2.2 |
| Special 4 amp. 300 watt 150 hour | 0.56 | 1.8 | 1.4 | 1.4 | | 3.0 |
| Standard 6.6 amp. 500 watt 100 hour | 0.53 | 1.9 | 1.5 | 1.5 | | 3.2 |
| Special 6.6 amp. 500 watt 100 hour | 0.46 | 2.2 | 1.7 | 1.7 | | 3.5 |
| TITANIUM ARC LAMPS, A-C. | | | | | | |
| Standard 220 watt | 0.42 | 2.4 | 1.9 | 1.8 | | 4.0 |
| Experimental 350 watt | 0.29 | 3.5 | 2.7 | (2.6) | | 5.4 |
| Experimental 500 watt | 0.22 | 4.6 | 3.6 | (3.5) | | 7.0 |
| Best values | 0.15 | 6.7 | (5.2) | | | |
| MERCURY LAMPS | | | | | | |
| Best values, glass tube | 0.5 | 2.0 | 1.55 | | | |
| Best values, quartz tube | 0.4 | 2.5 | 2 | | | |
| MOORE LIGHT | | | | | | |
| Best values, nitrogen | 1.8 | 0.56 | 0.45 | | | |
| Best values, neon | 0.7 | 1.45 | 1.1 | | | |

* Loss by reflector assumed 20 per cent for incandescent, 22 per cent for arc lamps.

It is interesting to note that the 6.6 amp. a-c. series enclosed carbon arc lamp, which has done practically all street lighting of America for many years, and has done it fairly satisfactorily, and which is still today the most widely used street illuminant throughout the country, does not even reach 200 c-p., but, as seen from Table II, gives only 175 available msph. c-p. About 400 c-p., or more than twice as much, is the lowest c-p. at which the gas-filled mazda lamp can be efficiently built (300 watts), while the 300 watt 4 amp. magnetite arc, which has been most successful in replacing the carbon arc in street lighting, gives an available 300 c-p., and the lowest titanium arc unit, of 220 watts, gives about 400 c-p. From this, it seems that the smallest units at which these high efficiency illuminants can be built are the industrially most important ones in street illumination, and even these are rather larger candle-powers than necessary for general street illumination in towns and cities. There is a general desire for more light, but more still is the desire for cheaper lighting, and there is a much greater appreciation of getting a reasonable increase of illumination—50 to 100 per cent—at a reduced cost to the city, than there is of getting much more light at the same price; while even a very great increase of light, if accompanied by an increased cost, is rarely acceptable in street lighting, except in special cases of decorative lighting, of white way lighting, etc., and such special application naturally represents only a small part of the country's lighting. This is well illustrated by the experience of the arc lighting industry: when the arc lighting engineers became so interested in "large units" as to lose some interest in the low power high efficiency arcs and began to push the big luminous or flame arcs, the replacement of the 175 c-p. enclosed carbon arc by low power luminous arcs, which had been going on rapidly before, practically stopped, and the country turned to the mazda lamp, which offered lower power and therefore cheaper units.

Very interesting is the appearance, in the gas-filled mazda lamp, of the first incandescent lamp with an efficiency within the range of the modern arcs; as seen, more particularly in Table II, there is a considerable number of illuminants with efficiencies of one to one and a half candles per watt, which may be classed as "medium efficiency illuminants." The gas-filled mazda lamp falls in this group, between the different sizes and efficiencies of the magnetite arc; and cost of maintenance and replacement, quality or color of the light, etc., then become

**TABLE II. RELATIVE EFFICIENCY OF ILLUMINANTS**

**(Irrespective of Size, in Available Mean Sph. C-P. per Watt)**

| | Available Mean Sph. C-p. per Watt | (Street Lighting) 10° C-p. per Watt | Available Mean Sph. C-p. |
|---|---|---|---|
| 3.1 watt per h. c-p. carbon filament | 0.21 | 0.4 | Any |
| 2.5 watt per h. c-p. gem filament | 0.26 | 0.5 | Any |
| 450 watt 6.6 amp. series enclosed a-c. carbon arc | 0.39 | 0.5 | 175 |
| Nitrogen Moore tube | 0.45 | | |
| 480 watt 6.6 amp. series enclosed d-c. carbon arc | 0.62 | 1.0 | 300 |
| 1 watt per h. c-p. mazda lamp | 0.64 | 1.25 | Any |
| 500 watt d-c. "intensified" carbon arc | 0.78 | | |
| 4 amp. 300 watt d-c. standard magnetite arc | 1.0 | 2.2 | 300 |
| Neon Moore tube | 1.1 | | |
| 0.5 watt per h. c-p. gas-filled mazda lamp | 1.28 | 2.5 | above 350 |
| 4 amp. 300 watt d-c. special magnetite arc | 1.4 | 3.0 | (420) |
| 6.6 amp. 500 watt d-c. standard magnetite arc | 1.5 | 3.2 | 750 |
| Mercury lamp in glass tube, best values | 1.55 | | |
| 6.6 amp. 500 watt d-c. special magnetite arc | 1.7 | 3.6 | 850 |
| 220 watt a-c. titanium arc | 1.9 | 4.0 | 420 |
| 300 watt yellow flame arc, best values | 1.95 | 4.0 | [585] |
| 500 watt white flame arc, best values | 1.95 | 4.0 | [975] |
| Mercury lamp in quartz tube, best values | 2.0 | | |
| Experimental 350 watt a-c. titanium arc | 2.7 | 5.4 | (950) |
| Melting tungsten in vacuum | 2.88 | | |
| 500 watt yellow flame arc, best values | 3.1 | 6.2 | [1550] |
| Experimental 500 watt a-c. titanium arc | 3.6 | 7.0 | (1800) |
| Titanium arc, best values (high power) | 5.2 | | |

factors in the selection between these illuminants.

The group of illuminants below one candle per watt, comprising the various carbon arcs and vacuum incandescent lamps, is hardly of much further industrial value in street illumination, while on the other hand, in the yellow flame arc and in the titanium arc, efficiencies can be reached which no incandescent lamp can ever approach, and the latter illuminants, within their field of application, therefore still remain unrivaled in efficiency.

### TABLE III. EFFICIENCY OF 300 WATT ILLUMINANTS

| | Available Mean Sph. C-p. per Watt | Available Mean Sph. C-p. |
|---|---|---|
| Mazda lamp (1 watt per h. c-p.) | 0.64 | 190 |
| Standard 4 amp. d-c. magnetite arc | 1.0 | 300 |
| White flame carbon arc, best | 1.2 | 360 |
| Gas-filled mazda lamp (0.5 watt per h. c-p.) | 1.28 | 384 |
| Special 4 amp. d-c. magnetite arc | 1.4 | 420 |
| Yellow flame carbon arc, best | 1.95 | 585 |
| A-c. titanium arc | 2.4 | 720 |

### TABLE IV. EFFICIENCY OF 500 WATT ILLUMINANTS

| | Available Mean Sph. C-p. per Watt | Available Mean Sph. C-p. |
|---|---|---|
| A-c. series enclosed carbon arc | 0.42 | 210 |
| Mazda lamp (1 watt per h. c-p.) | 0.64 | 320 |
| D-c. series enclosed carbon arc | 0.65 | 325 |
| Gas-filled mazda lamp (0.5 watt per h. c-p. | 1.28 | 640 |
| Standard 6.6 amp d-c. magnetite arc | 1.5 | 750 |
| Special 6.6 amp. d-c. magnetite arc | 1.7 | 850 |
| White flame carbon arc, best | 1.95 | 975 |
| Quartz mercury lamp | 2.0 | 1000 |
| Yellow flame carbon arc, best | 3.1 | 1550 |
| A-c. titanium arc | 3.6 | 1800 |

### TABLE V. RELATIVE EFFICIENCY OF VARIOUS C-P. OF ILLUMINANTS

| 200 MEAN SPH. C-P. | | 300 MEAN SPH. C-P. | | 400 MEAN SPH. C-P. | | 500 MEAN SPH. C-P. | | 1000 MEAN SPH. C-P. | |
|---|---|---|---|---|---|---|---|---|---|
| Type | Watt | Type | Watt | Type | Watt | Type | Watt | Type | Watt |
| A-c. carbon | 490 | A-c. carbon | 620 | Mazda | 620 | Standard magnetite | 400 | Gas-filled mazda | 780 |
| D-c. carbon | 380 | D-c. carbon | 480 | Standard magnetite | 350 | Gas-filled mazda | 390 | Standard magnetite | 700 |
| Mazda | 310 | Mazda | 470 | Gas-filled mazda | 310 | Special magnetite | 350 | Special magnetite | 550 |
| | | Standard magnetite | 300 | Special magnetite | 290 | White flame | 370 | White flame | 520 |
| | | Special magnetite | 270 | Titanium | 210 | Yellow flame | 280 | Yellow flame | 400 |
| | | | | | | Titanium | 250 | Titanium | 360 |

# MODERN THEORIES OF LIGHT

By Dr. Saul Dushman

Research Laboratory, General Electric Company

Dr. Dushman starts his valuable contribution to this issue by giving a brief review of the more important work that has been done in the past in building up our modern theories of light. He then passes to a discussion of the laws of radiation, which deal with energy distribution, at any temperature, as a function of the wave length; the formulae of Raleigh, Wein and Plank being given and discussed at length. The author shows that some sort of quantum theory is absolutely necessary to explain experimental facts, and proceeds to show the application of such a theory. In his conclusion he quotes Professor Millikan to show that there is no reason why we should not be able to assign some such structure to ether as will help in explaining many of the hardest problems before the scientific world.—Editor.

## INTRODUCTION

Dr. S. Dushman

BEFORE entering upon the discussion of the latest views that are held by scientists regarding the nature of light, it may not be out of place to consider briefly the different stages in the evolution of a theory of light which marked the progress of science from the middle of the seventeenth century to within the last few years.

Newton was the first one to formulate a theory of light based on definite experimental facts. Reasoning from ordinary observations on shadows he developed the idea "that light consists of exceedingly minute particles shot out from a luminous body, and causing the sensation of sight when impinging on the retina." This was a genuine corpuscular theory of light. Its great merit consisted in giving a logical explanation of reflection and refraction. It left, however, unexplained an ever-increasing number of phenomena, such as the colors exhibited by thin films, polarization and diffraction.

In 1678, Huygens suggested the wave theory, but his ideas remained dormant until Young, early in the nineteenth century, used the theory to explain interference, while Fresnel, by assuming the transverse character of light waves, was able to explain the polarization of light. These advances established the wave theory of light on a sound experimental basis.

Finally, Maxwell in 1873 propounded the electro-magnetic theory. The great achievement of this theory consisted in correlating electro-magnetic and light phenomena by demonstrating that both kinds of effects are due to waves transmitted through a hypothetical medium, the ether; and that electro-magnetic and ordinary light waves differ only in respect to wave-lengths.

The conclusions foreseen by Maxwell were, as is well known, experimentally confirmed about fifteen years later by Hertz, who succeeded in reproducing with electro-magnetic waves all the phenomena exhibited by light waves; while subsequently to Hertz, Lebedew, and then Nichols and Hull, showed that light exerts a pressure which is equal to that calculated by Maxwell on the basis of his theory, and *half of that prophesied* on the basis of any corpuscular theory.

Long before this, it had been shown that the ordinary visible spectrum is only a small portion of a much larger spectrum which extends on both sides of that portion that affects us as light. Extending towards the region of shorter wave-length we have the ultra-violet and Schumann rays, while beyond the red end of the visible spectrum we have the infra-red radiations which are manifested by their heating effect.

The following table gives the wave lengths of the different groups of radiations as they have been determined by different observers:

| Radiation | Wave-Length in Cms. |
|---|---|
| Schumann waves | $10^{-5}$ to $2\times10^{-5}$ |
| Ultra-violet | $2\times10^{-5}$ to $4\times10^{-5}$ |
| Violet . | $4\times10^{-5}$ |
| Green . | $5\times10^{-5}$ |
| Red | $6\times10^{-5}$ to $7.5\times10^{-5}$ |
| Infra-red (heat waves) | $7.5\times10^{-5}$ to $6\times10^{-3}$ |
| Longest heat waves so far isolated | $6\times10^{-3}$ |
| Shortest electromagnetic waves . | $6\times10^{-1}$ |
| Electromagnetic waves used in wireless telegraphy . . . | $5\times10^{4}$ to $3\times10^{5}$ |

It is seen that the visible spectrum comprises barely one octave of a range of electromagnetic radiations which extend from $10^{-5}$ to $3 \times 10^5$ cms. and higher. These radiations differ only with regard to the detectors that are used to determine their presence, and show gradual variation in properties with progressive increase in wave-length. There exists, it is true, a rather large gap between the shortest electromagnetic waves and longest heat rays, but this is probably due, on the one hand, to the inherent difficulty encountered in making an oscillator of very small dimensions, and on the other hand, to the difficulty of isolating longer heat waves.

Up to twelve or thirteen years ago this essentially Maxwellian conception of light radiation had been found to be self-sufficient, and physicists in general had been assuring themselves that the great discoveries in science had been made and the last word had been said upon the mechanism of light radiation. All future work was to be merely in elaboration of Maxwell's fundamental equations.

But this self-complacency was not destined to endure very long. In 1901 Planck published a paper in which he showed that the ordinary electro-dynamical methods of dealing with radiation did not lead to results in agreement with experimental data on the relation between energy distribution and wave-length as obtained from the measurements on the spectra exhibited by heated bodies. The discussion thus started by Planck struck at the most fundamental concepts of the electromagnetic theory. But the revolutionary effect of Planck's work did not cease there; it was found subsequently by Einstein, Nernst, and others, that similar considerations had to be applied to explain rapidly accumulating observations in other fields of physics. It was found that an absolutely continuous emission and absorption of radiant energy, such as was assumed by Maxwell is incompatible with the newer discoveries. Here then we have the origin of an atomic structure of energy, of the theory of light quanta, which has been the subject of so much discussion in recent years. It has been thought that a consideration of some of the experimental data leading to a quantum theory of radiation and a brief exposition of various other phenomena that have lent additional importance to this theory might not be uninteresting.

## RADIATION LAWS

If a solid or liquid is heated to a high enough temperature it emits light. This light may be resolved into a continuous spectrum and the distribution of radiant energy with wave-length measured by means of an instrument like the bolometer.* It is found that the curve giving the relation between intensity of radiant energy and wave length depends in general upon the nature of the body and also on the temperature to which the body is heated. But it has also been deduced theoretically and shown to be true, experimentally, that under certain conditions the thermal radiation emitted by a body is a function of the temperature only and independent of the material used as radiator. Balfour Stewart and Kirchhoff independently arrived at the conclusion that the radiation within a uniformly heated enclosure depends on the temperature of the enclosure and on nothing else. A body having the characteristics of such an enclosure would completely absorb all the radiation falling on it. Kirchhoff was thus led to the conception of what he termed a "black body" or full radiator, since every other material would absorb, and therefore emit, at any given temperature less energy than a "black body." No substance is known which is a perfect "black body" in this sense, although some materials such as lamp-black approach it quite closely, while platinum and white oxides depart to quite an extent from black body radiation. But, as was pointed out by Kirchhoff, it is perfectly possible to determine the laws of such radiation by using the radiation emitted from an enclosed space that is maintained at a uniform temperature.

Such experiments were carried out during the years 1897–1901 by Lummer and Pringsheim. They measured not only the variation in the total amount of radiant energy with the temperature, but also the variation in distribution of energy, at a given temperature, with the wave-length. Their results are shown in Fig. 1 where the ordinates are intensities, or emissive powers (which are proportional), and the abscissae are wave-lengths.†

As the temperature of a full radiator rises it first gives out heat waves only. When the temperature exceeds 600 deg. C., the radiations below 0.76 $\mu$ become intense enough to affect the retina of the eye. As the tempera-

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* A good description of this instrument as originally devised by Langley and subsequently improved by Lummer and Kurlbaum is given in Preston's Theory of Heat, Chapter VI.

† 1 $\mu = 10^{-4}$ cm. The visible spectrum is comprised between the values 0.4 $\mu$ and 0.76 $\mu$.

ture increases still more the body is said to vary from a dull red heat through cherry red, and orange, up to a bright white heat. This occurs at about 1500 deg. C. It will be noted that by far the largest portion of the spectrum is found in the infra-red region; but, as the temperature is increased the position of the wave-length at which the maximum emissivity occurs shifts towards the region of shorter wave-lengths. This is the cause of the gradual change in color of the body from red to white.

These experiments also confirmed some mathematical relations which had been deduced from the electromagnetic theory of light. In Fig. 1, the area contained between any curve and the $\mu$-axis is proportional to the total amount of radiant energy emitted by a full radiator at the corresponding temperature. If $E_\lambda$ denote the energy comprised between wave-lengths $\lambda$ and $\lambda + d\lambda$, then $E$, the total amount of energy emitted, is given by the relation

[*] $$E = \int_0^\infty E_\lambda \, d\lambda \tag{1}$$

About 1879, Stefan concluded from certain measurements of Tyndall that $E$ varies as the fourth power of the absolute temperature. This law was subsequently deduced by Boltzmann from thermodynamic consideration on the basis of the electromagnetic theory of light. The measurements of Lummer and Pringsheim, as well as later determination, have led to the following expression for the *Stefan-Boltzmann radiation law:*

$$E = 5.6 \times 10^{-5} \, (T^4 - T_0^4) \tag{2}$$

where $E$ is expressed in (ergs cm.$^2$) per sec.

If $E$ is denoted in watts per cm.$^2$,

$$E = 5.6 \times 10^{-12} \, (T^4 - T_0^4) \tag{2a}$$

In this equation $T$ denotes the temperature (absolute degrees Centigrade) of the radiator, and $T_0$ the temperature of the body receiving radiations.

A further advance in the theoretical treatment of this subject was made by Wien. "Starting with the well-grounded assumptions that (1) according to the electromagnetic theory the pressure of the radiation was equal to the energy in unit volume, (2) that the second law of thermodynamics, and (3) that Doppler's principle were applicable, and by postulating the existence of walls, enclosing radiant energy, that were completely black and others that were completely reflecting and diffusing, Wien was led to the conclusion that when the temperature increases, the wave length of every monochromatic radiation diminishes in such a way that the product of the temperature and the wave length is a constant,[†]" i.e.,

$$\lambda \, T = \lambda_0 \, T_0.$$

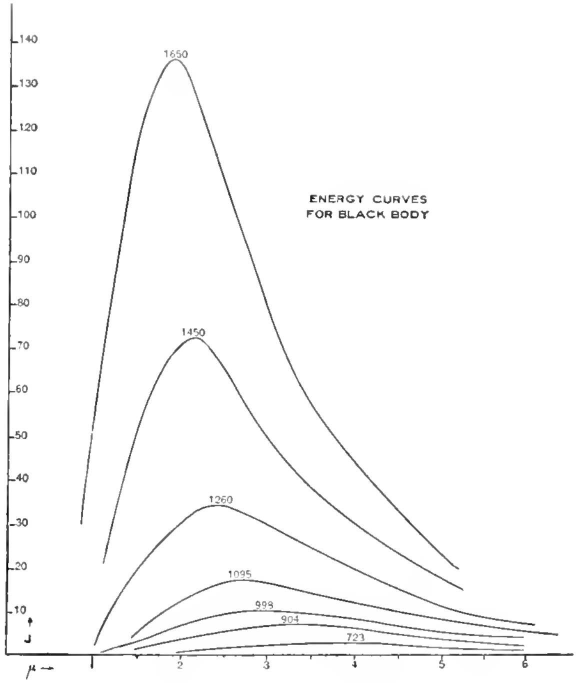

**Fig. 1.** Energy Distribution in Black Body Radiation

Hence for the wave-length of maximum energy, $\lambda_m$

$$\lambda_m T = \text{const.} \equiv A \tag{3}$$

Combining this with the Stefan-Boltzmann relation, Wien was led to the other relation that

$$E_{max.} \; T^{-5} = \text{const.} \equiv B \tag{4}$$

where $E_{max.}$ denotes the energy corresponding to the wave-length $\lambda_m$ and $T$ is the absolute temperature of the radiator.

Equation (3) is also known as the "*displacement law.*" Careful measurements have shown that the value of the constant $A$ is 0.29 (very closely) where $\lambda$ is measured in cms. and $T$ in absolute degrees centigrade, while $B$ is about $2190 \times 10^{-17}$.

Neither of these laws gives us any information, however, about the actual distribution of energy at any temperature as a function of the wave-length. In the notation of

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[*] $E_\lambda$ is therefore the derivative of $E$ with respect to $\lambda$. Similarly $E_\nu$ may be designated the derivative of $E$ with respect to $\nu$, where $\nu$ denotes the frequency of radiation.

[†] Optical Pyrometry—Waidner & Burgess.

mathematics, it still remained an open question as to the nature of the function $f$ in the relation $E_\lambda = f(\lambda, T)$ that could most closely represent the experimental data.

### FORMULAE FOR THE LAW OF DISTRIBUTION

Three solutions have been suggested and each is of extreme importance. The first is that of Rayleigh:

$$E_\lambda = ck\,T\,\lambda^{-4} \tag{5}$$

The second is that of Wien

$$E_\lambda = c^2 h\,\lambda^{-5}\,e^{\frac{-ch}{k\lambda T}} \tag{6}$$

while the third is that of Planck

$$E_\lambda = c^2 h\,\lambda^{-5}\,\frac{1}{e^{\frac{ch}{k\lambda T}} - 1} \tag{7}$$

Written in terms of the frequency $\nu$, instead of the wave-length $\lambda$, these equations become

$$E_\nu = c^{-2}\nu^2 kT \qquad \text{(Rayleigh)} \tag{5a}$$

$$E_\nu = c^{-2}h\nu^3\,e^{\frac{-h\nu}{kT}} \qquad \text{(Wien)} \tag{6a}$$

$$E_\nu = c^{-2}h\nu^3\,\frac{1}{e^{\frac{h\nu}{kT}} - 1} \qquad \text{(Planck)} \tag{7a}$$

In these formulae, $c$ denotes the velocity of light, and $k$ and $h$ are universal constants, while $e$ denotes the base of the natural system of logarithms. The products $c^2h$ and $ch/k$ are usually denoted by $c_1$ and $c_2$ respectively, so that $k = \frac{c_1}{c_2 c}$ while $h = \frac{c_1}{c^2}$.

The actual measurements of Lummer and Pringsheim and others show that of these three formulae, that of Planck is the only one that is valid over the whole range of the spectrum.

Wien's equation is applicable only at low values of $\lambda T$, while Rayleigh's equation fits the experiments only at high values of $\lambda T$. Other formulae have been suggested from time to time, but the above three are the only ones that are important. The equations of Rayleigh and Wien were deduced by perfectly logical arguments from the fundamental principles of dynamics; the equation of Planck was derived by making assumptions that are in absolute contradiction with these fundamental principles. The fact that the latter formula agrees with the experimental results while the equations of Rayleigh and Wien do not agree would be startling enough in itself without its further bearing on other physical phenomena. But the theory of Planck becomes of vast importance because it leads to a new conception of the mechanism by which light energy is transmitted. Now what about the considerations which have led to these different formulae?

It is obvious that the radiation emitted by a perfect radiator may be regarded from two points of view: Firstly, it may be considered as a body at *constant temperature*, to which, therefore, the considerations used in ordinary thermodynamics must be immediately applicable. Secondly, regarded as a source of electromagnetic waves, it ought to be possible to apply to these radiations the equations derived from the fundamental principles of electrodynamics. When the conclusions based on these kinds of arguments are combined, the results ought to be formula which express $E$ as a function of $\lambda$ and $T$.

### PRINCIPLE OF EQUI-PARTITION OF ENERGY

Now let us consider the manner in which the energy of a system and its temperature are related. The kinetic theory shows that in the case of gases such a relation may be arrived at by purely dynamical methods.

If $N$ denote the number of molecules in a gram-molar weight of a gas; $V$ the volume at pressure $P$ and temp. $T$, then

$$PV = RT = NkT \tag{8}$$

where $R$ and $k$ are universal constants.

The values of these constants according to the most recent determinations (Millikan, Phys. Rev. 2, 147, 1913) are as follows:

$N = 6.06 \times 10^{22}$ molecules per gram-molecule
$k = 1.37 \times 10^{-16}$ ergs per degree.
$R = 8.30 \times 10^{7}$ ergs per gram-molecule per degree,
$= 1.99$ calories per gram-molecule per degree.

Furthermore, the average kinetic energy $K$ of the $N$ molecules is calculated as

$$K = \frac{3}{2}\,RT = \frac{3}{2}\,NkT = 3\,T \text{ calories} \tag{9}$$

Thus, the average kinetic energy of each molecule is $\frac{1}{2}kT$ for each of the three directions in which it can move, or the average kinetic energy of a gram-molecule is $T$ calories for each of the three "degrees of movability."

If, now, the only effect of an increase in temperature on a mass of gas maintained at constant volume is to increase the kinetic energy of agitation of the molecules, then the heat capacity at constant volume per gram-molecule ought to be $\frac{3}{2}$ $R$; that is, 2.98 calories. This is actually found to be the case for monatomic gases, that is, those in which the molecules consist of individual atoms. The conclusion is therefore drawn that any rotational energy which molecules may possess adds nothing to the total amount of kinetic energy, which is important in the consideration of the specific heat of gases.

In the case of diatomic gases, Boltzmann considered the molecule as having a dumb-bell sort of structure. Such a molecule may be assumed to have five degrees of movability; for not only can the molecule as a whole move in three different directions, but the atoms within the molecule can rotate in two directions which are at right angles to the axis of the dumb-bell. If the average kinetic energy of the molecule is $^1{}_2kT$ for each degree of movability, more generally known as degree of freedom, the heat capacity per gram-molecule of a diatomic gas ought to be $\frac{5}{2}$ $R$. This deduction was again found to be in agreement with experimental data.

But not only was Boltzmann able in this manner to calculate the specific heats of gases; he also applied the same considerations to solids and thus arrived at an explanation of the Dulong and Petit law. According to this law the product of specific heat and atomic weight in the case of elements in the solid state is a constant which has a value of about 6 calories. This law had been derived empirically at the beginning of the nineteenth century; but until Boltzmann enunciated his theory, there appeared to be no reasonable explanation of such a relation. His argument was to this effect:

Consider an elementary substance in the solid state in equilibrium with its vapor. Assume for the sake of simplicity that the vapor is monatomic. We know that this is actually true in the case of metals like mercury, zinc and cadmium, whose densities in the vapor state have been measured. Now the energy of the atom in the solid state must depend upon the vibration of this atom about a position of equilibrium. It also follows from the fundamental principles of dynamics that in the case of any such source of periodic vibrations, an oscillator, the average kinetic energy is equal to the average potential energy. But from fundamental dynamical considerations it is evident that the only conditions under which thermal equilibrium can exist between the atoms in the solid phase and those in the gaseous is that the average kinetic energy of the atom in each state should be the same, and since the average energy of an atom in the gas is $\frac{3}{2}$ $kT$, it follows that the total energy per atom in the solid is $3kT$, or $3RT$ per gram atom. Consequently the atomic heat must be $3R$, that is 5.96 calories.

Boltzmann embodied these conclusions in a general law which he together with Maxwell deduced from fundamental dynamical considerations. This law is known as the *principle of equi-partition of energy*, and states that for any system in equilibrium the total energy is divided equally among the different degrees of freedom of the system. The number of degrees of freedom corresponds to the total number of terms required to define exactly the state of the system at any instant. Thus in the case of a monatomic gas, the molecule possesses three degrees of freedom, since its velocities in each of three directions must be known in order to define its energy at any instant. Similarly a diatomic molecule may be said to possess five degrees of freedom because it requires three terms to express its position in space and two other terms to express the position of each atom with reference to the center of equilibrium of the molecule.

To sum up the above discussion it is concluded from the fundamental principles of ordinary dynamics that in any system at equilibrium, the average energy is $^1{}_2kT$ for each degree of freedom. This therefore answers the question as to the relation between energy and temperature.

### RAYLEIGH'S FORMULA

Turning to the considerations of radiation as an electro-magnetic phenomenon, we may consider as Planck does, that the radiation is produced by means of linear oscillators, similar to those used in the production of Hertzian waves, which emit linear harmonic vibrations.*

The equations of electrodynamics lead to the following relation between the energy $U_\nu$ of the oscillator of frequency $\nu$ and the

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* During the decade that has elapsed since Planck first enunciated his radiation theory, the rapidly growing experimental evidence in favor of the electron theory has led to the conclusion that the oscillators postulated by Planck probably have their physical counterparts in the atomic structures. According to the most recent speculations (N. Bohr, Phil. Mag., July, September, and November, 1913), the atom is assumed to consist of a positively charged nucleus of very small dimensions and one or more electrons describing closed orbits around the nucleus. Such a system would produce the effect of an oscillating charge and thus give rise to linear harmonic vibrations.

intensity $E_\nu$ of the radiation emitted (or absorbed) by it.

$$U_\nu = \frac{c^2}{\nu^2} E_\nu \qquad (10)$$

where $c$ denotes the velocity of light.

Now consider an enclosure surrounded by absolutely opaque walls and containing black body radiation of the same nature as that emitted by a body at the temperature $T$. The radiation emitted by the oscillators is in thermal equilibrium with the walls of the enclosure and any bodies contained in it. According to the principle of equi-partition of energy the average energy of each oscillator must be the same, that is, independent of the frequency, and equal to that of a body with two degrees of freedom. This is evident if one considers the oscillator from the electronic point of view as an electron rotating about a positive nucleus. To define the position of such an electron at any instant requires only two terms.

Consequently, the average energy of the oscillator must be

$$U_\nu = kT \qquad (11)$$

Combining (10) and (11) we obtain the Rayleigh equation

$$E_\nu = \frac{\nu^2}{c^2} kT \qquad (12)$$

In other words, the principle of equi-partition of energy leads to the conclusion that the intensity of the radiation at any temperature increases with the square of the frequency. Now this is evidently not in accord with the experiments of Lummer and Pringsheim as shown diagrammatically in Fig. 1. Actually the Rayleigh equation agrees with the experiments for low values of $\nu$, but instead of $E_\nu$ increasing indefinitely with increase in $\nu$ (as demanded by the above equation) the experiments show that $E_\nu$ passes through a maximum and then *decreases with further increase* in frequency.

The argument may be put in another form. The total energy emitted at any temperature $T$ is

$$E = \int^{\infty} E_\nu d\nu$$

Substituting for $E_\nu$ from equation (12) it is evident that at any temperature $E$ must be infinitely great. But we know from the experimental confirmation of the Stefan-Boltzmann law that such is not the case. Thus, whichever way we look at the matter, the principle of equi-paritition of energy when applied to black body radiation leads to values of $E$ that are only partly in accord with actual determination. The question therefore arises: Why should the agreement between Rayleigh's formula and experiment hold only for large values of $\lambda T$? The only assumption made in the above argument is that the principle of equi-partition of energy is always valid. Evidently the assumption is justified for a certain upper range of values of $\lambda T$ and not for lower values, and yet the principle of equi-partition of energy is as valid as the fundamental dynamical equations from which it was deduced by perfectly logical methods. Why then the disagreement?

### WIEN'S FORMULA

Mention has already been made of the Wien displacement law. Since the law agrees with experiment it is obvious that there is every justification for the validity of assumptions from which it was deduced. Carrying the argument still further, Wien showed that any distribution formula must be of the general form

$$E_\nu = \frac{\nu^3}{c^2} F\left(\frac{T}{\nu}\right) \qquad (13)$$

This, then, must be the general form which a distribution formula must satisfy in order to be in accord with the three following principles, for each of which there is every experimental evidence:

(1) The existence of radiation pressure whose magnitude is calculable from electrodynamic equations,

(2) The second law of thermodynamics,

(3) The Doppler principle of the change in wave-length of a ray with change in position of the source.

But the above equations still left undetermined the form of the function $F\left(\frac{T}{\nu}\right)$. Wien, therefore, made two additional assumptions, namely (1) that the velocities of gas molecules follow the Maxwell distribution law; and (2) that the frequency of the vibrations emitted by a molecule depends only on its temperature. He thus obtained a law of energy distribution of the form

$$E_\lambda = c_1 \lambda^{-5} e^{-\frac{c_2}{\lambda T}} \qquad (14)$$

or

$$E_\nu = \frac{\nu^3 c_1}{c^4} e^{\frac{-c_2 \nu}{cT}} \qquad (15)$$

This equation was found to be in accord with experiment only for low values of $\lambda T$. Thus it is applicable in the visible region of the spectrum at lower values of $T$; but gives too low values of $E_\nu$ in the infra-red region and at higher temperatures.

### PLANCK'S THEORY

The failure of both the Rayleigh and Wien equations to account for experimental data showed conclusively that ordinary methods were not applicable in attacking this problem. Since, however, the method of reasoning adopted in arriving at the Rayleigh equation was perfectly logical, the only conclusion to be drawn was that the fundamental principles upon which the argument was based are not of as general validity as supposed.

Now for a number of years a gradually increasing number of facts had led many physicists to question the general validity of the principle of equipartition of energy. For one thing, while the law of Dulong and Petit is pretty generally true, the number of exceptions to it had been accumulating during the past century. Thus it was known that carbon, boron, and silicon have atomic heats lower than 6; but it was also observed that the atomic heats of these elements increased with temperature, and at high enough temperatures they behave "normally." Furthermore, the molecular heats of some diatomic gases like chlorine and bromine are nearly a calorie too high even at ordinary temperatures, and they become even greater at higher temperatures.

To explain these facts it would be necessary to assume that the number of degrees of freedom of a carbon atom or chlorine molecule increases gradually with the temperature. But the Boltzmann concept leaves no room for such a transition stage. An atom or molecule must possess a certain integral number of degrees of freedom; a degree of movability in any definite manner is either absent or present. There can be *no gradual acquisition* by any body of a degree of freedom. The conception of integral degrees of freedom thus presents many difficulties. Furthermore, it has been shown above that in the realm of radiant phenomena similar difficulties are met with. The principle of equi-partition of energy can therefore not be of as general validity as hitherto assumed. But this principle was deduced from the fundamental laws of dynamics, and is therefore just as valid as the latter. Here then was a Gordianknot that appeared as difficult tountie as the one of classical fame. It remained for Planck to apply to this case a similar remedy.

Planck starts out with denying the general validity of the principle of equi-partition but makes use of the fundamental electrodynamical equations in deducing his radiation formula. Doubt may be cast upon the theory, therefore, because of its assumptions; but that the conclusions from his assumptions are in excellent accord with experiment is undeniable. Furthermore, the fact that his arguments have been successfully extended into regions undreamt of when the theory was enunciated gives the latter the most prominent place in contemporary physics.

Planck's theory of complete radiations contains three groups of assumptions: Firstly, he asumes that there exists in the enclosure linear oscillators similar to those used in the production of Hertzian waves but of molecular dimensions, so that the frequencies of the harmonic vibrations emitted by them are of the order of magnitude of those present in the radiation from a black body. As in the previous section, the relation between $E_\nu$, the intensity of the radiation of frequency $\nu$ and the mean energy of the oscillator, $U_\nu$ is

$$U_\nu = \frac{c^2}{\nu^2} E_\nu \tag{10}$$

If there are present in the enclosure $N$ oscillators of frequency $\nu$, each having a mean energy $U_\nu$, the total energy is $NU_\nu$.

Now, as we have seen above, the principle of equi-partition of energy would demand for each oscillator an average energy of $kT$, equation (11), and the combination of this with equation (10) leads to the Rayleigh equation. This equation would ascribe to each oscillator an average energy *greater* than that found experimentally. The fact, however, that the Rayleigh equation holds for large values of $T$ shows that the average energy approximates more and more to $kT$ as the temperature is increased.

This leads Planck to make the second of his assumptions: that an oscillator cannot take up energy continuously, but *discontinuously in multiples of a unit quantum* $\delta$. As the temperature increases, the value of this multiple, $n\delta$, approximates more and more nearly to $kT$. The problem therefore to be solved is this: What is the average energy of an oscillator when it can take up or give out only a definite fraction, $\frac{\delta}{kT}$ of this at any instant? The theory of probability leads to the relation.

$$U_\nu = \frac{\delta}{e^{\frac{\delta}{kT}} - 1} \tag{16}$$

Combining this with (10)

$$E_\nu = \frac{\nu^2}{c^2} \frac{\delta}{e^{\frac{\delta}{kT}} - 1} \qquad (17)$$

For $\delta = 0$, this equation becomes the same as the Rayleigh equation, as we would expect, since the theory of Planck differs from that of Rayleigh in the fact that the former assumes a discontinuous variation of energy in an oscillator, while Rayleigh assumes the variation to be continuous.

The similarity of equation (17) with Wien's formula leads to the third and last assumption made by Planck. He assumes that the unit quantum which the oscillator can emit or absorb is proportional to its frequency, $\nu$; that is,

$$\delta = h\,\nu$$

where $h$ is a universal constant.

Substituting $h\nu$ for $\delta$ in equation (17) leads to the Planck equation, which is the most satisfactory formula over the complete range of radiations: From the experimental values of the constants $c_1$ and $c_2$ in the Wien equation it is possible to calculate the value of $h$. As a result of very accurate experiments on the determination of the elementary electric charge, Prof. Millikan assigns to this constant a value of $6.62 \times 10^{-27}$ erg. sec.

The obvious weakness in this argument is the fact that while Planck denies validity to the principle of equi-partitions of energy and consequently the fundamental dynamical equations upon which this principle is based, he yet assumes the validity of the electrodynamical equations, which are also deduced from these fundamental equations.

The same difficulty arises when one tries to obtain a physical representation of Planck's theory. We know that a wave-theory of radiation is absolutely necessary to represent all the other phenomena exhibited by radiant energy; that furthermore the phenomena of static fields and alternating currents of high and low frequency show that the wave theory represents the facts accurately in these cases.

Nevertheless, the agreement between the Planck equation and the experimental results of Lummer and Pringsheim and others lead inevitably to the necessity of assuming that the emission and absorption of radiant energy occurs in multiples of a definite quantum,

We cannot do better than quote Prof. Millikan in this connection:

"Planck has appreciated fully from the beginning the above-mentioned weakness in the method of development of his equation, and within a year he has modified his statement of his theory in the endeavor to meet this objection. The theory as outlined above implies that, since energy is always contained in the oscillator in exact multiples of an energy unit, both the absorption and emission of energy by the oscillator must take place in units—that is discontinuously. Planck now assumes that emission alone takes place discontinuously, while the absorption process is continuous. At the instant at which a quantity of energy $h\,\nu$ has been absorbed, an oscillator has a chance of emitting the whole of its unit, a chance which, however, it does not necessarily take. If it in this way misses fire, it has no other chance until the absorbed energy has risen to $2h\nu$, when it has again the chance of throwing out its 2 whole units, but nothing less. If again it misses fire, its energy rises to $3h\nu$, $4h\nu$, etc. The ratio between the chance of not emitting when crossing a multiple of $h\nu$, and the chance of emitting, is assumed to be proportional to the intensity of the radiation which is falling upon the oscillator."

Einstein has termed the quantity of energy $h\nu$ a *light-quantum*. It is evident that "this view of light-emission and absorption requires a complete reversal of our conceptions of the structure of light." According to the view which has hitherto prevailed, the light from any source spreads out uniformly round the source and any recipient of energy can take up continuously that fraction of the total energy which falls on it. According to the newer concepts, the light is emitted discontinuously *in time*, in amounts which correspond to multiples of $h\nu$. We have here, therefore, a sort of *atomistic theory of energy*. How such a theory can be reconciled with the ordinary wave theory it is as yet impossible to state, but there is no doubt that a fusion of the two points of view must occur.

## FURTHER APPLICATIONS OF THE QUANTUM THEORY

That some sort of quantum theory is absolutely necessary is emphasized by the existence of a large number of phenomena that have been observed during the past decade, and the explanation of which is only possible, at least, at present, on the basis of some kind of quantum theory.

First of all we have the specific heat relations of different elementary substances at very low temperatures such as those of liquid hydrogen. It has been mentioned previously that some elements of low atomic weight such as carbon, boron and silicon, obey the Dulong and Petit law only at very much higher temperatures. Now Nernst and other investigators have observed that at sufficiently low temperatures all the elements begin to exhibit atomic heats lower than 6, and that as the temperature decreases the atomic heats decrease and tend to become equal to zero at the absolute zero. Furthermore, the lower the atomic weight the higher the temperature at which this low atomic heat begins to appear. What is the explanation of these facts?

According to Einstein the observations are quite in accordance with what one would expect by applying the arguments of Planck to atomic vibrators. There are good reasons for assuming that the longer heat waves emitted by solid bodies are due to vibrations of the atoms themselves. Now assume that an atomic vibrator can absorb and emit heat energy only in multiples of a unit quantum $h\nu$ where $\nu$ is the frequency of the vibrator. Since the atom can receive or emit at the maximum $3kT$ calories (as shown previously), it is evident from the analogy between the Planck oscillator and Einstein's vibrating atom that the average energy of an atom will be given by an equation of the form

$$U_\nu = \frac{3h\nu}{e^{\frac{h\nu}{kT}} - 1} \qquad (18)$$

The only difference between this equation and (16), outside of the substitution of $h\nu$ for $\delta$ in the latter is due to the fact that the linear oscillator considered in deriving equation (16) has only two degrees of freedom, while that considered above has six degrees of freedom.

The average energy per gram atom may be denoted by $W$ where

$$W = \frac{3h\nu N}{e^{\frac{h\nu}{kT}} - 1} = \frac{3R\frac{h\nu}{k}}{e^{\frac{h\nu}{kT}} - 1} \qquad (19)$$

At very high temperatures, where $T$ is large compared to $\frac{h\nu}{k}$, equation (19) becomes

$$W = 3\,RT = 6\,T \text{ calories.}$$

But this is the Dulong and Petit law, and it is seen that this law has the same validity in the realm of specific heats as the Rayleigh equation in that of black-body radiation.

Differentiating (19) we obtain the equation for the atomic heat at constant volume namely

$$\frac{dW}{dT} = 3R \frac{e^{\frac{h\nu}{kT}}\left(\frac{h\nu}{kT}\right)^2}{\left(e^{\frac{h\nu}{kT}} - 1\right)^2} \qquad (20)$$

Now the actual specific heat determinations of Nernst and of those working with him, are found to be in accord with the results that are to be expected from (20). The curves showing the variation in atomic heat with temperature are all of the type indicated by (20). It is true that with increased accuracy in the measurements it has been found necessary to modify the right-hand side of equation (20) by adding more terms corresponding to different values of $\nu$, but the general character of the results remains the same. The necessity for discarding the principle of equi-partition of energy and assuming that each atom can take up energy only in multiples of a definite quantum $h\nu$ is apparently essential for an understanding of the specific heat phenomena at low temperatures.

Another set of phenomena to which the quantum theory has been applied successfully is that comprised under the heading of photo-electric effect. For a long time it has been known that when ultra-violet light strikes a metal surface electrons are emitted from the latter with a speed which is independent of the intensity of illumination, but depends only upon the frequency of the incident (monochromatic) lights. The number of electrons emitted increases, however, with the intensity of the illuminating source. In the case of highly electro-positive metals like sodium and potassium light of even lower frequency than ultra-violet causes the emission of electrons.

On the basis of the quantum theory it is possible to deduce a relation between the frequency of the incident light and the velocity of the ejected electron.

Denote the initial velocity of the electron leaving the surface by $v$ and let $m$ be its mass. Let $P$ denote the work required to carry an electron through the surface of the metal. The energy for this emission must be obtained from the incident light, and on the basis of the quantum theory this must be equal to $h\nu$. Consequently

$$\tfrac{1}{2}\,mv^2 = h\nu - P \qquad (21)$$

Denoting by $V$ the potential difference through which the electron must pass to acquire a velocity $v$, and combining (21) with the relation,

$$V\epsilon = \tfrac{1}{2} mv^2, \qquad (22)$$

where $\epsilon$ denotes the charge on an electron, we obtain the relation

$$V = \frac{h\nu}{\epsilon} - \frac{P}{\epsilon} \qquad (23)$$

By measuring $V$ for different values of $\nu$, it is evidently possible to test this conclusion. In the actual experiments it is more convenient to determine the minimum positive potential which it is necessary to apply to the illuminated surface in order to cut down the electron emission to zero. Such measurements are difficult to obtain with any degree of accuracy, and it is only within this year that excellent experimental confirmation of equation (23) has been obtained. At the meeting of the American Physical Society held in Chicago, November 29, 1913, Prof. Millikan announced that he had obtained such confirmation over a large range of frequencies, the observed value of $h/\epsilon$ being within five per cent of that calculated from other data.

A phenomenon closely related to the photo-electric effect is the ejection of electrons from surfaces bombarded by X-rays, and it has been shown that in this case also the velocity of the emitted electrons is proportional to the potential difference between the electrodes of the tube which produces the rays, that is, the "harder" the X-rays, the greater the velocity of the emitted electrons. Assuming, therefore, that the X-ray transfers a quantum of energy from the electron bombarding the anode to the electron emitted from the surface upon which the X-ray impinges, it is possible to calculate the frequency of the latter.

The calculation is similar to that of the emission velocities of photo-electrons. We have

$$V\epsilon = h\nu = \frac{hc}{\lambda} \qquad (24)$$

as in equation (23). If $V = 40{,}000$ volts

$$^{*}\lambda = \frac{hc}{V\epsilon} = \frac{6.62\times10^{-27}\times3\times10^{10}}{4.774\times10^{-10}\times\dfrac{40{,}000}{300}} = 3\times10^{-9}\text{cm.}$$

This is the order of magnitude of the wave-lengths which have been obtained by measuring the diffraction patterns produced by letting X-rays pass through crystals.

There is a still further similarity between the emission of electrons by X-rays and by ultra-violet light. Besides the normal photo-electric effects mentioned above, there exists a selective photo-electric effect which is characterized by the fact that at a certain frequency of the incident illumination there is emitted an abnormal number of electrons. The frequency at which this maximum emission occurs is characteristic of the substance illuminated and decreases with decrease in atomic weight. Similarly there exists a selective X-ray effect, so that at a certain definite voltage in the exciting tube, corresponding to rays of a definite hardness, there occurs an abnormal emission of electrons from the surface upon which the X-rays impinge, and here also the frequency of X-rays required to produce this abnormal emission is nearly proportional to the atomic weight of the excited substance.

We find therefore *a complete parallelism between the phenomena exhibited by X-rays and ultra-violet light.* But while the lowest wave-length so far measured in the ultra-violet is about $10^{-5}$ cm., the above measurements show that hard X-rays are electromagnetic waves with wave-lengths of the order of magnitude of $3\times10^{-9}$ cm. To produce X-rays with a wave-length of $3\times10^{-6}$ cm. would require potentials of about 40 volts, and recent work has shown that even with voltages as low as this it is possible to obtain qualitative indication of the production of X-rays. In other words, there is a gradual transition from ultra-violet and Shumann rays, which have a wave length of $10^{-5}$ cm., to hard X-rays having a wave length of $10^{-9}$ cm., and finally to the gamma rays which are nothing else but extremely hard X-rays.

There is still another point to be observed in this connection. While the application of the quantum theory to radiation and specific heats suggests emission and absorption of energy that is discontinuous with respect *to time*, the observations on emission of electrons by X-rays and ultra-violet light lead to the conclusion that the discontinuity exists here with respect *to space*. In other words, in order to account for the fact that the X-ray carries over unimpaired the energy of the electron that produced it to another electron that is emitted by it, it is necessary to assume that the amount of energy represented by it keeps together as an entity or quantum throughout the different transformations. A corpuscular theory of X-rays such as originally suggested by Professor

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* $\epsilon = 4.774\times10^{-10}$ electrostatic units, $h = 6.62\times10^{-27}$ erg. sec. and $c = 3\times10^{10}$ cm. To convert volts to electrostatic units it is necessary to divide by 300.

Bragg accounts for this fact very well; but such a theory is obviously not in accord with the diffraction experiments of Lane and the analogies exhibited by ultra-violet light and X-rays. To reconcile these apparently conflicting facts, it is necessary to assume for X-rays some form of "spotted-wave" theory, but as yet no physicist has dared to propose such a theory.

### CONCLUSION

We have attempted in the above remarks to show that in the case of at least four distinct lines of investigation the necessity has arisen for assuming an atomistic structure of energy in order to explain the purely experimental facts. In each case that has been considered, the same factor *h occurs* and the *unit quantity of energy*, *hν* plays a fundamental part. Whether this quantum represents a discontinuity in the rate of emission of energy as one class of investigators seems to think or whether it is more nearly in accord with a sort of corpuscular-wave theory is still a debatable question.

Regarding, therefore, the exact manner in which the electromagnetic wave theory of light will have to be modified in order to account for the above experimental results, there is as yet no agreement among the greatest living physicists to whom we look for guidance in such matters. The fact remains that while a wave theory is absolutely necessary in order to account for diffraction and interference phenomena, some sort of quantum theory is just as necessary in order to account for the laws of radiation, specific heat relations at low temperatures and the emission of electrons by X-rays and ultra-violet light That the two points of view are not absolutely incompatible seems to be the prevailing impression. As Prof. Millikan writes:

"I see no reason *a priori* for denying the possibility of assigning such a structure to the ether as will permit of a localization of radiant energy in space, or of its emission in exact multiples of something if necessary, without violating the laws of interference. That no one has yet been able to do this can scarcely be taken as a demonstration that it cannot be done. Fifty years ago we knew that such a thing as an atom existed, but we knew absolutely nothing about its structure, and it was customary to assume that it had none. Today, we know a great deal about the structure of the atom, but the position formerly occupied by it has been assumed by that thing which we call the ether. We know that there is a vehicle for the transmission of electro-magnetic energy, but we know nothing whatever about its structure, and it has been customary to assume that it has none. To deny the existence of this vehicle, which we have been in the habit of calling the ether, and to use the word "vacuum" to denote all the properties heretofore assigned to it by the experimentalists, namely, those of transmitting electro-magnetic disturbances, is a bit of sophistry in which he is little interested. We seem to be on the eve of learning something more about the properties of this vehicle, call it by what name you will, than we have known heretofore. Certainly there has never been a time when physics offered such task to its followers as now, nor ever a time when it needed more and better brains applied to these tasks."*

*References.*—(1) Prof. R. A. Millikan's paper in Science, January 24, 1913, is a splendid summary of the subject. The paper in GENERAL ELECTRIC REVIEW, July, 1913, is along the same lines.

(2) Campbell's Modern Electrical Theory.

(3) M. Planck's Wärmestrahlung, Second edition.

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* GENERAL ELECTRIC REVIEW, July, 1913.

# THE SPECTROSCOPE

### By Professor Elihu Thomson

In leading up to the subject of spectrum analysis, with which the author is mainly concerned in this contribution, mention is made of the identical nature of all electromagnetic waves in the hypothetical ether; and that of this entire range only about one octave is visible to the human eye. Probable reasons are advanced for this narrow range of sensitiveness. Brief mention is made of the discovery by Newton of the solar spectrum, and of its further investigation by Fraunhofer, the discoverer of the dark lines therein which bear his name. The interpretation to be placed on the regular occurrence of these lines is given, and the great significance that attaches to them in many fields of investigation is outlined. In certain modifications of the spectroscope the degree of precision and care necessary in their construction, and the skill and patience required in their manipulation, are seldom equalled in any other line of human endeavor.—Editor.

Prof. Elihu Thomson

OUR vision depends upon the perception by the eye of a limited range of waves or wave lengths in the ether. These are the light waves. They are ether waves of the same general nature as the wave disturbances used in wireless transmission and particularly the Hertzian waves given out by an electric oscillator. Heat radiation is of the same nature, but of too low pitch to be visible. Ultra violet rays and Roentgen rays are similar, but in this case the pitch is too high; the waves are too short to affect the eye. They are all energy waves and are physically identical electro-magnetic waves in the ether such as Maxwell first studied.

The probable reason for our not being able to perceive by the eye, lower or coarser waves than the red and shorter or higher pitch waves than the violet in the spectrum, is that vision would not be helped but probably hindered by light waves of greater range, inasmuch as many white objects as now seen would be dark or black under the higher rays, and many transparent media such as glass would be opaque. This condition has been strongly emphasized by the experiments of Dr. R. W. Wood in photographing with invisible rays. Objects would be similarly false in their effect and therefore misinterpreted if waves lower than the red were visible. Besides, since ultra violet rays are absorbed by the tissues of the eye, such tissues being opaque to them, there could be no need of retinal sensitiveness to them. Acuity of perception of objects also, according to an optical law, is less with the lower red rays than with those higher in the spectrum, so that perception by rays lower than red would, if it existed, be actually detrimental to vision. While, therefore, electromagnetic waves identical in nature with visible waves, may be produced in frequencies from the lowest up to Hertzian waves of millions and billions per second, and while the series may extend up to low invisible heat waves and may pass through and beyond the visible rays, to the ultra violet and lastly to Roentgen rays, out of this enormous range of pitch of identical waves only about one octave is visible. Evolution has determined the range so visible as best suited to the needs of the organism. The light waves are simply those wave lengths of electric ether vibration—energy waves, heat waves, or Hertzian waves, if one chooses to so designate them, which in the slow process of evolution of the eye have been selected for vision, or to which sight has adapted itself as conducive to the most comprehensive, acute, and perfect delineation of the objects in nature around us and with which we are directly concerned. This visual range is from about 400 millions of millions frequency up to about double that figure. Investigations show that the velocity of light, about 186,000 miles per second, holds good from the lowest to the very highest pitch of these waves.

When the visible waves reach the eye, in all wave lengths from low red to violet, and in proper proportion as in sun light, the light perceived is white, i.e., we call it white, but the sensation of white is also produced by combination of waves in which are only a fraction of the whole range. The explanation would take us too far into the theories of color perception. Suffice it to say that our perception of objects by sight depends on varying intensities and combinations of wave lengths giving shades and color, shadows and high lights. The eye itself is unable to discover whether an object is red, for example, because it reflects, transmits, or diffuses red rays only, or whether it is red merely because of an absence of green in the light from the body. Most colored objects, lights or pigments, or dyes, owe their color to a complex mixture of waves. Any instrument which deals with the light waves of different pitch so that they can be noted separately or successively is a spectroscope. A spectroscope provided with means for measuring the separation of the colors, or the value of the wave lengths of the rays, is a spectrometer. A spectrograph is a spectroscope with a camera attachment, whereby the peculiarities of the spectrum may be recorded on a sensitive plate photographically. The spectra of stars not visible to the eye may thus be recorded if the exposure given to the plate is long enough.

When Sir Isaac Newton, in about 1670, received the beam of sunlight entering through a hole in the shutter in a darkened room, upon a prism of glass and noted that the white light was separated or analysed into a band or spectrum of colors on a screen beyond, he was indeed using a crude form of spectroscope to discover the composite nature of the sun's light. The spectrum he saw was, of course, very imperfect, as owing to the shape of the opening in the shutter the colors overlapped and were not pure. Later a narrow slit was used instead, and Fraunhofer, himself a skilled optician, using such a slit and a far more perfectly made prism than was available in Newton's time, made a fundamental discovery. This was in 1814, when on examining solar light the dark lines in the solar spectrum were for the first time seen. They are known as the Fraunhofer lines. At first only the more evident of these lines were noted at intervals in the range of colors where light appeared to be missing—gaps in an otherwise complete set of waves from red to violet.

The interpretation of these lines, of which there are many thousands, came later when they were identified in position with the bright lines of metallic vapors in flames. With this advance there was born the science of spectrum analysis, or spectroscopy.

It had long been known that various metallic salts and the metals themselves would color an alcohol or bunsen burner flame in a way characteristic of the substance; but in the hand of Herchel, Brewster and others the spectra of such flames were seen to be bright lines chiefly occupying definite positions in relation to one another and having the colors which belonged to the position in the spectrum where they were found. The radiation was thus seen to be selective. Colored solutions, such as dyes, were also investigated and here again were noted dark or absorption bands crossing the spectrum or covering a portion of its length, indicating the color of the solution to be due to the absence of certain wave lengths. These spectra are called absorption spectra. The yellow sodium lines, called the D lines, at first puzzled the investigators from their almost constant appearance. The problem was solved when it was recognized that the spectroscope would detect almost infinitesimal amounts of some metals, and that sodium was everywhere present.

The salt spray from the ocean, drying up, would leave an imperceptible speck of sodium chloride which would be easily detected in a flame before the slit of a spectroscope. The science of spectrum analysis grew out of the recognition of the exceeding delicacy of the method, so small were the quantities of chemical substances capable of detection. In the hands of Kirchoff and Bunsen the foundations of chemical analysis by examination of the light emitted by hot vapors was laid. One of the most important steps in this development was the recognition of the fact that the dark lines of Fraunhofer were a case of absorption by vapor of the light from the same substance which would produce bright lines in the same position if hot enough. In other words cooler vapor absorbs the same wave lengths of light that it emits when hot enough to be luminous. Thus the *dark* D lines in the solar spectrum are due to sodium in the outer layers of the sun's atmosphere, through which shines the intense white light of the body of the sun below, the sodium vapor absorbing the light and being, as it were, opaque to light of the particular wave length.

The Fraunhofer lines then are absorption lines in a spectrum due to the fact that the light-giving surface of the sun is surrounded by innumerable elements in a state of vapor, cooler than the lower layers of the sun and each absorbing waves of just those wave pitches as would be given out if they were vaporized in an arc or spark. Doubtless if an opaque screen could be inserted between these vapors and the intensely luminous solar body below them, they would then give out a bright line spectrum if hot enough. Indeed, the bright line spectrum can be noted at the edge of the sun when the luminous body of the sun is covered by the moon in a total solar eclipse.

Our space does not permit following the gradual improvements in the spectroscope as an instrument and its application to the many fields of research or industry. We may note the extended use now made of the instrument, particularly in the form of spectrographs in modern astronomy. By it the chemical constitution, state of condensation, and temperatures of the stars and nebulae are indicated. Our own star, the sun, has yielded a rich and continued harvest to the spectroscopist. The great storms or sun spots area of the sun are shown to involve the motion of heated gases at enormous speeds. The protuberances at the edge of the sun, or solar prominences, are shown to be due to enormous jets, or vast outbursts of incandescent hydrogen. Recently in the hands of Dr. G. E. Hale, the instrument has been made to yield not only a knowledge of the condition of the sun's outer atmosphere at various levels, but has enabled him to demonstrate that stupendous electric effects accompany sun spots—motion of great vortices of electrons, and the magnetic fields produced thereby—utilizing the recently discovered Zeeman effect, or the influence of strong magnetic fields on the spectral lines given out by incandescent vapors.

According to conditions discovered by Zeeman, lines that would be ordinarily single, are doubled, trebled and polarized, in accordance with the direction of the magnetic field with respect to the course of the light beam traversing it from the incandescent vapors subjected to the field.

The displacement of spectrum lines known as the Doppler effect tells us of motion of the most distant stars towards or from us and gives us the speed of each motion. It even discloses motion of companion stars which are so close to each other and so distant that they never can be seen separately. This is the great class of stars known as "spectroscopic binaries. The Doppler effect gives us knowledge of the rates of rotation of the sun and planets. The spectra given by the stars enables them to be separated into great classes, according to their apparent temperature, their composition and inferentially their age. We obtain an inkling of what goes on in those remarkable bodies, temporary stars which suddenly brighten, and afterward gradually fade away. Helium gas was first known to exist by the spectroscope. It was seen that certain gas lines, not due to any gas on the earth, were present in the solar spectrum. Recently this gas has been discovered in small amounts in certain minerals and is now known to be a product of radium in its disintegration. The name coronium is given to another supposed gas, probably the lightest of them all, which gives certain lines in the outer layers of the sun's corona, but of which there is hardly a suspicion of its existence on the earth.

Investigation by the spectroscope of the colors of substances is very valuable in determining their nature. The coloring matter of the animal fluids, such as the bile or the blood, the colors of plants, the various dyes, colors of solutions and of pigments are investigated by their absorption spectra, and much valuable assistance so obtained in their identification, and much light also thrown on their more intimate chemical constitution. Spectroscopic measures of refraction and dispersion of light, even by colorless bodies, assists greatly in an understanding of their composition and molecular arrangement. The spectroscope combined with a photometer enables true values of the luminous effects of different lights to be obtained regardless of color; as the intensities of the several colors are individually compared by photometric methods. Hence we have an instrument, the spectro-photometer, as a modification of the spectroscope.

In like manner, spectro-thermometry allows the temperature of radiating bodies to be determined from an examination of their spectra. It is found that the temperature of a hot body considered as black body radiation is connected directly by a simple law with the wave length emission at maximum intensity or maximum energy in the waves. In a red hot body this maximum is of course in the red. As the temperature of the body is raised its light becomes whiter owing to the gradual addition of the higher rays of the spectrum and their growing intensity relatively to the lower rays. Hence, the product of the absolute temperature by the wave length of the emitted rays of greatest energy tends to be a constant. For the very high temperatures of incandescent tungsten filaments, it is important to possess a means for estimating at convenience the temperature of the filament from the nature of the light emitted.

The outlook for the future knowledge to be gained as to the intimate constitution of the chemical atom, and the relations of the elements to one another, is very promising. And much of this advance is to be expected from spectroscopic study and data now being accumulated. Each element is, when radiating light, characterized by what at first appears to be almost a haphazard set of spectral lines without relation to one another.

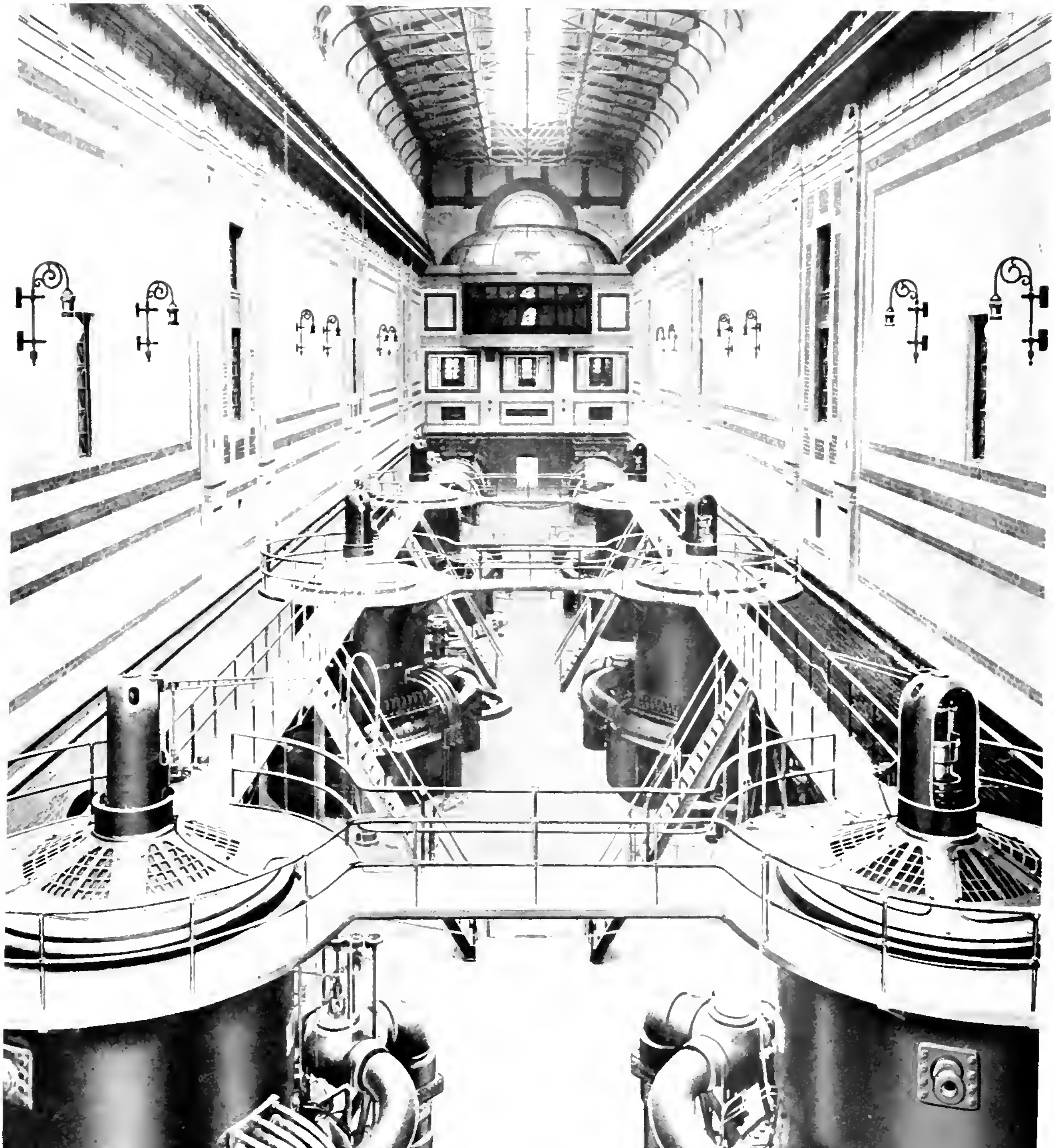
Recent work, however, discovers in them series related in wave lengths by mathematical laws and that the apparent haphazard character is probably only the result of our lack of knowledge of how to interpret our results. Doubtless, indeed, all the lines given out by an element are related according to some unknown laws and when these are discovered, we will at last possess an idea of the innate character of a so-called element and its relation to all the others. One difficulty is that the lines which appear in the visible spectrum are only a part of those which are present if we could as easily investigate the extension below the red, the infra-red region, and likewise could map the spectrum lines far beyond the violet end of the spectrum, as in the ultra violet. The field is so very large and the vastness of the already accumulated data such that progress must be slow or gradual.

The problems will be solved by persistent study, and perhaps by some great generalization the task will be simplified. Even the apparently simplest spectrum, such as that of hydrogen, when closely examined, is found to be quite complex. Furthermore, the spectrum emitted is largely governed by the conditions under which it is produced; temperature, pressure, electric state, etc.

Nevertheless, in the observation of spectra and the discovery of laws relating thereto lies the key to the structure of atoms, the number and orbits of electrons and other conditions.

The spectroscope is, however, so modern an instrument that it is remarkable how much has already been added to our knowledge by its use. All light from whatever source, including phosphoresence and fluorescence, come under its scrutiny. All media transmitting or in any way modifying light, such as the atmosphere, liquids, glass, minerals, color stuffs, dyes, pigments, are examined and yield valuable knowledge. Sometimes, the gain is in pure science or theoretical knowledge, or it may be highly practical, as in the study of glass for optical uses, or of colors for their identification.

The spectroscope, including the various forms of spectrometers and spectrographs, has many forms from the simple prism instruments commonly employed in the ordinary work, to the delicately ruled gratings of Rowland and the elaborately constructed interferometers and echelons of Michelson in which the resolving power or capacity to separate close lines in a spectrum is carried to the limit of possibility. For investigations of the Zeeman effect mentioned above the powers of these latter instruments are needed. They are based on the principle of optical interference, and their construction has demanded a degree of manipulative skill and care which is rarely to be found in any other human undertaking. The work of construction and adjustment of a small watch is ordinarily considered a delicate matter, but bears no comparison to the patience and skill, as well as extreme care required in the work of ruling a large grating for a diffraction spectroscope. Errors are forbidden and cannot be repaired. The work as a whole must be practically perfect or the instrument is useless. The manipulation of interferometers is a task of exceeding delicacy, demanding the highest skill and exhaustless patience.



WATERSIDE STATION No. 2, NEW YORK EDISON CO.

# THE CENTRAL STATION IDEA

By Joseph B. McCall

President, National Electric Light Association
and
President, Philadelphia Electric Company

It has been many years now since a centralized generation of power for a large district was first advocated by a few far-sighted engineers. In those days the plan was impracticable of execution, however, because of the insufficiently developed apparatus for the purpose. Now, with the enormously increased size of generating units having correspondingly higher efficiencies, and with the complementary high-voltage transformers and transmission lines, the day has arrived when the most economical means of securing power is to obtain it from a *central station*. This unified supply of power for a district from a single source briefly constitutes the "Central Station Idea." The following article, explaining this up-to-the-minute idea thoroughly, should be highly appreciated.—Editor.

J. B. McCall

GREAT ideas developed enthusiastically to a practical working basis are responsible for nearly all of the great modern business successes and now we have the *Central Station Idea.*

Although manufacturing development has been more or less "marking time," during the past twelve months, the *Central Station Idea* has been striding forward in "seven-league boots."

The *Central Station Idea*, the purchasing of power in large or small units from great, centrally-operated generating stations with numerous interconnected substations as opposed to the private plant is growing very fast in this country. This is a very good thing for the people as a whole, because the *Central Station Idea* was born of economy and fostered by efficiency; it is the very last word in economical and efficient power supply.

It is a great satisfaction to merchandise a product such as electricity, which is an actual benefit to the individual and the public at large, a commodity which is not merely desirable from the standpoint of the purchaser but which is also a mighty agency for producing the greater efficiency, the increased comfort and the better health of our nation. The magazine *Public Service* touched upon this subject in a very apt way not long ago:

"It is characteristic, perhaps, of the present day disposition to measure all success or achievement by the standard of dollars and cents, that in nearly every estimate of the vast advantages resulting from the use of electricity in the industries, the humanitarian side of the question has been either ignored entirely or dismissed with mention so slight as to be entirely out of proportion to its importance.

Without detracting in any way from the commercial value of electricity, as an agency in manufacture, it may be said from the standpoint of the world at large that its most beneficent influence has been wrought in improvement of labor conditions among the employees of the factories where it is used. Other causes, it is true, have contributed to these improved conditions, and much credit is due to the owners and managers of modern factories; but without the aid of electricity there would not have been the revolution in factory conditions that has been witnessed in the last few years.

In addition to these advantages from the labor standpoint, the public also gains greatly by the reduced prices of the cost of manufactured goods resulting from reduced cost of production through the use of electricity."

The development of the *Central Station Idea* has, of course, been an integral part of the development of the electrical industry which has made such wonderful strides during the present century. From an engineering standpoint, the art has developed to an extent almost beyond the dreams of even the technical mind. During the past thirteen years huge generating units have been produced, along with other pieces of apparatus, which show gratifying increases in efficiency; transmission problems have been overcome, permitting the carrying of great quantities of energy for long distances; consequent improvements in transforming and distributing devices over larger areas have taken place; a greater and more diversified use of the energy has been generated, whether in the nature of scientifically designed lighting installations for the smallest residence or the largest commercial building or for some unique and useful power application. The supplying of power for street railway purposes by the central station is becoming general practice, this being so because the diversity factors of the two branches of the industry permit the greater use of the dollar invested in generating apparatus, with consequent economies; and the era of the electrification of steam railways is at hand, the current for which should be, and probably will be, supplied by the central station, for the same reasons that apply to the street railway transportation.

The result of the development of this *Central Station Idea* shows a reduction in costs, a reduction in rates and an increase in income; greater, stronger and more staple business, attracting a constantly increasing class of investors. The advances and improvements have, however, not all been material in character. The industry, as a whole, has taken a livelier interest and has taken a different stand on all questions involving the welfare and safety of the employe, as shown by the incorporation of beneficial organizations, saving fund societies, service annuity benefits, etc., forming thereby a closer, stronger, more co-operative relation between the employer and employe, and effecting permanent organizations which will inevitably insure better service to the public.

The brief span of the present century has also witnessed the establishment of governmental regulation by state commissions, and the industry recognizes that such regulation, as to rates and service, coupled with protection to our business, permitting a reasonable profit for service and effort, is acceptable and desirable to all concerned, maintaining as should be the purpose of such legislation an equitable, fair and just consideration of the rights of both parties, the public and the corporation.

Recent figures show that the requirements for the electrical industry of the country, during the present year, will be over a million dollars a day and it is the feeling of financial men, who are charged with the responsibility of furnishing money for these requirements, that the securities of utility companies will be more desirable as investments under governmental regulation than they are without it, and that a larger and a wider market for these securities will be created wherever governmental regulation is found.

We have reason, therefore, to be very optimistic as to the future of the central station industry. We believe the time will come when, in every community, the *Central Station Idea* will be recognized as an economic fact, when there will be a central station source of supply for all electrical energy furnished for any purpose whatsoever, and it is not beyond probability that future years will see vast trunk lines transporting energy over many miles of territory and connecting large centers of population throughout the country.

# THE COMMERCIAL METERING OF ELECTRICAL ENERGY

By J. W. Lieb, Jr.

Vice-President, New York Edison Company

The accurate metering of all the energy generated by a central station, both that used by the operating company and that supplied to the individual consumer, is of fundamental importance to all operating companies. Mr. Lieb analyzes the essential features for a satisfactory metering system and discusses at length the most important items; the matters of testing and inspection of meters being dealt with in detail. The author shows how a good system of inspection can reduce the number of complaint tests, and gives figures showing what has been accomplished in this direction in the case of the New York Edison Company. It will be noted that the ratio of complaint tests to the total number of meters is astonishingly small, and is being still further reduced. The development of a meter testing force is among the other interesting subjects discussed in this able article.—Editor.

J. W. Lieb, Jr.

THE proper metering by the electricity supply company of the energy generated in its power stations, and delivered to its customers, is one of its most important functions. We shall endeavor to analyze the more important factors involved in the conduct of a typical metering system, without attempting on the one hand to cover the subject too broadly, or on the other hand entering into a discussion of innumerable minor details. Briefly, the important essentials of a good system of commercial metering are as follows:

(1) Metering accurately and completely all the energy generated, thus providing basic data for the operating and accounting systems.

(2) Metering accurately and completely all the energy consumed for company purposes on the system and in the substations.

(3) Metering accurately and completely the energy delivered to the consumer so that each shall receive a proper bill and the company receive its rightful revenue.

The importance of properly metering all generated energy and all energy used for the company's own service so as to provide proper operating and statistical data is obvious and does not require amplification. From the technical standpoint the metering of the energy in generating stations and substations does not ordinarily introduce any unusual or difficult problem which cannot be handled by an adequate system for taking care of the operation of meters on the customers' premises.

The third requirement considers the metering of all of the energy delivered to the customer and involves many factors to which it will be necessary to refer in some detail. Some of the more important elements to be considered in the operation of a meter department are:

The selection of the proper types of meters and their approval by the regulating authority.

Assignment of the proper type and capacity of meter to the individual installation.

A proper system of tests and inspections.
Inspection on installation.
Periodic tests.
Inspection to detect tampering.
Office test.
Consumers complaint test.
Public Service Commission complaint tests.
Methods of settlement of complaints.
Standards.
Organization of Department.
Record and statistics.

The determination of the acceptability of any new type of meter has been greatly simplified by the establishment of the Code for Electricity Meters. The code was issued jointly by the meter committees of the National Electric Light Association and the Association of Edison Electric Illuminating Companies, the membership of these two committees, from the standpoint of central station service, representing the large majority of meters in service in the country. The specifications of the code have been approved by the leading manufacturers of meters, and it has come to be regarded as a generally acceptable set of specifications for watthour meters by the manufacturers and users, and it serves as a criterion by which any manufacturer can evaluate his own product and judge of the acceptability of a new design of meter before it is formally presented for adoption. Recent rules and regulations of public service commissions have freely embodied wholly or in part the specifications of the code, notably the rules of both the First and Second District Commissions of the State of New York.

The assignment of the meter to any consumer's installation, whether done by the contract agent or representative of a service department, should be in accordance with definite rules, often somewhat empirical in their provisions, but carefully prepared by the company's meter engineer who is familiar with the performance characteristics of the types of meters used and the local characteristics of the services and installations. Such rules usually assign meters of a capacity equivalent to 100 per cent of the total connected installation for such service as window lighting, signs, air compressors, and for emergency or construction service, in order to protect the meter against overloads. Correspondingly, the rules usually assign meters of a capacity of 50 per cent or even less of the total connected installation equivalent for apartment or detached residence lighting, the contemporaneous use of the total installation in such cases being infrequent and of short duration. Between the 100 and 50 per cent classes of meter assignment there will be of course various intermediate classes depending on the nature of the installation and the service.

In Fig. 1 is shown a comparison of the meter assignment rules of an electricity supply company, the "normal" load test of the meter in terms of the connected installation prescribed for meter tests by one public service commission, and the "active" meter load as specified by another public service commission.

The initial test of any meter on the part of the electricity supply company is the laboratory test. This test is quite distinct from the investigations conducted to determine originally the acceptability of a type, but is a test of each individual meter to determine its acceptance or rejection as received from the manufacturer. The test follows a closely maintained routine of, (1) comparison of meter accuracy with standard instruments; (2) measuring the adjustment ranges, magnet and compensators; (3) phase to phase relations in the case of inductive loads; (4) determination of current and potential transformer ratios, and shunt resistance, where such apparatus is auxiliary to the meter; (5) finally the inspection of the mechanical construction of the meter and the gear train to check the constants and gear ratios.

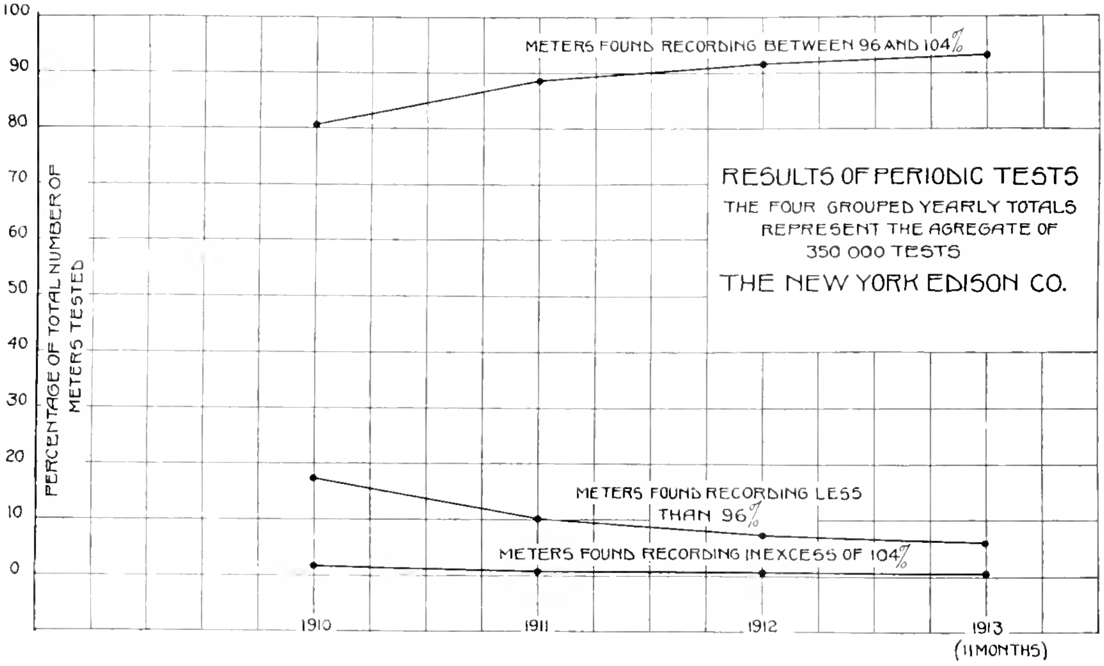


Fig. 1

With the completion of the meter installation in the customers' premises and usually within forty-eight hours thereafter a meter man should inspect and approve the work of the wiring or installation department, if the latter includes in its work also the setting of the meter. This inspection is to insure that the meter is in good operating condition, properly connected, and that the location is such as to insure the best possible metering conditions. In no sense is this inspection an accuracy check, although at this time such a test may be ordered at the discretion of the inspector. The detailed inspection immediately after installation includes the following:

(1) The examination of the general conditions of location that could affect the operation of the meter or affect the permanence of its calibration, i.e., excessive vibration, dust of any character, chemical fumes, dampness, proximity to stray fields or abnormally high or low temperatures.

(2) The setting and installation are inspected to prevent the placing in service of meters, their setting out of alignment, insecure fastening, incorrect connection or insufficient provision for future testing. At this time the possibility of the consumers, being able to divert unmetered current should also be covered by the inspection.

(3) The translating devices and their use in connection with the capacity and type of each meter are considered and the assignment of the meter as installed for the service approved or ordered changed.

(4) Notification to the accounting department as soon as the meter has been installed and connected with detailed information for placing the meter on the meter indexer's binder.

A proper system of service tests means primarily some basic schedule for periodic testing which constitutes the bulk of the work of the meter department. The periodic testing schedule of the public service commission of the First District of the State of New York is quoted in full below and is advanced as a typical example:

> "All direct-current meters installed upon consumers' premises shall be periodically tested according to the following schedule:
>
> Meters up to and including 25 amperes rated capacity shall be tested at least once in every 18 months;
>
> Meters exceeding 25 amperes up to and including 500 amperes rated capacity shall be tested at least once in every 12 months;
>
> Meters exceeding 500 amperes rated capacity shall be tested at least once in every 6 months.
>
> All types of alternating current induction meters shall be periodically tested as follows:
>
> Single-phase meters up to and including 25 amperes rated capacity shall be tested at least once in every 30 months;
>
> Single-phase meters exceeding 25 amperes rated capacity shall be tested at least once in every 24 months;
>
> Polyphase meters up to and including 150 amperes rated capacity shall be tested at least once in every 24 months;
>
> Polyphase meters exceeding 150 amperes rated capacity shall be tested at least once in every 12 months."

Supplementing a routine testing schedule such as the above, there may be special groups of meters tested at shorter intervals because an intimate knowledge of local conditions makes more frequent tests advisable, such, for instance, as meters set for emergency, temporary, or construction work. In many localities these constitute an appreciable and important group of meters measuring a considerable revenue, subject to severe and varying conditions and in service for limited periods. Meters for any class of service and of any capacity which from the records of the billing department show for continued periods a registration considerably higher than the average meter of the same capacity, can profitably be tested at shorter periods than those specified in the ordinary schedule of periodic tests.

Another group of meters which it is advisable to test at intervals shorter than those prescribed by the routine schedule of tests consists of meters whose monthly registration would raise a suspicion of tampering on the part of the consumer. An abnormal or sudden variation in consumption may be indicative of tampering and still not serve as a basis for legal procedure. Disregarding the legal aspects of the matter, however, the tampering may be such as to cause the meter to under-record, obviously reducing the consumer's bill, or to intentionally over-record so that the complaint test—which is even in such cases often insisted upon by the consumer—may show a fast meter, establishing an improper claim for a false rebate. This fake rebate claim might be for a part or all of the elapsed period back to the last previous test. With a meter in either condition, it is evident that frequent tests break up into short periods the time over which loss would occur from a slow meter and reduce the period for which an improper rebate might be claimed.

The foregoing paragraph leads naturally to the consideration of methods for detecting tampering. The obvious ones are, first, a periodic inspection survey of all meters and services. This method is, for a large system, expensive and likely to prove ineffectual. Second, all employees requiring access to services should be instructed to note and report immediately any evidence of tampering. Such inspections are infrequent and are not instigated by reasons having to do directly with tampering, so that this method is not complete. The third and most logical method of attacking the evil is through the constantly recurring weekly or monthly records of consumption handled by the meter indexers and bookkeepers. The bookkeepers should be instructed to watch carefully the monthly consumption and report any sudden or abnormal variation, any variation from normal may mean high or low or backward registration, or lack of registration. The report should take the form of a request for a careful inspection of the meter by a trained meter man. These inspections will result in repairs to damaged meters, the elimination of non-recording meters, and the correction of conditions which facilitate tampering, and the continued surveillance of premises where chronic tampering is likely to be practiced.

It is possible, of course, that many inspections thus called for by irregularities in the record noted by the bookkeeper may be due to perfectly natural and legitimate causes. Speaking for one large lighting system, however, it can be stated that these inspections and checks are justified by the irregular conditions frequently discovered and corrected, and the expense is amply warranted by the stoppage of losses.

These inquiry inspections just described form in themselves the source for a large number of tests known as office tests, a term defined by the First District Public Service Commission as follows:

> "An office meter test is a test of an electric meter by an electric corporation upon the premises where the meter is installed, by the direction of the corporation itself, of an officer or of an employee, that a special test be made."

A third but most essential single group of meter tests is composed of the complaint tests. The nature, volume and trend of these tests

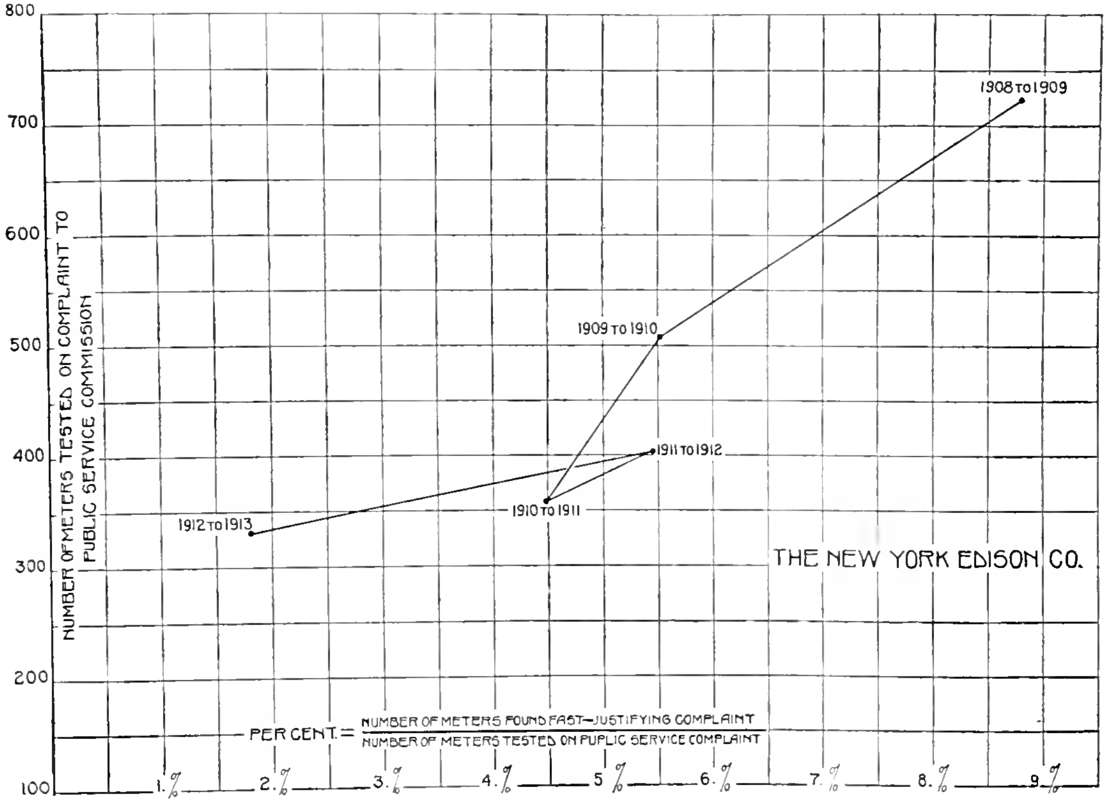


Fig. 2

afford a general index of the operating condition of the meters on any system. Fast meters obviously will cause complaints by the consumers, but complaints may also arise from meters which are allowed to become slow or defective and then suddenly brought to accurate condition as a result of a periodic or office test. The complaint tests, while all of the same character as to technical details, may be of very different significance in their origin and the interpretation of the results obtained. The lighting companies are as a rule ready at all times to make complaint tests of meters or detailed investigations of any consumer's installation without charge. Complaint tests may, therefore, be made by the company on direct complaint of the customer, often in the presence of his representative expert; by the public service commission on complaint to it; or by the city authorities on complaint to them.

A few years ago there was current a general impression of suspicion on the part of the public toward all metering devices and the electric meter shared to a large extent the prevalent distrust of the gas meter. This impression is confirmed by the fact that the public service commissions when first established directed their activities to a great extent to the investigation of metering matters, consideration of the performance of the types in current use, methods of maintenance and test, and the checking of standards. The consumers at first took advantage liberally of the new facilities afforded by the establishment of the commissions to ascertain the condition of their own meters.

The considerable demands made at first upon the commissions in this direction have gradually decreased and the number of complaint tests which they are now called upon to make has been reduced to a very moderate routine. This can be ascribed to at least two causes: First, the formulation and wide dissemination of the Code for Electricity Meters, and second, its general approval and acceptance by all interested parties. The code represented the best meter practice of the country and presented meter data and performance according to the highest possible

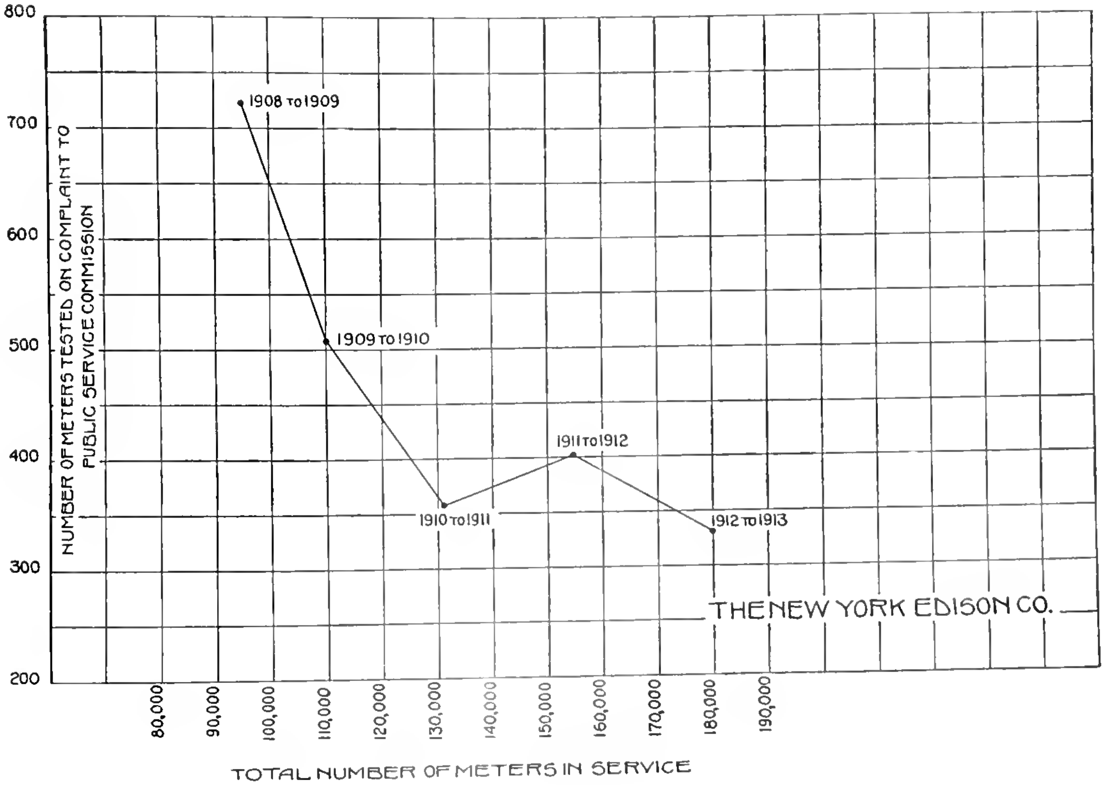


Fig. 3

standards, and it became available at an opportune time for the use of the public service commissions. A careful consideration by their engineers of the data contained in the code, the basis on which it was compiled, and its authoritative character assure them of its thoroughness and practicability meeting every reasonable requirement as measured by the highest performance standards.

The other cause which has tended to dispel the attitude of suspicion toward electric metering on the part of the public service commissions and the public has been the gradual appreciation by them of the high plane on which the lighting companies have practically without exception endeavored to maintain the metering of their product and the large expense and effort expended to insure accuracy for the individual consumer, avoiding all overcharge and irregular registration and securing to the company its just revenue.

Definite figures are now available which show conclusively the marked diminution in the number of complaint tests of meters made by the Public Service Commission for the First District on the circuits of The New York Edison Company. In analyzing the curves shown, it may be well to state the conditions under which complaint tests of meters are made by the public service commission on the consumer's premises and the testing fees charged by them.

The schedule for these charges is as follows:

SCALE OF FEES FOR TESTING METERS

| Amperes Rated Capacity | Fee |
|---|---|
| 10 or less | $1.50 |
| Over 10 but less than 15 | 2.00 |
| Over 15 but less than 25 | 2.50 |
| Over 25 but less than 50 | 4.00 |
| And for each additional 25 amperes or fraction thereof 50 cents. | |

If the meter is found fast to the prejudice of the consumer—the public service commission law fixing the limit at plus four per cent—the lighting company pays the cost of test; but if the meter is found accurate, below the four per cent limit, or is found slow, the consumer pays for the test.

It is fair to assume that, if fast meters recording to the prejudice of the consumer exist in any appreciable number, they would certainly appear among the complaint tests applied for to the commission, as the consumer is not likely to risk paying the charge for a test unless he believed that his meter was over-recording. This is particularly true in view of the fact that the consumer is aware that the company itself is willing to test his meter at any time without any charge whatsoever.

The data tabulated below and the curves in Figs. 2 and 3 show the decrease in number of public service commission tests during the last few years, as well as the marked decrease both in number and extent of inaccuracy of the so-called "justified" complaints. The figures are grouped in yearly periods from August to July, as the first tests of this character under commission jurisdiction were made in August, 1908.

PUBLIC SERVICE COMMISSION COMPLAINT METER TESTS
NEW YORK EDISON COMPANY SERVICE

| | Total Number of P.S.C. Tests | Number of Meters Found Fast (+4 Per Cent and Above) | Per Cent of Fast Meters |
|---|---|---|---|
| August, 1908, to July, 1909 (incl.) | 722 | 64 | 8.8 |
| August, 1909, to July, 1910 (incl.) | 507 | 28 | 5.5 |
| August, 1910, to July, 1911 (incl.) | 357 | 16 | 4.5 |
| August, 1911, to July, 1912 (incl.) | 403 | 22 | 5.4 |
| August, 1912, to July, 1913 (incl.) | 331 | 6 | 1.8 |

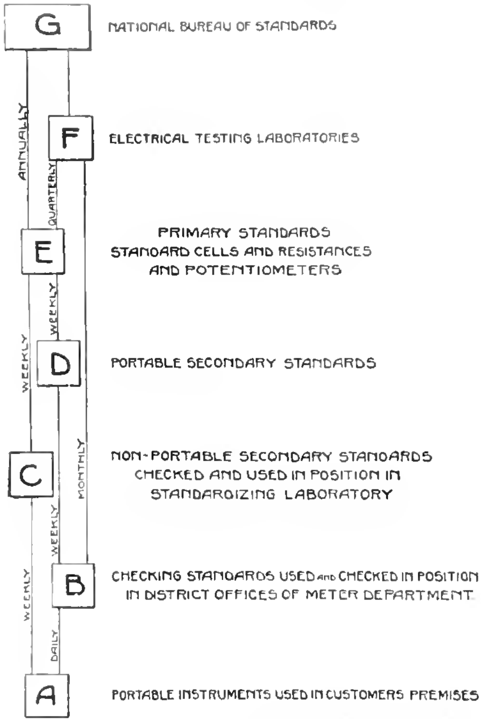
RATIO OF PUBLIC SERVICE COMMISSION COMPLAINT TESTS TO TOTAL NUMBER OF METERS IN SERVICE

| | Total Number of P.S.C. Tests | Total Number of Meters in Service | Per Cent |
|---|---|---|---|
| August, 1908, to July, 1909 (incl.) | 722 | 95,000 | 0.75 |
| August, 1909, to July, 1910 (incl.) | 507 | 110,000 | 0.46 |
| August, 1910, to July, 1911 (incl.) | 357 | 131,000 | 0.27 |
| August, 1911, to July, 1912 (incl.) | 403 | 155,000 | 0.26 |
| August, 1912, to July, 1913 (incl.) | 331 | 180,000 | 0.18 |

Continuing the consideration of tests made by the commissions it is to be noted that while specifications for the acceptance of types of meters and the frequency and methods of making periodic tests are prescribed in much detail, the methods or bases of settlements with the consumer where a meter is found fast have been left to the companies. The settlement in actual money that is to be refunded to the consumer is really what interests him. There are no laws or operating rules and regulations of the commissions which prescribe in a definite manner the bases of settlement with the consumer for a fast meter. It is left largely to the discretion of the company whether the allowance shall be for the full period back to the last test of record, or half the period, or half the rate of allowance to be extended over the full period shall be considered in adjusting the refund to the consumer.

The accuracy of the work done by the meter department is, of course, entirely dependent on the instruments used as standards and the system for maintaining their accuracy through periodic comparison with fundamental standards. The manufacture of instruments of precision and the methods of standardization have made great progress within the past few years, and high grade portable instruments are now available at a reasonable cost, making it possible to apply precision methods and primary standards in the field which were formerly available only for use in the standardizing laboratory. In order to eliminate every possible source of error in the standards, securing the highest degree of accuracy, it is necessary to provide, as a matter of routine, for systematic comparisons and careful checks. In Fig. 4 will be found a diagrammatic representation of the standardizing and check system developed by the New York Edison Company. It is only necessary to add that the system is supplemented by a complete set of records so that it is possible to refer to the accuracy condition of an instrument at any time in terms of the Company's fundamental standards.

In considering meter maintenance on a large system it is necessary to provide for conducting the operating details on a large scale. The work involved in conducting, as in one case we have in mind, three hundred thousand meter tests and inspections annually involves not only the work of the meter indexer and installation workman, but the gathering, training, maintaining and directing of a complete and efficient organization. A typical organization in the case of one of our large electricity supply companies is outlined in Fig. 5. Thoroughly competent meter testers are not obtainable as are skilled watch-makers, for instance, in answer to advertisements. It is necessary for each company to train them for its own work. Testing equipments, complete in their details from the standard instrument to the load box, of proper shape and weight for local conditions, are not available as a purchasable unit, but must be put together and adapted to the local conditions. As a result of the consolidation of outlying companies and the extension of the territory served, which has been going on for some time past in the central station industry, it is necessary to arrange for geographically located district headquarters which must be correlated under the supervision of the centrally located headquarters or department.



- THE NEW YORK EDISON CO. -
METER AND TEST DEPARTMENT
GRAPHIC REPRESENTATION
OF
SYSTEM OF INSTRUMENT STANDARDIZATION

Fig. 4

In the development and organization of an efficient meter testing force, it has been found that young men with a thorough grammar school or high school training ultimately develop into the best meter testers, although the period of instruction is necessarily longer than that required by

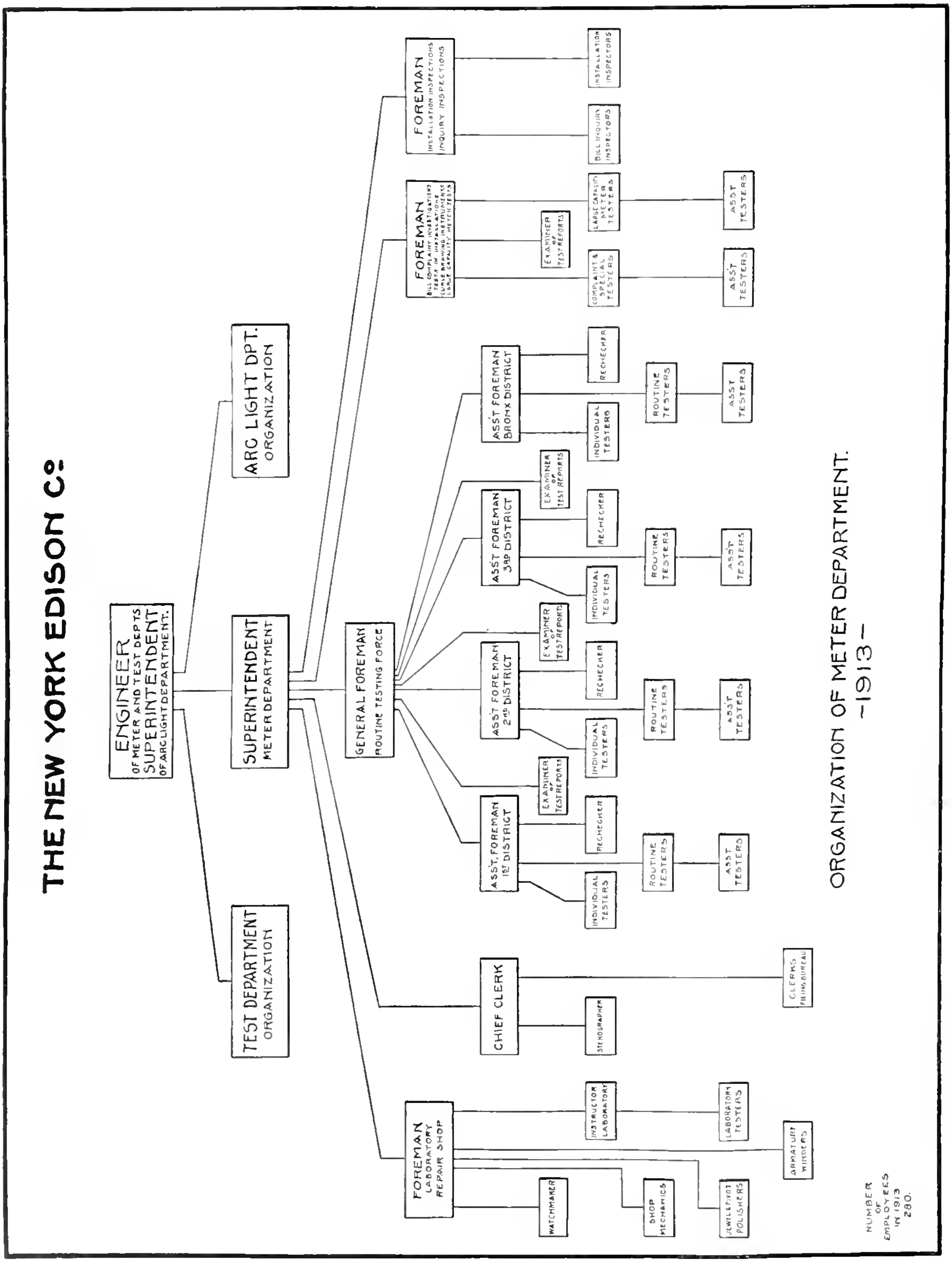

THE NEW YORK EDISON Co.
ENGINEER OF METER AND TEST DEPTS SUPERINTENDENT OF ARC LIGHT DEPARTMENT.
TEST DEPARTMENT ORGANIZATION
SUPERINTENDENT METER DEPARTMENT
ARC LIGHT DPT. ORGANIZATION
FOREMAN LABORATORY REPAIR SHOP
CHIEF CLERK
GENERAL FOREMAN ROUTINE TESTING FORCE
ASS'T. FOREMAN 1ST DISTRICT
ASS'T FOREMAN 2ND DISTRICT
ASS'T FOREMAN 3RD DISTRICT
ASS'T FOREMAN BRONX DISTRICT
FOREMAN BILL COMPLAINT INVESTIGATIONS TESTS OF INSTALLATIONS CURVE DRAWING INSTRUMENTS LARGE CAPACITY METER TESTS
FOREMAN INSTALLATION INSPECTIONS INQUIRY INSPECTIONS
WATCHMAKER
SHOP MECHANICS
JEWELL PIVOT POLISHERS
ARMATURE WINDERS
INSTRUCTOR LABORATORY
LABORATORY TESTERS
STENOGRAPHER
CLERKS FILING BUREAU
INDIVIDUAL TESTERS
ROUTINE TESTERS
ASS'T TESTERS
RECHECKER
EXAMINER OF TEST REPORTS
COMPLAINT & SPECIAL TESTERS
LARGE CAPACITY METER TESTERS
BILL INQUIRY INSPECTORS
INSTALLATION INSPECTORS
ORGANIZATION OF METER DEPARTMENT.
-1913-
NUMBER OF EMPLOYEES IN 1913 280.

Fig. 5

young men with technical or mathematical training in the technical school or college. Graduates of our technical schools and universities do not as a rule become permanent employees of the meter department, as they have open to them more lucrative positions, owing to their broader technical knowledge, and they regard the service in the meter department only as giving them a practical knowledge of testing methods. The man who enters the meter service with a less complete educational equipment is more apt to stay in the department, where he is brought into contact with other departments in the company's organization and obtains familiarity with the many kinds of apparatus and devices connected through the meters to the company's supply mains. These employees, therefore, if they profit by their opportunities for acquiring broad knowledge and experience, readily fit themselves for work of greater responsibility with higher emoluments in other departments of the company, or in other branches of electrical work.

Where geographical districts are used as parts of the large system, the training of the

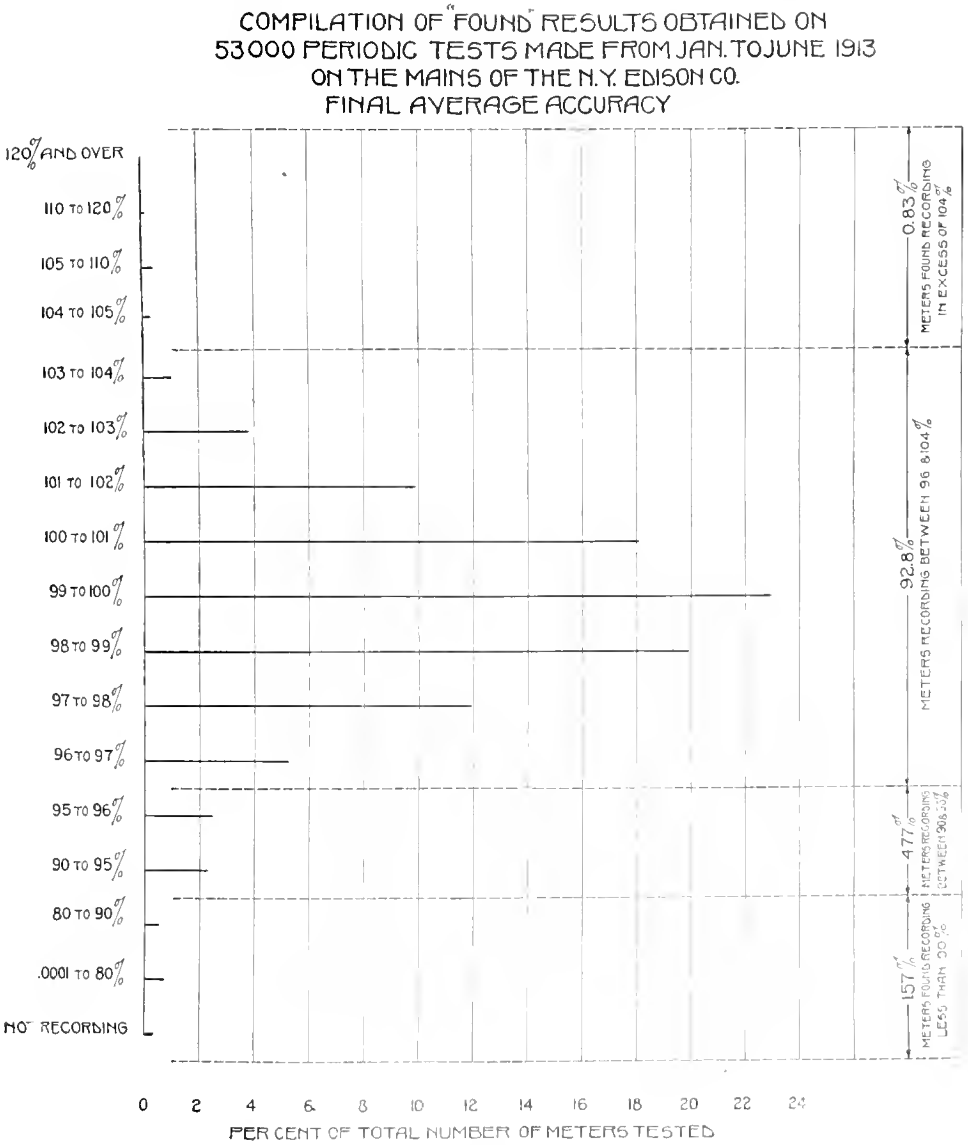


Fig. 6

men, the formulation of the methods of test, and the standardization of equipment should be carried out in every detail on a uniform standard, so that comparable efficiency may be obtained from the several units. The continual development of new meters and testing devices requires a constant process of investigation and improvement, so that the meters and their maintenance shall be conducted so as to obtain the highest possible accuracy at a reasonable cost.

The records of the meter tests are important from a commercial and legal aspect, constituting a signed and dated record of the condition of the apparatus on the readings of which the consumer is billed, and they constitute an index of the performance of the meter as an individual piece of electrical apparatus. To fulfill the former requirement, the meter test records, like any other reference data, to be of maximum value should be readily accessible and immediately available to those desiring to consult them. They should, therefore, be carefully filed and indexed in accordance with a system dictated by local conditions, either according to the consumer's name and address, or by the meter serial number.

From the standpoint of technical test data the records serve as a continuous running index or source of information on such matters as the suitability of certain types of meters for distinct classes of service, the performance of the various component parts of the meters, the methods of test in use when the meters were last tested, the accuracy of the standardizing of the instruments used, and the competence and personal equation of the men who made the test. The records of "found" accuracy on meter tests should therefore be carefully tabulated, scrutinized and analyzed before they are filed and lose their identity, in the aggregation of a day's or month's work. This may be illustrated by referring to Fig. 6, giving curves showing the metering conditions, and their gradual improvement is shown by the records of "found" results on periodic tests in the case of the New York Edison system, condensed for plotting in yearly totals. The results shown are based on the "final average accuracy" as prescribed by the First District Public Service Commission rules and composed of a composite of the accuracy of each meter at three loads, 10 per cent load, "normal" load and 100 per cent load, which as a single figure index of the performance of the meter throughout its entire range is probably as fair and representative a figure as can be obtained.

The load at which the meter is to be tested as the "normal" load under this plan is obtained by operating the meter under the various service conditions at the following percentages of the total connected installation:

CLASSIFICATION OF INSTALLATION TO BE USED IN TESTING METERS AT "NORMAL" LOAD

| | | Per Cent |
|---|---|---|
| A | Residence and apartment lighting | 25 |
| B | Elevator service | 40 |
| C | Factories (individual drive), church and offices | 45 |
| D | Factories (shaft drive), theaters, club entrances, hallways and general store lighting | 60 |
| E | Saloons, restaurants, pumps, air compressors, ice machines and moving picture theaters | 70 |
| F | Sign and window lighting and blowers | 100 |

*Final Average Accuracy*—After the accuracies at the three loads, namely, 10 per cent of meter capacity, "normal" load, and 100 per cent of meter capacity have been obtained, the *final average accuracy* is obtained from these three figures by multiplying the result of the test at normal load by three, and adding the results of the tests at 10 per cent capacity and 100 per cent capacity, and then dividing the total by five.

In curve No. 6 is shown the improvement in the results obtained in the periodic meter tests on the New York Edison system from 1910 to date:

Referring again to the data on the public service commission complaint tests it should be borne in mind that the results of the commission tests are checked by a contemporaneous test made by the lighting company's representative, the two groups of testers using different sets of instruments, maintained by different systems of standardization. The two sets of instruments are placed in series, the results obtained by the public service commission testers, checked as above, serving as the official record of the test. It should be observed that it is sometimes impossible to obtain the customer's consumption by a direct reading from the meter, owing to the fact that the meter was burnt out or became inoperative or "non-recording" from some other cause. In this case the consumer is rendered a so-called prorated bill, with the fact of its being prorated clearly indicated on its face. The prorating is obtained by a careful comparison of the readings of the meter during the previous months and for the similar period of the preceding year and represents the best judgment of the company as to what the consumption may have been during the period in question. In case the consumer raises any question as to the amount so "estimated" by the company, the matter is adjusted on such a basis as may be entirely acceptable to the consumer.

Looking at the matter from a commercial standpoint, it will be seen that questions of contract, rates, and classification of service, etc. are questions of the commercial policy of the company conforming to well established business laws, commission regulation, or company policy which are alike for each consumer. The introduction of the electric meter by the lighting company in the consumer's premises and the successive rendering of bills to the consumer month by month, based on the readings of the meter, may constitute a source of suspicion and question on the part of the consumer, which if allowed to remain may seriously impair the good will of the consuming public. It is, of course, the earnest desire of the lighting companies to eliminate all such questions, and to this end the supply meters must be kept up to the highest standard of accuracy. There must be constantly available a system of records so that the consumer, or his technical representative, may be satisfied by personal investigation and inquiry that the meters used by the company are of the proper type and so maintained as to accurately show the energy used by the consumer. While questions as to rates and conditions of service may arise in the relations of the consumer with the company, his continued good will and satisfaction with the service is largely based on the fact, either accepted by him or demonstrated to his satisfaction, that his individual consumption is being properly metered and correctly billed.

# A PLEA FOR THE STANDARDIZATION OF FREQUENCIES

By C. W. Stone

Manager, Lighting Department, General Electric Company

The author points out that there are as many as five different frequencies in use in this country today, although there has never been an excuse for more than two of them, 25 and 60 cycles. The latter frequency possesses decided advantages for incandescent and arc lighting circuits, and affords the manufacturer a greater range of speed and a more economical design for his generators and motors. The lower frequency was justified a number of years ago, when the operation of synchronous converters on 60 cycle circuits was far from satisfactory; but now that these machines have been improved to the point where their performance is entirely satisfactory at the higher frequency, it would seem that all parties concerned—the public, the operating companies, and the manufacturers—would be benefited by the gradual adoption of 60 cycles as standard.—Editor.


C. W. Stone

THE frequencies used in this country for the distribution of alternating current are 25, 40, 50 and 60 cycles, 125 and 133 cycles having practically disappeared. There are a few cases of 33 cycles.

There seems to be little excuse for any frequency other than the two most commonly used: namely, 25 and 60 cycles. Both 40 and 50 cycles are compromise frequencies which, if standardized before the wide development of both 25 and 60 cycles, would probably have been a more natural general frequency to use, 50 cycles being preferable. As matters are at present, however, 50 cycles is only used in a few isolated cases. Forty cycles is used more generally, but only in such limited areas as represented by the power companies in the Mohawk Valley, and in isolated mill installations. It is the opinion of the writer, therefore, that both 40 and 50 cycles should be discouraged.

True economic principles are not presented by adopting a system of distribution for some installation which would make it impossible to connect, either in emergencies or ultimately for good, with some other source of power, except through expensive and inefficient frequency changers.

Twenty-five cycles was adopted a number of years ago, as it seemed to be a frequency best suited to the classes of apparatus then available for transforming from alternating current to direct current, and as the larger lighting and power companies were using direct current primarily as their main load, and also as direct current was universally used for railways. The principal consideration in determining the frequency was the class of apparatus available for transforming alternating into direct current.

Conditions today are different, and the result is that 60 cycles is the frequency most generally used. This frequency is more generally applicable to all the varied conditions met with in the distribution of power than 25 cycles. More speeds are available with 60 cycles than with 25 cycles; for example, 1500 revolutions per minute is the highest possible speed for 25 cycles, whereas 3600 revolutions and intermediate speeds are available with 60 cycles.

The question of speed affects not only the driven apparatus, but also the generating apparatus. This is particularly true with steam turbine-driven machines, for with a speed of 1500 revolutions per minute, especially with turbines of less than 10,000 kw. the machines are more costly, less efficient, and require more floor space than those designed for 60 cycle operation.

Motors for 25 cycles are more expensive to build than 60 cycle motors. They are more bulky and less efficient, and have no better operating characteristics; and this same condition exists in the design of 25 and 60 cycle transformers.

The higher inductance of 60 cycle apparatus has a tendency to dampen out disturbances originating in the lines feeding them, this being particularly true with very high voltages.

Synchronous converters, which are used almost universally in this country for transforming from alternating to direct current, are now designed for operation on 60 cycle systems, and can be considered very reliable and efficient pieces of machinery under almost all conditions of service.

In the opinion of the writer, there has been a more general use of motor-generators in railway work, for transforming alternating current to direct current on 60 cycle systems, than was necessary. It would probably always be better to use motor-generator sets where it was thought inadvisable to install rotary converters on a 60 cycle system, however, than it would be to install frequency changer sets for 25 cycle apparatus which would be used exclusively for railway purposes, as the first cost would be lower and the overall operating efficiencies considerably higher.

As fuel becomes more expensive, there will be a still greater tendency to concentrate the production of power in larger systems, and to gradually eliminate all isolated power plants. It is obvious, therefore, that a frequency which makes it possible to tie in with the existing companies nearby, and to use the existing motors, etc., of the installation without paying for the losses incident to the use of frequency changers, represents a frequency having universal advantages.

We can consider, therefore, that in the course of time all the frequencies now used, other than those generally used, will eventually be eliminated, and consequently 25 and 60 cycles will be by far the most universal.

While 25 cycles is generated for lighting purposes in some localities, it is probable that it will never be generally used, whereas 60 cycles is almost universal and is destined to be the common frequency for such purposes. There are many reasons for this conclusion which are probably too well known to require discussion in this short article.

It is history that all power companies organized for lighting and power purposes, using direct current for general distribution, found that direct current, while of advantage in congested localities, was not suitable for use in the less densely populated districts, because of the expensive transmission lines required to eliminate the high losses. In consequence they adopted alternating current for all outlying districts, and almost universally selected 60 cycles, except in the early stages of the art, where higher frequencies were used; but today nearly all of these installations have been changed to a lower frequency.

It is also true that the growth of most places, while at first concentrated in certain districts, after a certain saturation is reached have to extend further from the center, and consequently into a district or zone requiring alternating current. Thus it is quite common to find that the alternating current load is increasing far more rapidly than the direct current, and, as pointed out before, the frequency most generally used for this service is 60 cycles.

Another reason for this increase in alternating current is that the growth in population necessitates more industries, and usually these are not built in the congested districts but in the suburbs, in the district fed by the alternating current systems. In cases where these manufacturing concerns require direct current for their purposes, synchronous converters are usually used for transforming.

Where railway companies, instead of increasing their own generating equipment, are now either purchasing power from the water power companies or central stations in their vicinity, or will do so in the future, they require direct current as a rule, and in consequence have no interest in the frequency of the supply system. The power companies furnishing this energy certainly cannot afford to install 25 cycle apparatus in their stations for this purpose alone; nor can they afford to throw away the power necessary for the operation of frequency changer sets, involving as it does energy losses of 10 per cent or more—usually more—as well as the interest and depreciation on the apparatus, the buildings, and the control equipment, and the labor involved in operation. In addition, the peak capacity of the stations is increased almost in proportion to the increased losses due to the operation of frequency changers.

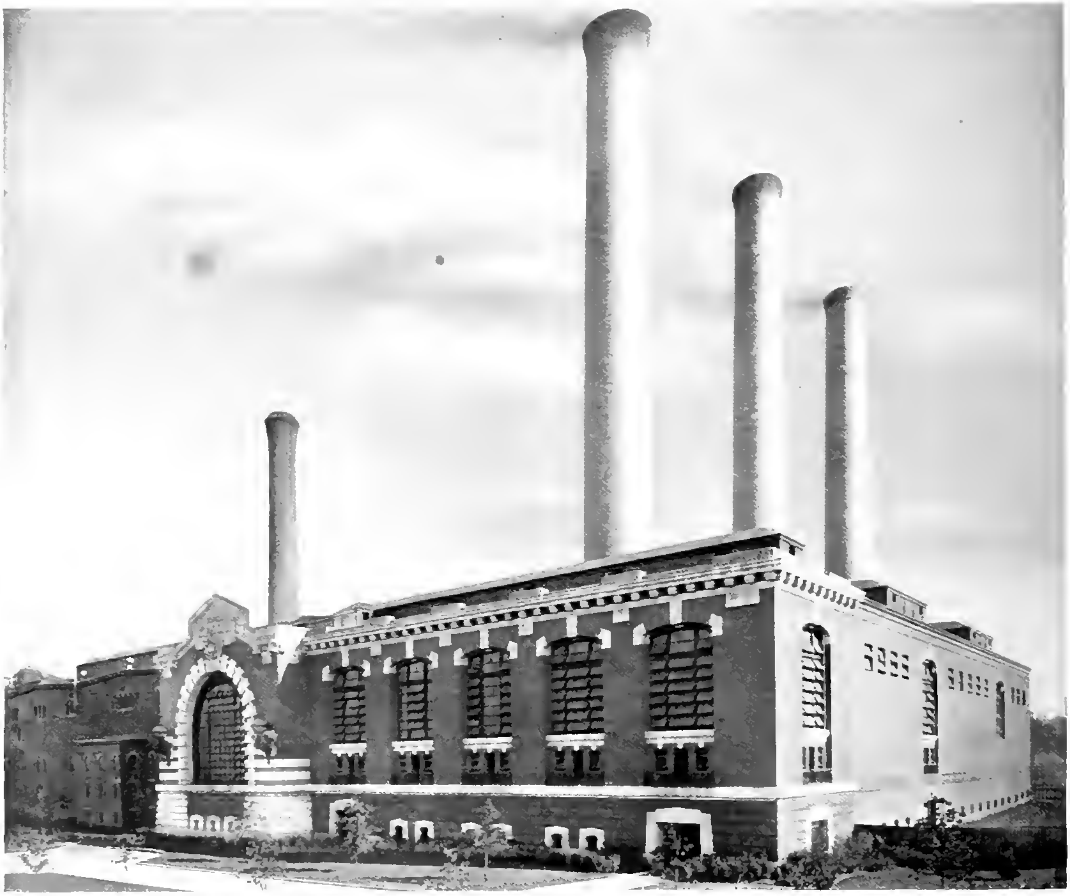
Another feature which should be considered is that the cost of apparatus is greatly affected by the multiplicity of its parts. This is true not only in first cost, but in maintenance cost. Take, for instance, a line of alternating current motors. Manufacturers are now forced to develop a complete line of motors for 25, 40, 50 and 60 cycles, each size usually for about ten voltages, and generally two or more speeds; each size of motor at each frequency, at each potential, being designed for enclosed, semi-enclosed, vertical, horizontal and other miscellaneous methods of operation—the entire line being duplicated over and over again due to the frequency.

This certainly is not a particularly economical manufacturing condition, and in consequence is reflected in the cost of all motors. If, therefore, the motors could be confined to simply 25 and 60 cycles, or preferably 60 cycles alone, great economies would result.

Transformers are another class of apparatus falling in this category. We have air blast, oil-cooled, oil-and-water-cooled, forced oil-cooled and other modifications of these designs, all arranged for many different voltages, and all the various frequencies duplicated in capacity for all the different conditions.

If all operating companies would, when it is necessary to increase the capacity of their stations, install 60 cycle machines in their outlying substations instead of 25 cycle apparatus, and further, as the demands of the central portions of their systems require additional equipments, remove the 25 cycle machines from the outlying stations to the main stations, or exchange them for new and larger 60 cycle machines, there would be a gradual elimination of 25 cycle apparatus. This would consequently increase the requirements for 60 cycle apparatus, which in the course of time would result in such a preponderance of 60 cycle apparatus that 25 cycles would appear only as an incidental frequency, and would have little bearing upon the cost of other apparatus. This could be done without in any way seriously affecting the operation of existing companies and their systems. Greater economies would result in feeder investment from such method of operation, and a considerable simplification in the operation of the systems.

From the foregoing it would seem that a determined effort should be made by all interested, in particular the operating companies, to eliminate as far as possible the further extension of 25 cycle systems, confining, as far as possible, all of their increased demands to the 60 cycle systems.



POWER HOUSE OF THE EDISON ELECTRIC ILLUMINATING COMPANY, BOSTON

# A REVIEW OF SYSTEMS OF TRANSMISSION AND DISTRIBUTION FOR LIGHTING SERVICE

By H. R. Summerhayes

Assistant Engineer, Lighting Department, General Electric Company

The main reason for the great number of systems of distribution that are in use today will be found in the rapid growth of the companies supplying electric lighting and power, and the demands made upon them; progress in the industry; differences of opinion among engineers; and the variety of purposes for which electrical energy is used. The author gives us a historical sketch of the development of each of the fundamental systems—direct current and alternating current—and shows how conditions in some of our larger cities have brought about a combination of the two. Each of the common methods of distribution is then shown diagrammatically and discussed in detail with particular reference to copper consumption, regulation, and its suitability for lighting and power.— Editor.

**H. R. Summerhayes**

In considering the methods of transmission and distribution of electrical energy for lighting and power in cities, the observer is at once impressed with the great diversity of methods and systems. In many of our large cities, 25 and 60 cycle current is transmitted to substations, and 60 cycle and direct current distribution systems are in operation side by side; and there is often presented the additional complication at some stations of 600 volt direct current supply for street railway service and 500 volt ungrounded power circuits for motors.

These conditions are due to various causes, among which may be assigned rapid growth and transition in the systems themselves and in the demand upon them; progress in electrical art; difference of opinion among engineers as to the relative advantages and disadvantages of different systems; and the great variety of purposes for which electrical energy is used.

Since most of the vast growth of these systems has taken place within a third of a century—and the progress of electrical science and industry has been so rapid that it has been difficult even for engineers active in the profession to keep abreast of ever changing practice—it may be of interest to trace the development of some of these systems from the earlier stages.

## DIRECT CURRENT

In 1879 and 1880 the Brush and Thomson-Houston open coil dynamos for series arc street lighting were introduced, and at about the same time came Edison's twin inventions of the high resistance incandescent lamp and the constant potential distributing system of feeders and mains, with lamps connected in parallel. These inventions form the basis of all the direct current lighting networks, and are in use today with changes only in detail.

In 1881 the first Edison plant for the supply of electric current to the public for lighting was established at Appleton, Wisconsin. The Pearl Street generating station of 2000 lights capacity, supplying a system of 50 miles of wires, was inaugurated in New York in 1882. A 3000-light Edison plant was started in the early part of 1882 in London. In the same year also, the Edison three-wire system made its appearance, using 220 volts across the outer wires, with 110 volt lamps connected between the outer wires and neutral, this arrangement requiring only 40 per cent of the copper of a 110 volt two-wire system. Thus the economical area of the system was greatly extended and the growth of the industry was rapid. Before the end of 1882 over 125 electric lighting plants, with a total capacity of about 25,000 lamps, had been installed on the Edison system, and by 1891 the total capacity of Edison direct current stations was over one and a quarter million lamps.

During the eighties, direct current systems were installed in many cities, including Boston, Chicago, Philadelphia, Brooklyn and others. The early direct current development abroad paralleled closely American methods, but later the lamp voltage was raised from 110 to 220 volts on most of the English and many of the Continental systems; so that the standard lamp pressure in England is now 200 to 220 volts, and the three-wire systems are operated there at 460 to 500 volts across the outers, as compared to 240-300 volts in American practice.

It is difficult to understand this divergence, although both systems possess advantages. American engineers claim that the 15 to 2 per cent inherent superiority of the 11 volt lamp in life or efficiency over the 220 volt lamp more than compensates for the saving in copper, which is the chief advantage of the English system.

We should not forget, however, in these days of unified electric systems, an incidental advantage of the higher voltage, namely, that of utilizing the 500 volt generator for street railway supply as well as lighting.

The railway voltage in England is frequently 500, and a station supplying both lighting and railway service may contain five machines, two for railway, two for lighting, and one spare. All of these are shunt wound for lighting service, at 480 volts, and are provided with an auxiliary series winding which is cut in by switches when the machine is used for railway supply.

Three-wire systems with 220 volt lamps have never been widely used in this country. The only two prominent instances are Richmond, Va., and Providence, R. I. Five-wire systems permitting the use of 550 volt generators, with balancer sets consisting of four machines so arranged as to obtain three intermediate wires between the outers and giving a lamp pressure of 110 volts between adjacent wires, were used to a limited extent abroad, but have mostly been discontinued. Notable examples were Vienna and Paris. The complication and difficulty of balancing on these systems outweighed the saving in copper.

The first Edison systems in this country were laid out for incandescent lighting; but within two years motors were connected, at first for 110 volts, but soon afterwards the present practice was established of using 220 volt motors connected across the outers, thus minimizing the unbalancing of voltage. Constant potential direct current arc lamps came into use in the early nineties, and thus, with the motor service, made the three-wire network a universal reservoir for all classes of power and light.

In some places where the power load was large as compared to the lighting, it was found expedient to install separate 500-volt two-wire power circuits; but in most large cities the combined power and lighting service gives excellent results.

The generators were at first belt-driven from engines, but the advantage of direct-connected units was early recognized and such machines were installed in large plants.

The small economical area of distribution required that stations be within a mile or less of each other for a dense load, and the result was that some of our larger cities soon contained several steam generating stations connected to a common network. As it was not always possible to locate the station conveniently with respect to a supply of condensing water, the exhaust steam was frequently sold for heating service. The next step was the installation of storage batteries to insure continuity of service; this being followed still later by the replacement of many of the early engine-driven generators by rotary converters or motor generators supplied from a-c. power transmitted from a central generating station.

In its essentials, the Edison three-wire system remains the same as at first introduced. Many of the original Edison tubes still survive in the mains of the network, but are supplanted by cables in the feeders and trunk mains. Cables are used for new work. The principal changes have taken place in the generating apparatus, and more recently in the lamps.

### ALTERNATING CURRENT

The first commercial alternating current plants in this country were installed in Greenburg, Pa., and Buffalo, N. Y. The alternating current systems were taken up and rapidly developed by Westinghouse, Stanley, Thomson and Houston and others. A single-phase frequency of 125 or 133 cycles was used in those early plants; the current being generated usually at 1100 or 1200 volts, single-phase. Lamps of 50 volts were used, for the 110 volt lamp as then made did not have a long life on alternating current.

These high frequencies appeared desirable on account of the transformers being much cheaper than those for low frequencies. Also the small belt-driven generators used in those days were less expensive if made for high frequencies. House to house transformers were at first used, that is, very small transformers having sufficient capacity to light only one or two houses.

These systems had an immediate application in small cities where direct current was not then established, and in the residential parts of large cities where the business districts were already supplied by direct current. An established direct current system with the advantages of efficient variable speed motors for elevators, etc., and continuity of service guaranteed by storage batteries, has seldom been displaced by alternating current.

A short time later a great impetus was given to alternating current progress by the development of the polyphase system and of the polyphase induction motor possessing the now well known advantages of high efficiency, good starting torque and simplicity of construction, absence of commutators, etc.

It was found desirable to use a lower frequency for the polyphase system, as the advantages possessed by the motor at low frequency outweighed the somewhat greater cost of transformers. Furthermore, while small belt-driven generators had been cheaper at high frequency, the tendency in the art was toward the use of direct-connected generators of lower speed, for which the lower frequency was more advantageous. Sixty cycles was established as standard practice in this country for general power and lighting service in the early nineties.

A prominent instance of one of the first alternating current installations to use 60 cycles was at St. Louis, where 1200 volt single-phase distribution was adopted with the 1200 volt feeders running from the station to transformers located at various points in the district supplied. These transformers had a three-wire secondary and supplied a three-wire low tension network which was interconnected like a d-c. network.

This frequency was also used in several of the early high tension transmissions from water power; but for the important Niagara Falls plant an international commission of engineers in 1895 recommended 25 cycles on account of the lower charging currents on a transmission network, and the adaptability of this frequency for use with synchronous converters and alternating current railway motors. A few plants at compromise frequencies, such as the Mechanicville station at 38 cycles, and some of the Western plants at 50 cycles, were installed for transmission work, and an effort was made to introduce 40 cycles as a universal frequency possessing the advantages of both 25 and 60 cycles; but it was found instead to have the disadvantages of both. It was not high enough for a-c. arc lamps and too high for synchronous converters of those days and for a-c. commutator motors.

Thus 25 and 60 cycles have survived as the standard frequencies in this country, each occupying a well defined territory of usefulness which is its own by right of superiority, with a broad stretch of debatable ground between for work where one or the other frequency possesses points of advantage.

In English and Continental practice a number of frequencies were quite widely used and such odd frequencies as 42 cycles, 33 cycles, 83 cycles and 100 cycles may still be found; but the tendency in foreign practice in recent years has been toward the standard frequency of 50 cycles for general distribution for power and lighting, with 25 cycles in special cases for supplying direct current railway substations, and even lower frequencies such as 15 cycles for a-c. railway work.

With the extension of a-c. lighting systems over larger areas and after familiarity with the terrors of insulating for 1000 volts had bred contempt, it was found desirable to increase the distributing pressure to 2300 volts, which has survived and become standard in this country, and to a large extent abroad.

At about the same time improvements in lamp manufacture enabled 110 volt lamps to displace those of 50 volts, with a consequent improvement in service because of less drop in the wiring from transformers to lamps.

In the early days of polyphase work, two-phase generators and distribution had considerable vogue because it was thought the balancing would be easier on two phases than three; but with the increase in size of plants and the introduction of regulators, less attention was paid to this fancied advantage of two-phase, and three-phase is now generally used on new systems.

### COMBINATION

In the late nineties most of our large cities were equipped with direct current networks in their business centers, sometimes supplied from several steam stations; while alternating current plants of various sizes existed in the residential and outlying districts of these cities. There were frequently several alternating current stations, for franchises had been granted to different companies and sometimes these stations were of different voltages, as 1000 and 2000, and different frequencies, as 125 and 60 cycles. Furthermore, the secondary voltage might be different and motor circuits two-phase or three-phase.

At about this time there began a movement toward the replacement of several small generating stations in a center of population by a single, large central station, located where cheaper coal supply and ample condensing water were available. Several ways were adopted for meeting this problem. In moderate size cities the central station was laid down to generate at a frequency of

60 or $62\frac{1}{2}$ cycles and at a pressure of 4000 volts, using for distribution the 4000/2300 volt four-wire three-phase system. This voltage was sufficiently high to insure economical distribution over fairly large areas, and the system was flexible inasmuch as it enabled 2300 volt single-phase feeders to be taken off from sub-centers of distribution for lighting, with four-wire three-phase feeders going to districts where considerable power was required.

In larger cities where the direct current load was already heavy and where the distances to be covered were considerable, 6600 or 13,200 volt transmission from the central station was adopted, with a frequency either of 25 or 60 cycles, according to the predominance of d-c. load or the views of the engineers with respect to the future sale of current to street railways.

The old generating stations were frequently retained and used for substations, the generators being replaced by motor-generators or rotary converters to feed the d-c. distribution systems. The a-c. distribution was taken care of by substations stepping down from the transmission voltage to 4000/2300 volts four-wire three-phase, or to 2300 volts three-phase. Feeder regulators were generally located in these substations. Where 25 cycles had been adopted it was necessary to install frequency changers in substations or in the main stations for the 60 cycle load, and in some cases this 60 cycle load has since grown to such proportions that it has been found expedient to avoid the losses in the frequency changers by installing 60 cycle turbine-generator units. This explains the situation which exists in many of our larger cities.

On the other hand, many cities which started with 60 cycles, as on the Pacific Coast, have found it unnecessary to use 25 cycles at all, since motor-generators can always be utilized for direct current supply and in late years the 60 cycle synchronous converter has become a successful machine.

Under the subject of "Combination" should be noted the consolidations of the lighting and power systems of towns in suburban districts with the central city system, as in Boston and Chicago, and the conversion of a number of small generating stations into substations containing either transformers, motor-generators or synchronous converters.

It is also interesting to note, as the tendency of the times, the high tension transmission networks in the south and west, covering vast areas with 60,000 volt and 100,000 volt main lines having parallel and branching lines at low voltage, such as 22,000 or 11,000. These networks supply great parts of towns and small communities with lighting and power, and are displacing steam power in mills and incidentally taking care of increasing amounts of farm loads.

Another development which is daily reaching greater proportions comprises networks, such as those in Illinois, connecting a large number of towns by a transmission at 33,000 or 66,000 volts, thus shutting down a number of small inefficient generating stations and getting the benefits of the better economy of a large station, as well as the diversity factor in load, better engineering, and the advantage of economies in management, purchasing, etc. Such networks are usually supplied, not from one station, but from several of the larger and more advantageously situated stations, these replacing a great number of the original small stations.

## STREET LIGHTING

Compared with the multiplicity and uniformity of systems for interior lighting, there have been a great variety of lamps and systems for street lighting. Most of the street lighting in this country has been done on the series constant current system, involving overhead wires and rather high voltages.

Abroad the series constant current system has hardly been used at all, the constant potential system being employed almost exclusively; although sometimes arc lights are run several in series across constant potential mains.*

One reason for this difference in practice is that most of the foreign systems have been underground; while in many places in the narrow streets a high voltage series overhead system would be more dangerous than under the conditions existing here.

The d-c. open arc lamps, run in series from a constant current arc generator, were widely used in this country and are still in use in some places. Alternating current open arcs or series circuits were very little

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*One exception may be made to this statement however. During the nineties a system was evolved consisting of constant current transformers and mechanical rectifiers, enabling direct current arc lamps to be run in series, the original source of supply being alternating current. These were used in England to a certain extent some years before the mercury arc rectifier and series d-c. system was devised, which is now so widely used in the United States. The mechanical rectifier was efficient but had a rather high maintenance charge and is now not much used.

used on account of their lower efficiency. Constant potential d-c. and a-c. open arc lamps were widely used, not for formal street lighting, but in business districts for auxiliary illumination, advertising, etc. Most of the plain open arc lamps, both a-c. and d-c., were replaced (beginning about 1899) by enclosed arc lamps, on account of the longer carbon life, steadier light, and less time required for trimming. The d-c. series enclosed arcs were run from arc dynamos and the a-c. lamps from constant current transformers. This constant current transformer system with a-c. enclosed arc lamps had and still has a very wide use, but has recently been superseded, largely by luminous arc lamps operated on series circuits supplied by rectifiers and constant current transformers. The use of constant potential flame arc lamps is increasing.

The series incandescent system operated from constant current transformers is undoubtedly the most economical system for districts where brilliant illumination is not required, and has been popular from the first for villages and small towns. The efficiency of this system has been greatly improved and its range extended by the use of mazda lamps, and in the near future, with the gas-filled mazda lamp, the field of this system will approach and overlap that of the series arc lighting system.

Still another system which has recently come into use here is ornamental lighting with clusters of incandescent lamps on poles, these being usually supplied on the constant potential system.

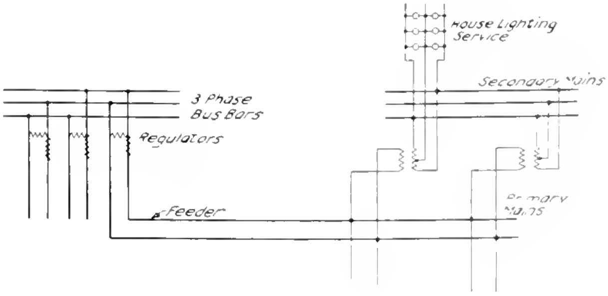


Fig. 1

## DISTRIBUTION SYSTEMS

Assuming that the generation and transmission are already settled, so that with either generating directly at the center of distribution at the distribution voltage, or generating three-phase at a distance and transmitting to the distribution center and there stepping down to the distribution voltage, there are a variety of distribution systems to choose from. A few of these will be discussed.

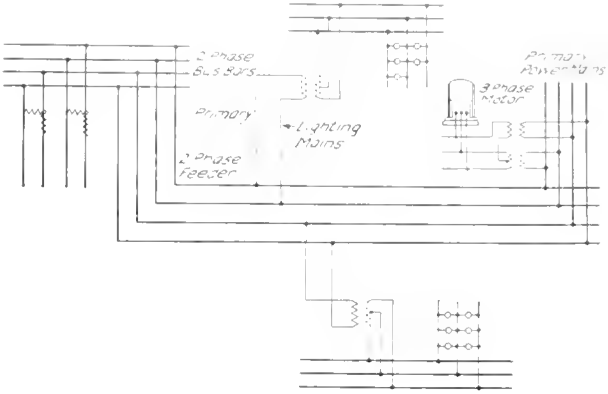


Fig. 2

### Primary Distribution

*Single-Phase Two-Wire* (Fig. 1).

Copper, comparative amount, 100.

For lighting distribution, single-phase feeders are run from the station, these feeders being connected in rotation to the three phases; that is:

Feeder 1 across phase A
Feeder 2 across phase B
Feeder 3 across phase C
Feeder 4 across phase A, etc.

Each feeder runs to a district in the city where several single-phase transformers, located at various points in the district, are tapped off from the feeder. These transformers step down to 110/220 volts for single-phase three-wire lighting networks. The voltage is controlled by feeder regulators.

*Two-Phase Four-Wire System — 2300 Volts* (Fig. 2.)

Copper, 100.

In this case two-phase is available in the station and four-wire feeders are run out, the lighting transformers being distributed equally on the two phases, which may be controlled separately by feeder regulators. The three-wire lighting secondaries supplied from the two phases cannot be interconnected but are usually run in adjoining areas. Where power is required, two low tension wires may be run from one network to the point on the other network where the motor is located.

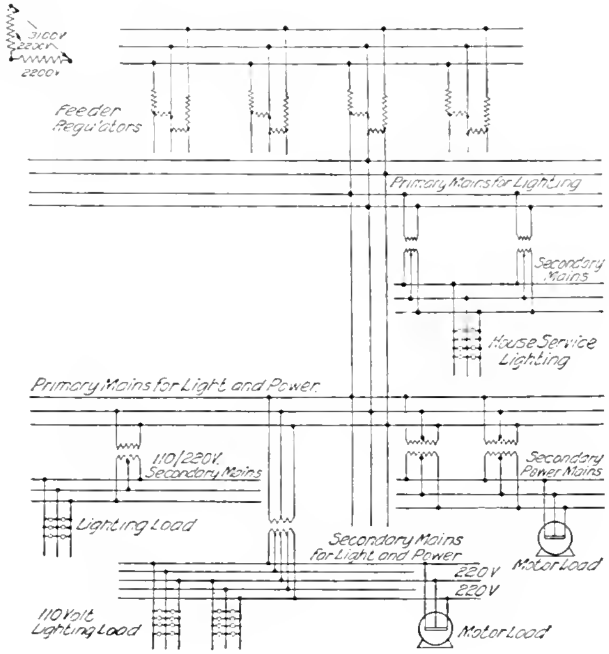


Fig. 3

Or, in the case of large motors, a special transformer bank of two transformers is tapped off the two-phase feeder. The copper economy of this system is not particularly good and the number of wires required are against it as compared to the three-phase system.

*Two-Phase Three-Wire* (Fig. 3).

Copper, 75.

One side of each of the two phases is connected to a common wire which acts as a common return for the two phases. This system has the advantage of employing only three wires and is a polyphase system capable of supplying either power or lighting, but it is very difficult to get good voltage regulation as the load on one phase reacts upon the other. It would not now be recommended for an important distribution system.

*Three-Phase Three-Wire System* (Fig. 4).

Copper, 75.

Three-wire three-phase feeders run out from the station with banks of transformers connected across all three phases for power supply, and single-phase lighting transformers connected at various points and distributed equally on the three phases for lighting supply. This is somewhat more difficult to balance than the two-phase system, but an equal unbalancing of load will not affect the voltage so much. Three-phase regulators may be used. Some companies connect all the lighting across one phase of a three-phase feeder and put a regulator on that phase at the station, sometimes also using the arrangement of transformers shown in Fig. 14. Less frequently the lighting is distributed on two phases, using two regulators. Unless special current transformer arrangements are used in the control of the regulators, this arrangement is likely to prove unsatisfactory.

A widely used combination employs three-phase three-wire feeders to the centers of distribution with single-phase regulators at the station. Single-phase branches are connected to the regulated phase, and a third wire runs from the distribution center only to points where power is needed.

*Three-Phase Four-Wire with Grounded Neutral 2300/4000 Volts* (Fig. 5).

Copper, 29.

This system is used for distribution over large areas in large cities where the density and area are larger than can be economically handled with 2300 volts three-phase. Standard 2200 volt transformers are used

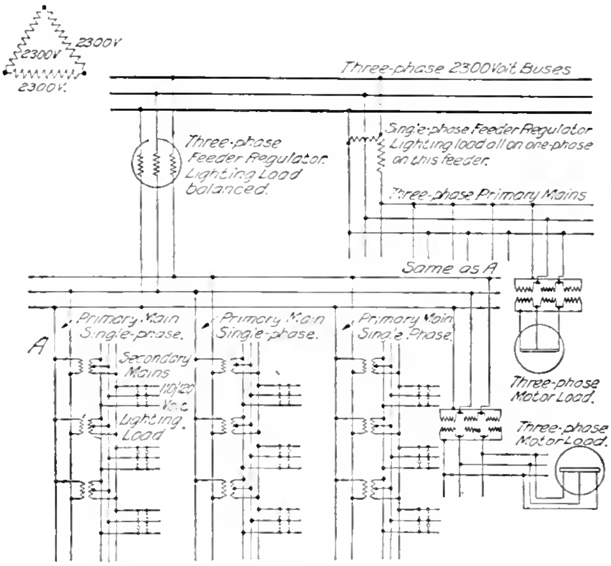


Fig. 4

between phases and neutral. The neutral is usually grounded at the generating station. The feeders run four-wire from the station to the center of the district to be served, whence single-phase branches at 2300 volts are taken off to various parts of the district, these branches being balanced on the three phases; that is, between each phase and neutral.

It is possible to get very good regulation, using a regulator on each phase at the station. This system is widely used in important cities and gives excellent service. Small power users may be supplied from two transformers connected open delta. At points where the load is dense and a large amount of power load divides honors with the lighting load, a three-phase four-wire secondary network may be fed from banks of transformers supplied from the three-phase four-wire primary feeder.

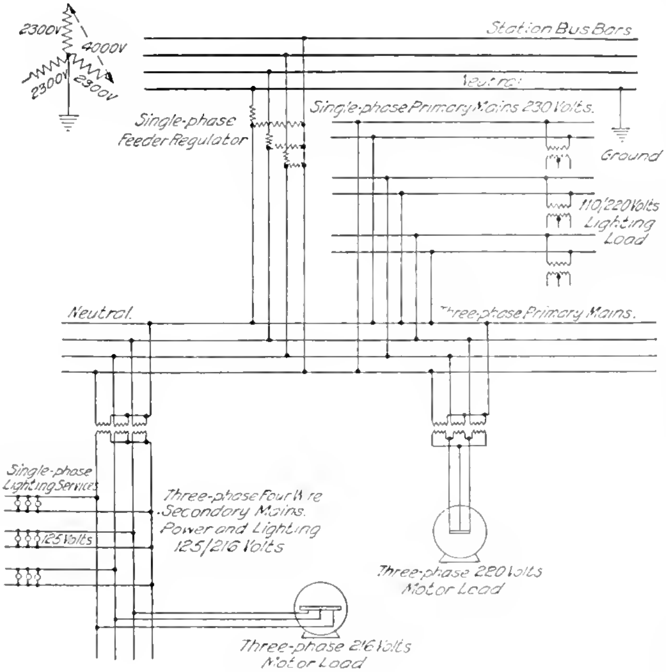


Fig. 5

### Secondary Distribution

*Direct Current Two-Wire System—110 Volts* (Fig. 6).

Copper, 100.

The advantages are simplicity, only two wires, low voltage; and the use of variable speed motors.

This system is limited in application, and is chiefly used in small isolated plants, and in buildings and small vessels. In larger buildings and vessels and for all central station work, the two-wire system has been displaced by the three-wire on account of copper economy.

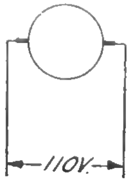


Fig. 6

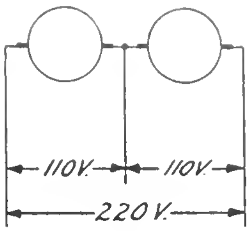


Fig. 7

*Direct Current Three-Wire System—110/220 Volts* (Fig. 7).

Copper, 31.

This is the Edison three-wire system now commonly used on large networks. As installed for underground service with feeders from a number of stations intercepting the network of mains at various points, and the whole network connected together and provided with storage batteries of 20 per cent of the capacity of the system as in our large cities, the continuity of service is unexcelled by any other system. On some of these networks there has not been a complete shut-down for over ten years. The low voltage permits the burning off of short circuits without interruption of service, except locally, and thus insures the localization of faults. Elevator and other variable speed motor service may be supplied. Only three conductors are required, and excellent regulation of voltage is readily accomplished.

*Direct Current Three-Wire System—220/440 Volts* (Fig. 8).

Requires about one-quarter the copper of the 110/220 volt system; that is, comparative copper economy 8. This system possesses all the advantages of the 110/220 system, but has the disadvantage that the 220 volt lamps are about 15 per cent less efficient, or shorter lived, than 110 volt lamps. There is also somewhat greater danger of shocks and more difficulty in insulating heating devices, etc.

*Two-Wire Single-Phase—110 Volts* (Fig. 9).

Copper, 100.

Can only be used for short distances for small amounts of power, and is now chiefly used in branches from secondary mains feeding small residences. Usually, however, all three wires of the secondary mains are connected to the house service.

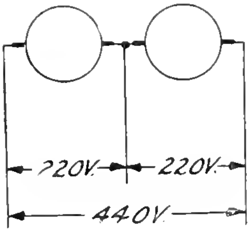


Fig. 8

*Three-Wire Single-Phase — 110/220 Volts* (Fig. 10).

Neutral one-half the size of either outside conductor. Copper, 31.

This system is commonly used on secondary networks or secondary mains for lighting. The mains may be supplied from several transformers, which are in turn connected to primary mains fed from the station. The system is simple, requiring only three conductors, but as it is only single-phase, does not permit the operation of polyphase induction motors.

An extended secondary network of this sort, covering a large territory and fed from a considerable number of transformers, compares very favorably with the direct current network, but has the disadvantage of not being able to use storage batteries, while variable speed motors on this system are not so cheap or efficient as d-c. motors. Furthermore, on account of the reactance drop, the weight of copper would have to be greater than for a d-c. system, and the sizes of conductors would be limited, that is, conductors would have to be laid in multiple for large sizes.

On account of the possibility of a transformer failure, causing other transformer fuses to blow and thus depriving the network of current, such secondary networks are usually subdivided into areas disconnected from each other, the several transformers in each area being fed from one primary feeder. If the areas are all interconnected, some arrangement would have to be made for the disconnection of transformers in the case of transformer failure, to prevent current flowing into the transformer from the network. Another reason for dividing the network into areas is to balance the load on the three phases. The feeder going to each area will be connected to a different phase at the station.

*Four-Wire Two-Phase* (Fig. 11).

Copper, 100.

This system requires the same amount of copper as two single-phase two-wire circuits but involves the complication of four wires. It has the advantage of being able to operate polyphase motors and lighting on the same system.

*Two-Phase Three-Wire* (Fig. 12).

Copper, 75.

This system has a common return for both phases, which accounts for the saving in copper. It has the advantage of permitting operation of polyphase induction motors and lighting on the same system, but it is difficult to regulate the load properly, since the load on one phase may affect the voltage on the other phase. Furthermore, in order to have all the wires capable of carrying overloads equally, the middle wire should be made 40 per cent larger than the others, in which case the copper economy becomes the same as the two-phase four-wire system.

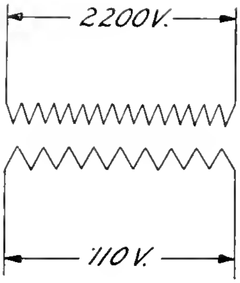


Fig. 9

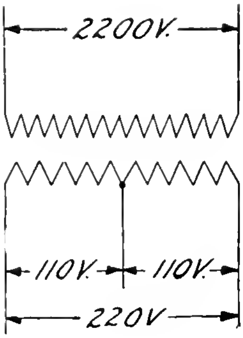


Fig. 10

*Three-Phase Three-Wire System* (Fig. 13).

Copper, 75.

This system is used occasionally for straight power work, or sometimes for combined power and lighting, the lighting load being balancing on the three phases; but since it is rather difficult to balance and not so good in economy as the three-phase four-wire system, it is not much used.

*Three-Wire Single-Phase Lighting with Separate Wire for Three-Phase Power* (Fig. 14).

With a neutral one-half the size of the main conductors, the copper economy for lighting is about 31 and for power 19. The lighting transformer supplying the three-wire system may be made as large as necessary, and if the lighting predominates the power transformers may be comparatively small, the fourth wire for power being run only to those places where power is required. This system obviously possesses a number of advantages and is very commonly used.

*Four-Wire Three-Phase with Grounded Neutral* (Fig 15).

Copper economy, with neutral one-half size, 29.

The lamps are connected between the line and neutral; and the motors across the three lines. It is desirable to use lamps of about 125 volts so that the motor voltage will be 215, or very close to the standard of 220. This system is very flexible and lends itself to the establishment of an extended combined power and lighting network, as the copper economy is good and unbalancing produces less disturbance of voltage than in a three-phase three-wire system. The neutral should be grounded as in the case of Edison three-wire systems. Chicago, Cleveland, Atlantic City and other places contain certain areas supplied by low tension networks of this character.

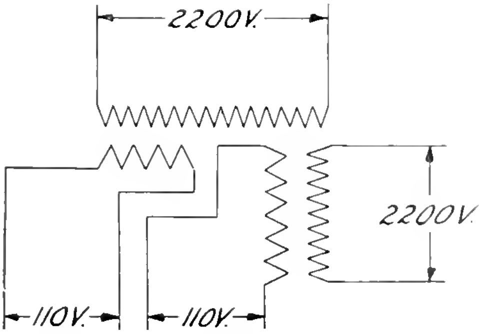


**Fig. 11**

There are a number of plants abroad employing this system in extended networks fed from transformer substations at various points. In all respects except as regards efficient variable speed motors and the continuity of service guaranteed by the storage battery it is practically the equal of a direct current system.

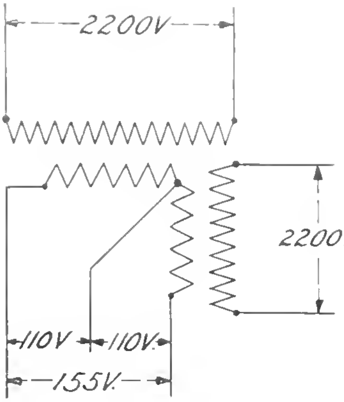


Fig. 12

When considerable areas of such secondary network are interconnected, it is desirable to arrange the transformers so that they will be disconnected from the secondary network in case of reverse current flowing from the network into the transformer; that is, in case of a short circuit in the transformer or feeder.

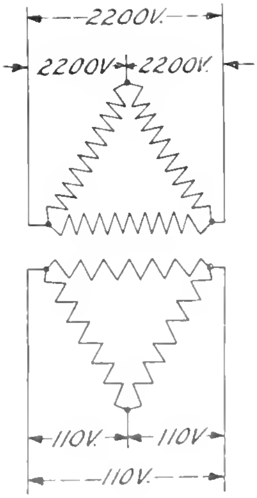


Fig 13

*Four-Wire Three-Phase Secondary Network with Grounded Neutral Supplied by Low Tension Feeders from Substations* (Fig. 16).

This system is largely used abroad, as in Dublin, Ireland; Hendon, Tottenham, and certain districts of London; and also in Shanghai, China. In this system, power is generated three-phase at 3000, 5000 or 11,000 volts and distributed by three-phase high tension feeders to a large number of substations located almost as close together as the stations on a direct current Edison three-wire network. Each substation contains several banks of transformers of large capacity, as compared to the outdoor transformers used in American systems. These substation transformers step-down from 5000 volts to a four-wire three-phase secondary busbar with 200 volts between phases and neutral and 346 volts between phases. From this busbar, 200/346 volt, four-wire, three-phase secondary feeders emanate. In many instances these feeders supply an interconnected network at different points, of which the substation is the center. Practice varies as regards connecting together the low tension networks supplied from the different substations. Usually they are kept separate. These systems are used where the load is fairly dense, or where a direct current network would ordinarily be used in this country.

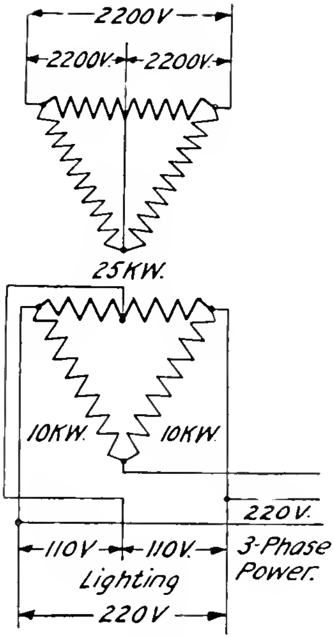


Fig. 14

The chief advantage possessed by this foreign system as compared to the American practice in alternating current distribution is efficiency at light load, since the transformer banks are large and their core losses small per kilowatt; and furthermore, because the number of transformer banks in service may be proportioned to the load. The system, however, requires a large investment in sub-stations and a large maintenance charge for station attendants. In this respect it is similar to the direct current system.

With the present day reliability of transformers and the development of automatic devices, we shall no doubt in the future see an ideal system in which large transformers are grouped in vaults with automatic devices for apportioning the number of transformers to the load and for disconnecting faulty transformers from the network and notifying the operator at central point.

## Regulation of Voltage

The systems of distribution used in this country are all based on the old Edison system of feeders and mains. It is aimed to keep a uniform voltage along the mains; that is to say, so nearly uniform that the variation of lights connected at different points will not be perceptible at different loads, the chief drop of voltage being in the feeders which can be compensated for at

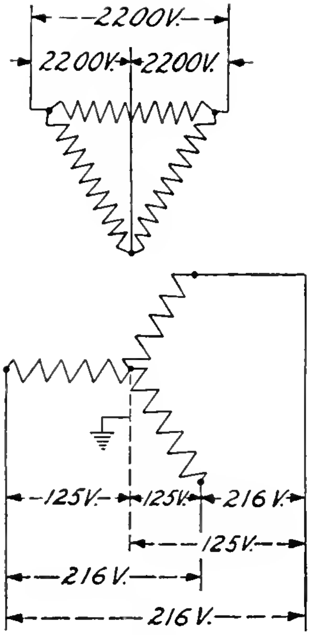


Fig. 15

the station. In the direct current system the drop is compensated for by having several busbars at different voltages on which the feeders may be thrown.

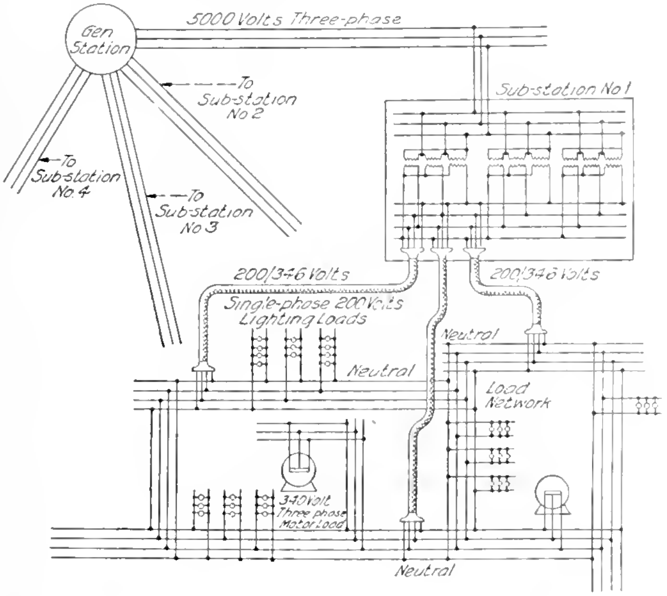


Fig. 16

In the a-c. system the feeders are usually high tension and the transformers may be considered a part of the feeder. Voltage regulators, usually of the induction type, are used to increase the feeder voltage at the station to compensate for the reactive and resistance drop in the feeders and transformers. These are hand operated in small systems and automatically operated by compensating voltmeters in the large systems. The secondary distribution in a-c. systems is laid out so that a very small drop may occur between different parts of the system, from no load to full load.

A variation in voltage of 2 to 3 per cent at the lamps used to be the goal that engineers strived to obtain with carbon lamps. Mazda lamps are less sensitive to slow variations in voltage, so that 4 to 5 per cent variation between minimum and maximum voltage does not mean poor regulation.

# THE EDISON THREE-WIRE SYSTEM

By R. H. Tapscott

Lighting Engineering Department, General Electric Company

Ever since the introduction of the Edison three-wire system, many years ago, it has been the one most commonly employed in secondary distributing systems. After leaving the distributing station, the general layout of all the systems of this type is practically the same, but for the securing of the neutral there have been many methods developed and a considerable number of these are in use today. It is of these that the author principally treats in this article. The advantages and disadvantages of each kind of neutral-producing apparatus are explained, the relative weights and efficiencies of the machines are given, and much valuable instruction is included which it has been found necessary to follow out in order to secure the successful operation of the system.—Editor.

**R. H. Tapscott**

To completely cover the subject of the Edison 3-wire system would mean a history beginning with the original Edison 60-light generator, and leading up through the period of the 125-volt engine-driven double machines to the present day alternating current high-voltage turbines and rotary converters. The feeder and main system of the Edison 3-wire system of today is essentially the same as the feeder and main system of the 2-wire system used with the old 60-light machines of 30 years ago. We will, therefore, consider only the up-to-date equipment, taking the various steps from the generating station to the consumer.

The direct current system is generally used in the congested districts of cities or towns and in hotels or office buildings, owing principally to two reasons:

First: A large portion of the load in either of these cases is the elevator load. The advantage of d-c. elevator motors over a-c. elevator motors is to be found in the ease of control, the perfection of the control equipment, and the increase in torque per ampere of direct current over alternating current. This means that for the same torque the regulation on the a-c. system would be inferior to the regulation on the d-c. system.

Second: The high line drop in a-c. systems due to the self inductance of the large capacity feeders run in close proximity to each other, the drop in the d-c. system being due solely to the resistance of the feeder.

The modern generating station consists of high-speed turbines with high-voltage a-c. generators. Alternating current is used through transformers in the more remote and sparsely settled districts, and through conversion for the d-c. service in the congested districts. In addition to this, in cities where there are more than one generating station, one of which is adjacent to or very near the d-c. load, a d-c. generating station may be advisable which could feed directly through the usual Edison feeders to the 3-wire mains.

Considering the a-c. turbo generators, the transmission to the substations will be 6600 or 13,200 volts, or even slightly higher, and the feeders will either be laid one for each converter or parallel feeders connected to a main bus in the substation. Under either circumstance there will be an auxiliary or emergency bus in the substation so that, when necessary, the feeders can be transferred from one converter to another, or separated from each other and a division of load made on the two busses. There will also be the usual ring bus or ties between substations for emergency service. In laying the mains from the generating station to any particular substation, due to the possibility of interruption to service caused by breaks in water mains or any other local disturbances, the feeders are laid through separate districts, even though this procedure greatly increases their length.

The greatest divergency will exist in the substations, for here we have the greatest amount of apparatus from which to make our selection.

The conversion units may be either synchronous converters or motor-generator sets. Synchronous converters have been almost universally used in preference to motor-generator sets on 25-cycle systems. On 60-cycle systems the motor-generator set has been preferred owing to its greater reliability than the earlier design of 60-cycle synchronous converters, and also owing to its supposed economy in power-factor correction. The present day 60-cycle converters are so reliable that we would not be justified in differentiating between the 25 and 60-cycle systems, but will assume that the synchronous converter would be used for either frequency owing to its higher efficiency. We shall, however, consider both types of units for the purpose of comparison.

If motor-generator sets are to be used, they will be of either the 2-unit or 3-unit type, with synchronous motors. In the 2-unit set we shall have either a 125/250-volt 3-wire generator or a 250-volt generator with a balancer set for obtaining the neutral, or, if a balancer set is not deemed desirable, the neutral may be obtained by means of a battery. The 3-unit set consists of a motor and two 125-volt generators. With this arrangement no other means of deriving the neutral is necessary.

If the synchronous converter were used, it would either be of the 2-wire 250-volt or 3-wire 125/250-volt type, and the voltage would be controlled by means of an induction regulator placed either in the high or low-tension side of the transformer or by a direct-connected synchronous booster, or a synchronous converter with regulating poles may be used. The economy in floor space of all of these synchronous converters, over the older type, has been greatly increased by the addition of commutating poles, thus allowing a considerable increase in speed.

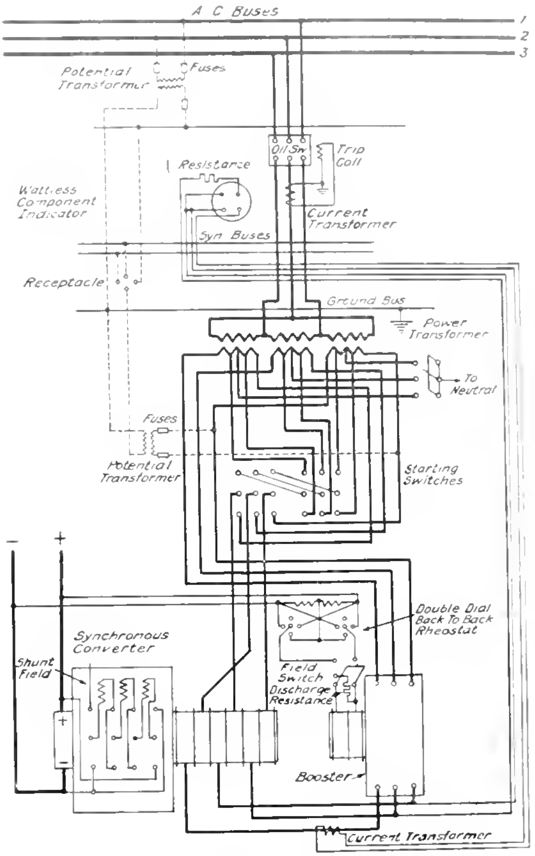


Fig. 1. Complete Diagram of Connections to a 6-Phase 3-Wire Synchronous Converter

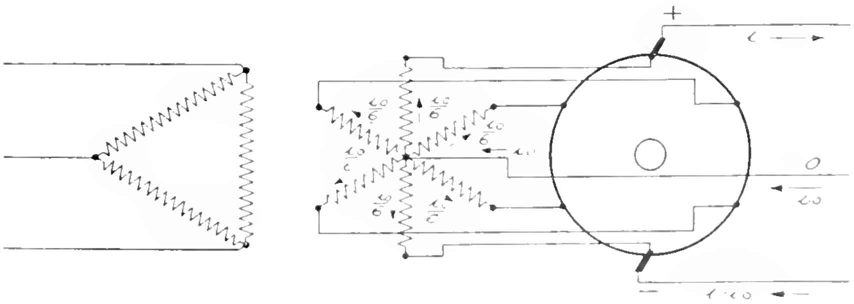


Fig. 1a. Simplified Diagram of Connections shown in Fig. 1

For the 6-phase synchronous converter, the transformers, which would usually be of the 3-phase type instead of three single-phase units, could have their secondaries connected in double delta or in diametrical. The double delta could not be used if the rotaries were of the 3-wire type as there would be no means of obtaining a neutral unless an additional compensator were installed. The advantage of the double delta seems to have been the fact that if one phase of the transformer were damaged, assuming the high tension to be delta connected, the converter could be run at reduced capacity on an open delta connection. As it has been found that if the transformers were diametrically connected in the secondary and delta connected in the primary they can

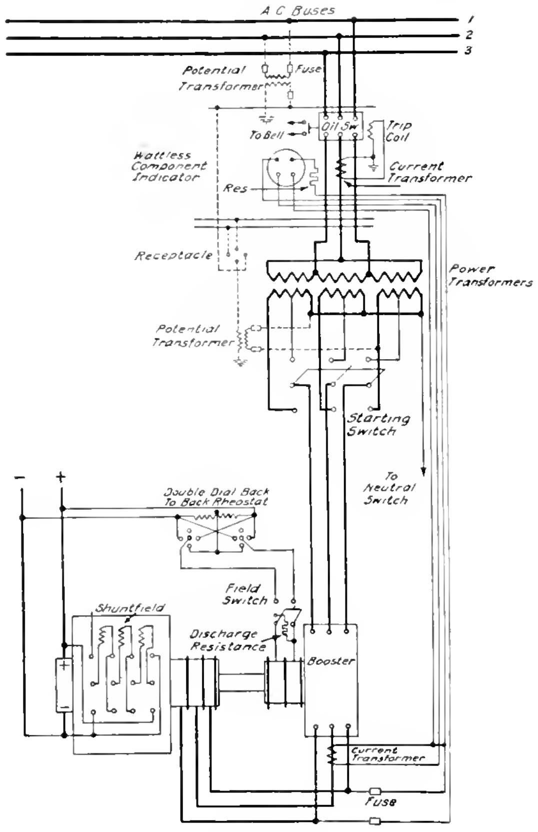


Fig. 2. Complete Diagram of Connections to a 3-Phase 3-Wire Synchronous Converter

also be operated from two phases under these same conditions with the same output, and, further, as this connection must be used for 3-wire service (see Fig. 1) there does not seem to be any further use for the double delta connection of the secondaries.

For the smaller synchronous converters, which would operate 3-phase, the straight Y-connected secondary, Fig. 2, would be satisfactory for 3-wire service if the transformer were of the 3-phase core-type construction. If three single-phase transformers were used, it would be necessary to use the distributed Y-connection, Fig. 2b, in order to neutralize the effect of the direct current in all three transformers.

The balancer sets mentioned could be either of the shunt-wound type for hand regulation or of the compound-wound type for automatic regulation. Figs. 3 and 4 show the connections of both the shunt and compound-wound balancer sets with cross-connected fields. This connection is necessary in order to obtain finer regulation for unbalanced loads.

If a battery is to be used in connection with the substation equipment and the neutral of this battery is grounded, and the neutral of the balancer is also grounded, or if the battery and balancer neutrals are connected together, it will either be necessary to use shunt-wound balancers or to use compound-wound balancers with the series

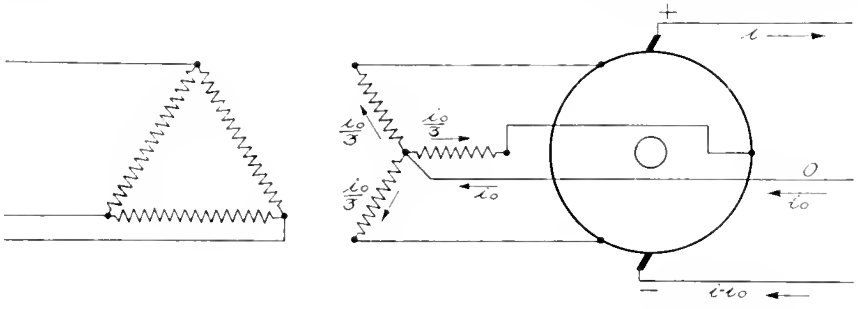


Fig. 2a. Simplified Diagram of the Connections for Using a 3-Phase Core-Type Transformer

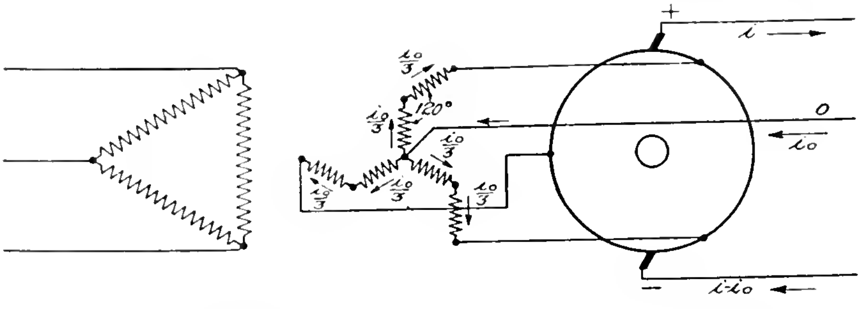


Fig. 2b. Simplified Diagram of Connections for Using Three Single-Phase Transformers

fields connected in series with the neutral wire (see Fig. 5) in order to obviate the possibility of a continuous interchange of current between the batteries and balancer sets, which would, in turn, lead to hunting of the sets.

If a battery is used for obtaining the neutral in connection with a 2-wire synchronous converter or motor-generator set and no balancer sets are used, or in any case where the battery neutral is tied directly into the neutral of the system, or, as is usual, grounded, a 3-unit booster set will be required for charging. This 3-unit set will consist of a motor, usually d-c., and two similar boosters. In order to cut down the initial expense of the boosters, and also to have some method of automatically disconnecting them from the line in case the battery is required for emergency service while it is being charged, an arrangement as shown in Fig. 6 has been used. This emergency may result in the battery being required for the d-c. load due to a shut-down in the conversion units or the main generating station, or it may be the requirement of heavy unbalanced current from the battery owing to trouble on the d-c. system which the other substations are unable to take care of. With this arrangement the 2-unit booster set is employed, and, while charging, the battery neutral is disconnected from the system, and the entire battery equipment charged from the one booster. The relays are so arranged that if the emergency arises, the battery neutral is reconnected to ground and the booster fields weakened, and the booster temporarily short circuited. With this system of relays and circuit breakers, there is no possibility of the battery remaining disconnected from the line when required for emergency service or for heavy unbalanced load.

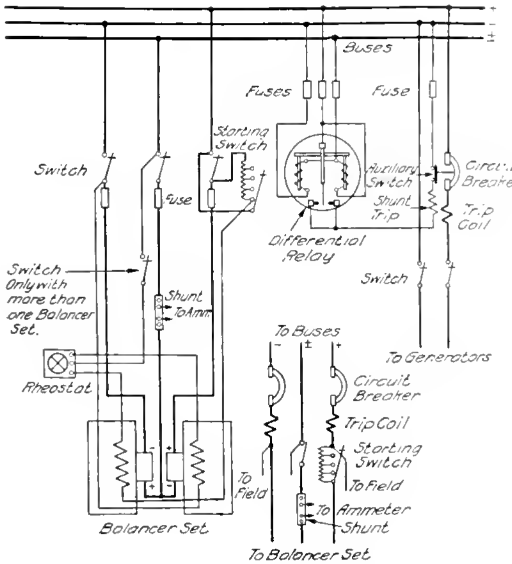


Fig. 3. Complete Diagram of Connections for a Shunt-Wound Balancer Set for Hand Regulation

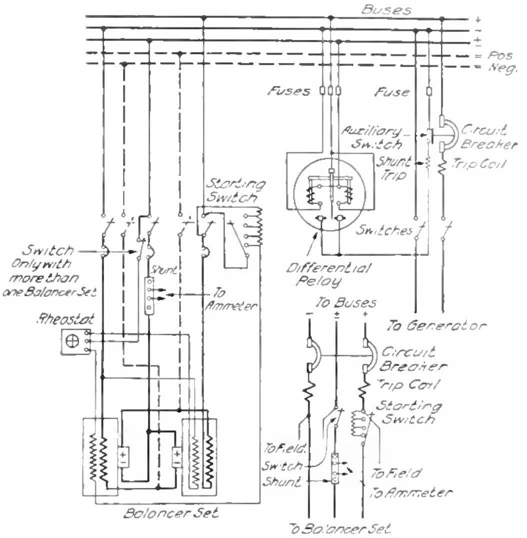


Fig. 4. Complete Diagram of Connections for a Compound-Wound Balancer Set for Automatic Voltage Regulation

To consider the various types of substation apparatus already mentioned from the standpoint of obtaining a neutral, the 3-wire generator either with collector rings and external compensator, or internal compensator and one collector ring, or with additional windings in the armature for deriving a neutral, would not allow of any compensation for the increased IR drop in the heavily loaded feeder, but would actually give the reversed condition due to the internal drop in the compensator and the direct-current armature, that is, the higher voltage will be impressed upon the lightly loaded side of the system instead of on the heavily loaded side. With a 3-unit motor-generator set or two 125-volt generators, compensation or compounding can be obtained on the heavily loaded side of the system, but it must be borne in mind that in obtaining unbalancing from two generators the total capacity is reduced by approximately the amount of unbalancing. In a 3-wire synchronous converter, with the neutral obtained from the neutral of the main transformers, the same condition exists as with the 3-wire generator except that due to the increased size of the transformers, which we may assume are used in place of the compensator of the d-c. generator, the voltage drop is materially reduced, and the voltage will not be decreased on the heavily loaded side of the system as much as with the 3-wire generator. It may happen that this unsuitability of apparatus to compensate for IR drop in the heavily loaded feeder may not be serious, for, with a certain distribution of the neutral in the 3-wire mains, the unbalanced current may be neutralized or taken care of only in a few of the substations. In this case, this unbalancing could be compensated for by small balancer sets in the particular substations where they were required.

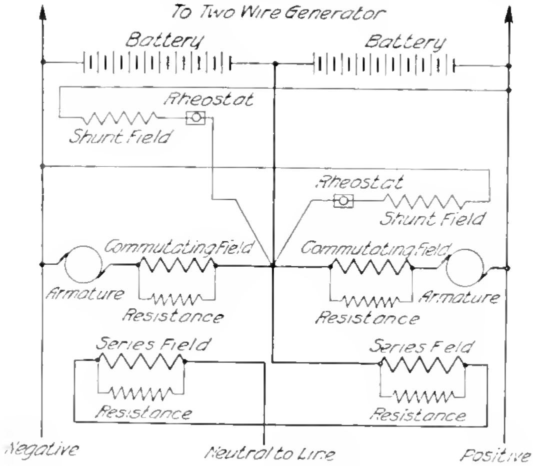


Fig. 5. Diagram of Connections for a Compound-Wound Balancer Set with Neutral Connected to Neutral of Battery

The shunt-wound balancer sets may be controlled by hand through the shunt fields to obtain the necessary increase in voltage required to compensate for the IR drop in the heavily loaded side of the system. With the compound-wound balancer with the cross-connected fields or with the fields connected in the neutral as in Fig. 5, adjustments can be made so that with unbalanced current equal to the ampere rating of the set (this rating should always be stated in neutral amperes) the machines will either compound flat, giving equal voltage on either side of the 3-wire system or may be over-compounded to automatically take care of the IR drop on the heavily loaded side.

In the matter of efficiencies of the various units, the order will be:

Three-wire synchronous converter, synchronous converter with balancer set, 3-wire motor-generator set, synchronous converter with battery, motor-generator set with balancer set, motor-generator set with two generators, motor-generator set with battery.

These efficiencies are calculated at full load with an unbalanced current of 15 per cent. The highest, or 3-wire synchronous converter, would be from about 90.5 to 93.5 per cent for 25 cycle and the lowest, or motor-generator set with battery, from about 85 per cent to 88 per cent.

The order of weights and dimensions will be approximately the same as the efficiencies.

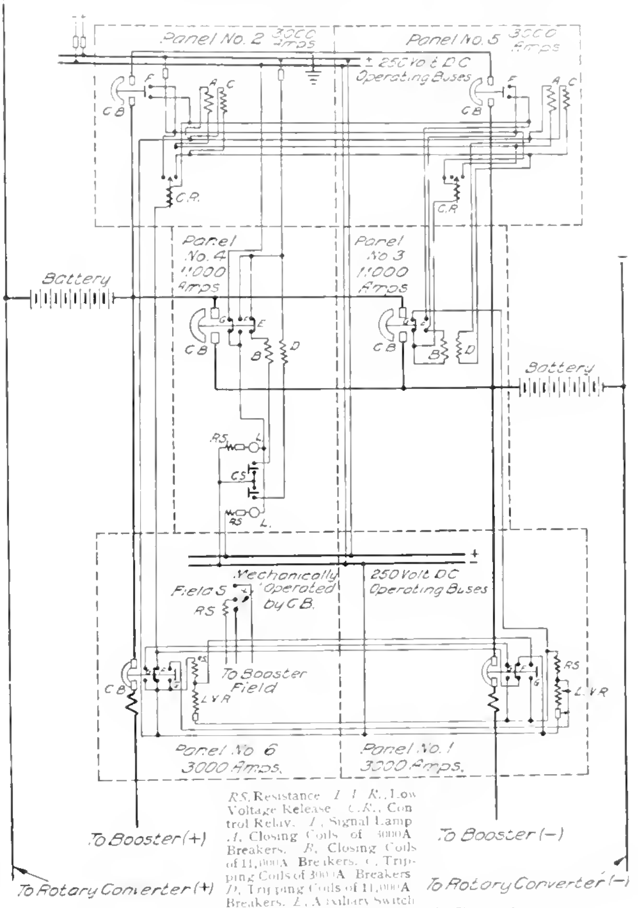
Considering the distribution, this is always of the Edison feeder and main system, the feeders being run from the substation to the various points of distribution where they are tied into the mains of the 3-wire net-work. Customers are invariably fed from the 3-wire mains and not from the feeders, although for large installations, separate feeders are sometimes tied into the 3-wire net-work on customer's premises. Fuses are used in the mains at the various junction boxes or points where the feeders are tied. These are of ample capacity so that they will open only on severe overloads or short circuits. The fuses insure the isolation of a short circuit to a very small section of the net-work.

In some cases the feeders are 3-wire, that is, include the neutral, whereas in other cases the neutral is run on the tree system in order that any unbalancing which may occur will be equalized on the system instead of being returned immediately to the nearest substation for correction. This, as already mentioned, reduces the number of stations from which heavy unbalanced current is required.

The feeders and mains rarely exceed cables of larger cross-section than 1,000,000 circular mils. If mains larger than this are required cables are usually run in multiple. Feeders larger than this are not required, since they are tapped into the net-work at various points which are determined by the loads and regulation required on the 3-wire system. They are usually fed from either two or three separate busses at the substation which are operated at voltages outside the normal, giving a range from low to high, varying usually from about 240 to 300 volts or 120 to 150 volts on either side of the neutral. The feeders contain pressure wires by which the voltage demand of any particular feeder can be determined and the feeders switched from one bus to another as the demand exists. The shifting of a feeder from one bus to another does not change the voltage of the 3-wire net-work in proportion to the difference in bus voltage, but merely causes a shift of load away from or to the other feeders according to whether the voltage of the particular feeder being changed is increased or decreased, with a consequent very slight change in voltage. To supply the three busses in the substation, different machines are connected to the busses as required by the load, or in some cases the machines are operated on one bus and the standby battery is used for an intermediate bus and a booster used for the high bus. There are some cases in which the feeders are very short and the requirements for three busses are not very great, but, in the majority of cases, the 3-bus installation works out to the best advantage.

It is no doubt a common impression that of all public utilities the water supply of our large cities is the most dependable. We will not enter into a direct comparison of the Edison 3-wire system with the water system, for one is usually dependent upon the other, but let us consider the remarkable service and size of some of the 3-wire systems. The net-work is almost self-protecting for, owing to the size of the mains and the fact that any point on them is fed from two directions, a short circuit will almost invariably burn itself out with the large current and low voltage available and will not be re-established on account of the very low puncture point of this voltage. The substations not only have a large spare capacity in conversion units but in most cases an enormous capacity in standby batteries. The generating stations are still larger for here again we have spare units and the total capacity is far greater than the d-c. capacity, since this latter is only for the crowded sections of the city and the main stations must also supply power and light to the more remote districts, also, in some cases, for a considerable portion of the railway load. These are some of the reasons why we hear of such figures on one system as 30 years of service with only two or three complete shut-downs aggregating in all not more than 12 or 13 hours.

As to size, the largest synchronous converter for lighting work that has been built up to the present time is of 3500 kw. with a two hour capacity of 4250 kw. or approximately 210,000 present-day lamps against the original main generator of only 60 lights. The largest substation for Edison service is in the neighborhood of 20,000 kw. as a normal output exclusive of batteries. One of the large operating companies today has a capacity of conversion units in their lighting substations of 275,000 kw. on the overload or two hour basis and a peak load on their 3-wire systems of approximately 135,000 kw. or over 1,000,000 amperes. As a standby, this same system has a battery capacity of about 37,000 kw-hrs. at the one hour rate but, owing to the design of these batteries, the fifteen minute rating will be almost four times this figure, or more than the peak load of the system. In another city we find in round figures 150,000 kw. in conversion units on the two hour basis and a battery of about 22,000 kw-hrs. on the one hour basis.



RS, Resistance. L V R., Low Voltage Release. C.R., Control Relay. L, Signal Lamp. A, Closing Coils of 3000A Breakers. B, Closing Coils of 11,000A Breakers. C, Tripping Coils of 3000A Breakers. D, Tripping Coils of 11,000A Breakers. E, Auxiliary Switch Opens when Breaker Closes. F, Auxiliary Switch Closes when Breakers Close. G, Auxiliary Switch Closes when Breakers Open

**Fig. 6. Complete Diagram of Connections Employed when the Battery and System Neutrals are Tied Together and no Balancer Sets Used**

# SYNCHRONOUS CONVERTERS *versus* MOTOR-GENERATOR SETS FOR LIGHTING SERVICE

By L. B. Bonnett

Lighting Engineering Department, General Electric Company

The higher efficiency of synchronous converters in many instances will make their installation more economical than that of synchronous motor-generator sets, and their unity power-factor operation may raise the power-factor of the system sufficiently for satisfactory operation, even when the a-c. load alone has a large lagging component. In the following article, the author assumes a concrete case of a substation supplying both d-c. and a-c. load, the latter of low power-factor. He then calculates the comparative losses and investment charges, which show an annual saving for this specific case in favor of synchronous converters. At the end are tabulated results of similar calculations for different assumptions of loads and transmission voltage.
—Editor.


L. B. Bonnett

For transforming from 25 cycle power to direct current for Edison light and power systems, it is almost universal practice to use synchronous converters. For 60 cycles there is considerable difference of opinion as to the relative advantages of synchronous converters and motor-generator sets. At one time, 60 cycle converters were decidedly inferior to the 25 cycle units, and many companies standardized the use of motor-generator sets. Of late years, great improvements have been made in 60 cycle converters, and the operating objections to them have been gradually overcome. Many companies, however, still strongly favor motor-generator sets because of the power-factor correction inherent in such sets. It is not the purpose of this article to go into the relative operating advantages, but rather to show that it is often more economical to use synchronous converters, even when combined with an a-c. load of poor power-factor. Their better efficiency may show a saving which more than counterbalances the increased losses in transmission and generators due to the lower power-factor of the system.

This is best shown by some concrete examples. Assume a substation five miles from the generating station supplied with 60 cycle 13,200 volt power through two three-phase 4 0 underground cables.

Fig. 1, curve "A," shows the kilowatts of d-c. load supplied by two 1500 kw. units, only one unit being used from 10:30 o'clock at night until 7:30 o'clock in the morning. Curve "B" shows an a-c. load supplied from the same substation at the power-factor shown by curve "D." For motor-generator sets assume two 1500 kw. shunt wound generators driven by high voltage 0.8 power-factor synchronous motors, and operated with constant excitation so adjusted as to give 0.8 power-factor at approximately normal load. At lower loads, therefore, the corrective kv-a. will be larger than if the excitation were adjusted for 0.8 power-factor at all loads, and it is obtained with small sacrifice in efficiency. For the synchronous converters assume high speed commutating pole shunt wound units with either series boosters or induction regulators for varying the voltage, and three-phase six-phase air blast transformers with suitable blowers, adjusted for approximately unity power-factor at all loads. The efficiencies assumed for various loads cover the complete losses from the high tension side of the transformer to the d-c. load, including the losses in the blower and a small amount for cable loss between the transformer and the converter.

Assuming an efficiency curve for the motor-generator sets, the input at the various points on the load curve is obtained and the difference between the total kilowatt-hours direct current and the total input gives 7980 kilowatt-hours daily loss in conversion. Curve "C," Fig. 1, shows the total kilowatts input to the substation. The wattless component of the a-c. input alone may be obtained from the kilowatts and power-factor. This, counterbalanced by the leading wattless kv-a. given by the motor-generator sets and combined with the kilowatts in curve "C," gives the kv-a. input to the substation (curve "B" on Fig. 2 at the power-factor of curve "E"). From this curve the amperes flowing may be obtained, and the average of the square of the amperes with the resistance of the transmission cables gives the $I^2R$ loss in transmission, which, for this case, equals 2900 kilowatt-hours per day. In the above we have neglected the capacity currents of the cables, as their effect on the comparison would be negligible. Curve "C," Fig. 1, shows that the average load is approximately 5035 kilowatts at an average power-factor of 96.5. This plus the average transmission loss gives 5170 kw. average power generated for this substation. With economical generation, we may assume the generator losses chargeable to this amount of power to be approximately 7 per cent. or 362 kw., which equals 8700 kilowatt-hours daily loss. This gives a total daily loss for the motor-generator substation of 19,580 kilowatt-hours.

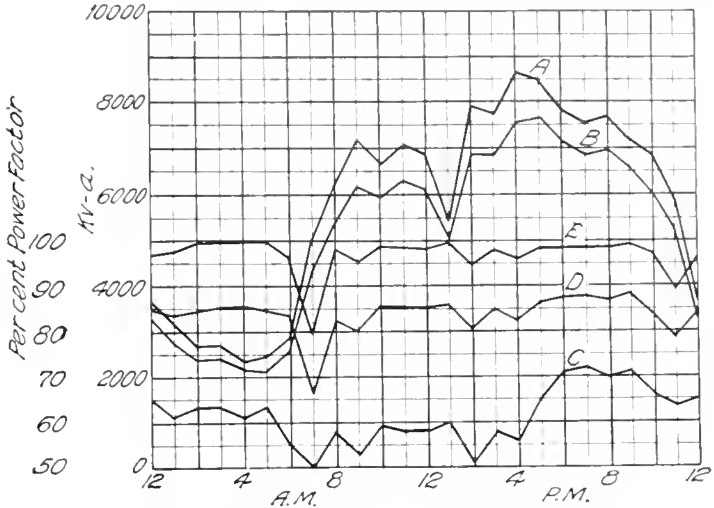


Fig. 2. Comparative Curves

A = Total Kv-a. with Rotary Converters.
B = Total Kv-a. with Motor-Generators.
E = Resultant P-f. of Line with Motor-Generators.
C = P-f. of A-C. Load Alone.
D = Resultant P-f. of Line with Rotary Converters.

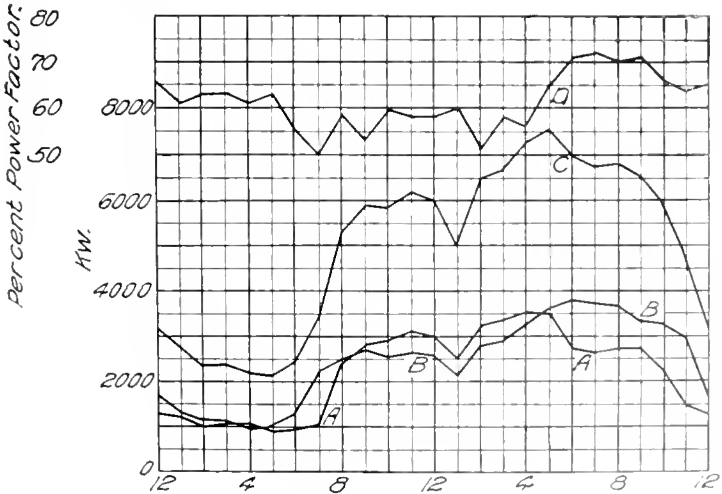


Fig. 1. Load Curve

A = Kw. D-C. Load.
B = Kw. A-C. Load.
C = Total Kw. Input to Substation.
D = Power-factor A-C Load Alone.

The same process of figuring for the converter substation gives a daily loss in the converters of 4880 kilowatt-hours. The total kilowatts input to the substation is slightly less than curve "C," Fig. 1—approximately 2.8 per cent lower, but too near it to show successfully on the small scale used. Fig. 2, curve "A," shows the kv-a. total combined load at the power-factor of curve "D." Based on curve "A" the transmission loss figures to be 3650 kilowatt-hours. Fig. 3 shows the approximate increase in losses of large high speed turbo-generators with constant kilowatt output and varying power-factor. This curve is approximately true only for high speed generators where the variable losses are small compared with the fixed losses. With slow speed generators having a large number of poles, the variable losses, and with them the increase in losses with decreasing power-factor, are relatively greater. The average load with synchronous converters is 4895 kw. at an average power-factor of 83.8 per cent, or 5047 kw. average power generated. Seven per cent of this equals 353 kw. loss. The curve, Fig. 3, however, shows that the losses at 83.8 per cent power-factor are increased 3.7 per cent over that for 96.5 per cent power-factor, making 366 kw. loss. This gives a daily generator loss of 8800 kilowatt-hours, or total losses for the converter substation of 17,330 kilowatt-hours a saving over the use of motor-generators of 2250 kilowatt-hours per day. At one cent per kilowatt-hour this gives a daily saving of $22.50, or $8225 annually in favor of synchronous converters.

The transmission line losses given above are based on the assumption that the same cable is used in both cases. If it is of correct size for the converter substation it could be reduced in the ratio of the peak kv-a. loads or as 8630 is to 7680 (see curves "A" and "B," Fig. 2). Such decrease in size would increase the resistance and therefore the I²R loss inversely in the same ratio. This gives an increase of 360 kilowatt-hours daily loss for the motor-generator station, which amounts to $1315 annually, making a total annual saving in favor of the synchronous converters of $9540.

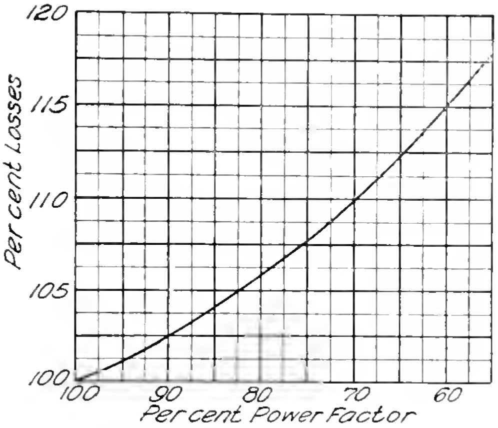


**Fig. 3. Comparative Curve**
Increase in Losses in Turbo-Generators.
Constant Kw. Output at Varying Power-factor.

Assuming a cable and duct cost of $15 per kv-a. for the five mile line, the increased cable required by the greater (by 950 kv-a.) peak of the synchronous converter station would be capitalized at $14,250. The generators and equipment from them to the busses must also have 950 kv-a. increased capacity, which at $10 per kv-a. is $9500; making an increased investment for the synchronous converter station of $23,750.

Considering all the losses, there is a difference in favor of the converter of 139 kw. in peak kilowatts generated. Power house equipment to generate this increased load, if capitalized at $100 a kilowatt, would amount to $13,900. Deducting this from the previous figure for increased investment, we have a total increased investment for the converter station of $9850. Interest and depreciation at 20 per cent equals $1970 annual charge. Subtracting this from the annual saving in losses leaves $7570 net annual saving in favor of the installation of synchronous converters. The foregoing assumes that motor-generator sets and synchronous converter equipments have the same cost, although, in general, the latter will be cheaper.

Reference to Fig. 4 shows that the efficiency curve of 4000 volt or 2300 volt motor-generator sets is higher than that of 13,200 volt sets and compares more favorably with that of synchronous converters. The second section of Table 1 shows results from assuming the same loads as before, but with lower voltage transmission. The transmission copper is assumed to be such as to give the same loss as in the case of the converter station. This case shows a net annual saving of only $620.

For 22,000 volt transmission, the efficiency curves of Fig. 4 show that results would be approximately the same as in the case of 13,200 volt transmission.

For still another case we will assume a 13,200 volt transmission consisting of four 3/0 cables with an a-c. load of twice that shown on curve "B," Fig. 1, or approximately twice the d-c. load. This shows a saving of $2390 annually for synchronous converters. The resulting power-factor of the system is of course not so high, the average being 86.9 per cent for the motor-generator station and 75.9 per cent for the converter station. At first glance this may seem low from an operating standpoint, but with the voltage of the feeders going out from the substation suitably controlled, the question of drop from the generating station to the substation becomes of less importance.

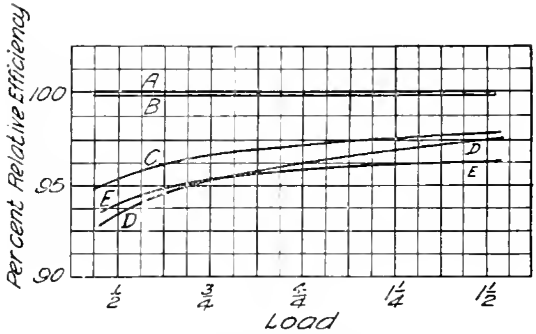
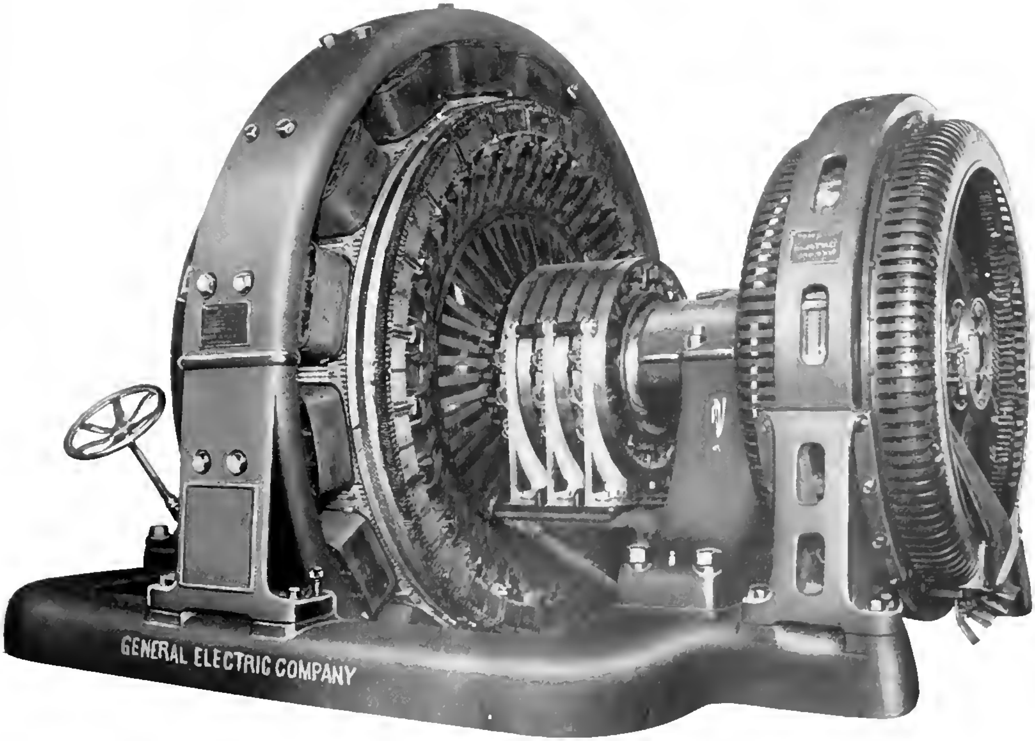


**Fig. 4. Relative Efficiencies**
*A* = Basis = Converter with 13,200 Volt Transformer.
*B* = Converter with 22,000 Volt Transformer.
*C* = 0.8 Power-factor M.G. Set, 2300 or 4000 Volt.
*E* = 0.8 Power-factor M.G. Set, 2300 or 4000 Volt with 22,000 Volt Transformers.
*D* = 0.8 Power-factor M.G. Set, 13,200 or 6600 Volts.

The load curves shown have a high load factor, but it would seem that a poorer load factor would show a greater saving for the converters as their efficiency does not drop as rapidly with light loads as that of motor-generator sets. This article is not intended as an argument that synchronous converters are always more economical than motor-generator sets, but it endeavors to show that each individual case should be investigated on its own merits.

TABLE I—SUMMARY

| TRANSMISSION VOLTAGE | 13.200 | | 4000 OR 2300 | | 13.200 | | 22.000 | |
|---|---|---|---|---|---|---|---|---|
| Loads | A-C. = D-C. | | A-C. = D-C. | | A-C. = 2 D-C. | | A-C = D-C | |
| Converting Equipment | Syn. Conv. | Motor Gen. | Syn. Conv. | Motor Gen. | Syn. Conv. | Motor Gen. | Syn. Conv. | Motor Gen. |
| Daily conversion loss, kw-hr. | 4880 | 7980 | 4880 | 6660 | 4880 | 7980 | Results Approximately as for 13,200 volts. | |
| Daily transmission loss, kw-hr. | 3650 | 3260 | 3650 | 3240 | 6380 | 5750 | | |
| Daily generator loss, kw-hr. | 8800 | 8700 | 8800 | 8600 | 13700 | 13400 | | |
| Daily saving, kw-hr. | 2610 | | 1170 | | 2170 | | | |
| Annual saving | $9540 | | $4270 | | $7930 | | | |
| Peak kv-a. | 8630 | 7680 | 8630 | 7600 | 14250 | 12680 | | |
| Average kw. generated | 5047 | 5170 | 5047 | 5115 | 7665 | 7759 | | |
| Extra peak kw. generated | | 139 | | 75 | | 116 | | |
| Extra investment: | | | | | | | | |
| Cable | $14250 | | $15450 | | $23600 | | | |
| Generators | $9500 | | $10300 | | $15700 | | | |
| Power house | | $13900 | | $7500 | | $11600 | | |
| Total | $9850 | | $18250 | | $27700 | | | |
| Interest—Depreciation | $1970 | | $3650 | | $5540 | | | |
| Net annual saving | $7570 | | $620 | | $2390 | | | |



# EXTENSION OF LIGHTING SERVICE THROUGH THE SOCIETY FOR ELECTRICAL DEVELOPMENT

By J. Robert Crouse

Manager of Sales, National Lamp Works, General Electric Company

Ever since the time when there sprung up several individuals who made the same kind of article, to be sold in the same district, sales competition has existed. The manufacturing company, the natural outcome of the individual manufacturer, continued this policy of jealous competition until at the present day each company while seeking to attract the attention of the public to its own particular wares is put to a by no means inconsiderable expense in educating the public to the usefulness of such devices in general. It is inefficient that each company should individually carry on this general educational work, for it could be much better accomplished by a single collective organization. In the electrical industry this organization is the Society for Electrical Development, which, with the earnest cooperation of central stations, manufacturers, jobbers, dealers and contractors, will carry on the educational work for the benefit of all and then leave its component parts to compete upon a rational basis. The following article explains the commercial conditions prompting the formation of this Society, defines its functions, shows how it is supported, and tells of its reception.—Editor.

J. Robert Crouse

PERHAPS the best way to introduce this subject is to quote from the notable address of Mr. Samuel Insull, delivered at Camp Co-operation, Association Island, September 4, 1913.

"At that time (referring to the very early years) the business of producing and distributing energy was mainly for the purpose of producing light, principally through the medium of the incandescent lamp. The business of supplying power was, so to speak, a by-product; just as much a by-product of the electric lighting business of that day as coke and tar and ammonia are by-products of the gas business of today. And notwithstanding that the incandescent lamp business has grown so that a hundred millions of lamps are consumed in this country in a year, today the electric lighting end of our business has become very largely a by-product. That side of our business which, thirty, twenty, even ten years ago, was the main portion of our business, was the portion of our business from which we got the necessary returns in order to pay a return to those investing their capital in our business, I say notwithstanding its importance as late as ten years ago, today, in looking to the future, I think that it is perfectly safe to say that the lighting end of the business is the by-product side of the business. If the business represented by the manufacturers here, of manufacturing lamps, is to increase by any such leaps and bounds as it has increased in the last ten years, the lighting business must become still further a by-product of the business, and, for the main basis, for a return on our investment we must look to the power business."

Mr. Insull, elsewhere in this address, states that the amount of energy used for incandescent lighting, as far as they have been able to check it, is from not more than 27 per cent under the best conditions, to 45 per cent under not as good local conditions, of the current produced at the station.

It seems to me that this statement from so authoritative a source is a sufficiently clear exposition of the evolution of the lighting business from the dominating activity in the early days to what Mr. Insull calls a by-product at the present time. A necessary deduction from this is that the interests of all who are engaged in the lighting branch of the industry are intimately and necessarily tied up with the progress of the other branches in heating and power work. Accordingly, while we, in the lighting business, must necessarily spend most of our energy along the line of perfecting and extending the lighting service, the conditions before recited should make a successful appeal for our sympathetic interest and active cooperation along broad lines of market development for all classes of service.

The principles involved in this trade movement are briefly covered as follows:

There are always some underlying, basic principles governing all change and progress, whether in the field of research, engineering, manufacturing or merchandising. These principles are of the same essential quality as the axioms in mathematics or refined statements of particular relations, such as $C=E/R$ in our electrical business. Such principles do not depend for their truth or power upon minority or majority assent, and when once fairly stated are assured of final acceptance, since essential progress must be made in harmony with them.

The progress in our electrical business during thirty years, notwithstanding the fact that less than thirty per cent of the population is electrically served, has been one of the wonders of the world; its contributions to the comfort, happiness and efficiency of our modern life are so great that we wonder how a preceding generation did without it. We may justly feel proud of such a magnificent business, which in every department of its development is so worthy of our best thought and effort.

The efforts of those engaged in the fields of research, engineering and manufacturing have shown the most marked results, since, while enjoying the stimulus of the friendly rivalry of other men and organizations, they have been free from the sort of competition which makes the accomplishment of useful results expensive and difficult. It is a matter of common observation that rapid progress has been made in discovery and research, in efficient engineering adaptation of discovery to practical manufacture, and in improved products tending to better the conditions of generation, construction and distribution.

However, in the field of selling and distribution we are challenged by the cold fact that no essential progress, meaning by this a decreasing ratio of sales expense to sales, has been generally accomplished. Not only this, but there is a prevailing opinion among the manufacturers, jobbers, dealers and contractors that the ratio of sales expense to sales tends to increase. The annual reports of some of the largest electrical manufacturers makes specific mention of this tendency as a fact in their operation. Among central stations this is doubtless less true, since by common consent they are properly monopolistic for the best results and are competitive only with other methods of furnishing service for light, heat, power, etc.

Our electrical business, technical in its very nature, has doubtless for that reason placed less emphasis in the past on aggressive selling and distributing effort—witness the fact that the first commercial papers in the National Electric Light Association appeared only so recently as 1905 and national advertising by individual companies began about 1907-1908.

It is estimated that the gross sales, and ratio of sales expense to sales for 1912, in the electrical business, were approximately as indicated in Table I

This $80,000,000 of sales effort, which is equal to one-fifth of the gross sales of all the central stations, is incurred by approximately 5000 central stations, 500 manufacturers, 200 jobbers, 5000 dealers and contractors, a total of 10,700 organizations. It is of special importance to note that $60,000,000 of this $80,000,000 sales effort is incurred by the manufacturers, jobbers, dealers and contractors who operate under complete competitive conditions, at a sales expense ratio of at least fifteen per cent, and tending to increase.

TABLE I

| Branch of Business | Gross Sales 1912 | Per Cent Ratio Sales Expense to Sales | Sales Expense 1912 |
|---|---|---|---|
| Central Stations | $400,000,000 | 5 | $20,000,000 |
| Manufacturers and Jobbers | 300,000,000 | 15 | 45,000,000 |
| Dealers and Contractors | 100,000,000 | 15 | 15,000,000 |
| Total | 800,000,000 | | 80,000,000 |

While Table I and its comments are broad generalizations, the reader is asked to check the principle and its application in his own particular case.

These facts in themselves are a challenge to commercial men which cannot be avoided. They justify the most careful search for causes and investigation of plans for improvement.

Whatever minor causes may be contributory to this failure in more efficient merchandising, the major one, which experience and facts disclose, is competition among these thousands of companies, resulting in expensive duplication of all kinds of sales efforts and failure to co-operate in a definite organized plan in those kinds of endeavor which effectively supplement and vitalize legitimate competition.

This competition consists, to a very great extent, of securing the business held by others and that of natural growth, which we may characterize as the existing market. A very large part of the selling effort is exerted on this existing market and dissipated in commercial friction and lost motion, with a resulting decrease in its creative effect.

The fact is frequently overlooked that the current-consuming devices for light, heat, power and other useful purposes are the only aspects of our business in which the public are or can be interested, while they constitute but a small part of the resulting business from the boilers to the devices the public uses. We are therefore all, without conscious organization, joint sellers of the final service.

This age of business, in which someone has said we live to do business instead of doing business to live, in the best sense, is, in the order of social development, the successor to the period when war, the extreme of competition, was the principal occupation. Business has inherited from this prototype many habits of enmity, antagonism and waste, which only the persistent cultivation of good fellowship, harmony and economy will gradually supplant. The most successful organizations which I have observed have given the greatest attention to the cultivation of harmony among their men, and the spirit of progressive, constructive effort. This same result must measurably follow similar conscious effort by an entire industry, especially one whose existence in its present form depends on the public's good will and appreciation.

The Society for Electrical Development proposes a broad, common organization of our entire industry: central stations, manufacturers, jobbers, dealers and contractors, controlled by a balanced representation from each, but not by any one alone, through which a part of this $80,000,000 of unorganized and competitive sales effort can be more effectively exerted through organized and co-operative effort in promoting and popularizing electrical service. These plans to teach the public to "Do it Electrically," though there are many more than can at once be undertaken, have been worked out and endorsed as entirely practical by many prominent men in our business.

The Society proposes at the start that a minimum of $200,000, or but one-fourth of one per cent of this $80,000,000 of competitive sales expense, be co-operatively expended. The basis of subscription is for manufacturers, and central stations, one-fifteenth of one per cent of gross sales, and one-twentieth of one per cent for jobbers, dealers and contractors, amounting, for illustration, in the case of the former, to $66.67 per $100,000 or $666.67 per $1,000,000 of gross business, and in the latter to $50 per $100,000 or $500 per $1,000,000 of gross business, the subscription being on an annual basis. This means in the case of a company having a fifteen per cent sales expense account, but one three-hundredth of their sales appropriations. There are few organizations which cannot locate competitive expenses of doubtful value equal to the Society's subscription. While individual subscriptions are comparatively small and in no sense burdensome, yet general co-operation in the movement will make a fund of $500,000 per annum available for progressive and aggressive market cultivation along these new lines.

This Society creates the organization and the fund through which some of our dollars can co-operate with the good will of us all in broad effective activity for the expansion of the market, while we continue with the most of our dollars to compete for our fair share.

This plan means real progress in the direction of more efficient distribution of electrical service through joint cultivation of our common market, the great preoccupied, incredulous, money-spending public, a result which our present systems neither accomplish nor promise ever to achieve on the old lines.

The plan presents a new kind of consolidation for sales efficiency through the means of a better balance of competitive and co-operative effort to which the popular thought will not now nor in the future take exception.

The plan means that electrical men, identified with this most wonderful of all businesses, will demonstrate for themselves, and by example for others, the true principles which underlie progress in more efficient sales distribution, through the creative cultivation of the market. The plan lends dignity to the art of selling, synonymous in the best sense with service, and marks a further point in the age now happily passing, when the selling spirit was symbolized in the economist's expression *Caveat Emptor*, "Let the buyer beware."

The limits of this article will not permit a discussion in detail of the plans of the Society for Electrical Development, further than to state that they cover broadly many lines of specialized activity in advertising, publicity, demonstration, etc., to teach the public to "Do it Electrically," which may be indicated by the following headings.

1. National Campaign of Advertising.
2. National Electrical Press Bureau.
3. Advertising Service through Agencies.
4. New Business Departments of the Technical Press.
5. School of Electrical Salesmanship.
6. Field Men to stimulate and develop local co-operation.

7. Field Men among Allied Trades, such as Architects, Builders and Contractors.

8. Campaigns of suitable Commercial Literature to Different Trades.

9. Special Prizes for Commercial Work, from which resulted, for instance, the Solicitor's Hand-Book which has been widely circulated.

This trade movement has received the endorsement of a group of men of [illegible] and international reputation (recently widely distributed in pamphlet form) as well as by practically all of the National Electrical Associations, so that, while its ideals for commercial progress are along such advanced lines, their practicability is well evidenced by these endorsements of both expert and general opinion.

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# SERVICE TO THE SMALL CONSUMER

## By S. E. Doane

Chief Engineer, National Lamp Works, General Electric Company

It is rather startling to learn that many European central stations include, at a profit, customers that have a connected load of only 15 or 20 watts, one company in fact carrying several thousand such consumers. Using these examples, the author recommends that our American central stations and supply dealers develop this field which has been so long neglected in this country.—Editor.

S. E. Doane

IT IS but natural that we, who are of the electrical industry, should come to regard the electric light as an almost universal illuminant when, as a matter of fact, the incandescent electric lamp is limited in its application to a relatively small part of the total field of artificial illumination. In the first place, about half of the population of this country is not within reach of central station service. This necessarily, to a great extent, excludes them from the advantages and conveniences of the incandescent electric light. In the second place, of the remaining part of the population residing in districts within reach of the central station service, but a small proportion is using electric service principally because our central stations have not generally as yet developed methods of rendering electric service to the smallest possible customers on a profitable basis. The central stations, entering the lighting field at a somewhat late date with methods of service which, to say the least, were not inexpensive, looked particularly toward the larger consumers as the profitable and desirable part of their load. In fact, it was not many years ago that some central stations doubted the possibility of serving even the larger residential lighting customers at a profit, while others regarded all residential lighting as a rather undesirable class of business. In consequence, they preferred to devote their attention to the larger commercial users of light and power.

The feeling that the small customers could be served only at a loss served to center the interest of the central station on the customers of larger size to such an extent that, until very recently, in this country very little has been done to reduce the cost involved in rendering service to the small consumers. The small customer, if served at all, must be served cheaply and, to serve the small customer cheaply, but at the same time profitably, the cost of service must be reduced to its lowest possible value.

The central stations in this country have not generally felt the immediate need of soliciting and developing the business of the very small consumers. Abroad, however, conditions have been somewhat different and the central stations have, for various reasons, found it desirable to give the smaller, and as we believed less profitable, consumers their most careful attention. It is not surprising, therefore, that we should find developed abroad methods for handling small customers' business which have served to render such business profitable and desirable from the central-station standpoint. The problem has been studied carefully from every angle and the details have been worked out with nicety; not only as to systems of charging and methods by which the expense of the wiring is financed for the very small customers, in order to remove some of the initial burden from their shoulders, but as to the method of billing, accounting and collecting which have all been modified with the particular object of reducing the expense involved in handling the accounts of these very small customers.

The results of the investigation by the foreign stations have placed them in a position where they do not simply tolerate the small customer, but where they actually solicit his business. Electric light is being extended into the homes of the poorest classes and the smallest possible customers using but one or two lamps of perhaps 15 or 20 watts each are being served by the central station at a profit. In fact, in Milan the average connected load of some 25,000 small customers is but 1.83 lamps, averaging about 22 watts per customer. It is needless to say that if our own methods of serving small customers were developed to this extent the thousands upon thousands of lighting customers, who are today within easy reach of the central station service and who because of the present methods of handling lighting business have been unable to avail themselves of the convenience and safety of electric light, would constitute one of the most important and profitable fields of electrical development open to us today.

Some of the systems and methods developed abroad for handling the very small customer's business are so unique that at first sight they may appear to be of more theoretical than practical value. However, the central stations abroad are actually obtaining today a not inconsiderable part of their revenue from the lighting business of the smallest possible class and the methods which they have developed are thoroughly practical and produce results.

The more progressive central stations in this country are already realizing the enormous possibilities which lie before them in rendering service to the thousands and thousands of small customers within easy reach of their existing lines. Within the year much will be heard of the foreign developments and practice. The report of the author's extended investigation of this subject abroad has already been presented to the National Electric Light Association's committee "Wiring of Existing Buildings" (of which he is a member), and the results of this investigation will be published in the very near future. Some of our own central stations are beginning to develop and devise means for opening up this enormous field and others will undoubtedly follow in increasing numbers. This extension of electric service to the smallest possible lighting customers will not only serve to increase the sale of electrical energy but the addition of this new business to the central station lines will open up a new field for the sale of wiring material and electrical supplies, and thus prove of broad benefit to the electrical industry.

Let us therefore do our utmost to bring about the extension of electric service to every possible customer within reach of central station service; let us enable these customers to discard their obsolete, dangerous and inconvenient lighting equipment, and in the future to "Do It Electrically."

# SOME RECENT DEVELOPMENTS IN CENTRAL STATION AND SUBSTATION EQUIPMENT

By J. R. Werth

Lighting Department, General Electric Company

In this article the author has selected for discussion some of the more important developments that have been made recently in the design and construction of switchboards, motors and generators. The reasons that brought about these improvements are pointed out and the manner of their accomplishment described and illustrated. The principal features relate to the standardization of switchboard panels, cast copper field coils, connection of end rings to rotor bars, forced oiling system for starting large machines, mica tape insulation of coils, and cooling vanes for commutator.—Editor.


J. R. Werth

To the central station man continuity of service is, in all probability, "the chiefest of virtues." Substation and central station equipment has in recent years been manufactured not only to secure reliability of service, but also with the aim of improvement along the lines of simplicity, safety and convenience of operation. It is the object of this article to give a few random examples showing how some of these features have been secured.

### Switchboards

The switchboard has often been called the brain of the central station and, as the problems of generation, distribution and control are different in each case, the "brain" must obviously be a little different for each installation. A switchboard inherently consists of so many separate items that it might seem almost a hopeless task to standardize and catalogue the various panels so that a suitable board could be selected by catalogue number to meet more than a few requirements. Until recently this was a fact. Now, however, it is possible to obtain for use on d-c. systems up to 600 volts and on a-c. systems up to 2300 volts complete switchboards for large or small stations made up completely of so-called "standard unit" panels which can be ordered direct from a publication by catalogue number. To accomplish this it has been necessary to standardize many thousands of separate and distinct panels which can be used in a very great number of combinations.

A type of switchboard manufactured by this system is shown in Fig. 1. It was built to fill a rush order, the previous equipment having been destroyed by fire. The elapsed time between the placing of this order and its fulfillment was in weeks what under the usual system would have been as many months.

The fact that a switchboard, for example, to control three rotary converters cannot be selected by simply multiplying by three the equipment listed for one rotary converter and that the problem of the selection of the correct number of voltage and current

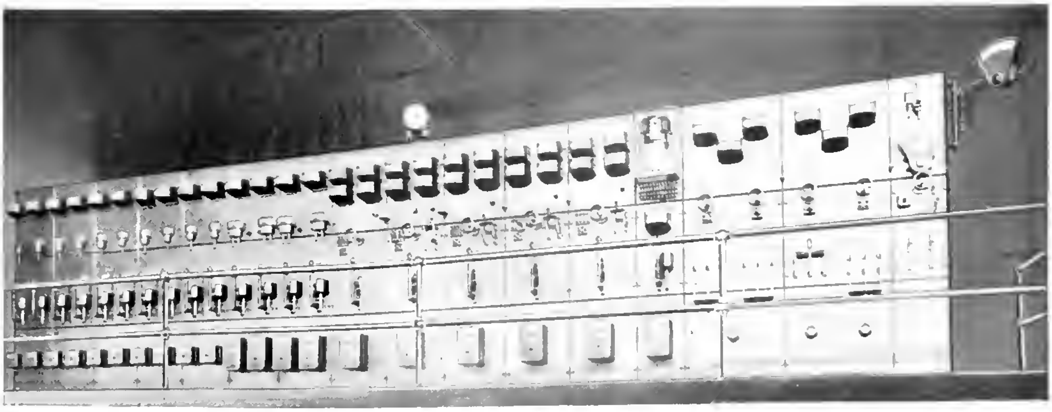
Fig. 1. A switchboard which was furnished in a remarkably short time because of being ordered on the "Standard-Unit Plan"

transformers varies according to the number of machines or feeders to be controlled, increase the difficulty of successfully listing these panels to meet every emergency. Therefore, a relatively enormous amount of work must be done in order to secure what, from the central station man's viewpoint, must be an extremely simple result.

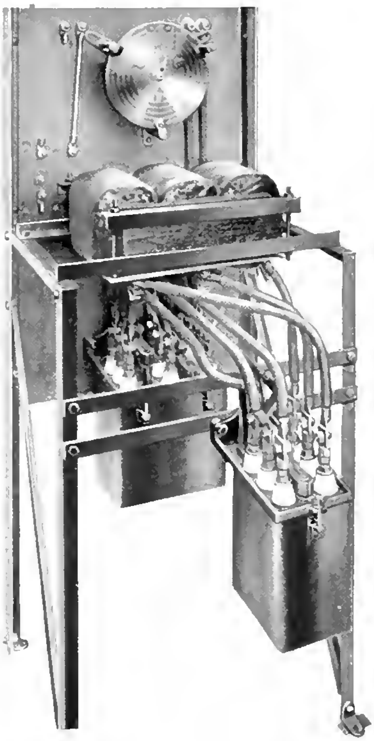

Fig. 2. 2200 Volt, 123 Amp., 470 Kv-a. Synchronous Motor Panel

The rupturing limits of oil switches shown in the tables may be of interest to some engineers. This information should apparently render the selection of the correct switch an easy matter. These tables have sometimes been used inadvisedly, not bearing in mind the fact that the selection of the proper oil switch depends directly on the available power which may feed into the short circuit at the instant when the switch is opened, and that the ratio between the kv-a. bus capacity and the "available power behind the short" depends on the system of connections, the protection afforded by other switches, the short circuit characteristics of the generators, and the resistance and reactance of the transformers and feeders.

For example, one central station company went exhaustively into the question of the proper equipment for a 500 kw. rotary substation. They ordered K-12 switches. A little later they decided to install in a different part of the city another 500 kw. substation. Here they also selected K-12 switches. In the first case, their selection was correct because the substation was one of several, all of which were connected to one 6600 volt feeder. In the second case, however, the selection of K-12 switches was wrong and the cheaper and smaller K-5 switch was subsequently substituted. It was amply large, due to the fact that a single feeder ran from the power station to this and only to this particular substation. By setting the large H-3 switch, at the power house end of this particular feeder, at the proper tripping value as regarded current and time, solely to meet the requirements of its one substation, a selective action between the switches was obtained.

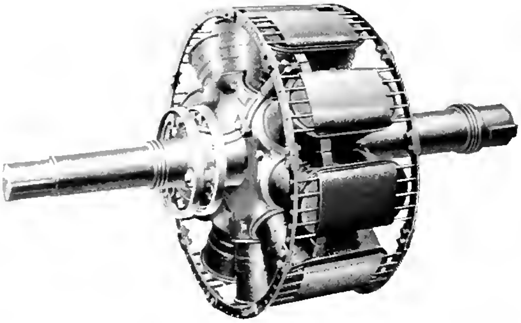

Fig. 3. Completely Assembled Field of a Synchronous Motor. The copper bars comprising the pole-face winding are tightly riveted to the sectionalized end rings

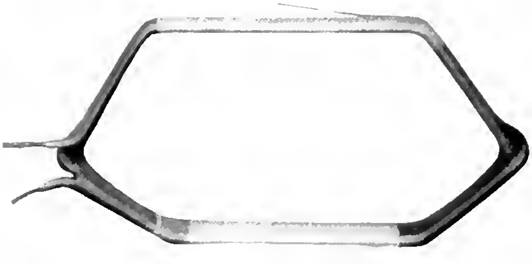

Fig. 4. Armature Coil Insulated with Mica Tape and Protected from Corona by a Tin Foil Covering

Under heavy short circuits, the H-3 switch at the power station would trip out and thereby relieve the K-5 switch at the substation of the duty of rupturing an arc beyond its capacity.

Fig. 2 shows an advance along the lines of simplicity and convenience. It represents the back view of a panel which controls a 470 kv-a. synchronous motor. Its unusual feature is the placing of the starting coils of the synchronous motor on the back of the panel instead of having them isolated, as has been previously customary for units of this size.

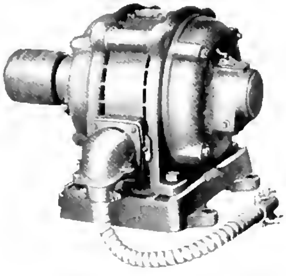

Fig. 5. A Five Horse-Power Induction Motor with Universal Terminal Box for Conduit Wiring

### Motor-Generators

Squirrel cage windings on synchronous motors were formerly built with the bars soldered to the end-rings of the squirrel cage. When a surge on the system caused pulsation and a rush of current through the bars, the solder would often melt and run out and the integrity of the electrical contact be destroyed. Fig. 3 shows a squirrel cage winding in which the bars are riveted to the end-rings, brass to brass, thus avoiding the necessity of using any solder. Not a single complaint has been received of poor contact at this point since this practice has been followed. The photograph also shows the fact that the squirrel cage has been divided into as many sections as there are poles. The advantage of this is that when it is desired to remove a damaged pole, that part of the squirrel cage belonging to that particular pole may be unbolted.

A much desired improvement in the ability of armature coils to maintain their insulating qualities is illustrated in Fig. 4.

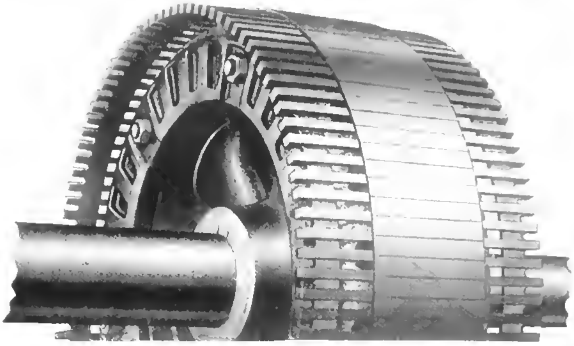

Fig. 6. A Squirrel Cage Rotor with Welded End Rings

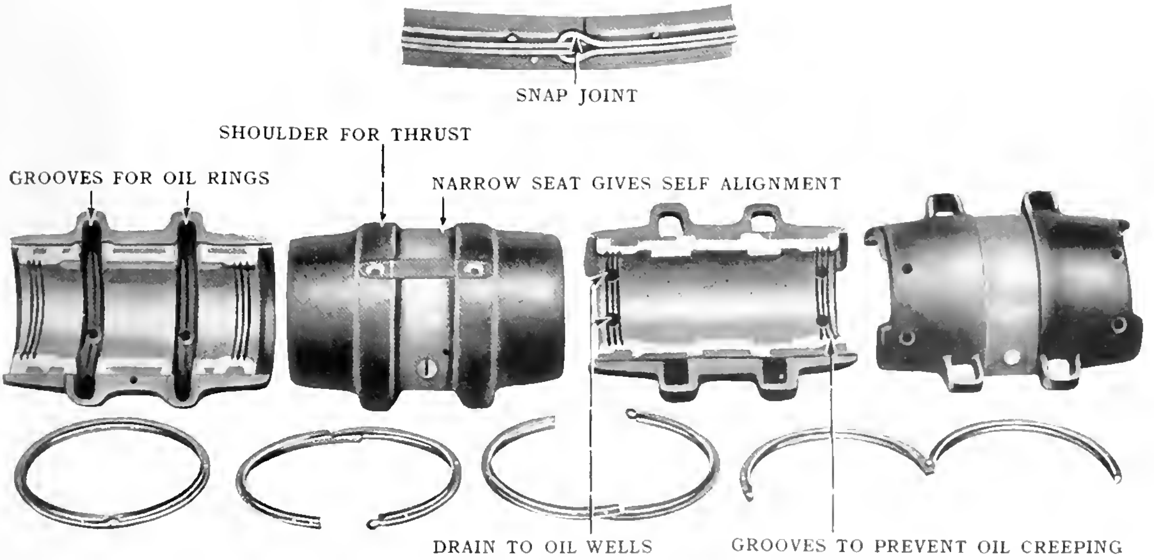

Fig. 7. This cut shows the Construction of Bearings and Snap Oil Rings

The use of mica tape has for several years proved advantageous. High-voltage armatures of 11,000 volts and above often tend to break down at the corners or bends of the windings. The mechanical strain is greater there, but, in the opinion of many engineers, it is inadvisable to appreciably thicken the insulation at that point in an endeavor to compensate for the tendency to break down. Thickened insulation acts like an extra blanket and keeps in the heat instead of permitting it to be radiated. The greater dielectric strength of mica suggested the use of solid sheets of it as a covering for the armature coil. This construction has been used by some manufacturers, but by others it has been considered as open to the objection that it piles up and thickens the insulation at the corners or bends of the windings, and also that a defect in the mica may go all the way through the solid sheets.

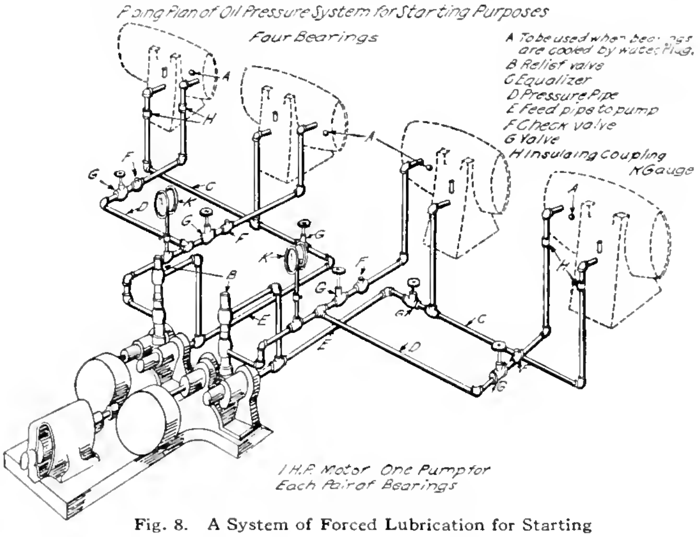

Fig. 8. A System of Forced Lubrication for Starting

On the other hand, by the use of mica tape wound on by hand, in a strip about $\frac{3}{4}$ of an inch wide, the strip being composed of many small overlapping pieces, the probability will be that a defect in one small piece will be offset by being covered by the overlapping piece which contains no imperfection.

Another characteristic of certain high-voltage windings which, in the past, has tended to shorten their useful life, has been the presence of corona. The mechanical and chemical action has often resulted in high-voltage armature windings being pitted and honeycombed so that when a sudden rise in voltage occurred on the system, the dielectric strength of the insulation would not be great enough to stand the increased strain and the armature coils would break down. The illustration, Fig. 4, shows an armature coil wound with tin foil from end to end of the armature slot, the ends of the foil being grounded on the armature core. A careful examination of many armature coils so treated has shown that the effect has been to eliminate the corona and give the coil a useful life of two to three times as long as it formerly possessed.

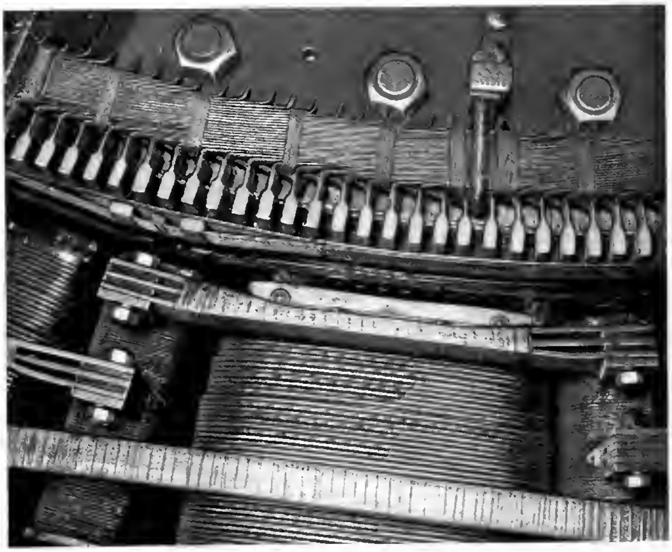

Fig. 9. A 2000 Kw., 250 Volt Direct Current Generator Equalized on Every Slot

Motor-generator exciter sets generally employ a squirrel cage induction motor as the driving unit. The exciter set is such a vital part of the central station that any improvement tending to increase its reliability is most welcome. The electric welding of rotor bars to the rotor end-rings as shown in Fig. 6 is an interesting advance in the art of perfecting the electrical circuit in the rotor, since it practically eliminates the chance of a high-resistance joint.

The universal terminal box for induction motors shown in Fig. 5 is made in sizes suitable for 2-inch conduits and below and is so obvious a convenience that it hardly needs comment.

To any one who has performed the somewhat tedious job of removing one of the old types of oil ring from a bearing, the snap oil rings with the hinge joint illustrated in Fig. 7 will appeal as distinctly a time saver.

A complete oiling system for the four bearings of a very large motor-generator set to insure easy starting is indicated by the diagram in Fig. 8. The writer has seen a large three-unit frequency changer set consisting of two synchronous machines, with an auxiliary motor used solely for starting, in which the starting motor was about two-thirds the size of the main units. The large starting motor was required because of the enormous torque necessary to "break" the shaft from its bearings after the set had been shut down several hours.

With a subsequent installation of the oiling system as shown, a small ¾ h.p. motor driving an oil pump forced the oil between the shaft and the bearings of the large set, floating the shaft on a film of oil, and the set was started without the use of a special induction starting motor, thereby saving valuable floor space and avoiding a continuous loss of energy necessary to keep the starting motor revolving 24 hours a day after its useful functions had been completed. After the set has started to revolve, sufficient lubrication is secured by use of the usual oil rings.

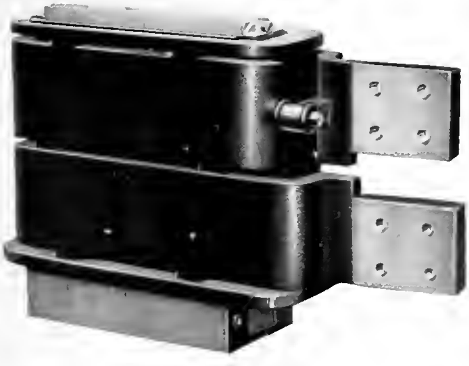

Fig. 10. Commutating Pole Piece with a Two-Turn High-Conductivity Cast Copper Coil

The direct-current end of larger motor-generators has, in some recent cases, been equipped with cast copper series field coils as shown in Fig. 10. The attractive features of this construction are its practical indestructibility and the economy of space with the resulting improvement of ventilation.

On direct-current armatures, inequalities in the magnetic circuits and different resistances in the multiple circuits running from the commutator bars through the brushes and studs to a common bus ring, will obviously cause cross currents, which, if excessive, will result in objectionable sparking at the commutator. Therefore for many years equalizers or miniature bus rings connecting equi-potential conductors have been used on the back of direct-current armatures, running from about every fourth slot to the corresponding slot under every alternate pole. Fig. 9 shows an amplification of this idea. Instead of being equalized on every fourth slot, this armature is equalized on every slot, and the resulting improvement in commutation has justified the additional labor.

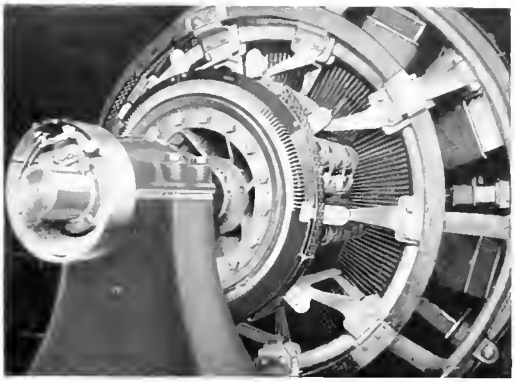

Fig. 11. Cooling Vanes on End of Commutator Protective Covering Partially Removed

The use of high-current-density brushes and improved ventilation of commutators has been the means of shortening the active commutator length. Fig. 11 shows the ventilating vanes on the outer edge of a commutator. The protecting covers, which in the photograph have been partially removed, are in practice placed over the ventilating vanes in order to afford the needed protection to the attendant.

The whole or partial disassembling of a large motor-generator often consumes valuable time, particularly if the direct-current brush rigging is supported from the pillow block or the magnetic frame. Fig. 12 illustrates an interesting mechanical improvement in that the brush rigging is supported from the base of the set. This

## RUPTURING LIMITS OF TYPE "F" OIL SWITCHES

Since it is obviously impossible to define limits of capacity which are applicable to every installation, the ratings given in these tables are based on the assumption that the switch will be connected directly to the buses and will be subject to maximum short circuit conditions. If, however, an intervening transmission line or transformer introduces sufficient reactance or resistance in the circuit, or if the generators have favorable short circuit characteristics, the switch can be given a much higher rating.

Refer all doubtful cases to the manufacturers with complete information including system of connections, size and characteristics of apparatus and line. Definite recommendations will then be given.

CLASS "A" SYSTEMS—All systems excepting those in Class B.

CLASS "B" SYSTEMS—Systems in which one or more generating units are turbo-driven, the reactance of any one of which with its connections to the buses is less than 8 per cent.

### SWITCHES FOR USE WITH SWITCHBOARDS

| SWITCH | | | KV-A. RATING OF BUS INCLUDING OVERLOADS OF ONE HOUR OR MORE | | | |
|---|---|---|---|---|---|---|
| Form | Volts | Amperes | Non-Automatic or Automatic with Time Limit Relays Set to Trip in not Less than 2 Seconds | | Class A | Class B |
| | | | Class A | Class B | | |
| UP TO AND INCLUDING 750 VOLT THREE-PHASE SYSTEMS† | | | | | | |
| K13 | | 200 | 5200 | 4200 | 2600 | 1500 |
| K5 | 600 | 300–500–800 | 5200 | 4200 | 2600 | 1500 |
| K5 | 4500–7500 | 200–300–500 | 11000 | 9000 | 5200 | 3000 |
| K12 | | 1200–1500–2000 | 17000 | 13500 | 8800 | 4600 |
| K12 | | 300–500–800 | 21000 | 17000 | 11000 | 5600 |
| K24 | 600 | 3000 | 20000 | 16000 | 12000 | 6100 |
| H3 | 4500–7500 | 300–500–800–1200–2000 | Above 21000 | Above 17000 | Above 12000 | Above 6100 |
| 751 TO 2500 VOLT THREE-PHASE SYSTEMS† | | | | | | |
| K13 ‡ | | 200 | 2600 | 1700 | 2600 | 1500 |
| K5 | 4500–7500 | 200–300–500 | 11000 | 9000 | 5600 | 3000 |
| K12 | | 1200–1500–2000 | 15000 | 12000 | 8000 | 4200 |
| K12 | | 300–500–800 | 20000 | 16000 | 9800 | 5200 |
| H3 | | 300–500–800–1200–2000 | 70000 | 56000 | 52000 | 27000 |
| H6 | | 300–500–800–1200–2000–3000–4000 | 70000 | 56000 | 70000 | 46000 |
| 2501 TO 4500 VOLT THREE-PHASE SYSTEMS† | | | | | | |
| K5 | 4500–7500 | 200–300–500 | 8400 | 6700 | 4200 | 2200 |
| K12 | | 1200–1500–2000 | 15000 | 12000 | 8000 | 4200 |
| K12 | | 300–500–800 | 18000 | 15000 | 9100 | 4800 |
| H3 | | 300–500–800–1200–2000 | 70000 | 56000 | 52000 | 27000 |
| H6 | | 300–500–800–1200–2000–3000–4000 | 70000 | 56000 | 70000 | 46000 |
| 4501 TO 7500 VOLT THREE-PHASE SYSTEMS† | | | | | | |
| K5 | 4500–7500 | 200–300–500 | 7000 | 5600 | 3500 | 1900 |
| K12 | | 300–500–800–1200 | 15000 | 12000 | 8000 | 4200 |
| H3 | | 300–500–800–1200–2000 | 70000 | 56000 | 52000 | 27000 |
| H6 | | 300–500–800–1200–2000–3000–4000 | 70000 | 56000 | 70000 | 46000 |
| 7501 TO 15 000 VOLT THREE-PHASE SYSTEMS† | | | | | | |
| K12 | 15000 | 300–500–800 | 11000 | 9000 | 5600 | 3000 |
| H3 | 15000 | 300–500–800–1200–2000 | 70000 | 56000 | 52000 | 27000 |
| H6 | 15000 | 300–500–800–1200–2000–3000–4000 | 70000 | 56000 | 70000 | 46000 |
| 15,001 TO 110,000 VOLT THREE-PHASE SYSTEMS† | | | | | | |
| K12 | 22000 | 300 | 8700 | 7000 | 4400 | 2300 |
| K21 | 22000 | 300–500–800 | 28000 | 22000 | 17500 | 9400 |
| K22 | 22000 | 300–500–800 | 28000 | 22000 | 17500 | 9400 |
| K24 | 35000 | 300 | 20000 | | 12000 | |
| K21 | 45000 | 300–500–800 | 40000 | | 20000 | |
| K22 | 45000 | 300–500–800 | 40000 | | 20000 | |
| K21 | 70000 | 150–300–500 | 50000 | | 25000 | |
| K22 | 70000 | 150–300–500 | 50000 | | 25000 | |
| K21 | 110000 | 100–300 | 50000 | | 25000 | |
| K22 | 110000 | 100–300 | 50000 | | 25000 | |
| H3 | 35000 | 300–500 | 70000 | | 52000 | 27000 |
| | 45000 | 300 | 70000 | | 52000 | |
| | 60000 | 300 | 70000 | | 52000 | |
| | 70000 | 100 | 70000 | | 52000 | |
| K15 | 70000 | 150 | 70000 | | 52000 | |
| K15 | 110000 | 100 | 70000 | 56000 | 52000 | |
| H6 | 15000 | 300–500–800–1200–2000–3000–4000 | 70000 | | 70000 | 46000 |
| H6 | 35000 | 300–500–800 | 70000 | | 70000 | |
| | 45000 | 300–500 | 70000 | | 70000 | |
| H6 | 60000 | 300–500 | 70000 | | 70000 | |
| | 70000 | 300 | 70000 | | 70000 | |

† ‡ See top of opposite page.

† For single-phase multiply above by 0.75; for quarter-phase multiply above by 1.50; for single-phase switches to three-phase buses use three-phase ratings; for switches used on line voltages less than that for which ratings are given, use kv-a. capacity corresponding to nearest voltage rating; the capacity of switches for intermediate voltages may be obtained by proportion.

Remote control switches are recommended for voltages above 3300

‡ Use of K13 oil switch for circuits 751-3300 volts.

The use of the K13 oil switch on circuits of 751 to 3300 volts, inclusive, is subject to the following limitations irrespective of the bus capacity of the station.

1. It is not to be used for railway service.
2. It is not to be used anywhere on a system, the maximum capacity of which exceeds 20,000 kv-a. (except as outlined in Clause 6) or in the line of any system subject to severe voltage disturbances.
3. It is not to be used anywhere in a generating station whose maximum capacity exceeds 2600 kv-a.
4. For systems 2600 to 5600 kv-a maximum generating capacity, it may be used in substations, providing a higher duty switch is interposed between it and the main station bus.
5. For systems of 5000 to 20,000 kv-a. maximum generating capacity, it may be used only under the following conditions:
   - (a) In a substation, providing transformer capacity not exceeding 750 kv-a. is interposed between the K13 switch and the line.
   - (b) On a substation feeder, providing a higher duty switch is interposed between the K13 switch and the substation bus.
6. When considering switches for connection to buses fed from the low-voltage units of motor-generator sets, the capacity of the system supplying energy to the motor-generator sets need not be considered. In such cases the sum of the rated capacities of the generator units of the motor-generator sets must needs come within the limits given in the above table to allow the use of the K13 switch.

A Form H switch is one for mounting in cells of masonry.

A Form K switch is one designed primarily for mounting on pipe framework. It has a removable iron cover.

permits the easy removal of the pillow block cover or the lifting of the upper half of the magnet frame, without disturbing the arrangement of the brush rigging in any way.

It is hoped that the scattered examples here mentioned of the various improvements may prove of interest to the central station man.

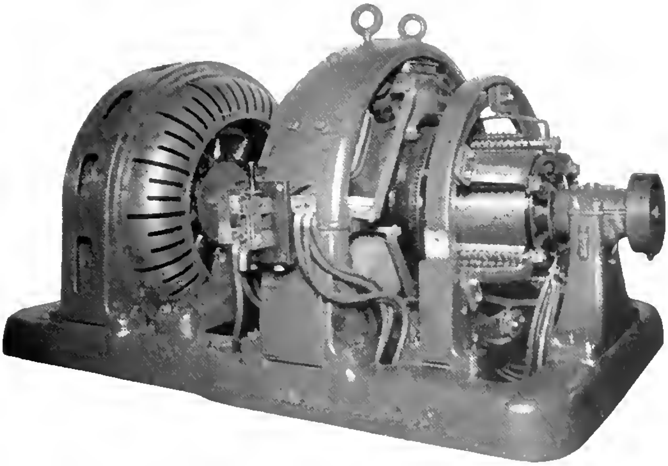

Fig. 12. A Synchronous Motor-Generator Set of Recent Design. The independent support of the brush rigging is clearly shown

# THE PROGRESS OF THE LIGHTING INDUSTRY

By E. P. Edwards

Assistant Manager, Lighting Department, General Electric Company

Seldom have we seen a more brief and at the same time comprehensive review of the epoch-making events which have made possible the present-day commercial generation and utilization of electricity than that which composes the first part of this article. The author proceeds to show that these advances have been but stepping-stones toward the realization of that long-predicted economical system of production and distribution of electricity—the *Central Station Method*. In connection with the latter section of this article we would call the reader's attention to the article, "The Central Station Idea" on page 201.—Editor.

**E. P. Edwards**

ARTIFICIAL illumination dates back to prehistoric times. Vegetable and animal oils were burned, through the medium of a wick, in open lamps until 1747, when Argand, a Swiss, invented his enclosed lamp embodying the fundamental principle of all modern oil-burning lamps.

Mineral oils were not introduced as illuminants until 1853.

The gas era began with the discovery of gas by Murdock, an Englishman, in 1779, thus securing a start of just 100 years over the first successful "incandescent" electric light.*

The discovery of electricity, however, antedates the achievements of Argand and Murdock by twenty-three centuries, as Thales of Miletus, a Greek, is reported to have noted in the year 600 B.C. the fact that amber and jet, when subjected to friction, possessed the power of attracting leaves, straw and feathers. It is quite certain that Thales did not realize the import of his discovery; at least he made no known use of it—did not even give it a name. On the other hand, it is certain that he possessed an equal knowledge with ourselves as to what electricity is, for we do not know today.

It was not until 1600 A.D. that a study of the phenomena of this unknown force was undertaken by Gilbert, an Englishman, on a scientific basis, and he first used the word "electrica," from which is derived "electricity," to denote substances possessing properties similar to amber, the Greek name for which is electron.

Otto von Guericke, a German, in 1663 built the first electrical machine capable of transforming mechanical into electrical energy. It consisted of a globe of sulphur fixed on an axis and rotated by a winch. Electrostatic current was produced, the machine being excited by the friction of the operator's hands held against the revolving globe.

Benjamin Franklin deserves an exalted place in the ranks of electrical engineers. It was he who demonstrated, about 1750, the identity of lightning discharges and the electric spark, invented the lightning rod, and contributed much other useful knowledge bearing on electrical phenomena.

The next step worthy of note was made by Volta, an Italian, in 1799. In this year he invented the voltaic pile and produced electric current by means of it.

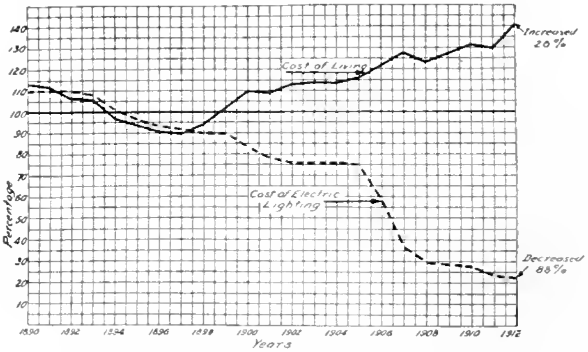

Fig. 1. Curve Sheet showing how the Cost of Electric Lighting has Rapidly Decreased while the Cost of Living has been Steadily Increasing

Sir Humphrey Davy, an Englishman, in 1808, working with a voltaic battery of 2000 plates, produced an electric arc between two carbonized wooden rods, and this was, properly speaking, the first incandescent lamp, and was, of course, the first arc light.

Oersted, a Dane, and Davy were the pioneer discoverers of the magnetic action

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* Note.—The arc lamp is, of course, an incandescent lamp, but the term "incandescent" is commercially used to distinguish Edison's development from the arc lamp.

of the electric current about 1820; but William Sturgeon, an Englishman, was the first to bring out an electro-magnet, which was further perfected by Henry, an American, and first used in telegraphy.

The remarkable invention by Faraday, an Englishman, in 1831, of a mechanical generator capable of producing kinetic electricity, paved the way of modern electrical development. His machine consisted of a copper disk rotated between the poles of a permanent horseshoe magnet. The principles laid down by Faraday, as a result of his experiments, were fundamentally the same as those upon which we are now working.

In 1844 Foucault, a Frenchman, was successful in substituting carbon taken from gas retorts for the soft wood carbon used by Davy, and while his discoveries represented a step in advance, it did not make possible successful competition between the new form of illuminant and gas, oil or tallow.

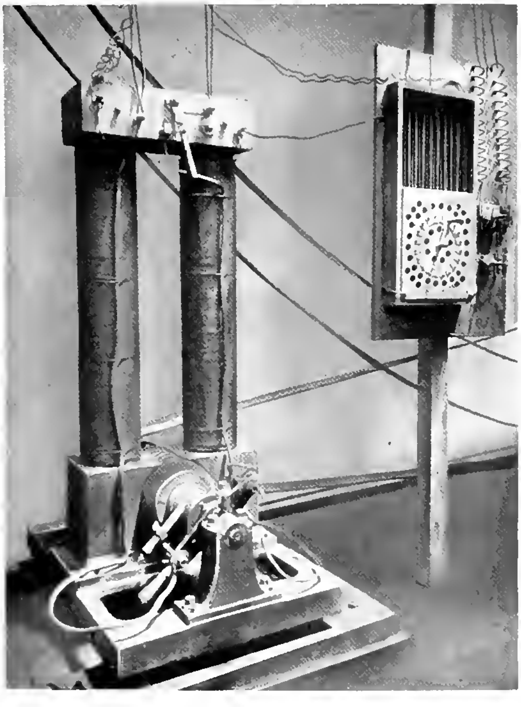

Fig. 2. One of Edison's First Generators

Credit for the next step in the development of the arc light belongs to Thomas Wright, an Englishman, who, in 1845, devised a lamp in which the carbons could be automatically adjusted.

In the next twenty-five years progress was slow but sure, the steps being marked by the invention of the drum wound armature in 1856, by Siemens, a German, the enunciation of the electro-magnetic theory of light in 1865, by Clerk Maxwell, an Englishman, and the development of the dynamo in 1870, by Grammes, a Belgian. The latter's inventions form the basis of present day electrical engineering.

Fig. 3. Exterior of an Early Central Station Lighting Plant, Appleton, Wis. Capacity 250 Lights or Approximately 11 Kw Interior View shown in Fig. 2. Page 256

Commercial dynamos, intended for producing electric light, were first built about the year 1866, but electric lighting was not established on a successful commercial basis until C. F. Brush, an American, brought out his series arc-lighting system in about the year 1878. This development in conjunction with the famous electric candles of Paul Jablochkov, a Russian officer, invented in 1876, are generally conceded to be the foundation stones of the arc-lighting industry. Jablochkov is also credited with being among the first to suggest the use of transformers, and while he, together with de Meriteus, Mordey, Gordon, Brush and others, took out patents on transformers, it was not until 1883 that Goulard and Gibbs, following this line of thought, introduced the first practical system making use of transformers. The first installation of a series arc-lighting system was made in Cleveland, Ohio, in 1879.

In 1883 arc-lighting companies began to take contracts for city street lighting, charging one dollar per lamp per night for the service: the units used being capable of producing 2000 candle-power.

The Thomson-Houston arc-lighting system was introduced about 1881, the first machine being of 25-light capacity.

Fig. 4. Interior View of the Fisk Street Station of the Commonwealth Edison Company, Chicago. Approximate Capacity 110,000 Kw.

While the arc lamp was fairly satisfactory for outdoor use, it obviously was not adapted to the needs of the individual consumer, and inventors as far back as Sir Humphrey Davy's time were working with the object in view of perfecting the small individual unit.

The first English patent on an incandescent electric lamp was taken out by DeMoleyns in 1841. In 1845, J. W. Star of Cincinnati, Ohio, took out a patent in England in the name of his attorney, King, covering a lamp consisting of a strip of graphite mounted in a vacuum. The first American patent was taken out in 1858 by Gardner & Blossom.

Many others were working along similar lines, notably Swan & Stearns in England, but Thomas Alva Edison was the first man to construct a commercially practical incandescent lamp. He proceeded on the theory that a successful lamp must be enclosed in a globe from which the air had been exhausted, fused at all joints, durable, and still cheap enough to be thrown away when broken. The first lamps of this character that were manufactured were sold for $1.50 each, and consumed about fifteen times the amount of energy for the same amount of light that is consumed by the modern lamp.

Edison employed various substances in his early experiments, notably platinum. The lamp which he brought out in 1879 employed a filament of carbonized bristol board cut in the shape of a horseshoe, enclosed in an exhausted glass bulb. Later on Edison used bamboo and many other substances for his filaments.

Edison's inventions marked the beginning of the era of incandescent lighting and the principles of his first carbon filament lamp are still embodied in the modern incandescent lamp.

Fox in England, and Edison in America, are credited with being the first two men who realized the commercial possibility of establishing public distributing stations. There is some conflict as to the exact date of establishment of the first of these plants. Four installations are worthy of note: the arc-lighting system in Cleveland in 1879; a public supply station erected by Edison in Pearl Street, New York, in 1881; another plant located in London in 1882, and the Edison plant at Appleton, Wis., installed during the same year. This last mentioned plant had a capacity of two hundred and fifty 10-candle-power, direct-current incandescent lamps. For all practical purposes we may say, therefore, that commercial arc lighting and incandescent lighting were introduced at the same time, and only thirty-four years ago.

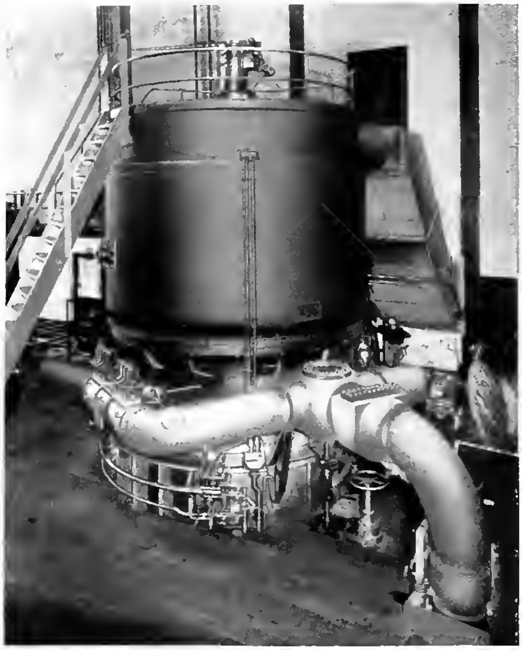

Fig. 6. Curtis-Turbine-Driven 20,000 Kw. Generator in the New York Edison Company Plant

It is obvious, from a historical review of the progress of the art, that the early investigators were bending all of their energy toward the development of electric light. It was not until 1873 that the fact was discovered that a dynamo of the Gramme type could be used as a motor, and it was not until between the years 1880 and 1884 that advantage was taken of this discovery, its possibilities realized, and electric power utilized for traction purposes.

Electric lighting, therefore, was the goal at the start and still is the "opening wedge" for electrical progress.

The first public-service stations were known as "lighting companies" and the large majority of them are so designated at the present time. The National Electric Light Association was organized in 1885 at Chicago, its original membership being of a very miscellaneous character, including manufacturing companies supplying electrical apparatus, fixture concerns, carbon and copper companies, isolated plant operators and a few central station representatives, all sharing in its management and direction. As the industry grew the Association was reorganized along its present lines, the voting membership being confined to central station companies. At the present time the membership, made up of various classes, is about 12,250, making it the largest organization of its character in the world, and numbering in its ranks central stations, manufacturing concerns, officials and other employes of these companies, and a large number of college and university professors; it has numerous affiliations throughout the country and members from all over the world.

The functions of the central station and the National Electric Light Association are much broader than the name implies; they are vitally concerned with the power problem, as a very large proportion of the output from central stations is used for power purposes, and the Association devotes a large part of its time to a study of this phase of the business, while still retaining its original name.

Today we find central stations in this country to the number of approximately 6000, furnishing current for lighting alone, equivalent to more than one hundred million 16-candle-power lamps—an average of more than one lamp per capita of our population.

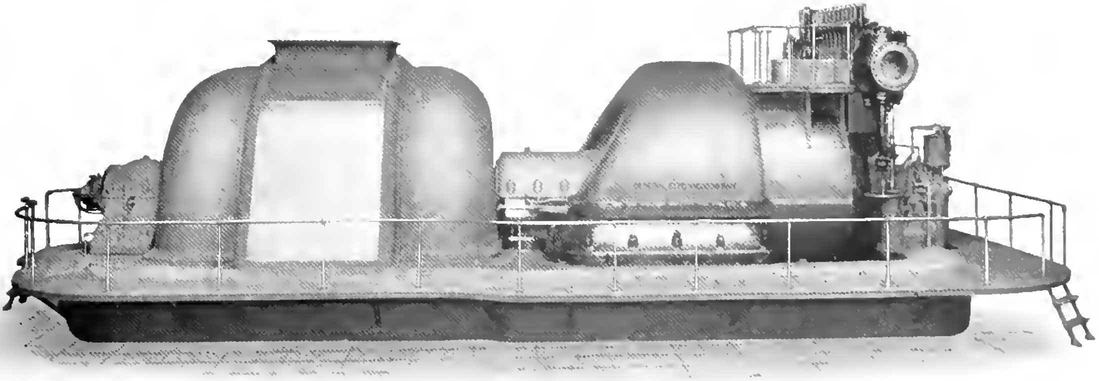

Fig. 6. Seventy Million Candle-power from One Machine. Typical Large Curtis Turbine Now Built in Sizes of 35,000 Kw. and Smaller

In addition to these public service lighting companies, there are about 1300 electric railway distributing stations and over 100,000 isolated plants in the United States generating electrical energy for both light and power purposes.

The aggregate continuous capacity of electrical generators installed in our central stations approximates twelve million kilowatts, with a daily output of seventy-five million kilowatt-hours. Statistics of isolated plants would greatly magnify these figures.

The investment represented in electrical generating stations and machinery amounts to over two and one-quarter billions of dollars. No accurate figures are available showing the grand total invested in the electrical industry. The statisticians have not been able to keep abreast of the rapid progress that has been made, and references to the latest encyclopedia will demonstrate that development is outstripping contemporaneous history by leaps and bounds.

Since the first central-station generator of twenty-five hundred candle-power capacity was built, there has been developed the modern single unit of seventy million candle-power capacity based on the specific consumption of the latest gas-filled tungsten lamps, and also individual plants with a capacity of 110,000 kw.

The steam turbine has made these large individual units possible and revolutionized the industry; conversely, electricity has made the turbine possible. Hero is credited with its first invention, 130 B.C., but the turbine did not begin to compete with, nor supplant, the steam engine until the principles employed by Parsons, Curtis and DeLaval were brought into their present high state of efficiency, through the efforts of the prominent engineers of the day, and this only within the last decade.

During the early stages of development, plants were installed only in the cities and larger towns where it was considered that the expense would be warranted. At the present time practically every "live" town of 1000 or more inhabitants has its own plant, or is served from some nearby station. Many towns of smaller population also have electric service. Electricity is not generally in use outside of these centers of population, but the time is rapidly approaching when it will be. The development of larger units makes possible economic concentration; smaller plants are giving way to substations served from a central generating point by means of transmission lines, which are rapidly networking the country. Our first so-called high-tension transmission lines, 4000 volts, were installed in about 1890 in Oregon, Colorado and California. They were of from ten to twenty miles in length. Today we have transmission lines two hundred and fifty miles long and with an operating pressure of one hundred and forty thousand volts. This practice of centralization is rapidly coming into vogue for many very good reasons, viz.:

1st. It is now possible to distribute power economically.
2nd. Because of the diversified nature of the load it is possible to reduce the cost and size of power-house equipment.
3rd. It is possible to operate the system with a better load-factor.
4th. The purchasing of apparatus, supplies and spare parts through a central source is of decided economic advantage.
5th. The centralization of the management, engineering and operating forces reduces the overhead expense.
6th. It is possible to serve certain classes of customers that the small independent plant cannot afford to serve.
7th. The consolidation of interests makes it possible to finance improvements, substitute new for obsolete apparatus and extend service into new territory.
8th. Better regulation and better protection can be provided for.
9th. And above all concentration can bring and has brought down the cost to the consumer far beyond what is possible with the relatively small independent or isolated plant.

The fact can be easily demonstrated that electricity is not in any sense responsible for the increased cost of living. The converse is true, as is aptly shown in Fig. 1.

Electricity is the cheapest, most convenient and safest form of energy, and it is used in practically every branch of art, industry and science. Electrical machinery can now be purchased for about one-fifth or one-quarter of what it cost in the early days and is far more efficient.

The same statement holds true of lamps and electrical supplies generally.

The first carbon lamps consumed from seven to eight watts per candle-power of light and had a relatively short life; the specific consumption of the latest carbon lamp is three and one-tenth watts per candle. Metallized filament lamps are a marked improvement over the carbon type, but the most satisfactory lamp so far developed employs the metal tungsten filament, the gas-filled mazda lamp of this type having a specific consumption of one-half watt per candle.

New uses are being found for electricity every day, and the history of its progress written five years hence will disclose many more remarkable developments that are not now even dreamed of.

# THE COMMERCIAL VALUE OF ELECTRICITY

By J. E. Kearns

Lighting Department, General Electric Company

Electricity is becoming more and more to be regarded as a commodity, in spite of its being intangible physically, for it performs much the same functions as other utilities commonly classed as commodities. In order that there be a demand for a commodity it must have a commercial value. The author of this article shows, in a historical manner, how electricity has advanced from its early stages of application to become a public utility almost as indispensable to a city as its water supply.—Editor.

J. E. Kearns

The criterion of today is commercialism. What does this mean with respect to electricity and electric service?

Any commodity, to have a real commercial value, first, must be useful, second, must have a market sufficiently broad to warrant its development, and third, must be manufactured on a basis and at a cost that will create and stimulate a requirement, until it eventually becomes a necessity.

Commerce, in its broad sense, means the distribution of products (manufactured or otherwise) affecting individuals, companies, corporations and countries, with a view of supplying their demands on a more efficient and economical basis. This gives a very broad market for most products; so broad that many articles are transported thousands of miles before being consumed.

These developments depend upon several conditions, e.g., upon a market for the commodity and the local conditions surrounding its production, such as the soil and climate, the presence of natural resources, and the cost of labor, but to a far greater extent upon the freedom and security of communication.

Very few of us treat and consider electricity as a commercial commodity, because the general idea of a commodity is that of something material. While electricity cannot strictly be considered as a material, its property as a medium for the transfer of energy legitimately places it in the category of commodities.

It is interesting to note that this commodity, representing today billions of dollars, has been of commercial value for only about one half of a century and that during this time its development, leading to the invention of the telegraph and ocean cables, has been the prime factor in making United States one of the leading nations in commerce.

The early commercial application of electricity was to supply power for lighting purposes, and its success in this field gradually led to its almost innumerable uses of today. This condition has been made possible only by the careful, consistent and indefatigable efforts of prominent engineers to develop the art and to improve the design of the generating units, converting machinery, transmission lines and distributing systems.

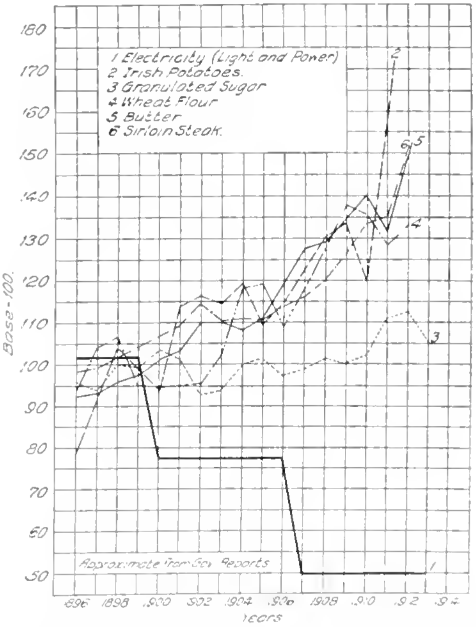

Fig. 1. Curves showing the Decrease in the Cost of Electric Light and Power and the Increase in the Cost of the More Common Staple Food Articles During the Past 18 Years

During the early stages of progress, the developments and extensions of electric energy were confined to communities of sufficient size to warrant the installation of a central station and, for a period of twenty years, the energies of engineers, bankers and promoters were confined to the improvement of the segregated plant; but, today, this condition is being gradually supplanted by a more conservative, effective and efficient method of distribution, namely, that of grouping towns and serving them from a central point of distribution.

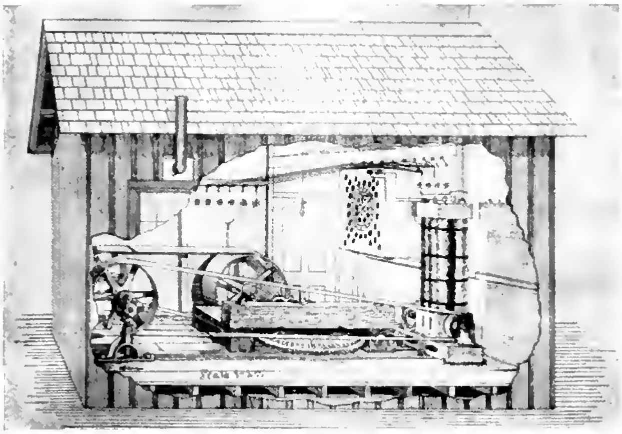

Fig. 2. Interior View of the First Central Station Lighting Plant, Appleton, Wis Capacity 250 Lights or Approximately 11 Kw. Exterior shown in Fig. 3, Page 251

This system of conservation has been made possible through the development of suitable generating equipment, distributing transformers, transmission lines and local substations for serving the smaller communities.

The generating equipment for such a system will usually consist of steam turbo-generators or, in cases where warranted, waterwheel generators supplemented by a steam turbine relay equipment, since there are very few localities where the water supply can be entirely relied upon. In this station would also be installed step-up transformers, protective apparatus and suitable switching equipments, together with whatever other apparatus is required for local distribution.

The transmission system would probably be of some reasonably high voltage, say, from 33,000 to 140,000, depending upon local conditions, and use suitable primary and secondary conductors carried on wooden poles or steel towers of approved cross-arm construction.

The local substation may consist of one of two types, the indoor type which is necessitated where revolving machinery is required, or the outdoor type which is used where stationary apparatus only is installed, such as transformers, etc.

This system appears to be quite complicated when compared with the first complete installation, which consisted of one generator, some simple switching equipment and a short transmission system. But, even as simple as this method may have been, it required considerable care and attention to insure its operation. The present system of distribution is made quite simple and effective by load dispatching which is taken care of by telephone orders for starting and stopping the machines and operating the switches, and, further, by the remote control of rotating substation apparatus from the main station.

Through the stages of progress, as may be suspected, many changes and improvements have been made. At the present day, we have single turbo-generator units of 35,000 kw. capacity as contrasted against the first "Jumbo" machine, of 700-lights capacity, exhibited at the Paris Exposition in 1881 where its size excited wonder and caused considerable excitement. This great gap is just as wide when we compare the old one-mile distributing system with that of the 250-mile system of today.

The unfortunate part of all this gradual improvement is the fact that it has developed nothing that could be called standard for this commodity, and it seems that the next logical step for the manufacturer and user is to improve the standards, paying particular attention to capacity, frequency, voltage and heating. It is further extremely desirable to dispense with the use of the multiplicity of transformer taps for voltage regulation and to use instead some regulating device. It seems only fair to mention here that the users are beginning to appreciate the value of standardization with respect to price and delivery, also with respect to its important bearing on their overhead charges. It is apparent, therefore, that the manufacturers also should put forth their keenest efforts to assist the public service companies' endeavors and make them, as they should be, mutual endeavors.

The inherent characteristics of electricity make it adaptable for innumerable and ever-increasing uses, as it is the only form of energy that can be produced economically in large quantities and be distributed great distances with but little loss for use in extremely small units. Many comparative values are available to prove this.

The commercial application of these characteristics has led to important electrical inventions and developments, which add to the comforts of life. Its safety at low potentials creates a demand for application where other commodities would be a menace to property and life.

It can safely be stated that if it were not for the great diversity factor of electricity its price per kilowatt would not be as low as it is today, namely, 50 per cent less than it was a few years ago; while most other commodities have shown a gradual increase in price. The time is not far off when it will be necessary to increase the price of the generating and distributing equipments, owing to requirements in design and complicated operation developed because of the increased demands of the public for safer operating machines, while the cost per kilowatt to the consumer of the energy will tend to remain about the same, due to an increased diversity factor.

This situation some might construe as being impossible due to competition, the keenness of which sometimes necessitates the sale of a commodity at a loss. This condition is gradually and surely disappearing, owing to the development of our high-speed electric-driven machine tools, by means of which the production of a commodity may be limited to existing conditions. To try to establish competition, as it existed in the past, would be maleficent, as it is directly contrary to the present economic system of production. The forcing of the price of a commodity below its finished cost must eventually mean ruin to the industry; therefore, the only logical step is co-operation and standardization, as this will mean not only an improvement in the products but a total lower cost which paves the way for increased consumption of the commodity and in turn means more business and gradual increase and continuity of prosperity.

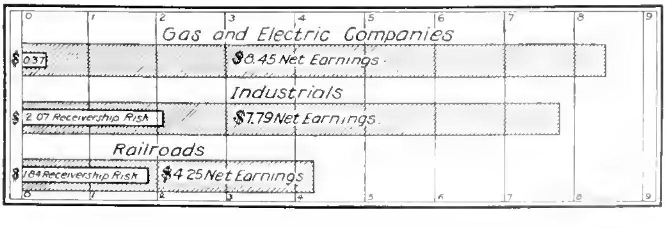

**Fig. 3.*** Comparative Safety of Gas and Electric and Other Forms of Investment

Just such co-operation as that mentioned has given electricity the great commercial and economic value it has today, for without it many of the inhabitants of small communities would not be enjoying its advantages, industrially, socially or otherwise. Co-operation of this sort has also been the vital force in the advancement and growth of everything in nature, and why, at this period, should the political aspirations of individuals or parties be allowed to destroy a natural and healthful commercial growth?

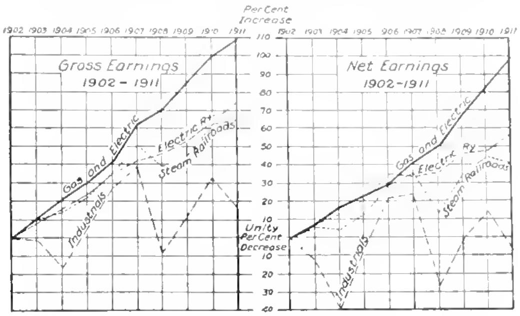

**Fig. 4 *** The Steady Increase in Gas and Electric Earnings as Compared with Railways and Industrials

As a further proof of the value of such co-operation, one has only to refer to the relative safety with which investments may be made in public utility securities. It is interesting to note that, during the past decade, the railroads have increased their capital stock only about 50 per cent, while the public utility corporations have more than doubled their capitalization during the same period. The primary value is represented by the fact that, even during periods of depression, earnings from the sale of electric energy have shown a gradual increase, in spite of reduced rates to the consumer, while the income from other industries was subject to sharp fluctuations.

Due to its intrinsic value, the popularity of this type of investment is gradually increasing, with the result that the public utility corporations will be able to finance future developments at a much lower cost, and this, of course, will be profitable to the communities served by giving them better service at a lower cost.

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* Figs 3 and 4 copyrighted by Henry L. Doherty & Co., New York.

The commercial value of electricity has developed beyond all expectations until now it forms one of life's most vital commodities, but, while requiring the utmost skill and talent for its production, it is the cheapest commodity available today. So important has this energy become (having reached a point where it is now an absolute necessity) and so diversified its uses, it is safe to predict that a universal failure in its production for ten days would cause untold suffering and business stagnation.

This shows how great is the value of continuity of service to a large community like New York or Chicago, which is made possible only by the care in the design and economic operation of the machinery and which represents a value that is often unjustly slighted in public appraisals.

Intelligent management in the electrical field by developing through co-operation, by removing obsolete and inefficient apparatus, by replacing the small wasteful plant by a properly-designed service station, and by conserving the natural resources has been able to place electric energy within the reach of all, and to enable the public utility corporations to deliver this energy for commercial welfare and individual benefit at a minimum cost to the consumer and at fair profit to the producer.

# SERIES MERCURY-ARC RECTIFIERS

By C. M. Green

Engineer, Rectifier Department, General Electric Company

The main division of this article describes the functions of the various component parts of a mercury-arc rectifier, viz., tube, constant-current transformer, reactance coil, exciting transformers, means of cooling, static dischargers, and panel board. The second section deals in a historical way with the commercial development of the rectifier. The good and bad points of the early rectifier outfits are described, and then the improvements which led to the elimination of these bad points are taken up step by step. The article concludes with some very pertinent suggestions as to how to avoid certain kinds of trouble in underground distribution systems, and also for the adjustment of the lamps themselves that they may be protected from burn-outs by a misapplied high voltage.—Editor.

C. M. Green

The constant-current mercury-arc rectifier is a device for obtaining constant direct current suitable for the operation of series direct-current arc lamps of either of the open or enclosed type from a single-phase constant potential supply which may be taken from a polyphase system. The apparatus has been designed to use all of the commercial frequencies from 25 to 140 cycles, and all the voltages which are in use today up to 13,200 volts primary.

There has been developed a series rectifier, having a capacity of 8500 volts, 6.6 amperes, which will operate from a three-phase supply, but which has not been put on the market for the simple reason that the single-phase rectifier answers all commercial requirements and is less complicated and expensive to build.

The arc, formerly called arch light, was discovered by Sir Humphrey Davy in the year 1820, and was operated from batteries. The cost of electricity from this source was so excessive, however, that it could not compete with other illuminants, and, as a result, remained a laboratory experiment for over half a century.

Charles F. Brush gave to the world the first complete series arc lighting system and many of the Brush arc generators and lamps are still in active service. The generators are, however, of relatively small capacity, the maximum size being 76.8 kw., 8000 volts, and 9.6 amperes, with an efficiency at full load of about 84 per cent.

During the past twenty years the whole system of generation and distribution of electrical energy has changed. In the early days the plants, whether water power or steam, were of comparatively small capacity and distributed over a comparatively small area; whereas, today the bulk of electrical energy is generated in large central stations by means of turbo-alternators and is transmitted long distances at high voltage to the many places where it is desired to be used.

During the early transition period many of the Brush arc generators were motor-driven, having an efficiency between terminals of about 75 per cent, whereas, the modern rectifier has an efficiency of approximately 92 per cent with a full-load power-factor of 65 per cent.

The direct-current arc has been invariably a more efficient means for the conversion of electrical energy into light than the alternating-current arc, and the rectifier is the latest apparatus used for the conversion of alternating to constant direct current for the operation of arc lamps.

## THEORY OF THE MERCURY ARC RECTIFIER

The theory is generally well known, but those who desire further information regarding this subject should refer to the article by Dr. W. R. Whitney on "Theory of the Mercury Arc Rectifier" in the December, 1911, issue of the GENERAL ELECTRIC REVIEW, also to the article by F. Parkman Coffin on "Physical Phenomena of the Mercury Arc Rectifier" in the October, 1913, issue of the GENERAL ELECTRIC REVIEW.

## FUNCTIONS OF VARIOUS PARTS OF THE RECTIFIER

The rectifier outfit may be divided into the following parts:

### Rectifier Tube

For rectifying the current, there is a tube which consists of an exhausted glass vessel containing two anodes, cathode, and two starting anodes, the cathode and starting anode arms being filled with mercury. The mercury arc permits the current to flow with comparatively little resistance in one direction, about 25 volts drop, and offers practically an infinite resistance in the opposite direction. A diagrammatic section of such a tube is shown in Fig. 1.

### Constant-Current Transformer

A constant-current transformer supplies constant alternating current, for rectification, from a constant-potential alternating-current source. Changes in voltage and current are obtained by varying the relative position of primary and secondary coils on the core, which also varies the impedance between primary and secondary of the transformer. The lower the load, the greater the distance between coils and the higher the impedance; and, as the load increases, the coils come together with a reduction in the impedance and increase in the power-factor. It also insulates the primary from the arc-lighting circuit, which is very essential because the circuits are more or less subject to arcing grounds, crosses with other circuits, etc.

### Reactance Coil

Reactance is used to store energy during the high part of the wave that it may be returned to the circuit during the low part of the wave.

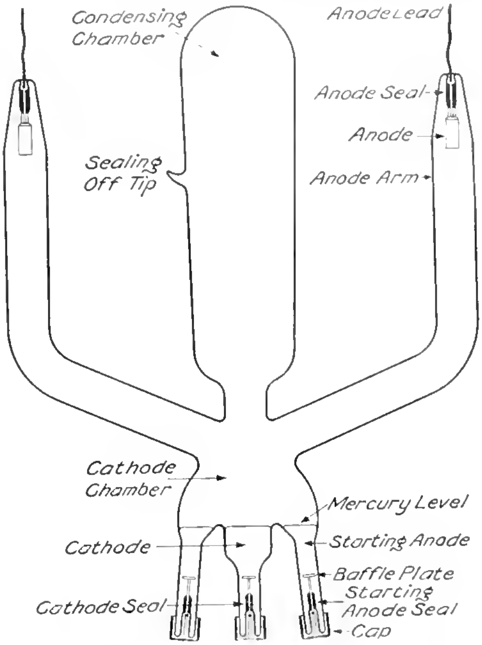


Fig. 1. A Diagrammatic Section of a Rectifier Tube Listing Its Various Parts

During the interval that the arc is running in both anode arms of the tube the reactance carries the entire load, its functions being similar to the flywheel of an engine.

### Exciting Transformer

This is a specially designed, highly insulated transformer with high reactance between primary and secondary coils so that the latter will stand short circuiting without injury. It has also a d-c. reactance to perform the same functions as the main reactance. This transformer contains no moving parts and, besides its fundamental purpose, serves to insulate the supply from the load circuit.

### Means for Cooling the Rectifier Tube

Tubes in the early outfits were cooled by means of an air blast from a blower, usually arranged as shown in Fig. 2. Fig. 3 shows the front of a rectifier board but the blower arrangement is not shown. These outfits were later changed from single to two tubes in series. Later the method of cooling was changed to that of submerging the tube in oil, the oil being water cooled, which is the present standard method.

### Static Dischargers

These are connected between the anode and cathode of the rectifier tube to protect the tube and remainder of the apparatus in case of trouble. In other words, during normal operation of the tube gases are apparently given off, and after shut down these gases are re-absorbed by the graphite anodes. When an old tube is started up cold the anodes run hot, the gases are driven out and apparently prevent the arc from transferring normally from anode to anode, similar to water in the cylinder of an engine. Then, the discharge from the reactance and secondary coils of the transformer may produce a discharge, when the voltage between anode and cathode reaches from 25,000 to 30,000 volts, as shown by needle points. Of course with oil-cooled tubes this cannot occur when static dischargers are added. They also have been installed at a number of stations using air-cooled tubes.

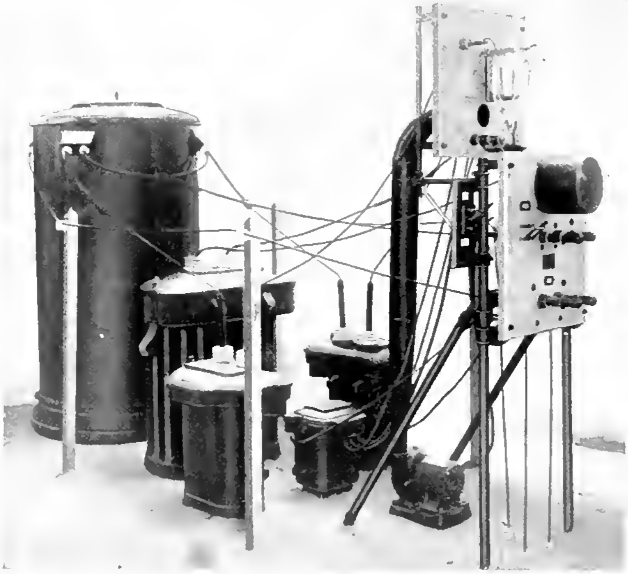


Fig. 2. An Early Mercury Arc Rectifier Outfit Showing Motor and Blower for Air Cooling the Tube

### Panel Board

This board at present has the following equipment, primary switch and fuses, load and short-circuiting switches, ammeter, and shaking handle.

## COMMERCIAL DEVELOPMENT OF THE SERIES RECTIFIER

The first commercial rectifier outfit was operated by Dr. Steinmetz for the purpose of running a few magnetite arc lamps on the streets of Schenectady above Union College in 1903 and 1904.

Feb. 22, 1905, 100 magnetite lamps were operated for a period of eight hours on a single tube and, with the addition of resistance in the circuit, or an all resistance load, the load on the tube was increased to 10,000 volts, 4 amp., or 40 kw.; on a tube with a little larger arms to 10,000 volts, 6.6 amp., or 66 kw.

In December, 1905, there were started at Portland, Oregon, some 75-light 4-ampere rectifier outfits. Considerable difficulty was experienced with the operation of the tubes during the following summer, for the temperature of the air reached about 100 deg. F. The capacity of the motors, driving the blowers for cooling the tubes, was gradually increased to 2 h.p. per tube. The difficulty was finally overcome by changing the sets from single tube to two tubes in series. In other words, it was found by factory tests that tubes, which would operate at 85 deg. but not at 90 deg. F. on 75 lamps, would operate up to 110 deg. F. when connected two in series and would give a guaranteed life of 400 hours.

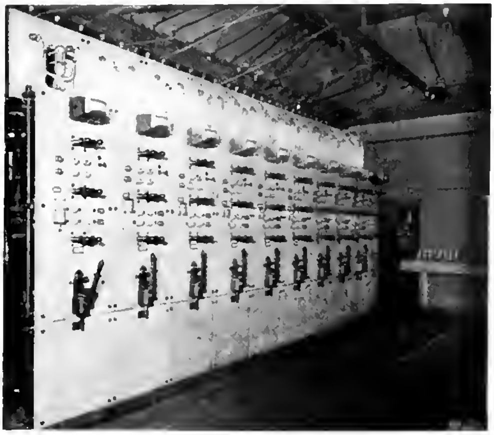


Fig. 3. An Early Installation of Ten Air-Cooled Rectifier Tubes and Switch Panels

In 1907 the method of cooling the tubes was changed from air to oil, the oil being water-cooled, which, combined with a partial consolidation of the apparatus, made a material improvement in the outfit.

In 1910 the various parts of the rectifier outfit, with the exception of the panel board, were all combined into a single piece of apparatus, and the panel board installed in front or elsewhere. Figs. 4 and 5 illustrate combined outfits.

### 50-Light, 6.6 Amp. Single-Tube Outfits

The load conditions on the tube were not quite as severe as with 75 lights, 4 amperes, but the first outfits were changed over from air to oil-cooled tubes, on account of unsatisfactory operation, and are still operating single tube. However, since conditions in a great many parts of the country made it impossible to keep the oil temperature down to 85 deg. F., many of these sets have been a constant source of annoyance, and their manufacture has therefore been discontinued. Some of the sets which have given excessive trouble have been changed over from single tube to two tubes in series.

It was assumed that water no hotter than 70 deg. F. would be used for cooling the oil so that an oil temperature of from 85 to 90 deg. could be maintained, but later developments showed that the city water of St. Louis, Montreal, New Haven, Bridgeport, Conn., and a number of other places would reach 85 deg. F. in summer, and, with the air up around 100 deg., it would be impossible to keep the oil down to 85 or 90 deg. F.

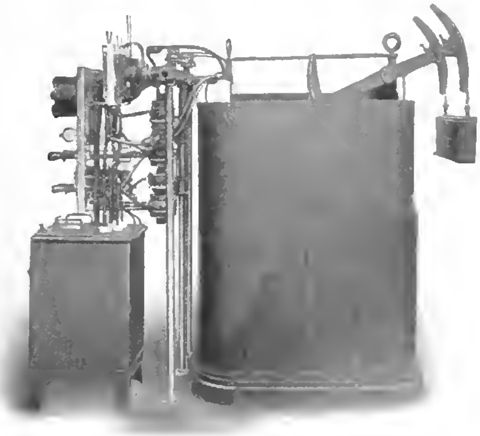


Fig. 4 A Later Rectifier Outfit than that shown in Fig. 2

### 50-Light, 4 Amp., Single-Tube Outfit, Oil Temperature 90 Deg. F.

In Texas, and some other parts of the country, water was not available to keep the oil at 90 deg. or below, and it was necessary to use ice. This, of course, was a decided handicap, and the outfits were changed over from single tube to two tubes in series, since which time their operation has been thoroughly satisfactory.

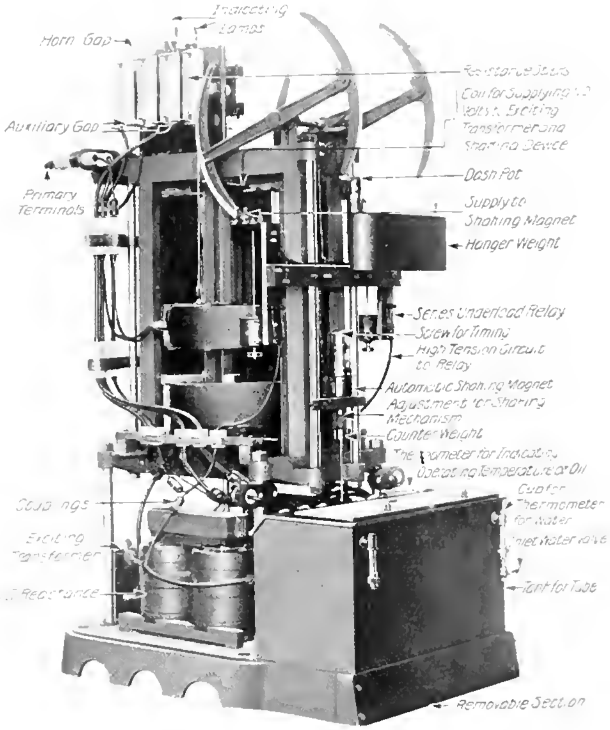


Fig. 5. A Complete Rectifier Outfit, Except for the Casing, of the Latest Type

There is an outfit which has been operating for over six months in Dallas, Texas, with tube tank 40 in. high and no cooling coils. It is a 50-light, 4-ampere, two-tubes-in-series outfit. This is a great advance over the use of ice in the old single-tube outfits.

### 50-Light, 4-Amp., 2-Tubes-in-Series Outfit

The operation of all these outfits (consisting of those which have been made by changing single-tube outfits to two-tubes-in-series outfits and others which have been built up new in the latter form) has been invariably so satisfactory and the tube life so much greater than guaranteed that it very strongly points to the fact that, where customers are obtaining their guaranteed average life of 400 hours, or even 600 hours, on failed tubes covering a period of six months, it would be a profitable investment for them to change over their old outfits from single tube to two tubes in series. This will result in a material reduction in expense of tube renewals, which reduction, in comparison with the expense of renewals on the single-tube outfits, ordinarily speaking will pay for the cost of changing over the outfits from single tube to two tubes in series in two to three years. This is in addition to the material improvement in their operation, fewer interruptions in service, etc.

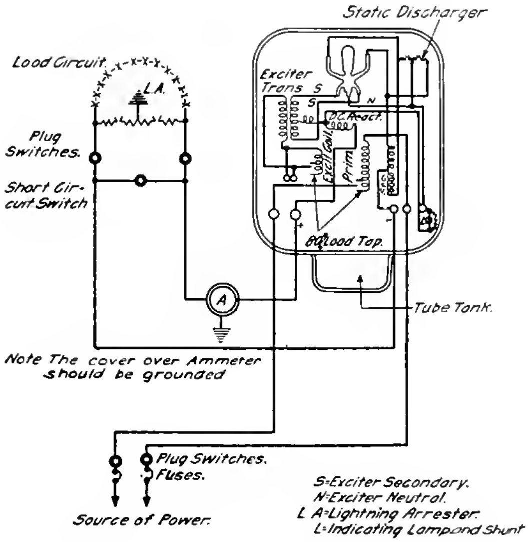


Fig. 6. Diagram of Connections of a Single-Tube Rectifier System

### Connections

The first connections sent out on the single-tube outfits are the standard connections of today; reactance between cathode of tube and line. Fig. 6 shows the connections for a single-tube rectifier.

Some companies made the statement in 1906 that they did not see the necessity for placing the reactance next to the cathode of the tube, as originally called for. There had been, however, no tests made up to that time to determine which was the better connection; and, as an intermediate step, quite a number of outfits were tried out with the reactance connected next to the center of the secondary of the transformer, thus simplifying and reducing the wiring. Later experiments showed that these outfits were sensitive to arcing grounds on the positive side of the line, crosses with other lines, as well as sensitive to inductive effects of high-voltage transmission lines in the near vicinity; whereas, with standard connections, these were not appreciable. Consequently those users, who have had difficulty with their outfits dropping load and with the cathode spot jump-over into the starting anode, have changed the connections so as to have the reactance between line and cathode of tube with a marked improvement in the service.

### Two-Tubes-in-Series Rectifier

The early outfits had no reactance between line and tube. A very marked improvement in service has been found by dividing the reactance and placing half of it between line and cathode of tube, or half next to each cathode. Fig. 7 shows the connections of a two-tubes-in-series rectifier.

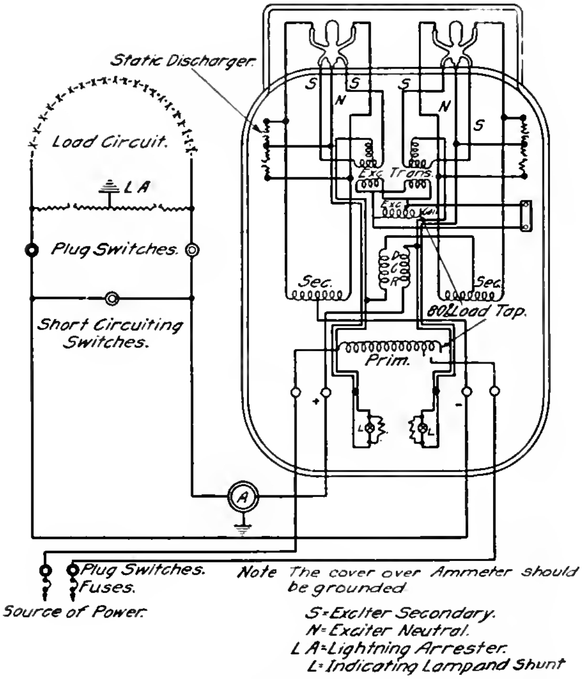


Fig. 7. Diagram of Connections of a Two-Tubes-in-Series Rectifier System

### Rectifier Tube Development

The lava bushing form of tube has undergone some minor changes. The punched iron anode form of tube is a later development and has shown a marked improvement over the former as it is less liable to damage in shipment and as it gives better satisfaction in service, both with air and water cooling. Fig. 8 shows both these tubes.

It is impossible to form a correct opinion of the comparative merits of different forms of rectifier tubes without a careful investigation of the tube life covering a large number of tubes and extending over several years time.

### Duplicate Two-Tubes-in-Series Rectifier

This new outfit was developed in 1913 in order to overcome the objection of the large central stations to the interruptions that occurred during the lighting hours when a tube had to be replaced. These interruptions amounted to about a one 5-minute period in two months service. The outfit has given satisfactory results, the spare tube taking the load in case of trouble.

The tank has been so designed that it can be used with either the old segregated outfits or the later combined units, or with the regularly designed outfit. See Fig. 9 for detailed internal construction of tank with oil removed.

### Connections

As the name implies, duplicate two tubes in series, it is simply a two-tubes-in-series outfit with duplicate tubes, two tubes being connected in parallel, either one of which may operate. For connections see Fig. 10.

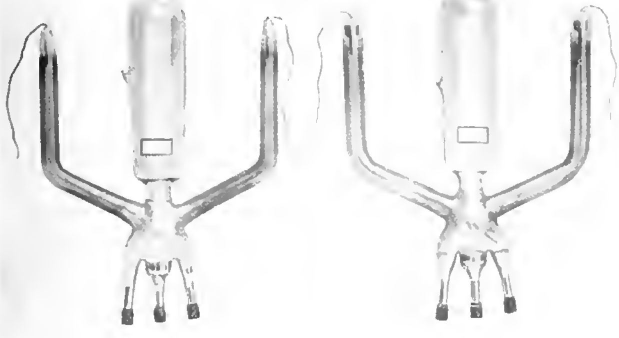


Fig. 8. Two Types of Rectifier Tubes. Tube with Lava Bushing Anode on the Left; Tube with Punched Iron Anode on the Right

### Voltmeter for Measuring Potential on Arc Lighting Circuits

There has been developed an arc-circuit indicator which is a high-grade, high-reading voltmeter and which is very useful in keeping track of the load on the circuits, also, for the purpose of locating grounds, and measuring the insulation resistance of the circuit to ground, etc. Such instruments should be obtained having a maximum scale reading of approximately 50 per cent above rated voltage of the rectifier, which is its open-circuit voltage.

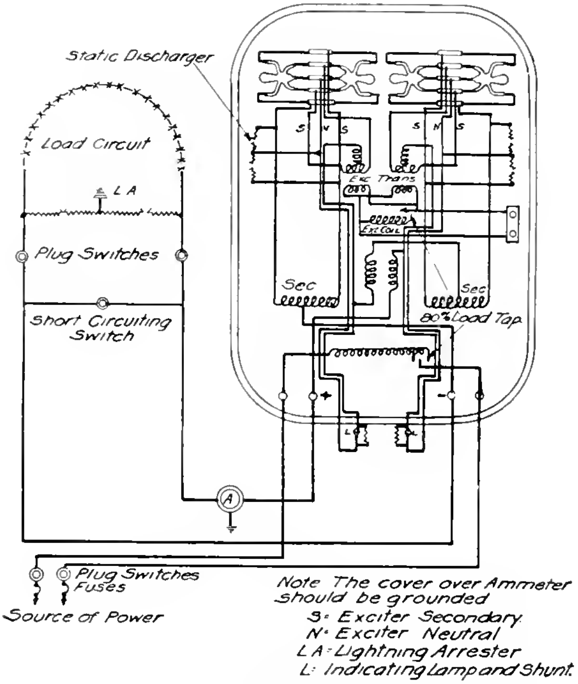
Fig. 9. Tube Tank for Duplicate Two-Tubes-in-Series Mercury-Arc Rectifier, Showing Internal Construction of Tank. No Oil

### Underground Cables

There has been a very steady increase in the number of circuits which are run underground, in comparison with those which have been run overhead; and, occasionally, in putting in these former circuits difficulty has been experienced principally due to the two following causes.

First: Insufficient dielectric strength of the cable, which in accordance with the recommendations of the A.I.E.E. should be called upon to stand a test of double the open-circuit voltage of the rectifier, which is practically three times its rated voltage.

Second: In installing and occasionally in repairing underground cables, the lead sheath on the same is not bonded where the cable is opened to go into the station or up to a lamp. The lead sheath on the single-conductor cable is similar to the secondary of a series or current transformer, and, if this lead sheath is left open, in case of surges on the circuit, there is liable to to be an appreciable voltage generated between the open terminals. This may seriously interfere with the operation of the apparatus, break down the cable, and in certain instances may produce arcing between the lead covering on the cable and other conductors, which might ignite the explosive mixture of gas frequently found in man-holes.



Note The cover over Ammeter should be grounded
S = Exciter Secondary
N = Exciter Neutral
L A = Lightning Arrester
L = Indicating Lamp and Shunt

Fig. 10. Diagram of Connections of a Duplicate Two-Tubes-in-Series Rectifier System

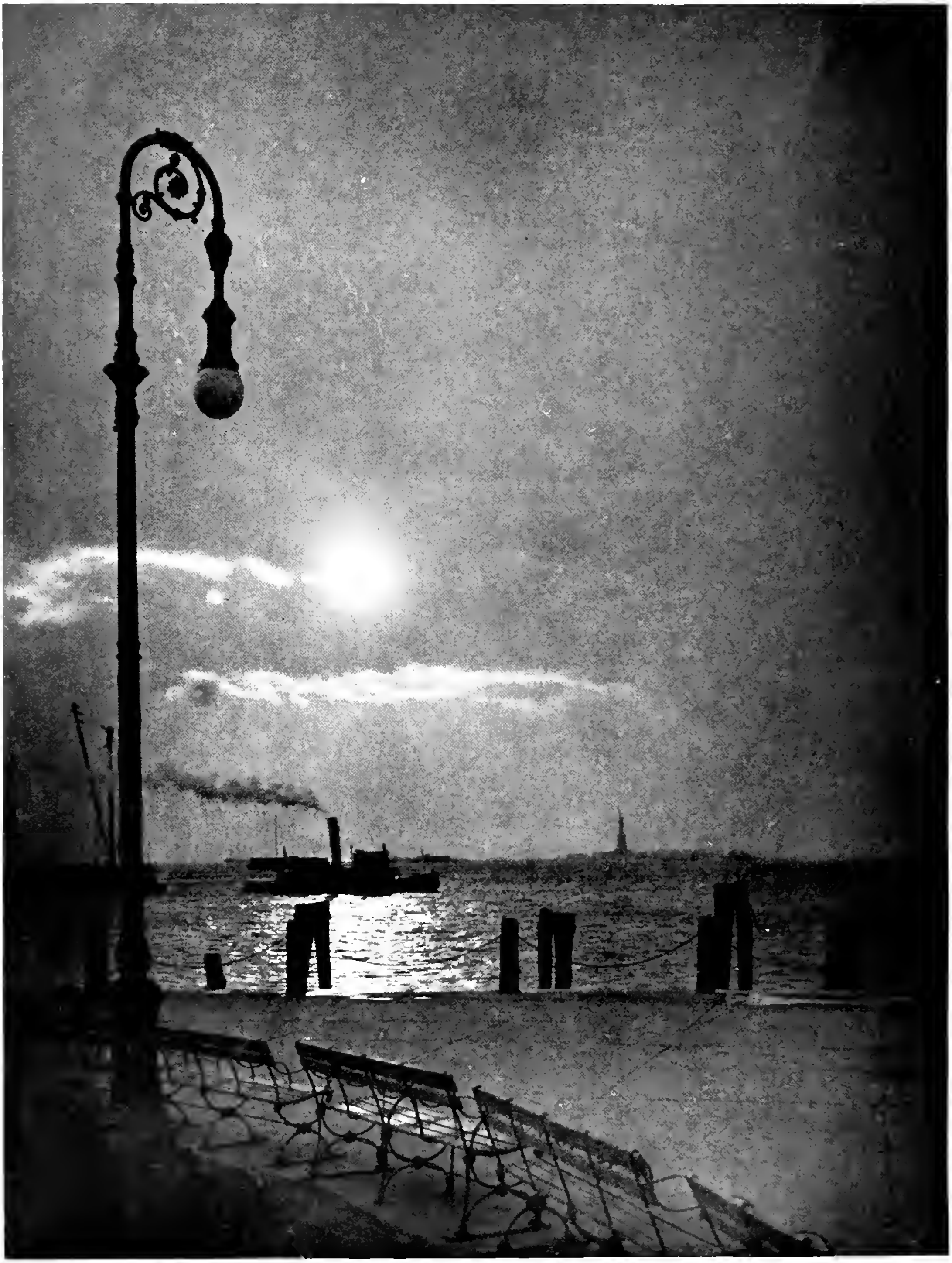
Arcing grounds and crosses with other circuits invariably interfere with the operation of any electrical apparatus, but, if the circuits are kept in good condition and will stand the insulation test as called for by the A.I.E.E., satisfactory service is invariably obtained.

### Lamps

The rectifier has introduced new problems in arc-lamp design, which were not necessary when operated from direct constant-current generators. When these machines flashed they required a very appreciable time to build up and allowed the electrodes or cut-out contacts in the lamp to come together long before the generator would supply its normal current. The same is not true of the rectifiers. These in case of flashing will frequently supply current to the circuit before the electrodes or cutouts in all the lamps get together, and, as a result, the insulation of some lamp may be broken down, or the shunt winding burned out. This difficulty has been taken care of in some forms of d-c. series lamps by inserting an additional automatic cutout, and in the magnetite lamps by keeping the distance between the carbon and copper contacts between $\frac{1}{32}$ in. minimum and $\frac{3}{64}$ in. maximum. As the lamps operate, the carbon contacts slowly burn away, and after a time the distance may become so great that it ceases to act as a spark gap, and consequently the insulation of the lamp may be broken down or the shunt winding burned out. When these latter adjustments have been made the trouble will cease.

Washington has just Installed the Luminous Arc Lamp for the Illumination of its Principal Thoroughfare, Pennsylvania Avenue

THE NATION'S CAPITOL



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View from Battery Park, New York City

# THE IMMEDIATE FUTURE OF THE HALF-WATT MAZDA LAMP

By L. A. Hawkins

Engineer, Research Laboratory, General Electric Company

The author does not attempt to predict what will be the eventual field of the gas-filled mazda lamp, but rather, by a consideration of the characteristics of the lamp, to determine the general directions of the development of this field. The gas-filled mazda does not manifest its wonderful efficiency until relatively high current values (large diameter filament) are reached, and it is probable that the first commercial lamps will be made for currents in excess of five amperes. For the multiple house circuits of 110–125 volts in general use, this would mean lamps of over 600 c-p., which are entirely unfit for average residence lighting. The most obvious field for the new lamp at present is series incandescent street lighting, replacing the old lamps on existing 6.6 and 7.5 ampere circuits. On a-c. circuits better efficiency would be obtainable by the use of 20 ampere lamps supplied with current from a compensator. The author states that the probable net result of the advent of this lamp in the arc lamp field will be to produce better arc lamps, and both types will co-operate in furnishing better lighting systems for all conditions.—Editor.

L. A. Hawkins

THE announcement last summer by the General Electric Company that an incandescent lamp had been produced with a specific consumption of one-half watt per candle naturally gave rise to much speculation upon the effect this new lamp would have on electric lighting. Since then, the characteristics of the new lamp have been fully described by Langmuir and Orange,* but speculation continues and some misapprehensions are manifest. Therefore it may be worth while to devote a few minutes to a consideration of the probable immediate future of the new gas-filled mazda lamp.

It would be equally presumptuous and futile to attempt to anticipate developments by mapping out the metes and bounds of that portion of the field of electric lighting which the gas-filled mazda lamp will eventually occupy. It is not the purpose of this paper to make any such attempt, but rather, by considering some of the well established characteristics and peculiarities of the lamp, to try to determine the general direction of probable development which may affect that development.

When a gas-filled lamp is compared with a vacuum lamp, its most striking characteristic, aside from its higher efficiency and higher intrinsic brilliancy, is that its efficiency varies with the size of the filament. In vacuum lamps the efficiency at a given filament temperature is independent of the diameter of the filament, except for the relatively slight effect on loss through leads. In gas-filled lamps the diameter of the filament is an important factor in determining the efficiency. The reason for this is that at a given temperature the wasted energy, i.e., the heat lost by conduction in the gas, is practically independent of the filament diameter, while the useful or radiant energy is proportional to the surface, and therefore to the diameter of the filament. Langmuir † gives the specific consumption of a tungsten filament at 2800 deg. absolute in nitrogen at atmospheric pressure as 1.54, 0.74 and 0.50 watt per candle for filaments of 1, 5, and 50 mils dia. respectively. It is clear from these figures that the large filament has in nitrogen an advantage over the small filament which it does not have in vacuum. Nor do these figures tell the whole story. A 5 mil filament at 0.74 watt per candle and a 50 mil filament at 0.50 watt per candle, though running at the same temperature, will not have equal lives. The larger filament should outlast the smaller several times. In order to get a comparison based on equal lives the specific consumption of the smaller filament must be raised or that of the larger lowered. The difference in efficiency will then be more marked.

The gas-filled lamp is thus at its best in large sizes, and it is therefore in large sizes that the first commercial development should be looked for. Large size means large filament diameter and that means large current. The filament can and should be coiled in a close helix, so as to give the effect of a larger diameter, but the permissible diameter of the helix is limited, because, if it is made too great in proportion to the diameter of the filament, the filament will sag rapidly early in the life of the lamp and

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* *Proc. A.I.E.E.*, Oct. 1913.

G. E. Review, Oct. and Dec., 1913.

† *Proc. A.I.E.E.*, Oct., 1913.

the efficiency will fall correspondingly. Therefore, even though the filament is wound in a helix, the specific consumption is relatively so much greater in low current lamps that the first commercial lamps, except for special purposes, will naturally be designed for currents above, rather than below, 5 amperes. For multiple circuits of 110 to 125 volts, this means lamps of over 600 watts, in which specific consumptions of 0.75 down to 0.6 w.p.c. in the larger sizes can be looked for.

Lamps of such wattage and candle-power are so far removed from the sizes of lamps adapted for house-lighting that it is not to be expected that the gas-filled lamp will be scaled down in the near future to house-size.

But there are other circuits on which the high efficiency mazda of more than 5 amperes is immediately applicable. Most street series incandescent circuits now carry 6.6 or 7.5 amperes, and on such circuits the new lamp can be substituted directly for the old and reduce the specific consumption to about 0.7 w.p.c.

A better efficiency is obtainable on alternating current circuits by using a lamp of 20 amperes or more, with a compensator to transform the current to the proper amount. With such a lamp a life of well over 1000 hr. can be obtained at a specific consumption measured on the primary side of the compensator of not more than 0.5 watt per candle.

This combination of a high current lamp and compensator has several advantages over a lower current lamp designed for direct connection in the circuit, other than its higher efficiency, amounting to at least 30 per cent more light for the same wattage. In the first place, on a series circuit, some kind of shunt protection is necessary to take care of burnt out lamps, and a shunt reactance is one of the simplest forms of such protection. This, in effect, is what the compensator is. Secondly, since these new lamps run much nearer the melting point of the filament than do the vacuum lamps they are more sensitive to excess current. The compensator can be designed to reduce the current rise in the lamp for a given rise in the series circuit. Even if the compensator is not designed to give this effect, the greater mass of the large filament, with its time lag in temperature, makes it less sensitive to sudden rises of current than is the lamp with the smaller filament. This time lag is very noticeable when current is thrown on or off a 20 ampere lamp. There is a very appreciable interval before the lamp reaches full luminosity or falls below incandescence.

On the basis of equal life, the large filament runs at a somewhat higher temperature than the smaller filament and therefore gives a somewhat whiter light, but this difference would not ordinarily be noticeable except where direct comparison is possible.

The 20 ampere lamp, with its high efficiency, high intrinsic brilliancy, and relatively white light, enters directly into the arc lamp field. Its efficiency is about three times that of the enclosed a-c. arc of 6.6 amperes, which still lights more miles of street than any other lamp, and is on the same order as that of the luminous arc. In connection with relative efficiencies, it should be remembered that it has been the practice to rate incandescent lamps in watts per mean horizontal candle-power, the measurements being taken on the bare lamp, while arc lamps are usually measured complete with casing, reflector and outer globe and rated in watts per mean hemispherical candle-power. In making comparisons care should be taken to reduce efficiencies to the same basis.

The 20 ampere half-watt mazda seems certain to find a field in street lighting. It can in the present state of its development be made efficiently in sizes as small as 300 watts, 600 candle-power, or even smaller by resorting to special expedients to prevent excessive heat loss through the leads when the filament length is reduced below that corresponding to 15 volts. There is no upper limit to the candle-power and wattage.

In connection with outdoor applications, one point is of interest and importance. The bulbs of nitrogen-filled lamps run much hotter than those of vacuum lamps. Temperatures approaching 200 deg. C. or even higher are to be expected. The reason is that, whereas in the vacuum lamp much the greater part of the energy in the filament is radiated directly through the bulb without heating it, in the nitrogen-filled lamp much the greater part of the energy is taken up by the gas as heat and so delivered to the bulb, with the result that the top of the lamp especially runs very hot. Now when cold water is suddenly thrown on an ordinary glass bulb at 200 deg. C. the bulb cracks. Therefore, for outdoor use it is necessary either to make the bulbs of special low-expansion glass that can when hot withstand a sudden cold shower, or so carefully to house the lamp as to prevent the access of water.

Housing is not a disadvantage for the larger lamps, since the intrinsic brilliancy is so high that a diffusing outer globe is desirable to prevent glare, and for the 20 ampere lamps the compensator must be housed anyway. In the design of the housing, however, it is necessary to provide adequate ventilation. A lamp which will last 1500 hours if properly ventilated will not last 50 hours if the ventilation is insufficient. This is because overheating of the glass sets free water vapor within the lamp which attacks the filament and rapidly spreads a dense black deposit over the bulb. Therefore if the lamps within it are to have a reasonably long life, the housing must be designed with a knowledge of the lamp requirements and its temperature limitations.

It is often asked what effect the half-watt mazda will have on arc lamps. In all probability its effect will be to make better arc lamps. The high efficiency, brilliancy, steadiness, relatively white light, and low cost of maintenance, will make the new lamp a dangerous competitor of the arc lamps; but the case of the arc lamp is far from hopeless. Half a watt per candle is a higher specific consumption than that of the most efficient arc lamps today, and in the race for still better efficiencies the arc lamp has the great advantage that, whereas at about 0.2 watt per candle a tungsten filament reaches its melting point, there is no such fixed limitation on the efficiency of the arc. In brilliancy the arc has a slight, but very little advantage. The slight relative unsteadiness of the arc is not a disadvantage in the eyes of some, who see in it a snap and vivacity which is lacking in the steady though brilliant incandescent lamp. The half-watt mazda, while much more nearly white than the one-watt per candle mazda, is not so white as the luminous arc or the white flame carbon arc. Further increase in arc lamp efficiencies will lower the cost of maintenance per candlepower, and, especially where the cost of power is high, will give the arc lamp a decided advantage.

Thus it is altogether probable that the net result of the advent of the new lamp in the arc lamp field will be that better incandescents and better arcs will co-operate in furnishing better street lighting systems for all conditions. In some cases those conditions will best be met by the mazda, and in others by the arc.

Another field in which the arc lamp must expect competition from the half-watt mazda is in projector, stereopticon, headlight, and searchlight work. The intrinsic brilliancy and high degree of concentration of filament which can be employed in the new lamp adapt it peculiarly for such applications, and should enable it to share this field with the arc.

In so far as the foregoing comments are in the nature of prophesy, they are properly subject to distrust. Prophesy was never more dangerous than in the art of electric lighting today, in which developments are following each other with unprecedented celerity. Other gases than nitrogen are giving excellent test results and may soon be in production. Other developments in arcs or incandescents may at any time disturb the balance of power and bring predictions to naught. One thing alone is certain: The art of electric lighting is advancing more rapidly than ever before, and in its progress will surely bring more and better light to everyone and ultimate benefit to all who are interested in the generation and use of electric energy.

# THE QUARTZ MERCURY ARC LAMP

By Dr. E. Weintraub

Director of the Research Laboratory, Lynn General Electric Company

A description is first given of the quartz mercury arc lamp as developed by the German firm of Heraeus. The principal characteristics of this lamp are discussed, such as the limitation of the current value imposed by the size of the mercury reservoirs, or heat radiating surfaces, and the initial instability of the arc when put in operation. The author then proceeds with a description of the quartz mercury arc lamp as made by the General Electric Company, and relates in detail some of the most interesting features connected with its development, such as the production of a satisfactory glass seal and of a suitable material for a solid anode. The article is concluded by a discussion of the efficiency of the quartz lamp as an illuminant.—Editor.

Dr. E. Weintraub

The quartz mercury arc lamp is distinguished from its predecessor, the glass mercury arc lamp, by the fact that a considerably larger amount of energy is concentrated in a given space, and by the concomitant features of a higher potential drop per unit length, a higher mercury vapor pressure, and a higher temperature. The greater concentration of energy leads to a greater efficiency of light production. This greater concentration of energy is made possible by the use of quartz as an envelope, a material which has a considerably higher melting-point than even the most refractory glass at present at our disposal.

The pioneer commercial work on the quartz mercury arc lamp is due to the Heraeus firm in Germany. It is therefore proper to begin this article by a description of the lamp they have developed and put upon a commercial basis.

### Heraeus 220 Volt Lamp

Fig. 1 represents the 220-volt d-c. 3.5 ampere type of lamp, which has had so far the widest application. The lamp consists of a tube connected at the ends to two mercury-filled reservoirs. One of these mercury reservoirs serves as an anode, the other as a cathode. It will be noticed that the arc tube is shaped differently near the reservoirs: toward the anode reservoir, the arc tube is shaped in the form of a sloping roof; near the cathode reservoir, the tube takes the form of a narrow thick-walled contraction. To the reservoirs are attached small, thick-walled quartz tubes which carry metallic conductors for the introduction of the current. The tube is exhausted to a fair vacuum.

Externally the lamp differs from the familiar glass lamp by the shortness of the light-giving tube, and the absence of a "condensing chamber." In this 220-volt type, the light-giving tube is only about 5 in. long.

The "ground joints" are attached to the reservoirs. It is not possible to seal metallic conductors into quartz in a manner similar to that common in exhausted glass vessels. A metallic conductor with a coefficient of expansion near that of quartz is found in a certain alloy of nickel and steel, but as the melting-point of this alloy is too low, and sealing it into quartz is impossible, recourse is taken here to a ground joint between a conical nickel steel plug and quartz. As one ground joint is not perfectly vacuum tight, two such ground joints in series are used and a seal of liquid mercury is placed on the top of the upper ground joint. On the whole, these ground joints if properly made are satisfactory so long as they are not exposed to any considerable temperature rise. This limitation has the disadvantage of reducing the number of possible designs of the lamp.

The mercury reservoirs are of a very large size as compared to the arc tube. The necessity of these large size reservoirs is best explained by referring to the volt-ampere curves of the quartz mercury arc lamp given in Fig. 2. It will be seen from these curves that when a certain current is reached, the voltage rises very steeply. The quartz lamps for reasons of light efficiency operate on that part of the volt-ampere curve which is practically parallel to the axis of the ordinates. In other words, the *quartz lamp under its operating conditions is a constant current device*, and no matter what the impressed voltage or the resistance in series, a current above a certain maximum value cannot be forced through the arc.

*This constant current value depends mainly on the size of the mercury reservoirs*, or, perhaps, more exactly on the rate at which heat can be dissipated from their surfaces. The three curves in Fig. 2 are obtained by varying the size of these reservoirs. In order to force even a current of 3.5 amperes, the size of the reservoirs has to be very large, in fact, much larger even than that actually used. Such large reservoirs are bulky and expensive, and in order to obtain a sufficient rate of heat dissipation, it was found preferable to attach metallic wings to the reservoirs; the heat dissipation is then regulated by the size of these wings, by their distance apart, and, of course, also by the size of the reservoirs to which they are attached.

The heat generated at the anode is greater than that at the cathode, and if no precautions were taken the anode mercury would distill over into the cathode. One way of preventing this would be to increase the heat dissipation at the anode over that at the cathode by increasing the surface. However, a complete balance could not be obtained by this rough means, and in the commercial type this is accomplished in an automatic way by the different shaping of the tube near the electrodes. The cathode reservoir is connected to the light-giving tube by a contracted part, in such a way that, during the operation of the arc, the mercury stands in this contracted space. The narrow column of mercury thus introduced between the arc and the reservoir conducts the heat away with difficulty, and this tends to increase the rate of vaporization of mercury as compared to that at the anode, where the mercury surface exposed is large and the heat generated at the anode spot is conducted away freely by the large mass of mercury. Should at any time the amount of mercury vaporized at the anode be larger than that at the cathode, more mercury will accumulate in the narrow cathode tube; the heat conductivity from the cathode spot will thereby be reduced and the amount of vapor generated at the cathode automatically increased. By these means, continuous operation is made possible.

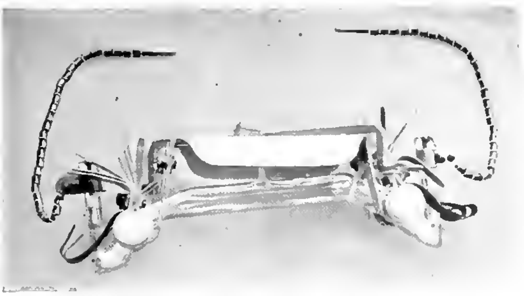

Fig. 1. 220 Volt, 35 Ampere D-C. Quartz Mercury Lamp, made by Heraeus, Germany

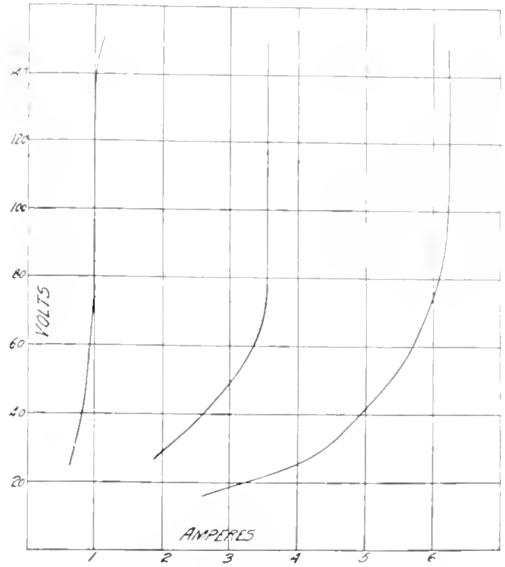

Fig. 2. Volt-Ampere Curves of Quartz Mercury Arc Lamp of Fig. 1

### Operation Characteristics of the Lamp

When conditions of equilibrium are reached, this particular type of lamp runs at 3.5 amperes and about 170 volts on a 220 volt circuit. The current is determined by the construction, especially the size of reservoirs, as pointed out above. The voltage is determined by the series resistance and can be varied at will. This voltage is, of course, equal to the impressed voltage minus the IR drop in the resistance—in this case, about 14 ohms.

Referring to the volt-ampere curve, Fig. 2, it will be seen that the volts across the arc rise rapidly with the current and it would seem as if a steadying series resistance were unnecessary. That such a resistance is indispensable is due to the fact that the instantaneous variation of voltage with current change is in the opposite sense from the permanent one. A decrease of current causes an instantaneous increase of arc voltage, which changes into a decrease only after some time. In other words, the instantaneous characteristics of the quartz mercury arc are the same as those of an ordinary arc.

The current and voltage values given above correspond to the final equilibrium reached by the lamp only some time after starting, when the mercury reservoirs are warm and the dissipation of heat is equal to the input. Immediately after starting, the resistance of the arc is low and the voltage drop is only about 30 volts. With a resistance of 14 ohms in series, this means that an initial current of about 15 amperes is flowing, a current more than four times the final equilibrium value.

*The high value of the initial current is characteristic of the quartz mercury arc lamp.* As the tube and its electrodes warm up, the current diminishes and the voltage rises. The time taken by the tube to get into equilibrium is about 15 minutes.

During this interval of time, the appearance of the arc also changes in a characteristic manner. At first the arc fills the whole cross section of the tube uniformly, but as the temperature and the pressure rise the luminous arc detaches itself from the walls of the tube and finally occupies only a small central portion.

### Other Types of the Heraeus Lamp

Besides this 220-volt, 3.5 ampere, d-c. lamp, the Heraeus firm has developed a 110-volt, 4-ampere type and a 220-volt, 1.5 ampere lamp. The first differs from the 220-volt type only in that the light-giving portion of the tube is much shorter, or about 1½ in. in length. The arc consumes about 75-80 volts. The smaller current type has smaller mercury reservoirs.

The Heraeus firm have also developed an alternating current lamp, but have not yet introduced it into commercial use to any extent.

As is probably familiar to the reader, the mercury arc is essentially uni-polar, and is not directly suitable for use on alternating current circuits of moderate voltage. By arranging connections similar to those of the mercury arc rectifier, it is, however, possible to have a mercury arc run on alternating current. The Heraeus a-c. lamp has two mercury anodes and one mercury cathode, and compensator connections with a neutral connected to the cathode.

It is to be expected that difficulties would be caused by arcing between the anodes, which takes place very readily when the anodes are made of mercury.

It will be observed that all the Heraeus lamps are multiple lamps. This is because the quartz mercury arc lamp is not suitable for series or constant current circuits without special arrangements. The cause of this is again the peculiar volt-ampere characteristic. The rapid rise of the voltage curve for even very small changes of current means that even small fluctuations either in the circuit or in the outside temperature (the latter changing the conditions of heat dissipation), would mean large changes of energy input into the tube, which in turn would mean rapid increase of temperature with further rise in voltage, etc., until destruction of the tube took place.

### General Electric Quartz Mercury Arc Lamp

The development of this lamp is the result of work carried out in the Lynn research laboratory of the General Electric Company.

The first problem attacked and solved was that of introducing current into exhausted quartz vessels, not by means of ground joints but by means of metallic wires sealed in in a vacuum tight manner.

In principle, the method used is that of interposing between the quartz and a suitable metallic wire different glasses of variable coefficients of expansion. The coefficient of expansion of quartz is in the neighborhood of $0.5 \times 10^{-6}$; the coefficient of expansion of platinum, which is the metal used in glass seals, is in the neighborhood of $9.0 \times 10^{-6}$. The glass with the lowest coefficient of expansion on the market has an expansion of about $3.5 \times 10^{-6}$.

To make possible the connection of this low expansion glass with lead glass, six intermediate glasses were necessary, these glasses being obtained from the glass factories.

To connect quartz to the low expansion glass, glasses were needed with intermediate coefficients of expansion. After considerable work, glasses filling the requirements were prepared, and it was found that four such "intermediates" were necessary to produce a reliable joint. In all, ten different glasses were therefore necessary to enable one to seal in platinum wire. This large number of intermediates made the method expensive, and it was also found that the reliability of the joints between the low expansion glass and lead glass was not sufficient for shop use.

Fortunately, we soon made the other and equally important discovery that tungsten wire could be sealed into the low expansion glass in a vacuum tight manner. The number of intermediate glasses was, therefore, reduced to only four, and tests on a large number of these seals have shown them to be reliable. They stand higher temperatures than any other vacuum seal, and, due to the higher electrical conductivity of tungsten, can carry more current for a given cross section. The tungsten leading-in wire, in combination with low expansion or heat-resisting glass, is also being used in a new type of rectifier and bids fair to become of importance in the field of gas-filled mazda lamps. These "graded" seals are not only cheaper than the ground joints, but they permit certain designs of tube that would be impossible with the ground joints.

The use of these graded seals, capable of withstanding relatively high temperatures, suggested at once the replacement of the mercury anode used in the Heraeus quartz lamp by a solid anode.

The solid material to be used as an anode in the quartz mercury arc lamp must have a very high melting point and a very low vapor tension. It must have a high melting point in order to withstand not only the normal temperature developed at the anode by the lamp current, but also the much higher temperature produced by the initial current, which is many times larger than the equilibrium current. The material must have a low vapor tension, because it would otherwise slowly volatilize and blacken the tube, especially in the neighborhood of the anode, a blackening which is the more serious as the light-giving section of the tube is short. Materials fulfilling these requirements were not known until recently, and among those available now, tungsten and tantalum are the best.

Fig. 3. Graded Glass Seals with Tungsten Leading-in Wire

The use of a solid anode has numerous advantages. Mercury vapor is now evolved only at one electrode, i.e., the cathode, so that the vapor pressure for the same current and the same size mercury reservoir is greatly reduced. Of course, balancing of the vaporization of mercury at the two electrodes is no more needed since no mercury is evolved at the anode; therefore the peculiar narrow space near the cathode can be dispensed with, thereby still further reducing the vapor pressure. This means that for the same current a much smaller mercury reservoir can be used and no wings are necessary.

Fig. 4. Anode formed of Tungsten Wire Wound into Flat Spiral

The elimination of the mercury anode reservoir, the reduction in size of the mercury cathode reservoir, and the elimination of the heavy quartz tubes used in the ground joints has reduced the amount of quartz and the amount of labor necessary to shape the tube to from one-third to one-half that of the corresponding device of the Heraeus type.

The peculiar difficulty of forcing large currents through the quartz mercury arc lamps was referred to above. This difficulty is greatly reduced in the case of the General Electric type of lamp. The volt-ampere curve has still the same characteristic in that the volts rise very rapidly when a certain current is reached, but, with a reasonably sized mercury cathode reservoir, currents as high as 6 or 7 amperes can be easily forced into the arc as against the 3.5 or 4 amperes of the Heraeus type. Still larger currents can be obtained if wings or a small condensing chamber are provided.

The General Electric type of lamp shares with the Heraeus type of lamp the slight disadvantage of large initial current; but, due to the smallness of the mercury reservoir, the time necessary to reach equilibrium is reduced.

Fig. 3 shows the graded seal with the tungsten leading-in wire. Fig. 4 shows the tungsten anode usually made from wire wound into a flat spiral. Fig. 5 shows the 110-volt, 4-ampere, horizontal type and Fig. 6 shows the 220-volt, 3.5 ampere, horizontal type, which were developed first to correspond to the units of the Heraeus lamp.

The cathode mercury reservoir is either horizontal or vertical. The graded seal with the tungsten leading-in wire is in the form of a drop seal on the cathode. The tungsten leading-in wire and the tungsten anode used are formed of one piece. The arc tube is shaped in the form of a sloping roof near the cathode, mainly for the purpose of steadying the arc.

Fig. 5. 110 Volt, 4 Amp., Horizontal Quartz Mercury Arc Lamp

Fig. 6. 220 Volt, 3.5 Amp., Horizontal Quartz Mercury Arc Lamp

Fig. 8. Alternating Current Quartz Mercury Arc Lamp. This lamp differs from the d-c. lamp in having two tungsten anodes instead of only one

Two types of mechanism have been developed for starting the arc. One consists of a shunt coil which starts the arc by tilting the tube; as soon as the arc is started, the circuit of the shunt coil is interrupted automatically. For the other type of mechanism, the tube is slightly modified in such a way that the mercury makes contact with the anode before the arc is started. A series coil is used which by tilting the tube starts the arc.

The design of the General Electric type of lamp lends itself readily to the construction of a vertical type which is more suitable for street and park illumination on account of its better light distribution. Such a type is shown in Fig. 7, together with the mechanism used, which is placed underneath the lamp so as to produce a unit suitable for ornamental lighting. In the Heraeus type of lamp, the construction of a vertical lamp is connected with such difficulties that it has never been attempted.

A very considerable advance was also made possible in the construction of an alternating current lamp. We saw that the Heraeus alternating current lamp was costly and

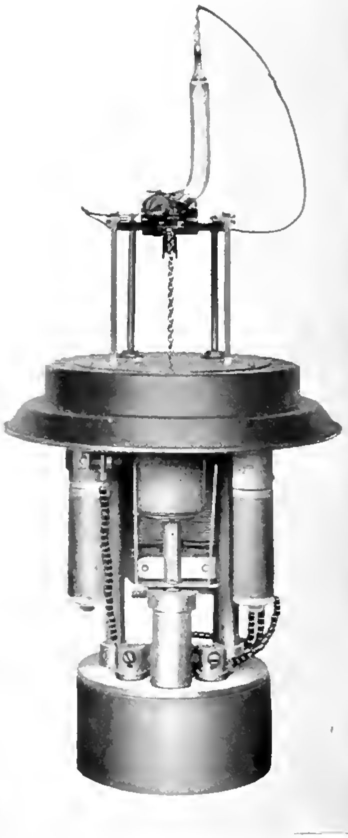

Fig. 7. Vertical Type Quartz Mercury Arc Lamp

offered difficulties in operation. The elimination of the mercury anodes has reduced the tendency to arcing to such an extent and has made the construction of the tube so simple that the General Electric alternating current quartz lamp is just as practical and satisfactory in operation as the direct current lamp. The construction will be seen in Fig. 8; it differs from the d-c. lamp only by the use of two tungsten anodes instead of one.

### Efficiency of the Quartz Lamp as an Illuminant

The horizontal type of quartz lamp has to be provided with a reflector above it and both the horizontal and vertical lamps have to be surrounded by a globe in order to cut out the harmful rays that penetrate through the quartz. In this respect, the quartz mercury arc lamp is in no way different from any other arc lamp. See Fig. 1 for reflector, and Fig. 9 for the general appearance of the General Electric horizontal lamp.

The use of the reflector and the globe causes a certain loss of the light flux and there is a certain amount of energy dissipated in the resistance in series with the arc. Taking all these losses of flux and energy into consideration, the General Electric 220-volt lamp, 3.5 ampere type, has a mean spherical specific consumption of 0.6 watt per candle, while the 110-volt, 4-ampere, type has a specific consumption of 0.75 watt per candle.

The life of the tubes is long. One thousand to ten thousand hours are the extreme limits, with an average of about three thousand.

Recent work done in the Lynn Laboratory and which can be only referred to here has led to a considerable increase in these efficiency figures. The 110-volt lamp has by this means given a consumption of 0.5 watt per mean spherical candle, and in the 220-volt type a corresponding improvement has been obtained. Lamps now on life test show that the life of these "high efficiency" lamps will not be materially less than that of the older type.

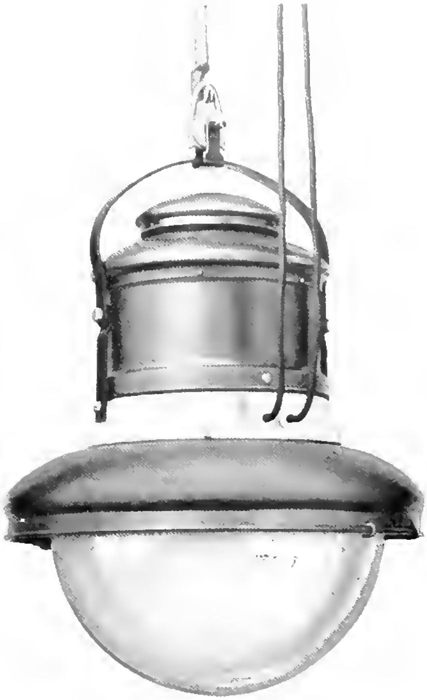

Fig. 9. General Appearance of General Electric Quartz Mercury Arc Lamp

# THE MANUFACTURE OF DRAWN WIRE TUNGSTEN LAMPS

By J. W. Howell

Edison Lamp Works, Harrison, N. J.

The incandescent electric lamp is the most widely used of all electrical devices, and although requiring the most exacting methods in its manufacture, is one of the simplest in its elements; yet it is surprising to find how little of an authentic nature has been written on the manufacture of incandescent lamps—possibly the most fascinating branch of the electrical industry. This article should therefore prove of much general interest; for the author has clearly outlined, with the assistance of some excellent photographs, each step in the manufacture of the mazda lamp, from the reduction of the tungsten ore and blowing of the bulbs to the final operation of "sealing-off" and testing.—Editor.

J. W. Howell

There are few persons, other than those directly associated with the production of incandescent electric lamps, who realize to what immense proportions this branch of the industry has developed, or who have a well-formed conception of the operations and difficulties involved in lamp manufacture, or of the methods that have been inaugurated for dealing with them. The purpose of this article is to present a short description of each of the principal steps in the manufacture of the high efficiency drawn wire mazda lamps that have now been on the market for some time.

Some idea of the magnitude of the business is conveyed by the fact that 120,000,000 incandescent lamps were made and sold in the United States in 1913.

Four factories contribute to the manufacture of incandescent lamps; namely, the glass works, in which the bulb and other glass parts are made; the filament factory; the base factory; and the lamp factory, in which the parts are assembled and the lamps made.

The glassware, consisting of the bulbs and tubes, is made by several manufacturers. The bulbs are blown in moulds by manual labor, requiring a high degree of skill, and their manufacture alone is a large industry. The glass employed for these parts must be of fine and constant quality and made to the same formula; for tubing from one factory must often be used with bulbs from another, and unless all factories use the same formula and maintain the same quality, this could not be successfully done. The glass is the same as that used for the finest cut glass; in fact, one factory which makes large numbers of lamp bulbs also makes cut glass articles of the highest quality—and American cut glass is the finest made.

The heart of the lamp is the filament. The filament gives the light, and light-giving is the whole function of the lamp. The other parts of the lamp perform necessary but subordinate functions; they support the filament, enclose it, protect it and lead electricity to it. The failure of any one of these other parts to perform its function will destroy the usefulness of the lamp, but only the filament is manifest in the operation of the lamp. Most of the great improvements in the energy consumption of the lamp have been brought about by filament improvements.

Edison's first commercial lamps (sixteen candle-power) were known as "8 to the horse power." Now, the mazda sixteen candle lamp would be 38 to the horse power, and would have a longer useful life than Edison's "8 to the horse power" lamp. With the same life it would operate with one-fifth the energy needed by Edison's first lamp, or with the same energy per candle it would last 50,000 times as long; so the lamp today may be said to be 50,000 times as good as Edison's first commercial lamp.

The mazda lamp with its filament of drawn tungsten wire is now superseding all other lamps. The production of this filament is due to the persistence of Dr. W. D. Coolidge in sticking to a problem which was generally considered impossible of solution. In the early stages of the development of the drawn tungsten wire, its production was attended with the greatest difficulty. At first a piece of a few feet long was a wonder, but now a piece a mile long and of absolutely uniform diameter is commonplace. It can be made far more accurately and of more uniform quality than the old carbon filament. The raw material used in the filament factory is a concentrated ore of tungsten, from which

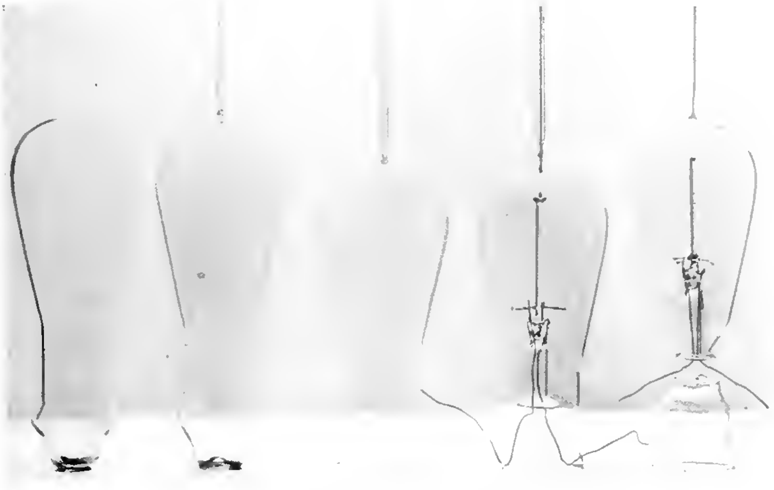

Fig. 2. Illustrating Different Steps in the Manufacture of Drawn Wire Mazda Lamps

pure tungstic oxide, a fine grained yellow powder, is obtained. This is "doped" and reduced to tungsten metal by hydrogen in an electric furnace; the metal produced being in powder form, rather coarse grained, gray in color, and very heavy. This tungsten powder is formed into ingots about ¼ in. square and 6 in. long by pressure alone, no binder being used. The pressure, which is very great, is applied transversely and compacts the tungsten so that the ingot can be handled. It is then placed in an electric furnace in an atmosphere of hydrogen and heated to a white heat, the effect of this heat being to compact and strengthen the ingot and make it a good conductor of electricity. The ingot is then placed in an atmosphere of hydrogen and heated to near the melting point, long enough to thoroughly sinter the ingot. The ingot now has a high luster, and the powder particles of which it is composed are welded together quite firmly. The square ingot now goes to a swaging machine. It is heated to white heat, taken out into the open air and swaged. During this operation a cloud of tungstic oxide rises from the ingot. The ingot is re-heated and swaged several times before the square ingot becomes round. The heating and swaging are continued until the ingot is changed to a rod, three one-hundredths of an inch in diameter and thirty feet long. Before this, when the rod is about six one-hundredths of an inch in diameter, it begins to have a fibrous structure. At three one-hundredths it has a well developed fibrous structure, but can easily be broken by bending back and forth once or twice.

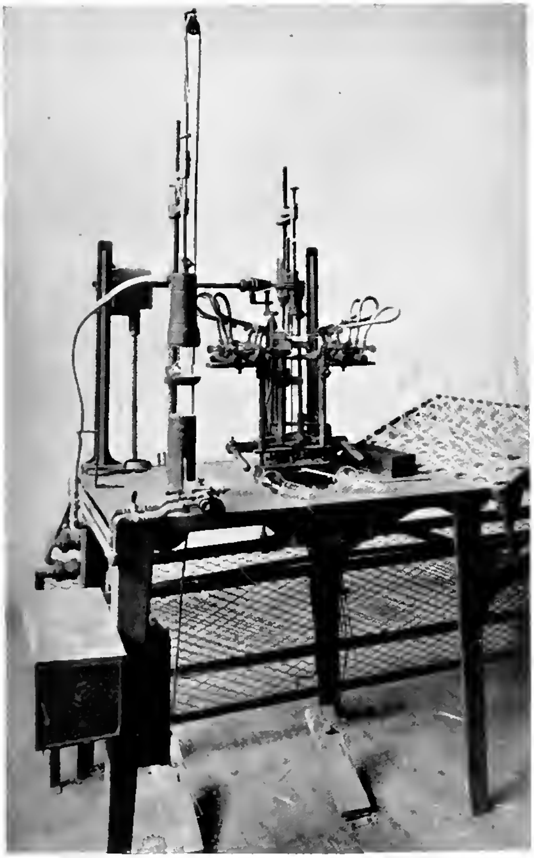

Fig. 1. Tubulating Machine

From thirty mils the rod or wire is reduced in size by hot drawing through diamond dies. The wire is heated to a bright red heat and is still red hot after passing through the die. This degree of heating is continued until the wire is only three mils in diameter, which is about the size of the filament in a 100 volt, 100 watt lamp. Below this, the temperature of drawing is reduced and the last drafts of any wire are made below red heat. The wire is now quite ductile and the last drafts may be made cold if desired. During this drawing the wire is lubricated with graphite, which forms a coating and prevents oxidation of the wire. It also lubricates the wire when it passes through the die. The last draft is made through a very perfect die which reduces the diameter of the wire very slightly, and in this way very long pieces are made which are the same size throughout.

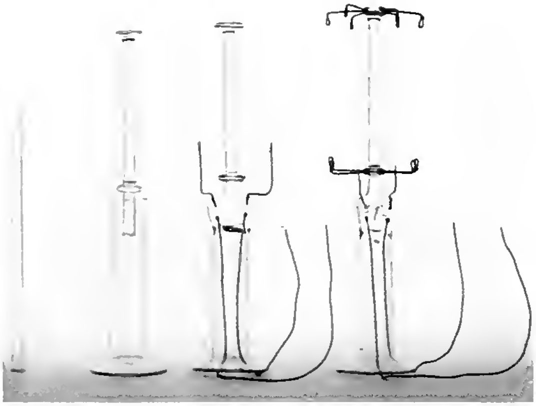

Fig. 3. Illustrating the Several Steps in the Construction of the Filament-Supporting Stem

The size of the wire down to three mils is determined by micrometer, but below this it is determined by weighing a standard length of wire; and the size is not expressed in mils but in normal amperes, which is the amperes required by the wire in a vacuum at a certain watts per candle. The filament in a regular ten watt lamp is about three-quarters of a mil in diameter, which is probably the finest wire ever produced by straight drawing. At a recent industrial exposition, a wire manufacturer exhibited some wire one and a half mils in diameter as a marvel of wire drawing.

Bulbs, tubing, filaments and bases are the raw materials used in the lamp factory. Bulbs as received are shown in Fig. 2. The round end of the bulb is smooth, the neck being long and its end ragged. The first operation on the bulb is "tubulating," by which the small tube is attached to the center of the round end of the bulb.

Fig. 1 shows a tubulating machine. The bulb is first placed in the holder on the left, where a fine jet of gas strikes the center of the round end and heats it red hot in a spot. Air pressure admitted inside the bulb blows out the hot glass at this spot and makes a small round hole, the size of this hole being regulated by the air pressure; the higher this pressure, the smaller the hole.

The bulb is then transferred to the tubulating machine proper, which holds the tube so that its end registers with the hole in the bulb. Gas fires heat the parts to the fusion point and they are melted together in such a way that the tube and hole are left open.

Fig. 2 shows a tubulated bulb. The structure which supports the filament is called a stem, and when the filament is on the stem, the whole is called a mount. Fig. 3 shows the stem construction and Fig. 4 a stem-making machine. The stem-making machine is fed with a short piece of glass tube, two leading-in wires, and a glass cane or hub.

The head of this machine rotates. In the second position the tube has a flare made on its upper end; in the next position a second operator puts the lead-in wires and hub in position; then the lower end of the glass tube is melted down upon the lead-in wires and hub, and when so melted the parts are

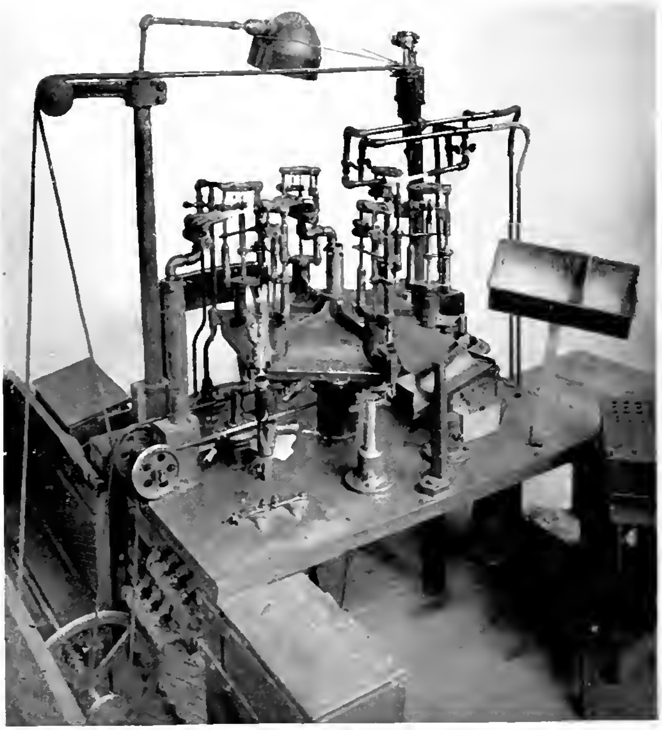

Fig. 4. Stem Making Machine

squeezed together, making a seal about the wires which is air tight.

The wire hooks, which support the filament, are then stuck in the glass hubs. Copper wires have been used for hooks in the smaller sizes of lamps and tungsten wires in the larger sizes, but tungsten wires are now supplanting the copper wires in all sizes. The stem is now ready to receive the filament.

In order to make a lamp of the desired voltage, candle-power and efficiency, the filament must be of exactly the right diameter, and must be cut exactly the right length. Sizes suitable for all standard types of lamps are carried in stock, all very carefully measured and labeled. To get the right length for the desired voltage, the wire is wound on an adjustable form which determines the length of each piece very accurately. The winding of the filament on the supports is done by hand. The operator draws a filament, already cut to length, from the form, attaches one end to a lead-in wire, winds the filament on the supports and attaches the other end to the other lead-in wire. The supports are then bent to space them properly and to put the right tension on the filament. The completed mount is shown in Fig. 3.

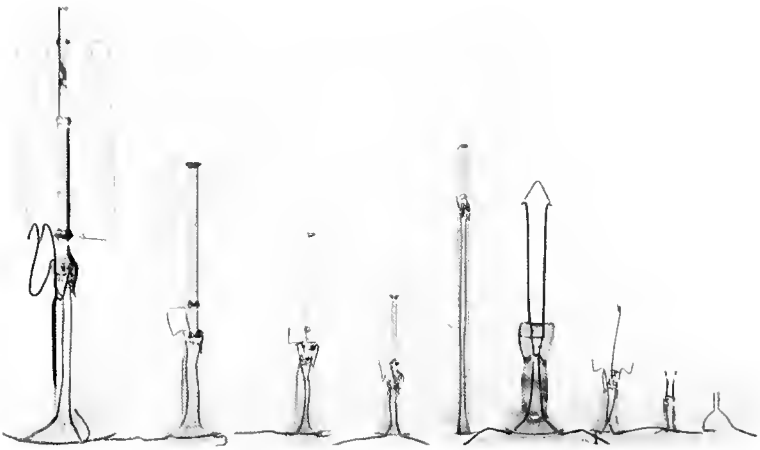

Fig. 6. Mounts and Filament Shapes

Where concentration of the light is desired, or where it is desired to put a long filament in a small bulb, the filament is wound on a mandrel to form a helix, with the coils slightly separated, as shown in Fig. 6.

The attaching of the filament to the lead-in wires is an important operation. Thin filaments are inserted in tubes formed in the end of the lead-in wires and the parts squeezed together. Large filaments are fused to the lead-in wires, and in both cases the material of the lead-in wires is a matter of great importance.

When the mounts are ready they are assembled with the bulbs already prepared. This assembly is done in the sealing-in operation, which is performed on the sealing-in machine shown in Fig. 5. This machine supports the bulb in a rotary holder, and supports the mount inside of the bulb in its proper position. The assembled

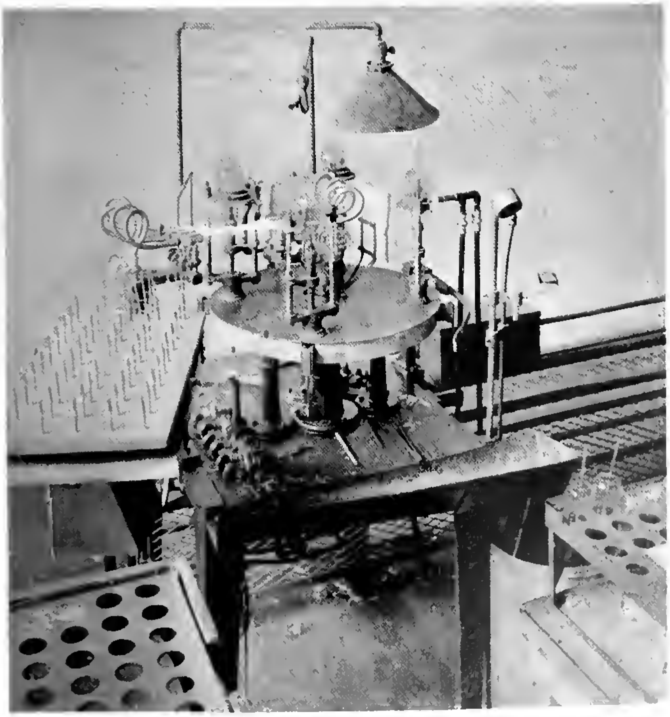

Fig. 5. Sealing-in Machine

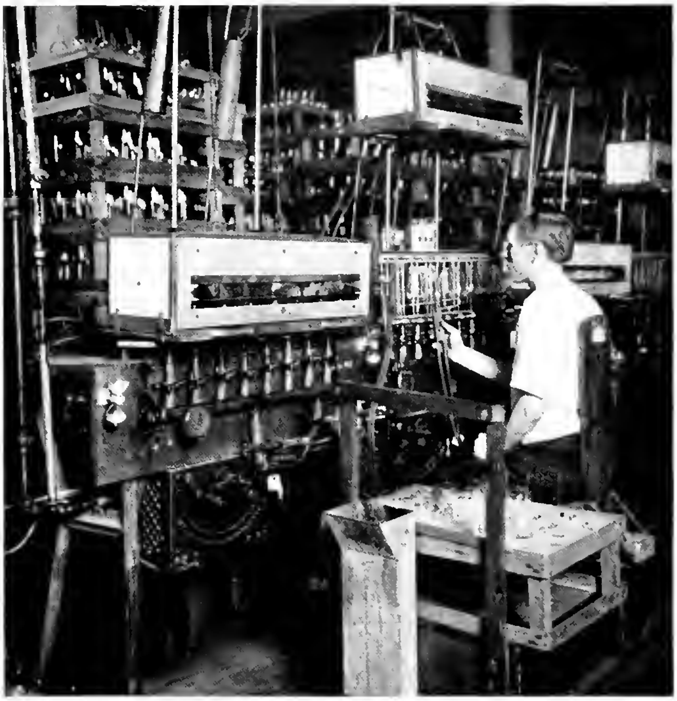

Fig. 7. Exhaust Table

parts are acted upon by three sets of gas fires; the first gently heating the neck of the bulb and the flare at bottom of mount; the second heating these parts until the neck of the bulb softens, and the glass sinks downward and inward until the neck of the bulb touches the flare and the two are sealed together. The third set, which are thin sharp fires, melts the neck of the bulb below the seal, thus cutting off the surplus glass. While the glass is still soft, the operator centers the mount in the bulb, and the assembling is complete. Fig. 2 shows the stages of the work in this operation.

The lamp is now ready for exhaustion. Fig. 7 shows an exhaust table. Its essential elements are a preliminary vacuum pump, a final vacuum pump, a manifold containing a chemical dryer with connections for pumps and lamps, a heater for heating the lamps, and electric connections by which the lamp may be lighted up or tested by induction coil for vacuum. The lamp is connected to the pump by slipping the tube which has been attached to the round end of the bulb into a rubber connection on the manifold. Where this tube is attached to the bulb, it is reduced in diameter, or contracted. This contraction limits the passage of the air, gases and vapors from the lamp, and is an important factor in the time needed to exhaust a lamp; but it aids the sealing off of the lamp and the appearance of the tip left on the bulb.

During exhaustion the lamps are heated. This heat frees the glass of absorbed gases and vapors so that the pumps and chemical dryer can remove them from the lamp. The exhaustion is continued for a certain time, which has been determined by experience, or until the induction coil test shows the vacuum to be good. This time is much longer for large lamps than for small ones.

The lamp is sealed off by melting the glass tube at its contraction close to the bulb; this melting closing the tube completely and sealing up the tip left

Fig. 8. Basing Machine

on the lamp so that it is perfectly air tight. The lamp is now ready for basing, sorting, cleaning, packing and shipping.

Inspections are very important in the lamp factory; imperfections or defects must be discovered as soon as they appear and before other work is done on the lamp, which would increase its value and consequently the loss if the defect is serious. A defective stem, if discovered right after the stem is made, causes at most the loss of the stem; but if not discovered until the stem is sealed in a lamp, may cause the loss of the lamp. So the work is carefully inspected after each operation by skilled inspectors, and all defective parts are rejected.

### Breakage

The lamp parts are fragile and many pieces are broken in the various stages of manufacture. The handling of these broken parts, and parts rejected by inspectors, so as to salvage as much as possible, is an important part of a factory superintendent's duty; in fact, a good idea of the competence of a factory superintendent may be obtained by inspecting his breakage department and his breakage cost item. All broken and rejected parts are taken to a breakage department, where competent operators salvage as much as possible, and return the repaired and saved parts to the factory departments.

Breakage is an expense which benefits nobody; it is made the subject of special work and reports, and each factory superintendent knows that his record depends on his success in keeping this expense within the proper limits.

Every successful lamp factory must maintain a life test department, for the quality of lamps can be learned only by a life test. These tests must be made at a known efficiency, and must be carried on long enough to determine the full value of the lamp. This means continuing a test until the lamp has failed, or deteriorated to a degree which tells the whole value of the lamp. Lamps should be life tested at their normal voltage, or a voltage so little in excess of that voltage that no very abnormal conditions are created. This voltage during the test must be held as constant as possible, and automatic voltage regulation of the utmost refinement is used for this purpose. Also, as lamps of many different voltages must be tested, suitable lines must be provided. These lines differ in voltage by only one volt, and to maintain all these lines constant, necessitates the use of transformers and compensators of the most careful design and construction, and conductors of large size.

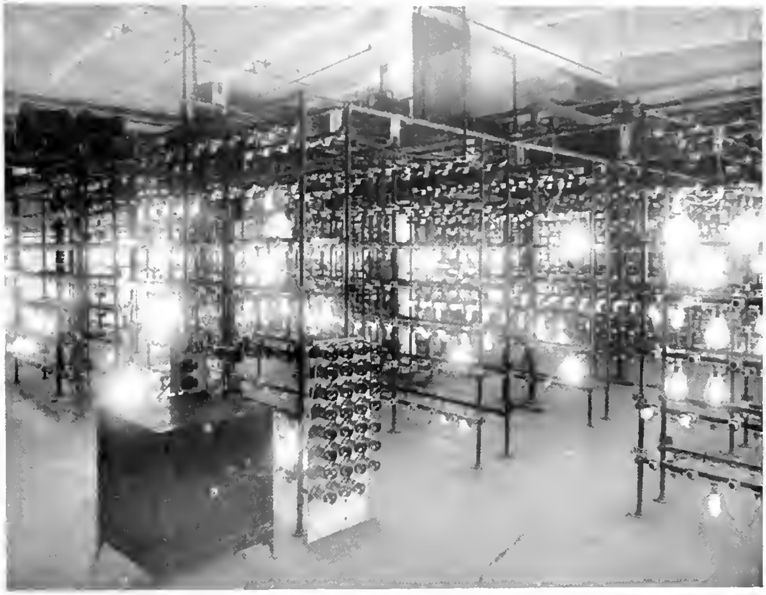

Fig. 9. Life Test

Before putting a lamp on test, it is carefully photometered and measured at exactly the voltage of the line on which it is to be tested, and subsequent measurements of candle-power and efficiency are all made at this same voltage. Satisfactory life tests require at least four hundred hours if the lamps are good. Burning lamps at higher voltages to get quicker results has been found unsatisfactory. Life tests are made frequently and at regular intervals on the regular product of each factory, in order to know the quality of the work done in each, and also in order to detect and correct any error which may be made in the factory. Life tests are also made on experimental lamps, and no change in method of manufacture can be made until repeated tests have demonstrated its value.

# CHARACTERISTICS OF MAZDA LAMPS

By Evan J. Edwards

National Lamp Works, General Electric Company

Mr. Edwards notes in the early part of his article that the term characteristics, as applied to incandescent lamps, refers to the relation existing between voltage, current, and candle-power and all dependent relations, while the relations which involve time, such as candle-power life curves, are termed performance. The characteristics as generally used by the illuminating engineer are usually only considered in an approximate manner, but the scientist and lamp manufacturer need more accurate data than can be obtained by approximate calculations. The author has given formulæ, curves and tables worked out to a great degree of accuracy, which should be of much value to the specialist interested in this work. The author wishes to acknowledge the valuable assistance rendered him in the preparation of this article, and in the experimental work involved, by Mr. C. L. Dows, his assistant.—Editor.

Evan J. Edwards

IT IS well known that several variations result from changing the voltage applied to incandescent lamps and that for a given filament material all the relations are fairly definite, and expressible with fair accuracy by simple exponential equations. These equations are extensively used by illuminating engineers and approximate values for the exponents have become a matter of almost common knowledge among them. Many data have been published * and nearly all the recent figures given agree within an accuracy sufficient for the purposes of illumination calculations, where, as a rule, transpositions are made over only short ranges of voltage and are needed only to a relatively low precision.

The particular type of construction used in the lamp and the normal efficiency taken as a basis affect the values of the exponents as ordinarily defined, but usually not to a sufficient degree to make it necessary for the illuminating engineer to revise his data every time slight changes are made in the manufacture of a lamp or the efficiency at labeled voltages.

There is, however, a need for data of the highest precision, notably in the case of the lamp designer who must make a table of manufacturing data which does not include any avoidable directional errors. Exact methods are also necessary in many special cases where computations are applied over wide ranges of voltage, such as for quick force testing of lamps, or the applications of considerable over-voltage for photographic work. The lamp manufacturer must obtain these relations to the highest possible degree of precision always for his latest product, and there can be little doubt but that these data will find a wider field of application.

The name "characteristic" has come to be applied to the relations existing between voltage, current and candle-power and all dependent relations, leaving the term "performance" to cover the relations which involve time, such as candle-power life curves. The former relations only will be considered in this article and, since they are all similar in that they can be approximately expressed as simple exponential equations, only one will be considered in the general discussion.

If the intensity values are obtained through a range of voltage, that is, considering that voltage is the independent variable and candle-power the dependent variable, the result may be expressed approximately by the equation

$$c\text{-}p. = Ce^k$$

where $C$ would be a constant depending on the size of the lamp and $k$ a constant depending on the filament material. It is seen that, if the candle-power and voltage values are expressed in terms of their ratio to normal, the constant drops out and the equation becomes

$$c\text{-}p. = e^k.$$

The exact relation, however, cannot be expressed by this simple equation where $k$ is taken as a constant for all ranges, and therefore, for accurate work, it is necessary to use a graph or to obtain an equation which more nearly coincides with the experi-

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*Cady:—Electrical Review and Western Electrician, November 25th, 1911.

Edwards:—Journal of the Association of Engineering Societies—Volume XLVIII., No. 4.

Note:—For other sources note references under above article by Mr. Cady.

mental values. There are many ways in which this can be done, but for the lamp man and illuminating engineer, it seems most convenient to retain the above simple form of equation, and to consider $k$ as a variable and a function of the voltage. The chief reason for adopting a variable-exponent form of equation is that it makes all computations very easy, using the log-log slide rule with which the raising to powers and extracting of roots is similar to the ordinary slide rule processes of multiplying and dividing. The part of the equation designated as $k$, then, is different for different percentages of normal voltages to which the reductions are made, and may be said to be defined always as the ratio of the logarithms to normal, that is, $k$ at any per cent volts is equal to the ratio

$$\frac{\log\text{ (ratio of c-p. to normal)}}{\log\text{ (ratio of voltage to normal)}}$$

A graph of this ratio plotted with per cent normal volts provides data for all transformations with absolute freedom from directional error, provided that the efficiency for which the lamp is considered normal has not changed.

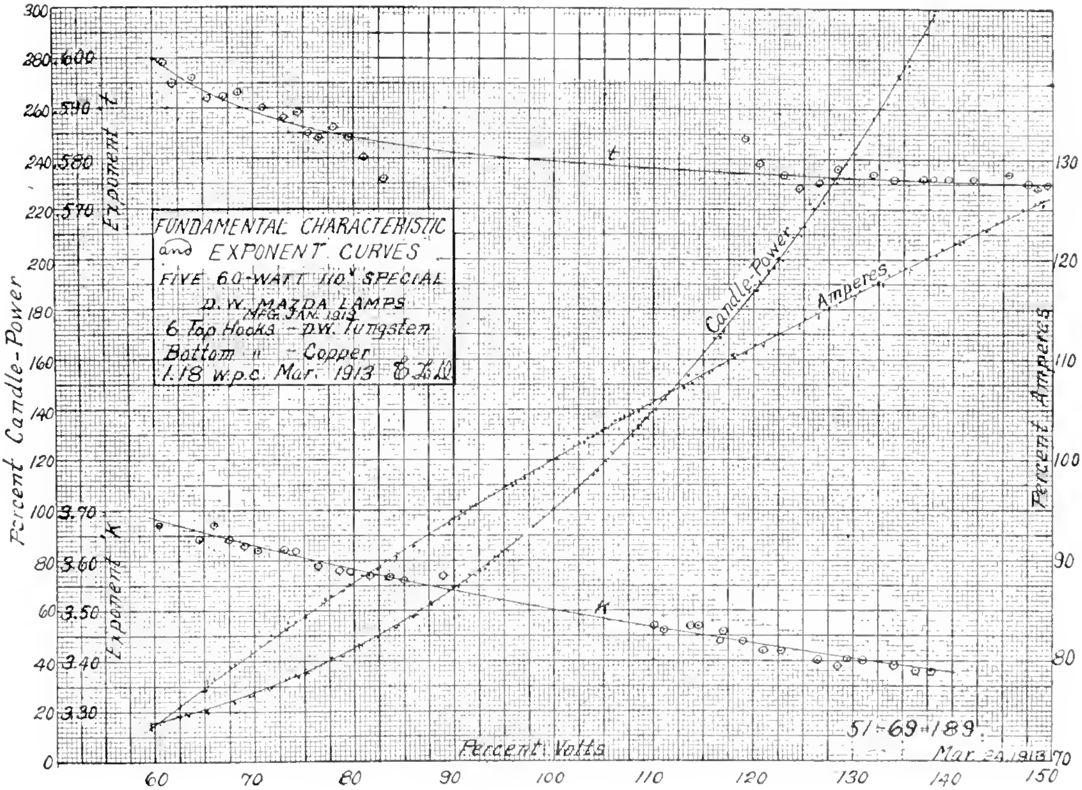

Fig. 1. Fundamental Characteristic and Exponent Curves for Mazda Lamps

As the voltage of the lamp is varied, the candle-power, the wattage, the current, the resistance and the efficiency all undergo changes. In using characteristic data it may be seen that there are fifteen combinations of the variables and that each combination may be expressed with either of the two variables as the independent one. Therefore, if all possible combinations are to be provided, thirty exponents would have to be available. Of all these relations, but two are fundamental. All the others may be derived by the use of very simple mathematical relations.

Since the greater percentage of incandescent lamps are operated or intended to be operated at a specified voltage and on a circuit of supposed constant voltage, it seems proper to consider voltage the fundamental independent variable. Candle-power and current are taken as the two fundamental dependent variables. All the other exponents may be derived from these two fundamental relations. In Table I will be found a list of those most commonly used, with their definitions in terms of the fundamentals.

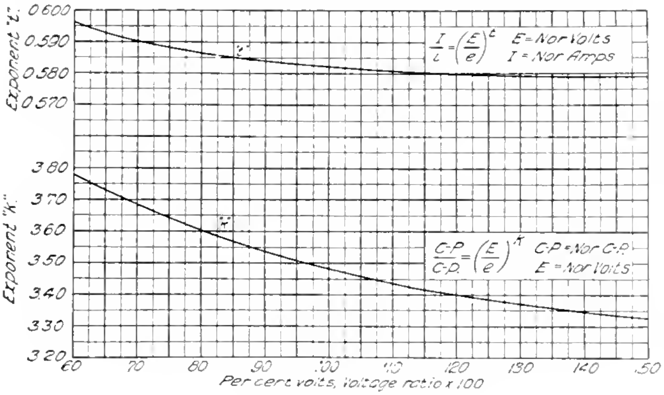

Fig. 2. "k" and "t" Curves for Mazda Lamps

The process of obtaining the values of the characteristic exponents is repeated at least as often as once each year by the laboratory with which the authors are connected and every detail of the work has become standardized. In order to furnish an idea as to the precision to which the figures are known, some of the more essential processes will be shown in detail. The lamps are first aged and then readings are taken on a highest precision photometer from 50 to 150 per cent normal voltage. Current readings are also taken over this range. Then by plotting a short range of volts with watts-per-candle, the voltage for assumed normal efficiency is obtained, after which all values are reduced to terms of ratio to normal. Next, the values are all recorded on very accurate cross section paper, a point for each observation on each of the groups of lamps entering the test. A sample of this sheet is shown in photographic reproduction in Fig. 1. It will be seen that the best representative curves have been drawn and the corresponding $k$ and $t$ values obtained and plotted. The points have been enlarged and the lines widened on this sample sheet in order to show more plainly in the reproduction; about 50 per cent of the points have been obliterated by the curves. The advantage of this method is apparent in that each sheet serves as a complete record and report of the test.

TABLE I

| Dependent Variable | Independent Variable | Symbol | Definition | Value |
|---|---|---|---|---|
| Candle-power... | Volts | $k$ | Taken as fundamental | 3.48 |
| Amperes . | Volts | $t$ | Taken as fundamental | 0.582 |
| Lumens-per-watt. | Volts | $g$ | $g=k-(1+t)$ | 1.90 |
| Watts ... | Volts | $n$ | $n=1+t$ | 1.58 |
| Ohms.... | Volts | $q$ | $q=1-t$ | 0.418 |
| Candle-power... | Amperes | $y$ | $y=k/t$ | 5.98 |
| Lumens-per-watt | Amperes | $j$ | $j=\frac{k-(1+t)}{t}$ | 3.26 |
| Ohms.... | Amperes | $m$ | $m=\frac{1-t}{t}$ | 0.718 |

After a sufficient number of separate tests have been completed, final conclusions for $k$ and $t$ are recorded on a separate sheet which becomes standard for the laboratories until further change is made necessary. Fig. 2 shows the present standardized $k$ and $t$ curves for mazda lamps. They are given on the basis of a normal specific consumption of 1.10 watts-per-horizontal-candle-power, which at present applies to the regular 40-watt multiple lamp. All tables and characteristic curves are now derived from these standardized fundamentals.

Fig. 3 shows a set of characteristic curves which are based on the curves of Fig. 2. It will be seen that voltage is considered as the independent variable and that the fundamental dependent variables, candle-power and current, together with the other dependent relations, watts, ohms, and watts-per-candle, are plotted against voltage. This form has been found the most convenient for everyday use.

The curves of Fig. 3 apply strictly to the regular multiple lamps up to and including the 100-watt size. For the high-wattage multiple lamps and the street-series line, where the cooling of the filament at supports is great, the characteristics are changed a measurable amount. The tendency of the cooling effect is to lower slightly the values of $k$ and $t$. The exponent $k$ on a 1.10 w.p.c. basis may go as low as 3.40 at 100 per cent normal volts in individual cases and the corresponding values of $t$ have been found as low as 0.56, but it is rather surprising to find how well the figures apply to all sizes and designs.

Fig. 4 shows the error which results from the use of the constant normal exponent, i.e., the use over all ranges of voltage of the values of *k* and *t* at 100 per cent normal volts as taken from the curves of Fig. 2. It is seen that for a range of 10 per cent above and below normal voltage the error in candle-power and watts-per-candle does not exceed 0.6 per cent and that the error in amperes due to the use of the constant exponent is practically negligible. For wide ranges in voltage, however, the error becomes great and the variable exponents must be considered.

It has been noted that the curves of Figs. 2 and 3 apply only when the normal values are taken as those for which the curves were obtained. However, the fundamental *k* and *t* curves can readily be transferred to any other normal efficiency basis; and it is, of course, necessary to transform all sheets to the same basis for comparison. In order to change to another efficiency basis it is necessary to first obtain the old-basis voltage corresponding to the new-basis efficiency; this value now becomes the new normal value. The voltage scale is now changed by referring the "old volts" to this new normal value. In like manner new scales of amperes and candle-power are formed, and from these new relations *k* and *t* may be calculated.

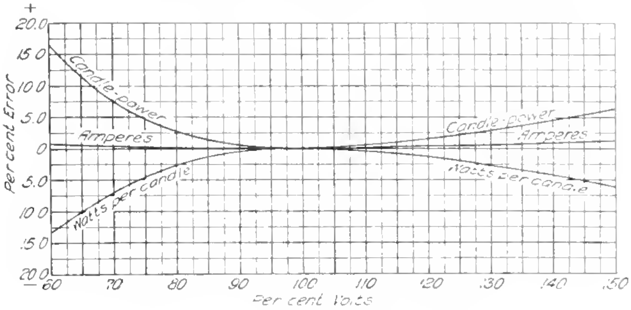

**Fig. 3.** Characteristic Curves for Mazda Lamps

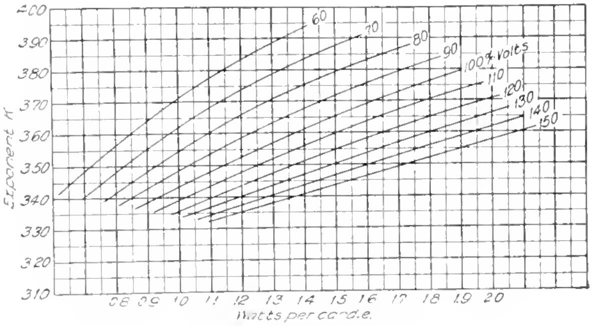

**Fig. 4.** Curves of Error Due to Use of Constant Normal Exponent

The families of curves shown in Figs. 5 and 6 furnish a ready means of making the conversions for the fundamental relations of Fig. 2. The values of *k* and *t* may be read directly at 60, 70, 80 per cent volts, etc., for any desired watts-per-candle within the range given. The values of *k* or *t* and per cent volts are now plotted and the *k* and *t* curves at the new efficiency obtained.

It should be noted that the watts-per-candle figures used in this discussion are watts-per-horizontal-candle-power for regular lamps, having a spherical reduction factor of 0.78.

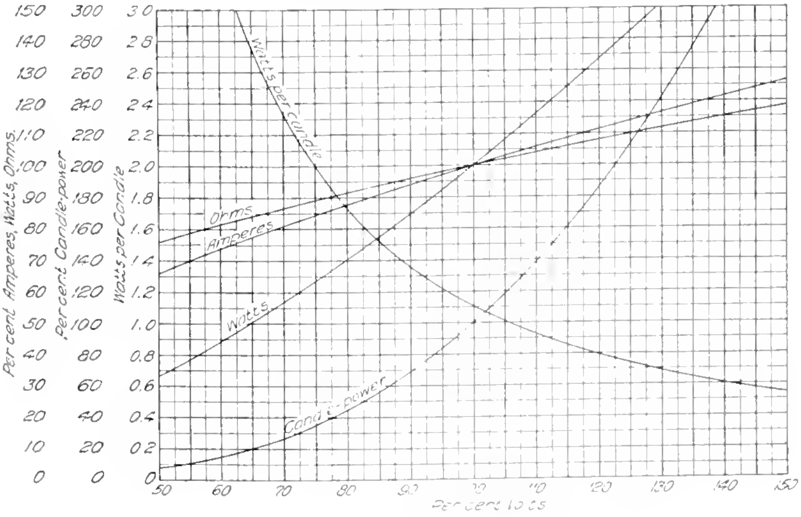

**Fig. 5.** Curves from which "k" Curves may be Obtained for any Desired Normal Watts-per-Candle Basis

Therefore, the true basis for the normal point is 1.41 watts-per-mean-spherical-candle-power, or 8.91 lumens-per-watt.

In conclusion it may be said that the data of this paper are given as being accurately representative of the present-day mazda lamp. They should not be considered as refined measurements on a few lamps, but rather as new conclusions from accumulated progressive data taken over a period of several years. The methods outlined are recommended as being convenient and proper. They are the survivors in a laboratory where the question of characteristic relations has necessarily been given an unusual amount of attention.

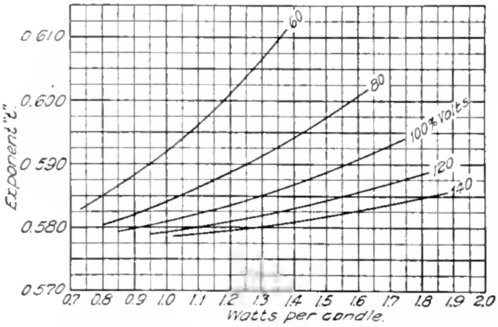

Fig. 6. Curves from which "t" Curves may be obtained for any Desired Normal Watts-per-candle Basis

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# SOME INSTANCES ILLUSTRATING THE INFLUENCE OF RESEARCH AND DEVELOPMENT UPON THE MANUFACTURE OF INCANDESCENT LAMPS

### By J. E. Randall

Consulting Engineer and Manager of Lamp Development Department,
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This article first lists in a clear and concise manner the principal improvements which have been made in the incandescent lamp since its earliest days. (Detailed descriptions of the individual steps which have been made have, of course, been given before in separate articles but, unfortunately for a clear survey, these have all been widely scattered as regards the time and place of their publication.) A very unique analysis is then made as to the source of each improvement, and due credit is given to the type of mind which produced it. As the conclusion of this analysis, the author shows that it is due to the collective efforts of three types of minds—research, development, and manufacturing—that the present-day lamp has reached its state of low cost and high efficiency.—Editor.

J. E. Randall

In the history of the incandescent electric lamp the twelve factors in development, mentioned below, stand out prominently because of their influence upon the industry:

1. *The long slender filament*, an idea that permitted the use of small lamp units upon the 110-volt circuit which has now become practically universal. Furthermore, the idea made possible, in the simplest way, the complete independence of each unit so far as concerns turning its light on or off.

Viewed from the present, the idea of "multiple-burning" lamps, the conception of the conditions necessary thereto, and, finally, the production of a filament sufficiently tenuous to meet the electrical requirements, yet sufficiently rugged to endure the knocks, must be regarded as the evidences of superior genius.

If Mr. Edison had given to the world nothing more than the idea of the "multiple burning" lamp, he should be ranked among its benefactors.

2. *The "treated filament."*

The idea of covering the carbon skeleton of a cotton thread with a coating of graphitic carbon, reduced from a hydro-carbon, was probably evolved for the purpose of producing more uniform filaments. This purpose was hardly accomplished. The real result was a surface which could be maintained at a higher temperature than had been possible with "raw carbon."

3. *The use of cellulose as a material from which to make a carbon filament "base."*

This development really caused an advance in uniformity and quality.

4. *Embedding the "knots" or joints between the copper and the platinum of the lead wires.*

Only those who made lamps before the general use of this device appreciate its value to the industry.

5. *The "flange seal."*

This device, now universally used, appeals only to those who have made lamps.

6. *Blowing bulbs in moulds.*

If today it were necessary to make bulbs by the "free-hand" method, incandescent lamps might be used to light exposition buildings, but would not be the universal light.

7. *Perfection of vacuum chemically.*

This idea, in conjunction with the moulded bulb, has had great influence upon the price of lamps.

8. *The metallized carbon filament.*

9. *The tantalum wire filament.*

10. *The "squirted tungsten" filament.*

Each of these three (8, 9 and 10) contributed a good share toward more efficient light.

11. *The filament of drawn tungsten wire.*

This is considered to be one of the greatest steps in the march of the industry. Drawn wire has justly entitled the tungsten filament lamp to the name, "The lamp of universal use."

12. *The lamp having a gas, at a pressure of approximately an atmosphere, within its bulb.*

This development puts the incandescent lamp upon a basis of equal competition with all other commercially used illuminants, so far as concerns efficiency. It has made available a satisfactory large lamp unit.

These twelve factors in development do not exhaust the list of those that are noteworthy, but they will serve to illustrate the subject to be discussed.

Numbers 4, 5 and 6 may be said to have been conceived, to have been developed, and to have been commercialized in the lamp factory. Unquestionably, all the others were conceived in the laboratories devoted to experiments.

Numbers 1 and 2 were conceived at a period in the history of the art when the distinction between a "laboratory" and a "lamp factory" was so hazy that even those employed in them called them, indifferently, by either name. These two ideas, then, were conceived, developed, and commercialized in a laboratory, or in a factory, whichever name one may choose to house the organization and the equipment employed in their utilization.

All of the others, seven in number, should be credited to laboratories; if we designate as a laboratory that portion of the industry that expends its effort in experiment rather than in production.

Cellulose came from the laboratory of a chemist.

Chemical exhaust came from an Italian who was really a scientist outside of the lamp industry.

Metallized carbon came from a research laboratory.

Tantalum wire came from a research laboratory.

Squirted tungsten came from an experimentalist who had never undertaken to make more than a few experimental lamps.

Drawn tungsten wire came from a research laboratory.

The lamp filled with nitrogen came from a research laboratory.

Some of the individuals credited with the seven factors were connected with the lamp industry, but they would not be called makers of lamps.

The succession in which these twelve factors have been mentioned is very nearly the temporal succession in which they were first proposed. It will be noticed that the last four have come since the industry had been brought to a well organized state, not only in this, but in other countries.

These four were conceived within the organization of laboratories equipped for the scientific investigation of problems dealing with illuminants.

Each one of the four added at least one new factor to our store of scientific knowledge.

Numbers 4, 5 and 6 were really new methods of using information or devices that already existed.

These two groups of factors illustrate the mental differences between the men who conceived them: one group comes from the minds of men trained to co-ordinate unrelated phenomena in such a way as to demonstrate new possibilities; the other group comes from the minds of men trained to apply existing knowledge to a betterment of methods.

A third kind of mind essential to manufacturing success is that found in men who can systematically and economically use better methods.

These three kinds of minds—research, development and manufacturing—illustrate, in a definite way, coordinate specialization of effort.

The incandescent lamp industry today feels the impulse of their cooperation.

There are three fields of effort—research, development and manufacture—lying side by side and overlapping somewhat at their boundaries through which new ideas in incandescent electric lamps are passed to the users of lamps, as the pigskin is passed by a team on the gridiron.

# THE FIELD OF THE GAS-FILLED MAZDA LAMP

By S. H. Blake

Engineer, Supply Department, General Electric Company

The advent of a really worthy illuminant into practical use always means a readjustment of established lighting practice, and in this article the prospective field and scope of the new gas-filled incandescent lamp are considered. As is now pretty well known, the gas-filled lamp shows its best performance at present when made for large current values (not appreciably below twenty amperes), which fact renders it highly suitable for series connection. The use of the high current lamp will in most all cases necessitate special wiring, fixtures, etc.; but the gain in efficiency and sturdiness should justify the change. The lamp is attractive from almost every standpoint, and, in addition to its use for street lighting, should prove immensely popular for the lighting of large interiors, doorways, etc.—Editor.

S. H. Blake

The advent of a radically new illuminant into practical use always means that there must be a readjustment of established lighting practice in order to make room for the new comer. Such a transition is now commencing, owing to the recent appearance of the wonderful gas-filled mazda lamp. It is interesting to consider briefly the prospective field and scope of this new light source in its present state of development.

It is very difficult to compare directly and to classify the various methods of producing artificial light, owing to the many varying factors that must be considered and weighed as to their relative importance. Furthermore, the particular qualities that make a certain light source well suited for some purposes make it entirely unsuitable for other equally important applications. The gas-filled mazda lamp, however, is strikingly attractive from almost every standpoint, as it embodies in one unit the desirable qualities of the incandescent lamp, namely, steadiness of light, constant color value, cleanliness in operation and low maintenance labor cost, etc., together with high efficiency and good quality of light when compared with the present standard practical arc lighting units.

Owing to the fact that the gas-filled mazda lamp in its present form gives its highest efficiencies when it is made for about twenty amperes, or more, the fact at once becomes apparent that this new lamp is highly suited for series connection. The only practical method of operating such high current lamps on *direct current* constant potential circuits will be to connect them in series-multiple, whereas for alternating current constant potential connection they may be operated either in series-multiple or from individual or group step-down transformers or compensators. If the lamps are made suitable for direct, single connection across one hundred and ten volts a-c. or d-c. constant potential, they will operate at a very appreciably lower efficiency than when made for high currents.

Even a casual consideration of the few essential characteristics mentioned will indicate that there are really two types of gas-filled mazda lamps with a well defined line of demarcation between them.

First, there is the *real* gas-filled mazda lamp, as we may call it, operating at high current and low voltage, the efficiency of which compares favorably with that of the magnetite arc lamp; and, second, there is the low current gas-filled mazda lamp which is practically an improved mazda lamp operating, to be sure, at attractive efficiency, but not, at the moment, in the same class with the high current lamp. In fact the only excuse for the low current type is that it can be operated on existing circuits without auxiliary devices, whereas the practical economical use of the high current lamp will involve the design and production of new apparatus and fixtures, as well as some changes in connections and practice.

For example, if it is desired to operate a 20 ampere gas-filled mazda lamp from a 110-volt constant potential circuit it will either be necessary to connect several of them in series, the number being dependent upon the candle-power of the lamps, or else if the circuit is alternating current a small transformer or compensator can be used to step the voltage down to the correct value for the lamp. Such a transformer or compensator should be preferably mounted with the lamp itself. The whole combination should have a cover or casing to give it a pleasing and finished appearance and to protect the lamp, socket and windings from weather conditions when used out-of-doors. Arrangements should also be provided for attaching suitable reflectors and provision should be made for a globe-holding device, as not only will diffusing globes sometimes be desirable but the hot glass bulb of the lamp should be properly protected from possible fracture due to rain, snow or sleet. It is also important that this whole structure be well ventilated so as to keep the interior parts as cool as possible. Thus, it is at once evident that special fixtures, etc., are necessary to properly use high current gas-filled lamps in actual service. If it is desired to use the 20 ampere lamps on existing series street lighting circuits, it becomes at once apparent that either the street wiring suitable for 7.5 and 6.6 amperes will have to be replaced with heavier wire, to say nothing of the rewinding of current regulating devices; or else individual series transformers or compensators will have to be used, as with the multiple lamp, involving complete fixtures, etc.

The use of these transforming devices for running multiple and series gas-filled lamps will, of course, lower the operating efficiency of the lamps and also reduce the power-factor slightly; but the greater efficiency of the high current lamp makes it well worth while to use it in this way instead of using the low current lamp without transformers. This procedure is further influenced by the fact that the large, rugged filament of the high current lamp should be expected to give longer and more reliable service than the thinner filament of the low current lamp.

It is significant to note that even the low current gas-filled mazda lamp compares very favorably with the multiple arc lamp, particularly on d-c., as the ballast resistance necessary to make such arcs stable on constant potential greatly reduces the input watts per candle efficiency, whereas no such loss is necessary in operating the gas-filled mazda lamp. To a less degree the efficiency of the a-c. multiple arc lamp is lowered by the losses in the ballast reactance, but the power-factor of such lamps is about 30 per cent lower than that of the gas-filled mazda lamp. In this field it is, therefore, probable that the gas-filled mazda lamp will become supreme except where conditions of severe vibration and rough handling make an incandescent lamp unsuitable, and in cases where the penetrating powers of the rays from the yellow flame lamp make it more effective.

For constant current connection the arc lamp is not handicapped to the same extent that it is for multiple operation, and before it can be predicted with any degree of accuracy just how far the gas-filled mazda lamp is liable to encroach into the field of series street lighting now practically dominated by the arc lamp, it will be necessary to determine by actual experience whether the gas-filled mazda lamp is inherently rugged and reliable enough to economically withstand the very trying conditions of this truly American method of operating street lamps.

The gas-filled mazda lamp will apparently meet European conditions better than it does ours in this country, owing to various causes. The practice in large cities abroad is to light the city proper with high candle-power units, generally arc lamps operating two or three in series on 110 volts or 4, 5 or 6 in series on 220 volts constant potential. These lamps are hung very high, quite close together and often are directly over the center of the streets. High candle-power gas-filled mazda lamps should work out well under such conditions, as they throw a bountiful amount of light directly below the lamp. The steadiness of the gas-filled mazda lamp is another great point in its favor from the European standpoint, while its yellowish white quality of light will be much superior to the light of the yellow flame lamps that are now used there so extensively.

The perfect steadiness of the gas-filled mazda lamp will also be a very decided point in its favor in this country, particularly for the lighting of large interiors, doorways and in front of buildings. For street illumination it will be an interesting study to watch the progress it makes against the magnetite lamp, which is undoubtedly a remarkable lamp for street lighting due to its beautiful white color, its ideal light distribution, and its low cost of maintenance. The "life" of the gas-filled mazda lamp will largely determine its success in this field, for the cost of even one renewal will be a relatively large part of the yearly maintenance cost of one magnetite lamp.

As to flame, quartz, titanium and other high efficiency lamps the introduction of the gas-filled mazda lamp instead of tending to discourage their further development should greatly aid to still more perfect them. Even now the efficiencies that it is possible to obtain with some of these lamps are twice as good as the best that can be secured with the gas-filled mazda lamp. The general effect of the gas-filled mazda lamp on such other lamp developments will probably be to enhance the relative commercial importance of the qualities of steadiness and constancy of color values and to redouble the efforts already being made to obtain still higher efficiencies. These several qualities will be sought in arc lamps by using higher currents and smaller diameter electrodes.

It would be entirely premature at this time to try to analyze the probable cost of operation and maintenance of the gas-filled mazda lamp compared with other lamps for equal illumination of streets, but it is not unlikely that such a comparison would show that the titanium and flame lamps are the most economical, practical illuminants at high cost of power and the magnetite and gas-filled mazda lamps when the cost of power is low.

# IMPROVEMENTS IN THE MAGNETITE ARC

By C. A. B. Halvorson, Jr.

Designing Engineer, Arc Lamp Department, General Electric Company

Efficiency is the keynote of this article. As the author points out, it is along this line that improvements in luminous arc lamps are to be expected, since in operation and maintenance they have already reached a high degree of perfection. Preparatory to describing what is being done to increase the efficiency, a thorough exposition is given of the proper method of rating lamps, in order to clarify much of the confusion which exists in comparing lamps of different types. After this phase of the subject has been placed on a rational basis, the means which are to be employed in bettering the present day high efficiencies are described and the amount of the improvement given.—Editor.

C. A. B. Halvorson, Jr.

THERE are in use, at the present time, in the neighborhood of 200,000 luminous arc lamps, including both the pendant and ornamental types. By far the majority of these are 310-watt lamps operating at 4 amperes, 75 volts at the arc. It is but natural that the users of these lamps, as well as those contemplating the purchase of new street-lighting units, should be vitally interested in the future possibilities of the luminous arc, principally from an efficiency view-point; since from an operating and maintenance view-point, the luminous arc lamp leaves but little to be desired. Moreover, due to the pure white color and the characteristic distribution of the light, the luminous arc is more effective physiologically than the other lighting units designed for street illumination.

With regard to efficiency, so much misunderstanding exists at the present time as to the comparative rating of street illuminants that, before describing certain improvements in the luminous arc, which is the principal object of this article, a brief review and discussion of the several methods employed may be of interest.

In incandescent lamp work the following practice is customary:

"The mean horizontal candle-power has been adopted by long practice as the conventional measure of the performance of an incandescent lamp. This, of course, originated through the need of a simple comparison of one lamp with another of the same type, before the necessity of comparing lamps of different types arose. It is a very useful unit, if properly used; but under present conditions should be accompanied by a reduction factor, from which the mean spherical candle-power (and hence the total lumens) can be figured. Lamp manufacturers usually give with the candle-power rating of a lamp either the reduction factor, mean spherical candle-power, or total lumens."*

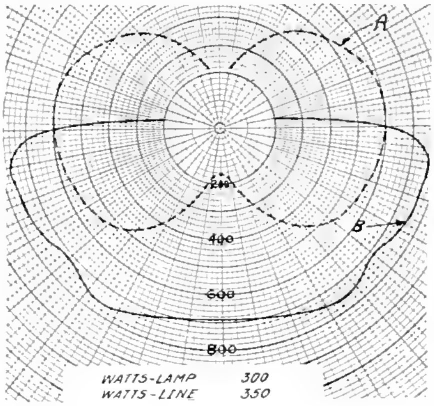

Fig. 1

| | A | B |
|---|---|---|
| Mean Horizontal C.P. | 600 | 600 |
| Watts per Mean Horizontal C.P. | 0.50 | 0.58 |
| Mean Spherical C.P. | 510 | 411 |
| Watts per Mean Spherical C.P. | 0.59 | 0.85 |
| Mean Spherical C.P. per Watt | 1.70 | 1.17 |
| Mean Hemispherical C.P. | 518 | 733 |
| Watts per Mean Hemispherical C.P. | 0.58 | 0.48 |
| Mean Hemispherical C.P. per Watt | 1.73 | 2.10 |

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* Quoted from "Interpretation of Photometric Curves," G. H. Stickney, General Electric Review, November, 1912.

It should be noted that ratings given under this method cover only the lamp itself, or, to state it in another way, the raw material; however, from these data the engineer can design suitable fixtures or complete lighting units to meet any specific requirements.

Thus, if an incandescent lamp, giving the characteristic light distribution curve shown in Fig. 1 as curve A, is rated at 0.5 watt per mean horizontal candle-power and consumes 300 watts, the mean horizontal candle-power is found to be 600. The spherical reduction factor of such a lamp would be 0.85; consequently, the mean spherical candle-power would be 510 and the specific consumption 0.59 watt per mean spherical candle-power. It is perfectly clear, however, that such a distribution curve is not suited to the majority of cases met with in street lighting and that the original light distribution must of necessity be modified by proper devices designed to redirect into the lower hemisphere that light found above the horizontal (curve B, Fig. 1). Therefore, a further increase in the specific consumption of watts per mean spherical candle-power would occur due to unavoidable losses in auxiliary devices, etc. Now, the spherical reduction factor has been changed to 0.68, there being practically no light above the horizontal, and consequently the just rating will give a specific consumption of 0.85 watt per mean spherical candle-power instead of 0.5 watt per mean horizontal candle-power, which was the original rating.

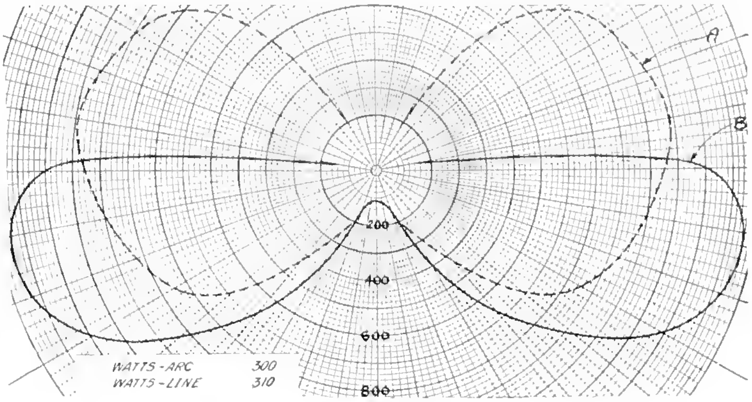

Fig. 2

| | A | B |
|---|---|---|
| Mean Spherical C.P. | 763 | 607 |
| Watts per Mean Spherical C.P. | 0.39 | 0.51 |
| Mean Spherical C.P. per Watt | 2.54 | 1.96 |
| Mean Hemispherical C.P. | 711 | 1035 |
| Watts per Mean Hemispherical C.P. | 0.42 | 0.30 |
| Mean Hemispherical C.P. per Watt | 2.37 | 3.33 |

Fig. 3. Arrangement of Electrodes and Form of Arc Employed for Data of Fig. 2

In arc lamp work, on account of the close relations existing between the lamp mechanism and the arc, it always has been customary to consider only the distribution curve of the complete unit equipped with proper devices and glassware to give some desired result. Thus, it is evident that the losses, due to the redirection of the light, etc., are always included in the resultant distribution curve.

Fig. 2, curve B, shows a characteristic distribution curve of a luminous or magnetite arc lamp. It is very unfair to the light source in so far as the spherical rating is concerned, since curve A indicates the characteristic light distribution curve of the luminous arc *per se*, or, as we may say, of the raw material from which the illuminating unit as a whole is developed or designed.

The arrangement of arc and electrodes for obtaining curve A, Fig. 2, is indicated in Fig. 3, the lamp mechanism being used without any auxiliary devices. From the foregoing, it is apparent that in order to compare dissimilar units for some specific purpose, it is first necessary to obtain the light *source values;* i.e., all lighting units must be reduced to the simplest form, which, in the case of the luminous arc lamp, would be the lamp mechanism operating an electric arc drawn between a pair of vertical electrodes surrounded with a globe to keep out transverse air currents, as these would affect the operation of the arc.

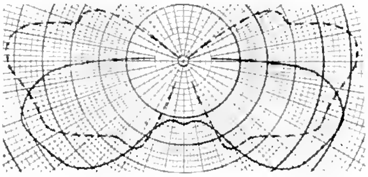

Fig. 4

The distribution of light in a vertical plane from such an arc arrangement, Fig. 3, is shown in Fig. 2, curve A. Such a distribution curve may now be compared with curve A, Fig. 1, since they are both made under similar conditions representing the performance of the bare light sources or, we may say, the raw material. However, it is perfectly obvious that complete lighting units giving curves with these characteristics, would be of little value in the design of ordinary low-intensity street illumination where an extended distribution is desirable, but, on the other hand, are of the utmost importance in the design of "White Way" or ornamental street lighting.

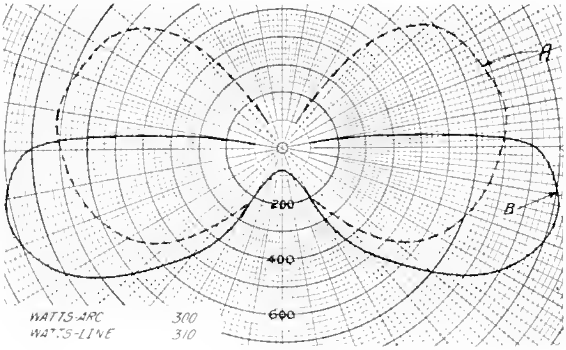

Fig. 5

| | A | B |
|---|---|---|
| Mean Spherical C.P. | 572 | 412 |
| Watts per Mean Spherical C.P. | 0.52 | 0.75 |
| Mean Spherical C.P. per Watt | 1.91 | 1.33 |
| Mean Hemispherical C.P. | 532 | 735 |
| Watts per Mean Hemispherical C.P | 0.56 | 0.42 |
| Mean Hemispherical C.P. per Watt | 1.77 | 2.37 |

As an illustration of this, refer to Fig. 4, where two curves, A and B, are shown. The former represents the characteristic light distribution from an ornamental luminous arc lamp with a clear globe and the latter shows the characteristic distribution of the same kind of arc consuming the same amount of energy, but in the pendant luminous arc lamp such as is used ordinarily in American cities. It is clear from these curves that merely giving the mean spherical ratings in both cases would be unfair to one of the lamps and that in order to intelligently select the proper lighting unit for some specific purpose, the distribution curves should be given in addition to the values in any one of the various ratings now in common use.

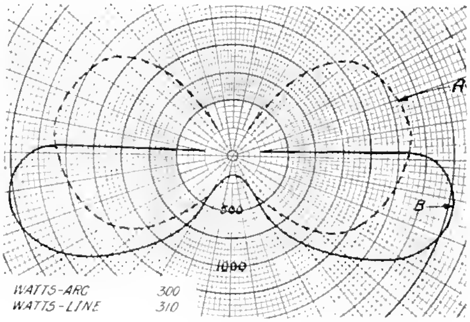

Fig. 6

| | A | B |
|---|---|---|
| Mean Spherical C.P. | 1141 | 844 |
| Watts per Mean Spherical C.P. | 0.26 | 0.37 |
| Mean Spherical C.P. per Watt | 3.80 | 2.72 |
| Mean Hemispherical C.P. | 1065 | 1477 |
| Watts per Mean Hemispherical C.P. | 0.28 | 0.21 |
| Mean Hemispherical C.P. per Watt | 3.55 | 4.76 |

During the past few years a vast amount of research work has been done in attempts to increase the efficiency of the magnetite arc. Two lines of endeavor have been followed. One line of experimental work has been directed toward the production of an electrode which would support an arc of higher efficiency; while the other line has been directed toward the production of luminous arcs of maximum efficiency, without regard to the utilization of these electrodes in standard lamps. Both lines of endeavor are nearing completion, with the result that in a short time electrodes should be available which will operate in luminous arc lamps and which will support an arc giving an efficiency of from approximately 2.0 to 2.5 spherical candles per watt (see Figs. 2 and 5).

It may be noted that there is considerable difference between the values given for the two curves, but they are of the same order and Fig. 5 shows what has been obtained from electrodes in actual commercial service. The same may be said also of Fig. 2, although as yet this particular electrode has been subjected to less commercial operating experience. It will be observed in Fig. 2, curve A, that the specific consumption is 0.42 watt per mean spherical candle-power. With the proper arrangement, the upward light can be redirected to between 10 and 15 degrees below the horizontal, with a maximum value of 1360 candle-power, and a specific consumption of 0.30 watt per mean hemispherical candle-power, or an efficiency of 3.33 mean hemispherical candle-power per watt. The value of such a distribution curve, in the design of street illumination, is immediately apparent; but little light is given directly below the lamp, while the maximum values, which are at the most advantageous angles for street illumination, show an efficiency of 4.4 candle-power per watt.

There is no reason why electrodes supporting arcs of even greater efficiency cannot be used with a modified lamp mechanism. Fig. 6, curve A, shows the distribution of light from one of these extremely efficient arcs where a maximum of 1600 candle-power is easily obtainable at 300 watts. With the proper arrangement, a maximum of over 2000 candle-power at 10 to 15 degrees below the horizontal may be obtained. Such efficiencies as 4 to 5 mean hemispherical candle-power per watt, or specific consumptions of 0.2 to 0.25 watt per mean hemispherical candle-power, are not immediately available commercially, but may be regarded as reasonably sure of attainment and are indicative of what may be expected of the luminous arc lamp within a comparatively short time.

However, the commercial gain in efficiencies already made, Fig. 7, curves A and B, assure the future of the luminous arc lamp, for, with the inherent advantages of superior light distribution and unexcelled color, it is extremely doubtful if any competitive illuminant will be found within the immediate future to supersede it. In this connection it is interesting to note what Dr. Steinmetz says with regard to the requirements of street lighting:

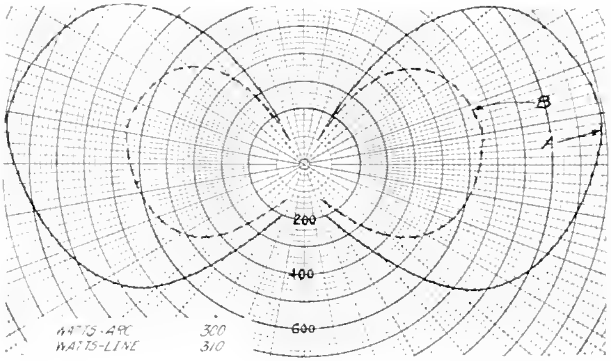

Fig. 7

| | A | B |
|---|---|---|
| Mean Spherical C.P. . . . | 763 | 458 |
| Watts per Mean Spherical C.P. | 0.39 | 0.65 |
| Mean Spherical C.P. per Watt | 2.54 | 1.53 |
| Mean Hemispherical C.P. . | 711 | 426 |
| Watts per Mean Hemispherical C.P. | 0.42 | 0.70 |
| Mean Hemispherical C.P. per Watt | 2.37 | 1.42 |

"It is a physiological and pyschological phenomenon, and as such cannot well be expressed numerically, except in general, that, where low intensity illumination is contemplated, as in most of the street lighting, the white color has a material advantage in physiological efficiency."†

"The success which has attended the ornamental luminous arc lamp, principally on account of its pearl white color and high efficiency, promises to be augmented by these improvements in electrodes which make possible a large reduction in the energy required per unit, necessary to produce certain desired effects now-a-days considered so essential to the success of spectacular or so-called White Way lighting."‡

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† Quoted from "Efficiency of Illuminants," Dr. C. P. Steinmetz, GENERAL ELECTRIC REVIEW, November, 1912.

‡ From "New Types of Ornamental Luminous Arcs," GENERAL ELECTRIC REVIEW, November, 1912.

# THE FLICKER OF INCANDESCENT LAMPS ON ALTERNATING CURRENT CIRCUITS AND STROBOSCOPIC EFFECTS

### By Dr. Irving Langmuir

Dr. Langmuir's contribution to this issue is an able article on the complex phenomenon of flicker. This phenomenon is influenced by the intensity of fluctuation and the frequency of an a-c. circuit and by a number of physiological factors. The most important consideration from a commercial standpoint regarding flicker is the determination of how a lamp will behave on a given circuit. Formulæ are given in this article which will enable a ready determination to be made of the behavior of different types of lamps on any circuit, special attention being paid to the modern gas-filled lamp. It is interesting to note that under ordinary conditions the effect of a helical winding is to decrease the candle-power fluctuation in about the ratio of 1.4 to 1, and that with a similar filament in gas the effect is much greater than with a helical winding in vacuum. Owing to our incomplete knowledge of this subject, we believe that Dr. Langmuir's article with his formulæ and tables, will be of much interest and value to the illuminating engineer.—Editor.


Dr. Irving Langmuir

SINCE the introduction of metal filament lamps, the flicker that occurs when low wattage lamps are run on 25 cycle alternating current has attracted considerable attention and has often been experimentally investigated.

The flicker is a physiological effect caused by the fluctuations in the intensity of the light source. If the frequency is either too high or too low, no flicker will be observed, even though the candle-power of the source may vary through a fairly wide range. Furthermore, the perception of flicker depends to a marked degree on the intensity of the illumination and on its distribution. Flicker can often be observed in the light thrown by a lamp on a large white wall, although by looking directly at the lamp or at objects near it, no flicker will be noticed.

The variations in intensity of a fluctuating light source produce, besides the flicker, other striking effects observable when the eyes are moved from one object to another, or an illuminated object is moved across the field of vision. This motion gives rise to a stroboscopic effect characterized by the production of a series of multiple images. Frequency in this case has very little effect, except that with very high frequency a more rapid motion is necessary to make the separate images distinct from one another.

Flicker, therefore, is a complex phenomenon dependent not only on the magnitude of the intensity fluctuations, but on the frequency of the alternating current and a number of physiological or psychological factors.

In any discussion of the flicker of incandescent lamps, however, the first element to be considered should be the actual magnitude of the fluctuations in the intensity of the light. This fluctuation completely determines the degree of stroboscopic effect obtainable and at least allows comparison to be made between the flicker produced by different types of lamps operating on current of the same frequency.

The ease and accuracy with which the candle-power fluctuation may be calculated from simple thermal data, seems to have been generally overlooked by most of those interested in the technical side of the question. Several years ago the writer developed some simple equations by which the fluctuation could be calculated from the ordinary characteristics of lamps and from the specific heat of the material of the filament. Since then, O. M. Corbino has published a series of papers on the theory of "periodic temperature fluctuations of metallic filaments heated by alternating currents" (see Physik. Zeitschrift *11*, 413, 1910, and *12*, 292, 1911). Corbino has made elaborate experiments to test his equations and to determine the various thermal constants involved.

The object of the present paper is to call the attention of lighting engineers to some of the most important of Corbino's formulas and to modify and simplify these in such a way that they may be of more direct application to lighting problems. The simplified formulas will then be used to calculate the magnitude of the candle-power fluctuation in various types of lamps with especial reference to gas-filled lamps.

The heating effect of a sine wave alternating current varies periodically according to a sine wave of double the frequency of the current. During the part of the cycle in which there is low energy input, the filament temperature falls, since the radiated energy exceeds the input. During the time of high input, the temperature rises, as more energy is supplied than can be radiated. The temperature of the filament therefore rises and falls with double the frequency of the alternating current. The magnitude of the temperature fluctuation evidently depends on the manner in which the resistance and radiating properties vary with the temperature and also on the heat capacity of the filament. From a knowledge of these factors, the temperature variations and from this the candle-power fluctuation may be calculated.

### Derivation of Formulas

Let us consider the temperature fluctuations in a lamp filament supplied by alternating current of the frequency $f$.

Let $e$ = instantaneous potential applied to the lamp

$i$ = instantaneous current

$r$ = instantaneous resistance

$w$ = instantaneous heat dissipation from filament in watts

$T$ = instantaneous temperature of filament (absolute scale)

$c$ = specific heat of the material of the filament

$m$ = mass of the filament

$\theta$ = variation in the temperature of the filament from its mean value $t$.

We will consider that the applied potential is a pure sine wave.

$$(1) \qquad e = e_0 \; sin \; \omega t$$

where $\omega = 2\pi f$

The power input into the filament is $e^2\ r$, and this must equal the sum of the radiated power and that necessary to raise the temperature of the filament.

$$\frac{e^2}{r} = w + mc\,\frac{d\theta}{dt}$$

or

$$(3) \qquad rmc\,\frac{d\theta}{dt} = e^2 - wr$$

It has been found that both the energy radiated and the resistance of tungsten lamp can be expressed as a power of the absolute temperature of the filament.

That is, we can place as a very close approximation

$$(5) \qquad r = r_0\left(\frac{T}{T_0}\right)^{n_R}$$

$$(6) \qquad w = w_0\left(\frac{T}{T_0}\right)^{n_W}$$

where $r_0$ and $w_0$ are respectively the resistance and wattage at the temperature $T_0$, the average temperature of the filament.

If we assume that the variations in $r$ and $w$ are relatively small, we may place

$$(7) \qquad r = r_0\left(1 + \frac{n_R}{T}\,\theta\right)$$

$$(8) \qquad w = w_0\left(1 + \frac{n_W}{T}\,\theta\right)$$

We can now substitute these values in (3). However, since we assume the variation in $r$ to be very small, we may put $r_0$ in place of $r$ in the first member of the equation, although in the second member, which consists in a small difference between two relatively large quantities, we use the values given by (7) and (8). We thus obtain, by neglecting second order terms,

$$r_0 mc\frac{d\theta}{dt} = e_0^2 \; sin^2 \; \omega t - w_0 r_0\left(1 + \frac{n_R + n_W}{T}\,\theta\right)$$

The solution of this equation (excluding transient phenomena) is of the form

$$(9) \qquad \theta = \theta_0 \cos\,(2\;\omega t - \psi)$$

where

$$(10) \qquad \theta_0 = \frac{1}{\sqrt{\left(\frac{n_R + n_W}{T}\right)^2 + \left(\frac{2\,c\,m\,\omega}{w_0}\right)^2}}$$

We thus see that the variation in the temperature of the wire is a simple harmonic function having twice the frequency of the applied e.m.f. The amplitude is given by (10).

The two terms under the radical sign in equation (10) are of very unequal magnitude. The value of $n_W$ for tungsten in a vacuum is about 4.7, while $n_R$ is 1.2. For tungsten filaments in gases, $n_W$ is less than 4.7, except in hydrogen, where it may become as great as 10. In any practical lamp, however, $n_W + n_R$ will never exceed about 6. The temperature of the filament of any practical lamp will be at least 2000 deg. K (absolute temperature), and the term $\left(\frac{n_R + n_W}{T}\right)^2$ will thus never exceed 0.000009. The second term under the radical must always be greatly in excess of this; otherwise the fundamental assumptions made in the derivation of the equation are not fulfilled and the equation ceases to be of value. This is apparent from the following considerations:

If the second term were small compared to the first, then the equation would reduce to

$$\theta_0 = \frac{T}{n_W + n_R}$$

This would give a value of $\theta_0$ of at least 330 deg., so the total variation of temperature would be over 660 deg. With such a temperature range as this, the power ($w_0$) radiated from the filament would vary in about the ratio of 1 to 3.5, so that equation (8) would not be even approximately fulfilled.

It can be readily shown that if $\theta_0$ is to be as small as 100 deg., the second term in the radical must be about 10 times as great as the first, and that to neglect the first term entirely, would make an error in $\theta_0$ of less than 5 per cent.

Since the flicker in ordinary lamps is caused by a temperature variation with a range much less than 200, it is evident that we can neglect the first term under the radical, in the applications of this formula.

Equation (10) therefore assumes the very simple form

$$(11) \qquad \theta_0 = \frac{w_0}{2\ cm\omega} = \frac{w_0}{4\ \pi fcm}$$

The candle-power ($H$) of a filament is related to its temperature ($T$), by the equation

$$(12) \qquad \log H = A - \frac{11230}{T}$$

where $A$ is a constant characteristic of the filament.

Let us now calculate the candle-power fluctuation that would be produced by the periodic change in temperature of amplitude $\theta_0$.

For small variations in temperature equation (12) can be written

$$(13) \qquad \triangle \log H = \frac{11230}{T^2} \triangle T$$

If we let $\triangle T$ represent the total fluctuation in temperature, then $\triangle T = 2\ \theta_0$ and $\triangle \log H$ becomes

$$\log \frac{H_{max.}}{H_{min.}}$$

If we change to natural in place of common logarithms and consider such small fluctuations of temperature that the relative change of light intensity is also small, then we have

$$(14) \qquad ln \frac{H_{max.}}{H_{min.}} = \frac{H_{max.} - H_{min.}}{H_{mean.}}$$

This is the measure of the relative change in candle-power and will serve as the best measure of the candle-power fluctuation. Since, however, the candle-power of a filament varies extremely rapidly with its temperature equation (14) will cease to hold for larger temperature fluctuations, although (13) may still be very accurate. It will be better, therefore, for us to adopt the following definition of the relative candle-power fluctuation ($F$):

$$(15) \qquad F = ln \frac{H_{max.}}{H_{min.}} = 2.30 \log \frac{H_{max.}}{H_{min.}}$$

Combining this with (13) and remembering that $\triangle T = 2\ \theta_0$ we obtain

$$(16) \qquad F = \frac{51600}{T^2}\ \theta_0$$

Combining this with (11), we obtain

$$(17) \qquad F = 4100 \frac{w_0}{f cm\ T^2}$$

### Application of Formula to Flicker of Tungsten Lamps

To apply this formula to the calculation of the candle-power fluctuations of tungsten lamps, we need first to know the specific heat of tungsten at the operating temperatures of lamp filaments. Corbino has determined this quantity from measurements on lamp filaments and obtains the value 0.0425 calories per gram per degree at 1500 deg. C. His temperature measurements above this temperature were probably not reliable, but he has experimentally determined the quantity $\frac{CT}{n_R}$ up to the normal operating temperature. Combining Corbino's data with our data for $\frac{n_R}{T}$ at the normal operating temperature, we obtain 0.049 calories per gram per degree, or

$C = 0.205$ watt seconds per gram per degree. Equation (17) thus becomes

$$(18) \qquad F = 20000 \frac{w_0}{fmT^2}$$

This equation gives the relative candle-power fluctuation of any tungsten lamp in terms of the power consumption ($w_0$), the frequency ($f$), the mass of the filament ($m$), and the absolute temperature of the filament ($T$). The equation holds equally as well for gas-filled lamps as for vacuum lamps.

We see that the fluctuation, $F$, is inversely proportional to the frequency of the alternating current and directly proportional to the power consumption. The introduction of gases into lamps therefore tends to increase the candle-power fluctuation since it increases the power consumption at any given temperature. On the other hand, winding the filament into a tight helix tends to decrease the fluctuation, since it decreases the ratio of power to mass of filament.

The practical application of the formula (18) therefore requires data characteristic of the particular type of lamp under consideration. We will therefore discuss its application under the following headings:

### Lamps with Filaments in Vacuum

The loss of energy from filaments in vacuum occurs almost entirely by radiation. The power consumption is approximately proportional to the 4.7 power of the absolute temperature. From equation (18), we thus see that the candle-power fluctuations in such lamps increase with 2.7 power of the temperature.

In tungsten lamps running at 1.0 watt per candle, the temperature of the filament is about 2400 deg. K, and the power consumption is about 0.54 watt per cm. for a filament 1 mil in diameter. The mass of a filament 1 mil in diameter is 0.098 mg. per cm. of length.

Substituting these data in (18), we obtain the following formula, which gives the relative candle-power fluctuation of a tungsten lamp at 1 watt per candle in terms of the frequency of the current and the diameter ($d$) of the wire in mils.

$$F = \frac{19.2}{fd} \tag{19}$$

For most purposes, it is more convenient to have a formula which involves only quantities directly measurable on the lamp.

The current necessary to maintain a filament at 2400 deg. K. is 0.197 $d^{3/2}$ amperes, where $d$ is the diameter in mils. From this and the data previously given, we get the relations: ($l$ = length in cm.)

$i = 0.197\ d^{3/2}$

$w_0 = 0.54\ dl$

$m = 98 \times 10^{-6}\ d^2l$ (grams)

From these three equations, we can readily obtain

$$\frac{w_0}{m} = \frac{5500}{d} = \frac{1860}{i^{2/3}}$$

Substituting this in (18) together with $T = 2400$ gives

$$F = \frac{6.48}{fi^{2/3}} \tag{20}$$

This gives the relative candle-power fluctuation in tungsten lamps with filaments in vacuum operating at one watt per candle. When the lamps are run at any other specific consumption, the constant 6.48 should be replaced by a quantity which depends on the operating temperature. Thus we find the fluctuation ($F$) can be expressed by the formula:

$$F = \frac{A}{fi^{2/3}} \tag{21}$$

The following table gives the values of $A$ for different specific consumptions and temperatures:

TABLE I

| Watts per Candle | Temperature | A |
|---|---|---|
| 3.0 | 2050°K | 3.64 |
| 2.0 | 2160 | 4.22 |
| 1.5 | 2250 | 5.05 |
| 1.25 | 2315 | 5.62 |
| 1.00 | 2400 | 6.48 |
| 0.80 | 2490 | 7.40 |
| 0.50 | 2730 | 10.56 |
| 0.30 | 3050 | 15.60 |

### Effect of Helical Winding

A straight filament of length $l$ and diameter $d$ has a mass $m$ and requires a power $w_0$ to maintain it at a temperature $T_0$. If this filament is now wound into a tightly coiled helix, the mass remains unchanged, but the power consumption to maintain the wire at $T_0$ decreases materially, since the wire now radiates only from those parts that lie on the outer surface of the helix. The effect of helical winding is to decrease the ratio $\frac{w_0}{m}$ and therefore, by equation (17), to decrease the candle-power fluctuation in the same ratio. It is evident that the greatest possible reduction thus obtainable with filaments in vacuum by winding into a helix would be in the ratio $\pi$:1. Practically, however, the effect would be much less than this. Under ordinary conditions the effect of helical winding is to decrease the candle-power fluctuation in about the ratio 1.4:1.

With filaments in gas, the effect of helical winding is much greater than in vacuum, for not only the radiated energy but also the heat carried from the filament by convection, is decreased by concentrating the filament into a smaller space.

### Candle-Power Fluctuations of Straight Filaments in Gases

We see from equation (15) that the presence of gas increases $F$ in the same ratio as it increases the wattage at a given temperature.

In general, for a filament of any given diameter in a given gas, $F$ will be given by an equation of the form (derived from 107).

$$F = \frac{\text{constant}}{fd} \quad \frac{w'}{w_0}$$

where $w'/w_0$ is the ratio in which the power is increased by the presence of the gas. For straight filaments in nitrogen, the writer has already published (Trans. A.I.E.E. for 1913, p. 1912) a table of the specific consumption of filaments in nitrogen at various temperatures as compared with that in vacuum. From these data the following table (II) is prepared of the function $\frac{\text{const}}{d} \frac{w'}{w_0}$ which, for convenience, we will call $\beta$.

The relative candle-power fluctuation is thus equal to

$$F = \frac{\beta}{f}$$

TABLE II—VALUE OF $\beta$ FOR STRAIGHT FILAMENTS IN NITROGEN AT ATMOSPHERIC PRESSURE

| Temp. of Filament | Watts per Candle in Vacuum | Diam. 1 Mil | Diam. 2 Mil | Diam. 5 Mil | Diam. 10 Mil | Diam. 20 Mil |
|---|---|---|---|---|---|---|
| 2400 | 1.00 | 92 | 30 | 7.8 | 3.0 | 1.3 |
| 2600 | 0.63 | 94 | 32 | 8.6 | 3.4 | 1.5 |
| 2800 | 0.45 | 98 | 34 | 9.4 | 4.0 | 1.7 |
| 3000 | 0.33 | 102 | 36 | 10.2 | 4.4 | 2.0 |

Table III gives similar data for straight tungsten filaments in hydrogen at two different pressures, 100 mm. and 760 mm.

TABLE III—VALUES OF $\beta$ FOR STRAIGHT TUNGSTEN FILAMENTS IN HYDROGEN

| Temp. of Filament | Watts per Candle in Vacuum | 760 MM. OF $H_2$ |  | 100 MM. OF $H_2$ |
|---|---|---|---|---|
|  |  | Diam. 1 Mil | Diam. 2.8 Mil | Diam. 2.8 Mil |
| 2000 | 3.4 | 340 | 64 | 46 |
| 2200 | 1.7 | 370 | 70 | 50 |
| 2400 | 1.0 | 410 | 78 | 66 |
| 2600 | 0.63 | 520 | 96 | 90 |
| 2800 | 0.45 | 620 | 118 | 132 |
| 3000 | 0.33 | 780 | 146 | 176 |
| 3200 | 0.26 | 1000 | 188 | 260 |
| 3400 | 0.21 | 1200 | 226 | 360 |

This has been calculated from data on the power consumption of tungsten wires in hydrogen, published in the *Physical Review* (Vol. 34, p. 418, 1912), and from other similar data more recently obtained in this laboratory. It is interesting to note that the fluctuations are greater when the lower pressure of hydrogen is used.

As an example of the use of these tables, let us calculate the candle-power fluctuation of a 5 mil tungsten wire in nitrogen when run at the temperature equal to that of a filament running at 0.45 watts per candle in a vacuum. We see from Table I that $\beta = 9.4$ and therefore

$$F = \frac{9.4}{f}$$

With a 60 cycle current, $F$ would thus be 0.157. This means that the candle-power would vary periodically (120 cycles per second) with an amplitude of approximately 7.8 per cent. The ratio of the extremes in candle-power would be 1.078:0.922, or 1.17.

It is evident from Table III that the amount of fluctuation that can be obtained with straight filaments in gases, especially hydrogen, is enormously great.

For example, for a one mil wire run at 3000 in hydrogen at atmospheric pressure, we have

$$F = \frac{780}{f}$$

Thus, with a frequency of 3900 cycles, the relative candle-power fluctuation would be 0.2; that is, the candle-power would vary between extremes 0.9 to 1.1 of the mean candle-power. With a frequency of 780 cycles, the value of $F$ would be unity. Since we defined $F$ as $\Delta ln\ H$ and since $ln\ 2.72$ is unity, we see that the value $F = 1$ corresponds to a change in candle-power in the ratio of 1:2.72.

With currents of such high frequency of course the flicker would not be noticed, but with a rotating mirror, the stroboscopic effect would be very apparent.

A qualitative study of the stroboscopic effects obtained with tungsten lamps and of the effects caused by the introduction of gases, has been made by C. F. Lorenz (*Electrical World*, Nov. 30, 1912). The results obtained seem to be in general accord with the equations derived in the present paper.

### Experimental Determination of Candle-Power Fluctuations

The equations already given should render it possible to calculate accurately the relative candle-power fluctuations in any type of incandescent lamp run on alternating current.

The greatest source of uncertainty is due to lack of extensive experimental data on the specific heat of tungsten at high temperatures. The error that could creep into our equation from this source would hardly exceed 5 or 10 per cent.

It was thought well, however, to put the equations to a practical test by making an actual determination of the candle-power fluctuation on a couple of lamps.

For this purpose an eight-pole synchronous motor was fitted up with a rotating sector consisting of a disk with eight teeth along its circumference. The space between the teeth was made equal to the width of the teeth. This rotating sector was set up in front of the opening of a portable Weber photometer, which was sighted on the test lamp. By running the synchronous motor from the same alternating current supply as that used for the test lamp, it was possible to determine the candle-power of the lamp at any part of the cycle. The rotating sector was shifted in front of the photometer so that first a maximum and then a minimum reading was obtained, each reading corresponding to the average candle-power during one-half of a cycle of temperature fluctuation, the two half cycles being displaced 180 degrees in phase.

Two test lamps were studied.

The first lamp was a standard tungsten lamp having the following characteristics when run on direct current at its rated voltage:

28 volts
0.453 ampere
9.3 candle-power
12.7 watts
1.37 watts per candle.

This lamp was photometered through the rotating sector when running at 28 volts on 29 cycle alternating current.

In shifting the phase by moving the rotating sector, the ratio of the maximum to the minimum candle-power was found to be 1.23 as the average of a number of closely agreeing determinations. The maximum and minimum values thus measured are not the true maximum and minimum, but are averages during two half cycles. It can be readily shown that the maximum variation in candle-power is ½ π, or 1.57 times the average variation during one half cycle. The value of $F$ is thus found to be

$$F=\frac{\pi}{2}\ ln\ 1.23=0.324$$

This means that the relative candle-power fluctuation is 0.324 of the mean candle-power. Or, more accurately, from equation (15), the ratio of the true maximum candle-power to the minimum is 1.38, or again, if we take 9.2 to represent the normal candle-power of the lamp, the instantaneous candle-power varies between the limits 7.8 and 10.8.

Let us now compare this result with that calculated from our equations. Since the lamp was a regular tungsten lamp with exhausted bulb, we can calculate $F$ from equation (21), taking the proper value of $A$ from Table I.

As the lamp was running at 1.37 watts per candle, we interpolate between the values for $A$ given for 1.25 and 1.50 watt per candle, and find $A=5.3$. Substituting this, together with $f=29$ cycles and $i=0.453$ amp. in equation (21), we obtain

$$F=0.31$$

This value is in first class agreement with that found by direct photometer measurement, namely, $F=0.325$.

The second lamp tested was a 6.8 ampere nitrogen filled lamp. The characteristics on direct current were

19.1 volts
6.80 amperes
237 candle-power
130 watts
0.54 watts per candle.
Temperature of filament 2850 deg. K.

This lamp was photometered through the rotating sector when running at 19.1 volts on 26 cycles alternating current. The ratio of the average maximum to the average minimum reading was 1.07. This gives, for $F$

$$F=\frac{\pi}{2}\ ln\ 1.07=0.104$$

With this lamp no flicker was observable, and it was only with difficulty that any stroboscopic effect could be detected by watching strips of white paper pasted onto the rotating sector.

The calculation of $F$ may be carried out as follows: The specific consumption of a filament in a vacuum at 2850 deg. is 0.42 watt per candle (see Table III), as against 0.54 watt per candle for the test lamp which had a helical filament in nitrogen. At constant filament temperature (therefore constant resistance), the current taken by a lamp must be proportional to the square root of the wattage. Therefore, if the nitrogen in this lamp had been pumped out, while the filament temperature was maintained constant, the current would have been decreased in the ratio $\sqrt{54} : \sqrt{42} = 1.13$. We have seen that the effect of helical winding is to decrease the wattage consumed by a given length of wire in the ratio 1.41:1. The ratio of the current taken by a straight to that of helically wound wire in vacuum is therefore $\sqrt{1.41} = 1.19$. Hence the ratio of the current in the nitrogen filled lamp to that which would be required to heat the same wire to the same temperature in vacuum after uncoiling it, is

$$\frac{1.13}{1.18} : 1, \text{ or } 0.95$$

The wattage is therefore less in the ratio $(0.95)^2:1$ or 0.90. Therefore, if we calculate from equation (21) the relative candle-power fluctuation for a filament taking 6.8 amperes at 2850 deg. K. in vacuum and multiply the result by 0.90, we obtain the calculated value

$$F = 0.9 \frac{11.5}{2.6 \times 5.8^{2/3}} = 0.123$$

The value of $F$ may also be obtained more directly (by equation 18) from the weight of the filament. In the nitrogen lamp used in the above test, the weight of the filament ($m$) was found to be 0.101 gram. Substituting this together with $w_0 = 130$, $f = 26$ and $T_0 = 2850$ in (18) we obtain

$$F = 0.127$$

Both these calculated results are in satisfactory agreement with the value 0.104 obtained experimentally.

### Candle-Power Fluctuations in Commercial Tungsten Lamps

The experimental tests having shown that the equations give results in agreement with observations, we may now calculate the candle-power fluctuation of various standard tungsten lamps run at their normal voltages on alternating currents of various frequencies. These results are given in the two tables (IV and V).

TABLE IV—CANDLE-POWER FLUCTUATIONS ($F$) FOR 110 VOLT TUNGSTEN LAMPS WITH EXHAUSTED BULBS

| Watts | Amperes | Watts per Candle | F |  |  |
|---|---|---|---|---|---|
|  |  |  | 25 Cycles | 40 Cycles | 60 Cycles |
| 10 | 0.091 | 1.30 | 1.08 | 0.68 | 0.45 |
| 15 | 0.136 | 1.25 | 0.87 | 0.54 | 0.36 |
| 20 | 0.182 | 1.17 | 0.72 | 0.45 | 0.30 |
| 25 | 0.228 | 1.14 | 0.64 | 0.40 | 0.27 |
| 40 | 0.363 | 1.10 | 0.48 | 0.30 | 0.20 |
| 60 | 0.545 | 1.07 | 0.37 | 0.23 | 0.15 |
| 100 | 0.91 | 1.02 | 0.27 | 0.17 | 0.11 |
| 150 | 1.36 | 0.90 | 0.22 | 0.14 | 0.09 |
| 250 | 2.27 | 0.90 | 0.16 | 0.10 | 0.07 |
| 500 | 4.55 | 0.90 | 0.10 | 0.06 | 0.04 |

TABLE V—CANDLE-POWER FLUCTUATIONS ($F$) FOR NITROGEN FILLED TUNGSTEN LAMPS WITH HELICAL FILAMENTS

| Amperes | Watts per Candle | F |  |  |
|---|---|---|---|---|
|  |  | 25 Cycles | 40 Cycles | 60 Cycles |
| 3.0 | 0.9 | 0.25 | 0.15 | 0.10 |
| 5.0 | 0.7 | 0.14 | 0.08 | 0.06 |
| 6.6 | 0.6 | 0.11 | 0.07 | 0.05 |
| 10.0 | 0.55 | 0.08 | 0.05 | 0.04 |
| 20.0 | 0.40 | 0.05 | 0.03 | 0.02 |

If the values of $F$ given in these tables be multiplied by 100, the result will express the candle-power fluctuation directly in per cent.

It is seen at a glance from these tables that the candle-power fluctuations in the nitrogen filled lamps are negligible. Thus a 5.0 ampere nitrogen filled lamp on 25 cycles shows a total fluctuation of candle-power of only 14 per cent, an amount too small to be observable, being less than that of a 250 watt vacuum lamp.

A Good Example of Modern Illumination

# PRESENT TENDENCIES IN STREET LIGHTING

By Dr. Louis Bell

Consulting Engineer, Boston

Dr. Louis Bell shows in this article that the present tendencies of street lighting are hard to define, owing to the transition stage through which we are passing, and it is pointed out that other considerations besides specific consumption, such as steadiness and cost of maintenance and supplies, are important factors in determining the selection of lamps for street lighting. The size of units, the spacing, and the type of lamp should be selected with due reference to the specific requirements of the individual locality. The author deals amusingly with the real purpose of street lighting. The article is concluded with a few remarks concerning the inefficiency of some of the modern types of lamps which are being considered for street lighting purposes.—Editor.

Dr. Louis Bell

Just at the present time we are passing through a transition period in street lighting. The old order of things is passing away and it is by no means certain what will come out of the turmoil of change. In street lighting, as everywhere else, a steady movement toward higher efficiency is going on and yet one cannot be safe in predicting off-hand that the only criterion by which illuminants for street lighting are to be judged will be specific consumption. Ten years ago street lighting in this country was, so far as electrical illuminants are concerned, chiefly a matter of enclosed arc lamps, either d-c. or a-c. and series incandescent lamps such as had been used for a decade previously. The introduction of the enclosed arc did not make for light-giving efficiency, for it was perfectly well known to those acquainted with the facts, even at the time mentioned, that the enclosed arc showed something like twice the specific consumption of the open arcs which had preceded it when the latter were properly run with a good grade of carbons. From the mere standpoint of watts per candle the change to the enclosed arc was a step backwards.

The choice of the new illuminant depended then upon something altogether outside the efficiency. To push the analysis a little further, the fundamental advantage of the enclosed lamp was its great steadiness compared with the open arcs as commonly operated. There has never been to the writer's knowledge a circuit of first class open arcs, in the European sense of the description, regularly operated on this side of the Atlantic, on account not so much of the cost of trimming in labor, but from the fact that the necessary grade of carbons has never been readily obtainable in this country and can be imported only at large expense. Open arcs such as are found in Vienna today would have kept the enclosed lamps from even a look-in at the street lighting business; but taking conditions as they were, the man on the street liked the new lamp because it possessed conspicuously a quality which its predecessor lacked. The enclosed lamp was, moreover, desirable from the standpoint of the central station as somewhat cheaper and more convenient to operate, and its use was therefore pushed by that sort of psychological appeal which good salesmen have always been able to make. If an article has certain clear and conspicuous points of merit the insistent iteration of these to the exclusion of all other matters by merely crowding them out usually produces an effect.

About five years ago, with the introduction of the metallic filament lamp things took on a new aspect. It was perfectly obvious to the engineer that these lamps were immensely more efficient as light producers than the enclosed arcs, and as soon as they became available in reasonably large sizes a process of substitution began. It was preceded, however, by another movement, also psychologically interesting. The matter of distribution of light by small units suddenly came to the front. It had been seriously considered when the old carbon lamps were available, but these were too inefficient to allow the plan to be tried on an effective scale. With incandescent lamps more efficient than the arcs, the call for better distribution by a multiplicity of small units was vigorously raised. In some respects the demand was very reasonable, for if there is any one thing in which American cities have sinned, from the standpoint of good lighting, it has been in the use of arcs at a spacing so wide as to reduce the minimum between lamps to a quantity which for seeing purposes is practically negligible.

The first fruit of the new movement was the tungsten cluster, very beautiful and effective in its proper place, but frequently most ineffective and entirely unsuited to its environment. The place of tungsten clusters is where a moderately strong illumination only is required, where an appropriation sufficient to place the posts rather close together is available, and above all where decorative fixtures harmonize with artistic surroundings. A beautifully and symmetrically built business street, with buildings not too high, can be lighted by tungsten clusters with wonderfully effective results; but the same fixtures placed on a shabby straggling street with dirty gutters and slovenly sidewalks deserves almost to be classed as a practical joke. The same criterion holds good with respect to the boulevard type of arc introduced to compete with the tungsten cluster where the retention of arc lights seemed for one reason or another desirable.

The move in the direction of smaller units than the arc lamps furnished was on the whole a healthy one, since it enabled pretty good lighting to be maintained in streets where the requisite number of arcs for their proper utilization would be out of the question. It seems to be a tendency of the human mind, however, to follow an apparently reasonable idea with unreasonable pertinacity, hurrying along the broad highway until it dwindles into a footpath and finally terminates in a squirrel track which runs up a tree. Hence came extreme examples of sub-division of units such as may be found in Toronto, where of late there has been a storm of protest against lack of light. The fact is that in the last resort the choice of illuminants comes down to a matter of psychology which cannot be reasoned out on theoretical principles beforehand. People almost universally like a brilliant effect, particularly in the center of a city. They like brilliant lights, even glaring ones. This perhaps may be an inheritance from the time when their savage progenitors danced around the camp fire in the days when fire making was an art new to man; but whatever the cause, the fact remains that the ordinary person, the man on the street, would not be satisfied with artificial moonlight even if he could get it. One cannot, therefore, push the subdivision of units too far, nor can he by any amount of preaching persuade his fellows not to like the glitter and snap of a brilliantly lighted room or street.

Fundamentally street lighting is, and was, a police measure, introduced nearly two hundred and fifty years ago as a defense against brigandage. Such remains its function up to the present time to a very considerable degree. All of a city that is at all thickly inhabited, requires a certain effective amount of lighting for police purposes, enough to enable the guardian of the peace to distinguish between a worthy burgher late home from his club, and a gentleman with a jimmy sneaking around for a chance to pry open a window. Within that part of a city in which the traffic is dense and in streets largely used at night, something a good deal more effective is required, enough to enable one to distinguish faces, read addresses, dodge automobiles and keep from tripping over projecting paving stones. Finally, there is a certain amount of outlying territory in which lights are desirable for the guidance of traffic rather than for illumination, merely as markers of the way to prevent pedestrians from wandering into the gutters and inebriated chauffers from trying to climb telegraph poles alongside the road. It is perhaps in this minor lighting that the interesting theory of silhouetting finds application.

There are, then, many distinct phases of street lighting and it is perfectly safe to say that no one system of illumination can meet all of them equally well in the utilitarian sense, let alone in the artistic sense. And now we have the gas-filled lamp coming into the field, and improvements in arcs to meet the new competition are undoubtedly on the road. It is something of a feat to improve the efficiency of the incandescent lamp by 30 or 40 per cent, but this change is by no means as great from the dollars and cents standpoint as was the change from the carbon lamps to the first metallic filaments. People who expect that the cost of street lighting is going to be cut in two by the "half watt lamp" are due to be grievously disappointed. In the first place the gas-filled lamp as it appears at present does not run very close to 0.5 watt per candle-power except in sizes which bring it into direct competition with flame arcs at 0.2 or 0.3 watt per candle-power, and long-burning at that. The first effect of the new comer ought to be the complete wiping out of the whole tribe of open and enclosed carbon arcs, except the intensified arcs invaluable in color discriminations. They can advantageously be replaced by the medium sized gas-filled lamps, even if these are worked at 0.6 or 0.7 watt per candle instead of at 0.5.

In the smaller metallic filament lamps the gain in efficiency is worth taking, particularly on account of the improved color of the lamp. In the actual saving of energy the gain is not impressive so far as the present outlook for the smaller lamps goes. In a 100 c-p. lamp, for example, on all night service, the gain would be from present figures something like 100 kw. hours—worth saving, but by no means revolutionary. Very possibly higher efficiencies of the metallic filament lamp may come into sight, but there is absolutely no chance for the wholesale saving in energy that was brought about by the abandonment of the carbon filament lamp. Meanwhile, where brilliant lighting is desirable and the new incandescent has to make a frontal attack on the flame arc, the battle will not be an easy one to win. The writer saw long-burning flame arcs, very fine and steady, in Paris, which were actually doing a little better than 0.2 watt per m.l.h. c-p., in units taking less than 500 watts. There is a great gap left yet between this and the efficiency of any lamp that depends on an incandescent filament. Unless it should prove possible to make very revolutionary improvement in the incandescent filament, far beyond anything as yet promised, the best of the arcs can save enough energy to hold their own for some time to come. The writer will, however, be much disappointed if the gas-filled lamp or some successor in business does not within two or three years make the enclosed arc as hard to find as a whale oil lamp.

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# A NOTABLE DEVELOPMENT IN ORNAMENTAL STREET LIGHTING

By Walter C. Allen

Electrical Engineer of the District of Columbia

There has recently been installed in the central section of the city of Washington, D. C., a luminous arc lighting system which possesses a number of unique features, these principally being the result of the special ornamental design of lamp adopted. The following article briefly reviews the steps which led up to the new system, shows the locations of the lamps on maps, describes in detail the construction of the poles and the special diffusing globes which are employed, and furnishes some very interesting figures on both the investment and the maintenance cost of the installation.—Editor.

Walter C. Allen

Three years ago, after experimenting with various kinds of illuminants, a system of improved lighting with incandescent electric lamps was adopted for the principal avenues and boulevards of the District of Columbia. Since then, over sixteen hundred such units have been installed and are now in successful and satisfactory operation on more than eighteen miles of streets. This method, however, has not been extended to the heart of the business section of the city, nor to that portion of Pennsylvania Avenue connecting the Legislative and the Executive groups of buildings, where a higher intensity of illumination appears desirable. Any system of lighting for this broad, well-known avenue must be efficient in operation, pleasing in design and in keeping with the dignity of the capital city of the nation. After a careful study of the conditions, supplemented by experiments with sample installations, it is believed that the approved plan described below meets all the requirements.

Before entering into the details of this unique system, a brief reference to the history of the lighting of this avenue may be of interest.

The first definite plan for any extended lighting system, as far as the official records show, was adopted seventy-one years ago, when Congress appropriated $2500.00, in 1842, for erecting and lighting lamps on Pennsylvania Avenue between the Capitol and the "President's Square." Although the records are silent as to the kind of lamps, they must have been some form of oil lamp, as it was not until July, 1848, that the first gas light company to operate in the District of Columbia was granted its charter by Congress, followed the next month by another act authorizing the laying of gas pipes and the erecting of one hundred lamp posts in this thoroughfare. The lighting of these lamps, as well as those in and around the Capitol and the President's house and grounds, was paid for by the general government and was placed under the jurisdiction of the Commissioner of Public Buildings, a Federal officer. The lighting of other public streets was maintained by local taxation as a municipal function of the corporation of Washington City. This arrangement, which applied to other kinds of improvements and which gave a national character to Pennsylvania Avenue, continued for about twenty-five years, when changes in the relations between the Federal Government and the Municipality were inaugurated, resulting in the present form of government by commission, with general authority over all the public streets.

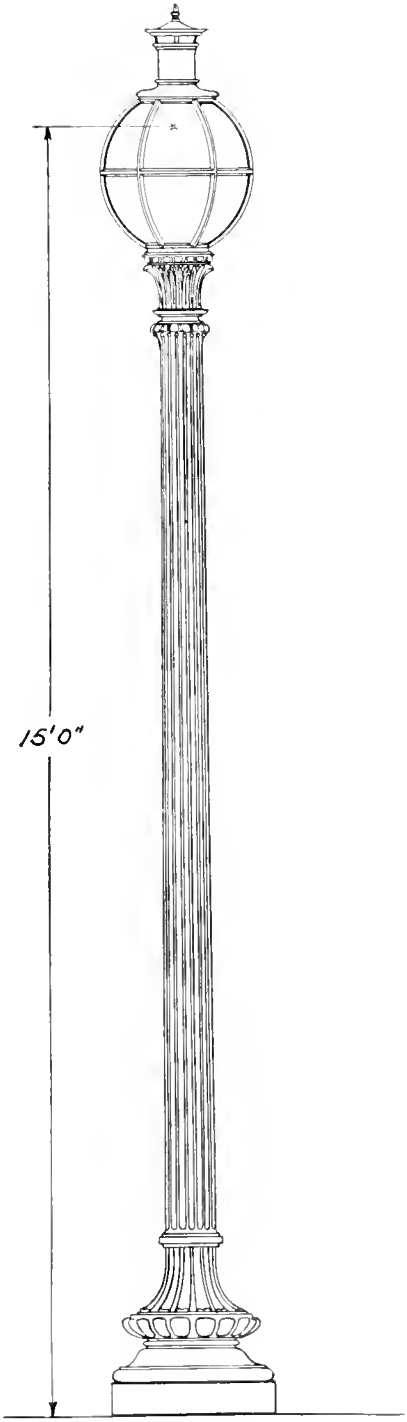

**Fig. 1.** Drawing showing the Ornamental Type of Diffusing Globe and Pole Used in the Installation Described

For the thirty-eight years, from 1848 to 1886, gas was the only illuminant used for the lighting of Pennsylvania Avenue, although experimental installations of electric arc lamps were made on that and other streets from time to time during 1884 and 1885. In October, 1886, a contract was entered into between the District of Columbia and the Potomac Electric Power Company for electric arc street lighting at the rate of 65 cents per lamp per night ($248.20 per lamp per year) on a sunset-sunrise schedule; and twenty-four such lamps were erected on the south side of this avenue. At that time, 123 gas lamps at $20.00 each per annum were used to light the street on a moonlight schedule, totalling 2600 hours.

When the enclosed arc lamp was perfected and after thorough tests with experimental installations, the old open series lamps were replaced in 1902 with multiple enclosed lamps, and these are now being supplanted by lamps of the type described in this article.

Before the adoption of this plan, several other methods of improving the lighting of Pennsylvania Avenue were considered. One involved the erection on "isles of safety" of two rows of standards in the roadway close to the outer rails of the street car tracks, supplemented by lamps at the curb lines among the trees. This plan was described in an illustrated article in the "*Illuminating Engineer* (N.Y.) for January, 1909, (Vol. 3, No. 2). It was formally referred to the Commission of Fine Arts in 1911, whose report states that:

> "Members of the Commission are personally familiar with a large number of the instances, both abroad and in this country, illustrated in the paper

accompanying the report on the plan, and each of the members has independently reached the opinion that in every case of long straight avenues the appearance of the streets has suffered materially from the presence of the posts in the midst of the street. Therefore, in spite of the fact that such a method of lighting has been tried in many important thoroughfares, it is believed that lamps on tall posts, with isles of safety in connection, near the middle of the roadway, would confuse and seriously injure the appearance of Pennsylvania Avenue, the most important vista in the Capital. Another consideration, which is both practical and aesthetic, is that the presence of these posts and islands in the roadway would interfere with the best handling of parades."

Fig. 2. Photograph showing the Ventilator, Diffusing Globe and Casing Containing the Lamp Mechanism of One of the Units

The elimination of a roadway plan of lighting practically fixed the position of the posts at the curb in line with the trees. In 1912, experiments with both tungsten and luminous arc lamps were made with posts in this position on a portion of the Avenue, resulting in the adoption of the system herein described.

### Lamps

The greatest interest in the technical features of this installation centers around the lamp itself and its novel treatment. The standard 6.6-ampere luminous arc lamp of the General Electric Company, fully described in the issues of December, 1911, and November, 1912, of the GENERAL ELECTRIC REVIEW, is used for this purpose, equipped, however, with special parts to adapt it to its unusual method of installation. The standard form of globe used by the makers of the lamp has been replaced by an elongated spherical-ribbed frame holding segments of alabaster glass. The main insulator on which the lamp mechanism rests is enclosed in the ornamental cast-iron casing, instead of being exposed as in the standard forms. Trimming is done in the usual manner by removing the spun-metal ventilator and raising the upper fume box and insulator on the specially constructed flat slide rod. The lamp mechanism is so adjusted in the frame that the shadow cast by the rod is thrown on one of the ribs, and as it is not greater than the width of the rib the globe is left absolutely shadowless. By this operation, access is also given to the interior of the globe for cleaning and adjustment of the upper parts, while the terminals and lower coils are reached through a door in the ornamental iron casing. More room for working around the lamp may readily be obtained by removing the upper half of the ribbed frame, Fig. 3. Figs. 5 and 6 show the details very clearly.

Fig. 3. View showing the manner in which the Globe Can be Dismantled for Cleaning. Transparent glass is here used only to show the lamp

**Ribbed Frame and Glass**

After many experiments in various metals, the General Electric Company found that aluminum gave the best results in casting the ribbed frame, which is made in two hemispheres, an upper and a lower. It is not a true sphere, being described about two centers two inches apart, see Fig. 7. It is not insulated from the post, but rests upon the cast-iron casing, and is rigidly held to it by three set screws. Fig. 4 shows the dowel pin on the inside of the casing, used to hold the lamp mechanism in its proper position. The glass, known as "polycase alabaster," is specially designed for use with luminous arc lamps and is made by the Gleason-Tiebout Glass Company of Brooklyn, N. Y. Difficulties in manufacturing moulded segments of glass of this character made it necessary to first blow the glass as a sphere to the proper diameter, approximately 23 inches, grind the top and bottom openings to size, and then cut the globe in segments to fit the ribbed frame. As far as is known, this is the first instance where it has been possible, on an extended scale, to fit blown glass to cast metal frames with any degree of accuracy. The inner surfaces of the ribs are lined with felt and the glass is held against them by equalizing spring fasteners shown very clearly in Figs. 7 and 8. This fastener is so designed that the pressure is distributed equally on all panes, besides providing for irregularities in thickness and allowing for expansion and contraction. The glass segments are inserted from the inside of the frame, and can readily be replaced while in position on the post.

Two densities of glass are used, "medium" in the upper half and "light" in the lower

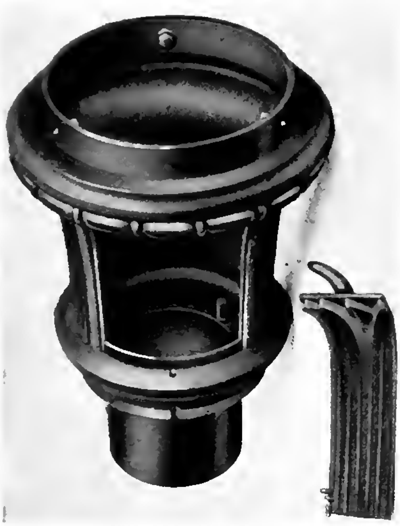

Fig. 4. Casing Container of the Lamp Mechanism

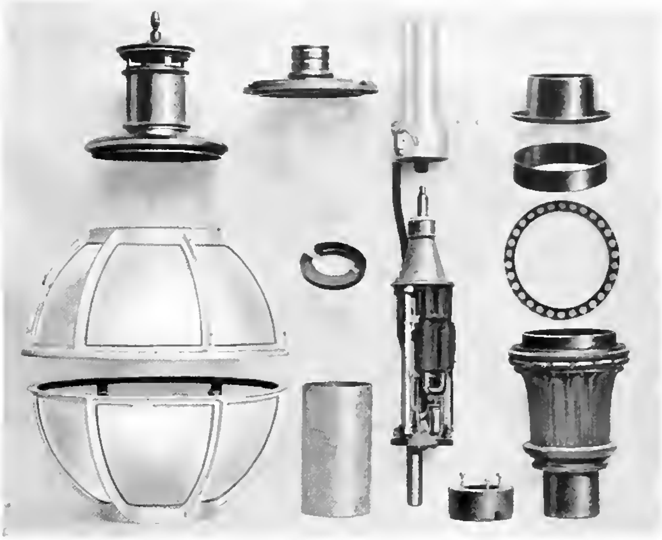

Fig. 6 View of the Parts Making Up the Lamp Unit

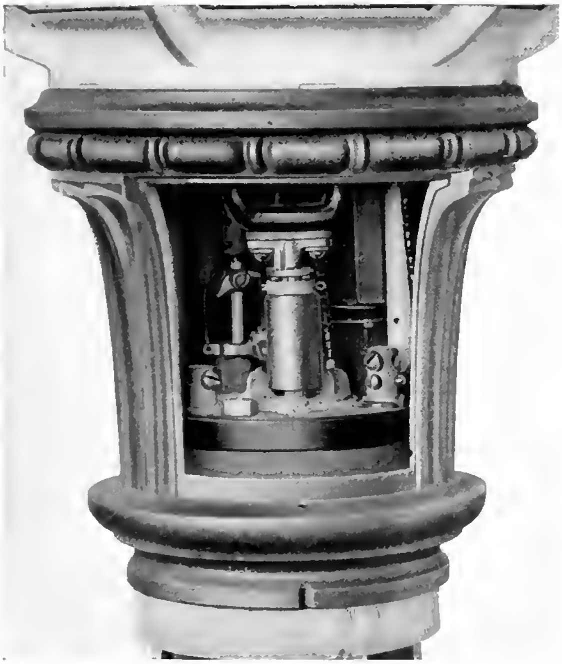

Fig. 5. View of the Lamp Casing Mounted at the Top of the Pole, Door Removed to show the Lamp Mechanism

half of the frame, both of which give such perfect diffusion that no shadows, no portion of the lamp mechanism, and not even the arc itself are visible. When the lamp is in operation, the glass becomes a luminous surface radiating a powerful, yet soft light, without glare.

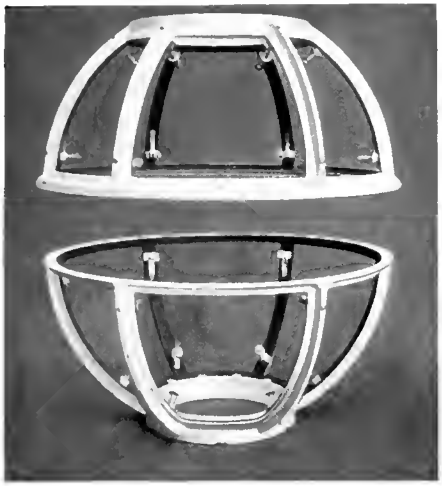

Fig. 7. The Two Semi-spherical Halves of the Globe Frame Located According to their Respective Centers

Fig. 8. The Means Used for Holding the Glass in the Frame of the Globe

### Insulation

Insulators of special General Electric waterproof compound, instead of the standard glazed porcelain, are used between the lamp mechanism and the top of the cast-iron post. These are tested at 20,000 to 25,000 volts. As stated above, they are placed within the iron casing. A specially shaped ring of the same composition is placed on the top of the aluminum frame to insulate the spun metal ventilator and upper fume box from the post. A cylindrical lining of mica, the sides of which are $\frac{3}{16}$-inch thick, is placed around that portion of the mechanism within the cast-iron casing.

### Posts

The posts were designed by James Rush Marshall and Albert L. Harris, of the firm of Hornblower & Marshall, architects, of Washington, D. C., and follow the lines of the posts, also designed by them, that are used in the improved incandescent electric lighting system of that city and which have been so favorably commented upon. See Fig. 1. For description of this incandescent electric lighting system, see the *Illuminating Engineer*, N. Y., for January, 1912, Vol. VI., No. 11.

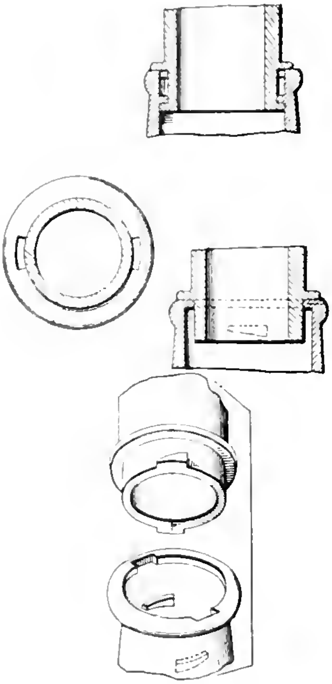

Fig. 9. Drawing showing the Method of Fastening the Lamp Pole to the Base

In casting the posts for the Pennsylvania Avenue installation, the Union Foundry Company, of Anniston, Alabama, used a very ingenious device, patented by them, for locking the shaft to the base. (See Fig. 9, which is reproduced from the Patent Office

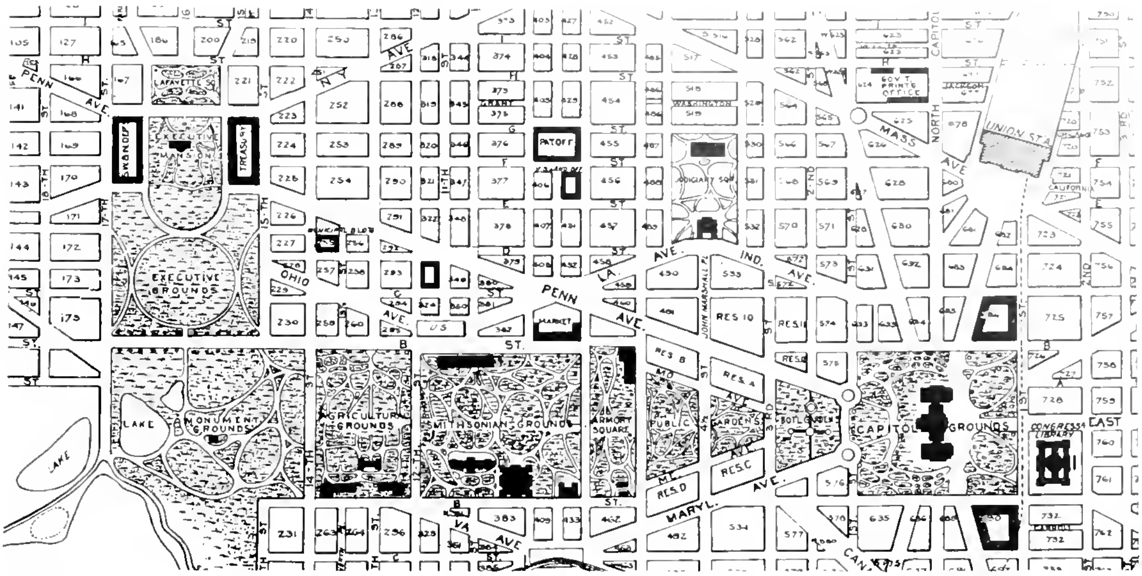

Fig. 10. Map of the Federal Government Section of the City of Washington showing that portion of Pennsylvania Avenue which is Lighted by the New System

drawings.) By a single turn of the shaft after inserting it in the top of the base the two are locked firmly together. This method obviates the necessity for bolts or set-screws to hold the two parts together, and greatly facilitates the erection of the posts.

Full-size plaster models were made by John J. Early, sculptor, of Washington, D.C., from the architects' drawings, with several types of lamp casings and globes, among them the standard design of the General Electric Company, a one-piece globe, and a spherical ribbed frame. From the study of these several combinations the final design was evolved. The accepted models were then sent to the foundry, and from them, as guides, the patterns were made.

The section of the city covered by this improved lighting installation is that portion of Pennsylvania Avenue which is shown in Fig. 10. Fig. 11 illustrates to scale the manner in which the intersecting streets form open spaces, and shows the typical arrangement and spacing of the posts.

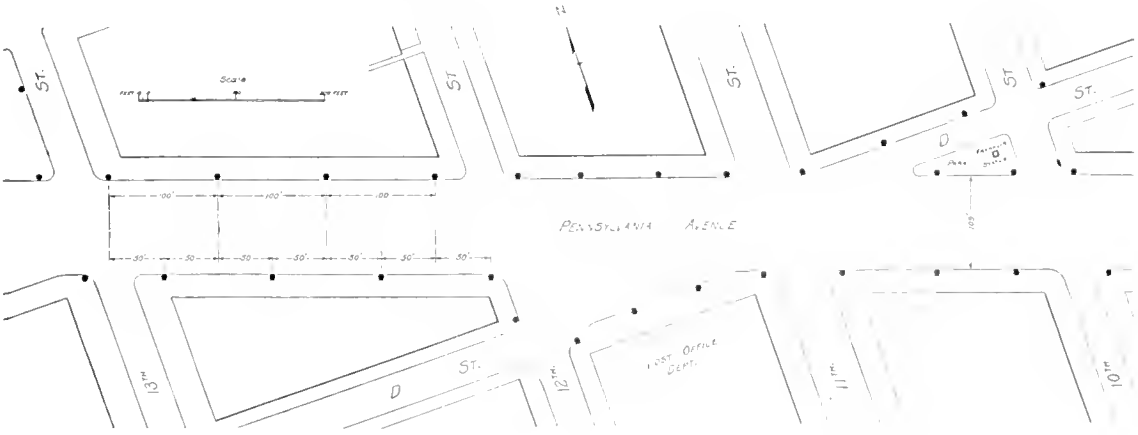

Fig. 11. A Scale Drawing showing the Location of the Lamps in the Neighborhood of the Post-Office Department

Fig. 12. Two Views of Pennsylvania Avenue Taken Toward the Treasury Building showing the Appearance of the Lighting Units as Installed

Along the unbroken length of the avenue, the distance between curbs is 109 feet; this is increased to as much as 200 feet at the open space in front of the Post Office Department building where the usual triangular parking is omitted. (See Fig. 11.) As these numerous open spaces are in reality a part of the avenue proper, the improved lighting has been carried around them, an average spacing of 100 feet between posts being maintained both on the main throughfare and on the offsets.

The cable for this installation is single conductor No. 8 B.&S. gauge copper, insulated with 8/32-inch varnished cambric and protected by a ⅛-inch lead sheath. The conduits into which it is drawn were laid many years ago, and are in the roadway within three feet of the curb on both sides of the street. The cable is carried up the post to the lamp terminals without breaking the lead covering, no cut-out being used in the base of the post. Two circuits are used, with the lamps on the two sides of the street connected alternately thereto. With this arrangement, it will be possible to burn half of the lamps after midnight and still give a sufficient and fairly uniform illumination.

The following figures refer to the main avenue only; the offsets are not included:

Length of roadway on center line, 6356 feet.
Width of roadway, 109 feet.
Square feet of roadway, 692,804.
Number of lamps, 123.
Total watts at 520 each, 63,960.
Annual maintenance cost ($97.50 each), $11,992.50.
Watts per linear foot, 10.06.
Watts per square foot, 0.0923.
Cost to maintain per linear foot, 1.886.
Cost to maintain per square foot, $0.0173.

The exact figures of the cost of installation are not at hand; they are estimated to be $170.00 per unit, exclusive of the posts, ribbed frames, glass and special parts, which are furnished by the municipality and cost as follows:

| | |
|---|---|
| Cast-iron post...................... | $26.90 |
| Cast aluminum ribbed spherical frame | 37.50 |
| Special parts...................... | 3.00 |
| | $67.40 |

The installation of cables, erection of posts, etc., is made by the Potomac Electric Power Company at its own expense, which company also maintains the lamps at the rate of $97.50 each per annum, less $4.40 deducted as interest and depreciation on the municipally owned posts, in accordance with the Acts of Congress establishing rates for street lighting in the District of Columbia.

Fig. 13. A Near View of One of the Lighting Units

Everyone connected with the development and installation of this lighting system has shown a lively interest in making it an ornament to the Capital City and a model for other municipalities, and to them the thanks of the citizens and officials of the District of Columbia are due.

# AN EXAMPLE OF A MODERN ARC-LIGHTING SYSTEM APPLIED TO THE LIGHTING OF BOULEVARDS

By G. N. Chamberlin

Engineer, Arc Lamp Department, General Electric Company

The immense advantage of the luminous arc-lighting system in congested districts has been firmly established. The mushroom-like growth of popularity with which the "White Ways" have been received attest this fact. This article shows that its use in the more thinly populated sections promises to meet with equal success, and describes an example of such an installation.—Editor.

G. N. Chamberlin

THE employment of the ornamental luminous arc for the lighting of principal business thoroughfares has been met with such favor that, as a natural consequence, its use is now being rapidly extended to the lesser populated areas. The suitable illumination of public highways has not as a rule been given the careful consideration that it deserves. When such large sums are spent in the building and up-keep of parkways, boulevards, and shore drives, it is thoroughly in keeping that the lighting units should be of the same high order of excellence.

The following example will clearly illustrate the immense improvement in lighting which can be secured along such highways.

At the expiration of the contract for boulevard lighting, the engineers of the Massachusetts Metropolitan Park Commission, being familiar with the excellent illumination obtained from the luminous arc, approached the Lynn Gas & Electric Company relative to the illumination of that section of the North Shore Boulevard from the Bath House, Lynn, to Monument Square, Swampscott, a distance along the ocean front of about two miles. A thorough consideration of the subject resulted in a contract which provided for the installation and maintenance of forty lamps by the Lynn Gas & Electric Company.

The lighting system previously employed consisted of gasolene mantle lamps, two on a pole. The poles were about 12 ft. high and the lamps were equipped with large clear globes arranged in the usual manner. Fig. 3 shows a portion of this boulevard at

Fig. 1. The Method Used in Filling the Lamps of the Old Gasolene-Mantle Lighting System

Fig. 2. View showing the Laying of the Ducts through which the Luminous Arc Lamps are Supplied with Current

Fig. 3. A Day View of One Section of the Boulevard taken before the Installation of the Electric Units

Fig. 4. A Night Photograph showing a Portion of the Boulevard as Lighted by the New Luminous-Arc System

Fig. 5. A Day View showing the Location of the Luminous-Arc Units Furnishing the Lighting shown in Fig. 4

the time the old lamps were used. The mantles were rated at 32 c-p. each but, under service conditions, some were found to run as low as 15 c-p. and a number of tests showed an average of about 25 c-p. per mantle. Each lamp contained a small reservoir which held only enough gasolene for one night's burning. The method used in filling these reservoirs is shown in Fig. 1.

The light given by these lamps was, however, thoroughly inadequate for either the automobilist or pedestrian. Photometric tests made in the center-line of the street with a Sharp-Miller photometer gave an average of 0.03 foot-candles opposite the lamp and an intensity halfway between the lamps far below the reading limits of the instrument.

The new lamps which were turned on for the first time Christmas night, 1913, are of the ornamental luminous arc type, operating on a 4.0-ampere rectifier circuit and consuming about 300 watts each. The arc is placed 18 ft. from the ground, and the lamps are spaced from 200 to 300 ft. apart on the shore side of the Boulevard. A light-diffusing globe is used which distributes a well-diffused and pleasing white light. Fig. 6 shows a complete unit installed. These tall, slender poles with a single globe at the top are in no way conspicuous but, when attention is directed to them, they are found to be artistic in design, harmonizing perfectly with the beautiful stretch of boulevard maintained by the Commonwealth of Massachusetts.

The work on this installation was started Dec. 3rd, and completed Dec. 23rd. Some idea as to the method of underground construction used can be obtained from Fig. 2. Fig. 5 shows a section of the Shore Drive with the luminous units installed.*

Fig. 4 is a night view of the roadway and promenade. Photometric tests, made under similar conditions to those with the old gasolene lamps previously mentioned, show for the luminous arcs 0.37 foot-candles in the center of the road opposite the lamps and 0.008 foot-candles halfway between the lamps. This is about twelve times the illumination secured from the gasolene mantle lamps; and it is rather interesting to note that this increased illumination is being furnished at less cost than that of the previous gasolene installation. Although the roadway

Fig. 6. A Complete Luminous-Arc Unit as Installed in the Boulevard Lighting System

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* It will be noted that at the time of writing this article sufficient time had not elapsed to allow of removing the old units.

presents a dark, poor reflecting surface, the single units are of sufficient intensity to make use of the now generally understood silhouette principle of lighting.

The promenade is of granolithic construction having a better reflecting surface and shows figures in excellent relief.

A very pleasing sight, since the installation of these arc units, is the white crests of the breakers along the beach. The intrinsic brilliancy of the light source is also noticeably low and does not interfere with the ocean view from the residences on the opposite side of the Shore Drive.

From the results now being obtained, it would seem certain that the ornamental luminous arc lamp can be used as economically and efficiently for this class of work as for the illumination of the more densely populated areas.

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# SOME SPECIAL FIELDS OF INCANDESCENT LIGHTING

By G. H. Stickney

Assistant to Sales Manager, Edison Lamp Works, General Electric Company

In making a survey of the fields of incandescent lighting, we find that they naturally divide themselves into two classes; viz.; those that require an individual treatment in order to conform to artistic requirements, and in which ornamentation is largely the governing factor; and those which can be more or less standardized in practice and in which utility is the first essential. In designing installations of the first class the case must be worked out on its own merits; precedent, where there is any, counting for little, and standardization being reduced to collection of descriptions of existing installations. In the second class, however, where decorative effects are of secondary importance, the results from several similar installations can be averaged, and the data so obtained, with possibly slight modifications, can be used for future work. Fortunately, most of our lighting problems belong to the second class and are becoming to a certain extent standardized. Some of the more important branches of lighting in this class that are fast becoming standardized, such as street car lighting and the use of concentrated filament, with parabolic reflectors and lens systems, are reviewed in the latter part of the article.—Editor.

G. H. Stickney

The problem of extending the application of incandescent lamps by securing their right use in existing fields and determining applications in new fields is exceedingly interesting, especially at the present time when improvements of great value are succeeding each other with astounding rapidity. These remarkable improvements, along with the increased interest of the public—for good lighting is its own best advertiser—has brought about wonderful changes, influencing every human activity of work or play.

The popularity and extended use of an illuminant depends upon its being applied in such a manner as to give the greatest service and satisfaction to its users. On this account it has been found profitable by manufacturers of illuminants to expend considerable sums in studying the requirements of the various fields of illumination, in order that their customers may be properly informed as to the best selection, equipment and arrangement of lamps.

With the present practice of concealing the wiring, changes in lamp locations are expensive, and it is important that an effective arrangement of lamps be determined before the structure is completed. This presents quite a contrast to the custom of ten or fifteen years ago, when it was the practice to add the lighting to a completed structure, so that comparatively little trouble and expense were involved in later changes.

While in the past there have been master architects and engineers who have acquired wonderful facility in the use of lighting units, each one has held his methods as his personal stock in trade, to be kept secret as far as possible for his own benefit. The result was that, in a very large proportion of installations, the arrangement of lights was not such as to give the best effect, and there was a tendency on the part of the rank and file to follow such rule-of-thumb methods as happened to be known. With the twentieth century has come the new idea of co-operation and this is having a remarkable effect in improving the practice in the design of lighting installations.

In undertaking such installation designs, we find that lighting problems naturally arrange themselves into two classes; first, that in which individual treatment is required to conform to artistic requirements; and second, that in which the practice can be more or less standardized.

The first class includes those problems in which decorative effect is the predominating feature. Although in most cases of this sort the actual distribution of light follows fairly definite and well-known methods, individual treatment is necessary principally with regard to the ornamental design of fixtures and, to a certain extent, in carefully proportioning the illumination factors for the particular conditions. Unquestionably this element of individuality is sometimes abused in the effort to produce something different from what has already been done well, without regard to whether it meets the particular conditions better or worse than the usual practice.

In recording the practice in regard to any such special effects, it has been necessary to use what is sometimes called the "case system," in which particular installations are described, since the experience in completed installations cannot be interpreted directly in designing new ones.

In the majority of lighting installations, however, utility is the first essential, and ornamental features, while they should not be neglected, have to be restricted for the sake of economy. So, in studying the practice for these problems of the second class with the idea of improving future installations, the results obtained in a number of similar successful installations can, to a certain extent, be averaged and constants thereby determined, standardizing the practice for that particular type of work. We have sometimes called this method of treatment the "method of averages." For example, if by experiment or observation, we find a particular arrangement of lighting units especially advantageous for the lighting of weave rooms of a certain type, this arrangement can be standardized and used with very slight modifications for future work. This method is particularly applicable for classes of lighting where the individual installation is small but the number of similar installations very large. While a single installation might not warrant the expense of expert study, the class does if the results can be made available in such a way as to improve the practice. An interesting example of work along this line was an investigation carried on under the direction of the writer in endeavoring to improve the lighting of ordinary small stores such as are found in all communities. In the course of this investigation the lighting of approximately 800 such stores was examined and record made of the principal simple constants and features peculiar to this class.* Since a a large number of small store installations are planned by those not familiar with the technical terms and methods often employed in illuminating engineering, it was important that the results be expressed in as simple English as possible, and it was found practicable to express the quantity elements in terms of the electric power per square foot required by standard mazda lamps equipped with efficient reflecting devices. It is, of course, to be anticipated that some of these quantitative values will be affected by changes in the efficiency of lamps as well as by the constantly rising standard of lighting, and that the values may have to be revised from time to time. On the other hand, the tendency of these two variables is to compensate for each other so that the data will not become obsolete as soon as might otherwise be expected.

Commercial, industrial and street lighting are, in a similar way, being more or less rapidly standardized with regard to their particular sub-classes, especially where conditions are sufficiently established to warrant standardization.

Probably one of the most important and one of the most difficult elements to standardize is that of quantity, since this is determined as a compromise between useful effect and cost; and it is largely for this reason that the method of averaging results in a number of successful installations becomes so valuable.

A special problem in lighting which is exciting considerable attention and interest at the present time is the lighting of street railway cars. Until very recently all street railway cars were lighted by means of bare, low-efficiency carbon-filament incandescent lamps. Owing to the rough service, excessive voltage variation and low cost of power, practically no advance in car-lighting was made until the drawn wire tungsten-filament demonstrated its ability to withstand these severe conditions. The conspicuous advantages offered by the mazda lamp were the narrower range of light-intensity variation with fluctuating voltage and a very considerable saving in power. The 23 watt mazda

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* See Law-Powell paper on "The Lighting of Small Stores." Trans. Illuminating Engineering Society, 1912.

has recently been substituted for the 64 watt carbon lamp by a considerable number of street railways. This gives a small increase in illumination delivered with a considerable reduction in power consumption. A study of the problem of car lighting, however, showed that the light could be more efficiently distributed and the illumination made more pleasant to the passengers by the use of prismatic or translucent reflectors; and if, at the same time, a smaller number of lamps of higher power could be used, the cost to the operating company could be considerably reduced, both as to reflector equipment and lamp maintenance. Investigations and tests have been made on the cars of the Bay State Street Railways, as well as on those of a number of other street railway companies. This has resulted in the development of a new method of car lighting which is being adopted especially with regard to new equipments, where an expense for re-wiring will not be involved. *

As an example of new fields of incandescent lighting made possible by the drawn wire tungsten filament, we have the so-called "concentrated filament" lamp applications, in which the lamp is used in connection with a parabolic reflector or lens system in the production of beams of light. The new feature here involved is the possibility of making an incandescent lamp in which the filament is coiled into a small space, approximating a point, a feature which has not been practicable with any of the former types of filaments. Since an approximate point source has very conspicuous advantages for such lens and reflector work in securing a very much higher degree of utilization of light, its importance will be recognized.

Formerly the arc was the only electric illuminant which met these requirements economically, and while today the electric arc gives a degree of concentration and brilliancy that has not yet been equalled by the mazda, it has limitations due to the fact that it is essentially a high-power unit and requires mechanism and skilled attention to keep the light source accurately at the focal point.

The first important application of the concentrated filament lamp has been in automobile headlights and small searchlights, which are now considerably used. The locomotive headlight is another application which is assuming considerable importance, and much study is being given to the determination of the requirements for this service. Up to the present time there have been two distinct practices: one which demanded a high-power headlight, and the other a low-power one, which is little more than a marker. The former has seemed to be desirable on single-track railroads without block signals, while the latter has been used on roads having block signals and two or more tracks. Certain objections have arisen to the use of high-power headlights on the latter class of roads because of the blinding effect of an opposing headlight on the engineer and its interference with the reading of signals. Investigations have not gone far enough to determine a practice to standardize, but it is apparent that in a large majority of cases, a headlight of intermediate power will be required. Since the proper solution of this problem involves the safety of a large number of people transported by the railroads on night trains, as well as large property interests, the problem warrants careful and extended study, and it is probable that within the next year the standardization will be fairly definite.

Another class of lighting which will be largely extended by the use of the concentrated filament mazda lamp is that in connection with small and moderate sized stereopticons and small moving picture machines, in which the simplicity and economy possible with this lamp will greatly extend its use. To what extent the mazda lamp will compete with the arc on the larger machines remains for future development, but investigations are now being carried on covering these and many other lens applications. Here again the individual installation is relatively small, but the aggregate use likely to be very wide and extended.

These few examples suggest the enormous amount of work yet to be done to standardize the lighting practice. There are many other fields not mentioned which are demanding study and attention, both for the sake of extending the business and securing better living conditions.

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* "Latest Practice in Street Railway Lamps," V. L. Staley, GENERAL ELECTRIC REVIEW, December, 1913, p. 955.

# INTERIOR ILLUMINATION

By A. L. Powell

Edison Lamp Works, General Electric Company

In this article the author divides the several kinds of lighting in vogue today into two distinct classes, as was done by Mr. G. H. Stickney in his article beginning on page 315; one class embracing those cases where ornamentation is the first consideration, and the other covering those installations where light efficiency is of prime importance. Those cases coming under the first class are the only ones considered in this article. All artificial illumination is accomplished by one of three methods of distribution, viz., direct, semi-indirect, and totally indirect; the main characteristics of each of which are herein enumerated. As examples of lighting installations that demand special attention from the decorative standpoint, the author has selected for discussion the illumination of art galleries, drafting rooms, hotels and stores, and states for each case the requirements in such matters as intensity, diffusion, direction, distribution, color, and steadiness of the light. Incidentally, economy should always be considered, but never to the extent of sacrificing correct illumination for lower cost of illumination.—Editor.

A. L. Powell

THIS very broad subject is logically divided into two quite distinct classes: One, in which the decorative element and artistic effect of the completed installation demand primary consideration, and where efficiency in terms of light effective on a certain area is of secondary importance. This class of illumination includes church, library, residence and store lighting, and will be the particular phase treated in this article. The other class is industrial lighting, where efficiency of light utilization must be investigated first and the architectural features are practically eliminated. This special division is discussed in another article in this issue.

The systems of illumination may be classified in two fashions:

First, as to arrangement of lighting units producing general illumination, local illumination, localized general illumination, or a combination of two. Most problems of decorative interior lighting are solved by general illumination; that is, the system is designed to give approximately even illumination over the entire working space, or room area. Of course special cases arise which demand local lighting in conjunction with the general illumination, as, for instance, in illuminating the walls of an art gallery with small angle steel or mirrored glass reflectors, or in lighting the music rack of a piano in the residence.

Second, as to the method of supplying illumination to the working plane. The three systems in common use are termed, direct, semi-direct and totally indirect. All three systems are applicable for interior illumination, although each has its limitations, advantages and disadvantages.

*Direct Lighting:* Ordinarily this system results when the lighting device is so arranged that it is quite evident that over half of the emitted lighting flux is directed downward or to the side, reaching the surfaces to be illuminated without being reflected by the walls or ceiling. As this system, when properly designed, is the most efficient and was the primal method of utilizing light, and as the color of surroundings has less effect on the resultant illumination, it is the method most frequently met in practice. This classification would include clear or frosted bare lamps, lamps totally enclosed by diffusing media, and lamps with reflectors, either opaque or translucent, which direct the light downward.

*Semi-indirect:* This system employs a diffusing or translucent device to direct most of the light to the walls or ceiling to be redirected for use, a part of the light being diffused through the glass.

It has been the practice of some engineers to use the term "indirect" for fixtures which have a very dense translucent reflector below the lamp, with less than 15 per cent of the resultant illumination direct from the lighting unit. The claim is that the brightness of the fixture does not exceed the brightness of the ceiling; therefore the efficiency of the eye is as good as under a totally indirect system. However, the layman is prone to look at the lighting equipment from a decorative standpoint, and these units would therefore be termed "semi-indirect."

Another point which would prevent the adoption of this 15 per cent factor is that the classification might have to be confirmed by an illumination test in the room where the unit is installed, for an equipment which might be just on the border line if installed in a room with a very light ceiling, would be indirect under this classification. Then, if the ceiling became dirty, reducing the indirect component of the illumination, the direct portion might be more than 15 per cent, as specified. Thus, the system would become some other type than indirect.

*Totally Indirect Lighting:* With this system all the light emitted by the fixture is projected to the ceilings or walls and thence reflected to the objects to be lighted. Cove lighting falls under this class, and also those equipments which conceal the light source by interposing an opaque reflector between it and the working plane.

The indirect systems are only economically applicable for use in rooms in light finishes, and, generally speaking, they are less efficient than the direct systems. They have marked advantages, however, in very even distribution of light, absence of glare, and minimization of shadows.

While there are many splendid examples of totally indirect lighting, the semi-indirect seems to meet with almost universal favor; it possesses all the advantages of the totally indirect and has, in addition, several good features: First, the place where the light originates is readily detected by the layman (which is a natural condition, for during a long period of years man has grown used to seeing the source of light, either in its full brilliancy or shaded); second, the fixture does not show up as a dark spot against a white background; third, it is possible to make the units of etched and tinted glass, which are really things of beauty; and fourth, the semi-indirect is under most conditions a little more efficient than the totally indirect system.

Whatever system is adopted, the relation of the lighting to the architecture should be given much consideration. This is a feature which in the past has sometimes been neglected. Now, however, the introduction of many types of diffusing and directing media has drawn the attention of everyone to the great possibilities for effects which may be secured with the aid of artificial lighting. Direction and color of light play such an important part in the design of an interior, that a simple means of investigating the effects produced by any given system is desirable. Many lighting engineers have constructed boxes arranged somewhat in the form of a miniature theatre, with means for directing the light from above, below, at the sides, etc., and also means for changing the color. In this box are placed various pieces of ornaments, pilasters, friezes, etc., and the direction of light is varied. The play of the shadows and high lights is remarkable and often startling in its variations. Then a portion of colored decoration is placed in position and mixtures of various colored lights introduced until the desired result is secured. Slight experimentation along this line may often save much time and expense to the designer.

It is obviously impossible to discuss all classes of interiors, but a few types have been chosen and a brief summary of their requirements is outlined, accompanied by a few illustrations showing the method employed to carry out the ideas embodied in the text.

The classes outlined are widely diversified and the illustrations show the use of quite different systems, as it is desirable to demonstrate in as brief a manner as possible the wide range of application of illuminating devices.

### Art Gallery Lighting

Three factors which are prominent in the correct lighting of art exhibits are: (a) direction of light; (b) color of light; (c) intensity.

(a): When lighting paintings the light source should be arranged to throw practically all of its light on the exhibit and none in the eye. This must strike the work at such angles that it is not directly reflected into the eye, and yet it must cover completely the surface to be illuminated.

In lighting statuary, it is necessary that the units be located so that daylight is simulated, and corresponding shadows formed. Horrible distortions often result from the incorrect placing of lighting units around a piece of statuary.

(b): The color must be approximately that of average daylight, to avoid distortion of the paintings, for we see objects by reflected light and regardless of the color of the surface. If the same color is not present in the light source, the object appears black, or, in other words, reflects no light. For example, a red apple appears black under a pure blue light.

(c): The intensity of light must be such that all the important parts are readily discernible. This requirement varies with the

Fig. 1. A Good Method of Low-Intensity Direct Illumination, Especially Suited to Art Gallery Lighting

Fig. 2. A Well-designed Semi-indirect System for Lighting a Drafting Room

Fig. 3. An Example of Good Lighting in a Department Store

Fig. 4. An Excellent Method of Lighting a Dining Room, Semi-indirect Units being Employed

nature of the exhibition. For instance, a delicate pen and ink sketch demands a higher intensity of illumination than an impressionistic painting, for the discerning of detail is of more importance. Again, a picture in light colors will require less light effective on it than one in dark tones, for it will reflect more light proportionately. This discrimination is only of use where individual lamps light individual paintings; otherwise the intensity of light on the picture walls must be sufficiently high to light the dullest painting to the correct intensity.

In general, a painting gallery should have a relatively low intensity, 1 to 2 foot-candles, of well diffused general illumination. This is necessary to prevent contrast, to facilitate passage about the room, and to provide light for the reading of catalogues, etc.

The exhibition walls should be the most brightly lighted portion of the room. They should have an intensity of from 5 to 10 foot-candles, depending on the character of the exhibition, as explained above. One method of obtaining this, which gives excellent results, is the use of correctly designed, properly located, asymmetric reflectors. Individual angle steel, aluminum interior finish, one piece mirrored glass, or sectional mirrored glass trough reflectors are found in general use.

A little calculation, supplemented by experimentation, is necessary for satisfactory service, always bearing in mind, in the art gallery, to avoid direct reflections from the cover glasses or glazed surfaces.

Quite frequently the galleries themselves are works of art, and the lighting must therefore be designed to be consistent with the period of decoration of the building, thus assuring architectural conformity.

Fig. 1 shows a commercial art gallery with a low intensity of general illumination from direct lighting units. The walls are illuminated by small lamps in specially designed trough reflectors.

### Drafting Room Lighting

The ideal condition is an even distribution of well diffused light of high intensity; there should be no objectionable shadows. These requirements may be met with the following systems:

(a) Semi-indirect or totally indirect illumination, undoubtedly, gives the best satisfaction. With these systems, sharp shadows are avoided, glaring light sources are not visible, and the light is well diffused. When a semi-indirect system is used, the glass should be quite dense and have a low intrinsic brilliancy; the walls should be light in color, and the ceiling pure white. The installation should be maintained in good condition to obtain maximum efficiency. From 5 to 9 foot-candles intensity is required. The power necessary to produce this illumination will vary widely with the conditions of the reflecting surfaces.

Fig. 2 shows the application of a semi-indirect system to an engineering drafting room.

(b) Direct general illumination with a high intensity, 6 to 10 foot-candles, with very closely spaced bowl-shaped reflectors and bowl frosted lamps.

Due note must be taken of the arrangement of boards relative to the windows, locating the lamps so that, as far as possible, the direction of artificial light is the same as that of daylight. Lamps must be hung well out of the angles of vision, and every effort made to avoid glare.

(c) A system which is quite frequently found is the use of diffuse general illumination, using 1 to 2 foot-candles, supplemented by a local lamp for each drawing board. This unit may be one of several varieties, fixed or movable, attached to the wall or to the drawing board, with opaque or diffusing reflector and various sizes of lamps. In any case, it is open to the usual objections of local lamps; namely, liability of glaring reflection, loss of time in shifting the lamps, and a relatively high maintenance cost.

Tracing may often be satisfactorily accomplished by having the top of the tracing table made of etched glass, and lamps with suitable reflectors placed below the glass, illuminating the work from beneath rather than above.

### Hotel Lighting

This is one of the fields where the decorative element is a dominant feature. As a result of this, the practice varies widely, and it is therefore only possible to delineate a few of the important points.

The marquise is usually outlined with low wattage all-frosted lamps, or clear regular lamps in opalescent caps. This furnishes adequate illumination for the reception of guests, and also serves as an advertising medium. The entrances are often illuminated by lantern type fixtures with clusters of lamps, the design of the fixture harmonizing with the period of the building.

The lobby is the portion of the structure which exhibits the most novelty in its lighting, and direct, semi-indirect or totally indirect systems in elaborate forms have all found application.

The crystal chandelier and glass wall fixture, or candle-stick, central units and wall brackets with candelabrum lamps, find wall brackets with candelabra lamps, find much favor in the ball room, and produce the sparkling, cheery illumination which is so desirable here.

The parlors, writing rooms, and the like are usually illuminated to a very low intensity by decorative portable or local lamps, as privacy is desirable here, and lights concentrated at various points seem to produce this effect.

Corridors should be illuminated with efficient units, as these lamps are burned continuously.

For bedrooms, side wall brackets equipped with 25-watt bowl frosted lamps and diffusing reflectors should be located at the sides of the dresser and chiffonier. A central diffusing ceiling unit is also desirable for furnishing general illumination.

Fig. 5 shows a bedroom illuminated by a totally-indirect lighting fixture. The distribution of light is even and the appearance pleasing.

Two systems are in general use in the dining rooms: One provides a moderate intensity of general illumination (see Fig. 4, showing the application of this system using a very shallow opalescent dish as a semi-indirect lighting unit); the other system supplies a very low intensity of general illumination, which is supplemented by lights on each table. Low wattage, all frosted mazda lamps with decorative silk or glass shades are applicable here. This arrangement is usually to be preferred, as it creates the air of coziness and comfort so desirable in rooms of this nature.

Utility of lighting is of much more importance than artistic appearance, in the service departments, kitchens, pantries, etc. A high intensity of illumination will increase the efficiency of the service by facilitating cooking, reducing breakage, and, primarily, promoting cleanliness. Enameled steel reflectors with clear mazda lamps, since they are efficient and sanitary, find application here.

### Store Lighting

There must be the correct quality and quantity of light to insure advantageous

Fig. 5. A Pleasing Light Distribution in a Bed Room secured by a Totally Indirect Unit

presentation of goods, and there must be no discomfort arising from the lighting system.

In general, we may divide stores into three classes: Ordinary small stores, large dry-goods and department stores, and high grade shops.

In the small stores, high efficiency of light utilization, low initial cost, low maintenance, and simplicity are the prime factors. Artistic appearance cannot be had cheaply, and the amount spent for light in this case is of necessity low.

On account of this demand for efficiency, the direct lighting system is usually the only one applicable. Reflectors should be chosen to give distributions suitable for the type of store to be illuminated. Some, for instance, require a maximum light on the counters, with less on the side walls; others need the highest intensity on the walls; and some, as the manicuring parlor, demand localized lighting. Considerable data have been published on the subject, giving results of investigations and recommendations.

The department store should have a harmonious system of lighting for the entire building. Efficiency and artistic appearance have more nearly equal weight. Artistic lighting implies good diffusion, and this cannot be obtained with the commercial illuminants without some absorption of light. We must balance the two factors; that is, sacrifice some of the efficiency to obtain good diffusion and a harmonious layout. In general, any floor in a department store requires the same intensity of illumination throughout, except where there are departments requiring special lighting, such as rug racks, cut glass, etc. Therefore, for the sake of appearance, if nothing else, it is best to have one type of unit used throughout the entire floor. It is essential to space the units symmetrically with the bays and columns, and it is also very desirable to hang the lamps at the same height. Suitable diffusing or enclosing globes should be used and the system maintained carefully, as this adds greatly to the appearance of the store.

Fig. 3 shows the use of the one-piece totally enclosing opalescent balls in a department store.

The high grade shop is usually small in size, lavishly furnished, located in some fashionable section, and only the best grade of goods handled. The proprietor is accustomed to spending large sums for rent, equipment and general up-keep, and more money can be spent for individuality of layout. A distinctive lighting system is therefore appropriate. Artistic appearance is the predominating factor and efficiency is secondary consideration. The lighting system should harmonize with the architecture and preferably be designed to be strictly in accord with some predetermined plan.

In concluding an article of this character, a summary of the points which are desirable qualities of good illumination is in order. In brief these are:

*Intensity of Illumination:* That is, the correct amount of light must be supplied on the object to be illuminated.

*Diffusion of Light:* This implies the avoidance of glare in its many forms and the elimination of sharp contrasts.

*Direction of Light:* Important when lighting works of architecture and art, and also objects with overhanging parts likely to cast shadows.

*Distribution of Light:* This quality varies with the nature of the service, some interiors demanding an even illumination; others a concentrated light.

*Color of Light:* Of extreme importance in lighting fabrics, paintings, and the like.

*Steadiness of Light:* This is always an essential if our eyes are to work at maximum efficiency without undue strain. Reliability and continuity of service have much weight in connection with interiors where crowds are likely to congregate, as in the store, assembly hall, and the like.

*Economy:* This factor must always be considered but never to the extent of sacrificing adequate and correct illumination for a low cost of operation.

# THE ILLUMINATION OF ART

By M. Luckiesh

Physical Laboratory, National Electric Lamp Works, General Electric Company, Cleveland, Ohio

This contributor points out that without light there could be no art, and that after the artist has completed his work the results may be either marred or beautified by the quality and direction of the light used to illuminate it. Some of the illustrations show very plainly what incorrect artificial illumination can do to give an incorrect rendering of the artist's work. Correct lighting for paintings in art galleries is one of the difficult subjects dealt with in this article.—Editor.

**M. Luckiesh**

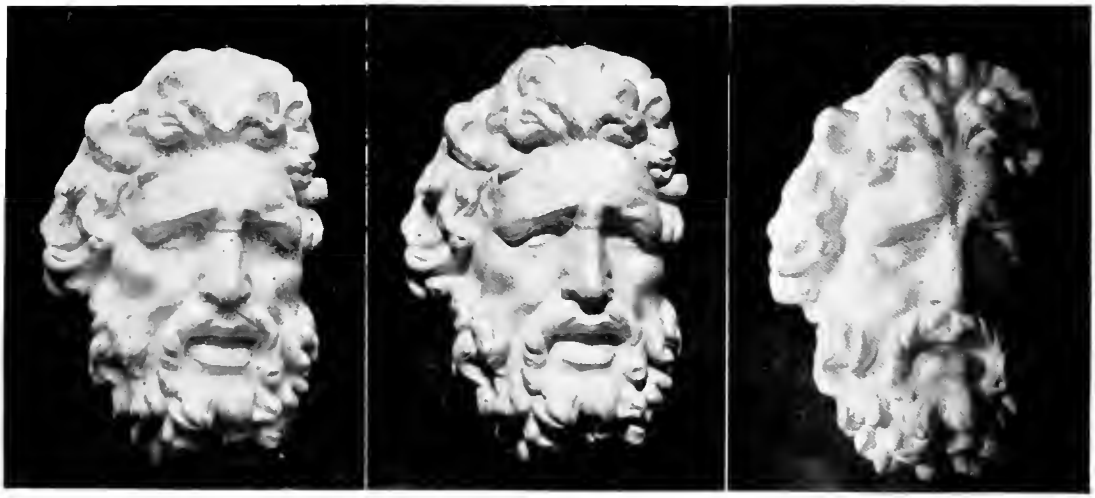
All works of art in the field of sculpture, architecture and painting depend for their expression upon the combination of light, shade and color. Light is essential for the existence of a subject to paint or a form to model. It is therefore the first requisite to art because it illuminates the subjects and as far as vision is concerned it creates them. Light is likewise the final requisite in art because it illuminates the artist's product and here again it has complete control. The artist with his brush or chisel is in reality a mediary who awaits in readiness to transfer a mood or expression of light to a permanent record. He is a link between two lightings. Light then creates art subjects, the artist preserves them, while proper lighting makes these records visible in all their beauty. In fact proper lighting can even overcome certain handicaps which to the artist are insurmountable.

Art in general is badly lighted. This is due to a variety of causes, chief among them being the lack of knowledge regarding the possibilities of lighting. The field of art therefore offered a worthy problem for research. Obviously the method of procedure was to investigate the effect of lighting on light, shade, and color in works of art, for it is in the combining of these factors that the creation of art is found. The distribution of light determines the light and shade in a sculptural work or in a painting. The relative amounts of direct and diffused light determine the character of the shadows in sculpture. Therefore the expression of a sculptured model depends upon the position of the light source and the relative amounts of direct and diffused light. The importance of proper lighting in this branch of fine art is well illustrated in Fig. 1. Here the head of Loacoön, that most expressive work among the antique, is lighted by a single light source from various sides. It is impossible to give empirical rules for the lighting of art because art can not be manufactured nor can the lighting be applied by rule of thumb. Each subject must be studied separately and the lighting should be the result of a combined knowledge of the science of lighting and an appreciation of art. In large exhibits of sculpture a procedure which should prove successful would be to place the works in a long narrow room, lighting them predominantly from one side. Greater control of light would be found in dividing this long room into stalls and controlling the reflecting power of the walls in order to obtain a proper relation of direct and diffused light.

In the lighting of paintings will be found an interesting field for the endeavors of the lighting artist. If possible both the position of the light source and the quality or tint of the light should be carefully determined for each painting. Here it is well to state that the writer's experiments show that each painting should be treated specifically. The limitations of pigments are a source of much trouble for the artist. In fact they present handicaps which the artist alone cannot overcome. The range of brightness in a landscape is usually many times greater than the range obtainable from pigments. That is, the artist's white is not nearly as many times brighter than his black when illuminated by the same light flux density as is necessary in depicting nature. However, by directing more light upon the high lights in a painting than upon the dark portion a great increase in contrast range can be

Fig. 1. Effect of Distribution of Light on Sculpture

secured This is illustrated in Fig. 2. It is evident that different moods are expressed by the painting. It should be borne in mind that the object in lighting is to carry out the artist's hope and intention. Therefore, there is but one mood to be sought. To give the painting a lighting which would tend to create another mood would be assuming that lighting can produce art, which is quite certainly untrue. The lighting will be serving well if it is done in such a manner that the artist's hope is realized. The quality of light is of highest importance because it affects all three factors—light, shade and color. It is well known that the standard illumination for paintings has been daylight. Daylight, however, differs with time and place. Paintings are done in many kinds of daylight varying both in intensity and quality. They are then illuminated by many kinds of daylight and artificial light. If the painting remains a work of art throughout all this abuse then the production of a work of art is a simple matter. But this cannot be; therefore each painting should be treated with a lighting adapted to it. Fig. 7 shows the effect of quality of light on a picture specially painted for the purpose. In one case the mountain has completely disappeared. The most practical scheme resulting from the writer's experiments involves the correction of each picture to daylight appearance by adding to the ordinary artificial light those rays demanded by the picture under consideration. This can be done by the use of colored lamps or glass. The proper proportion can easily be attained by varying the relative sizes of the clear and



Indirect Direct Daylight

Fig. 2. Effects of Different Systems of Lighting in a Room with Central Lighting Unit and Windows on Two Sides. Cast Hung on Wall at Height of Five Feet

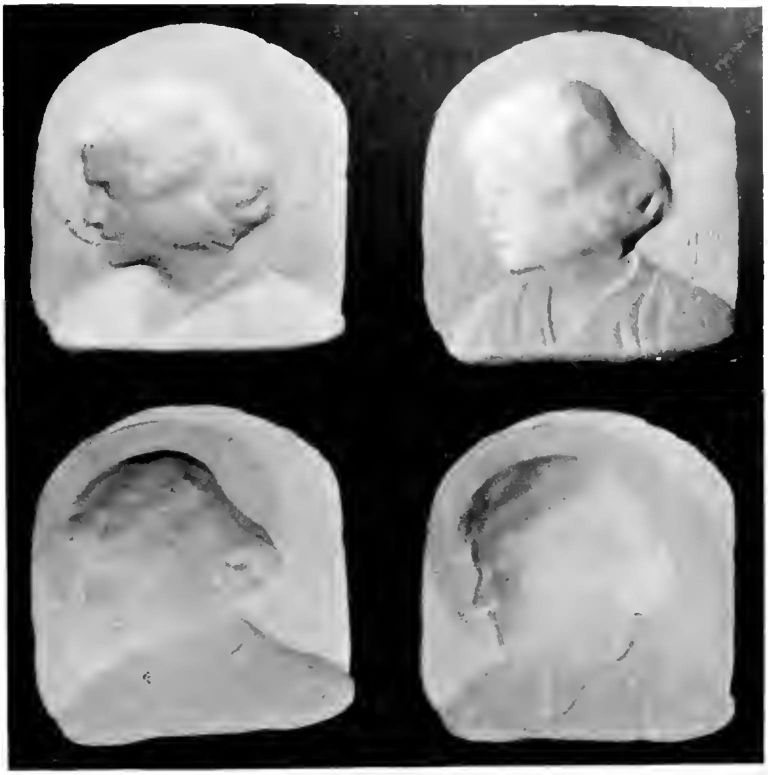


Fig. 3. Effect of Distribution of Light on a Very Low White Relief

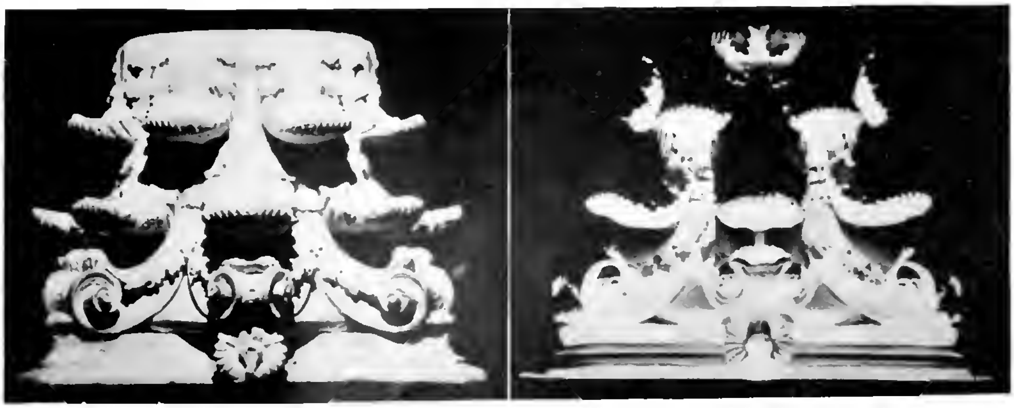


Fig. 4. A Capital Lighted from Above and Below

Fig. 6. Relative Direction of the Predominant Light to the Direction of Shadows in a Picture

colored lamps or by other means. This scheme obviates the necessity for correcting the entire spectrum when for instance there are no blue colors in the painting.

This scheme has recently been applied to a large temporary art exhibit in Cleveland and has met with the approval of all concerned. The lighting of art promises an extensive field of endeavor for the lighting artist. Further it is gratifying to note the growing importance of the lighting specialist, for here he has been permitted to tread on most delicate ground, where as one artist expressed it: "Lighting is everything."

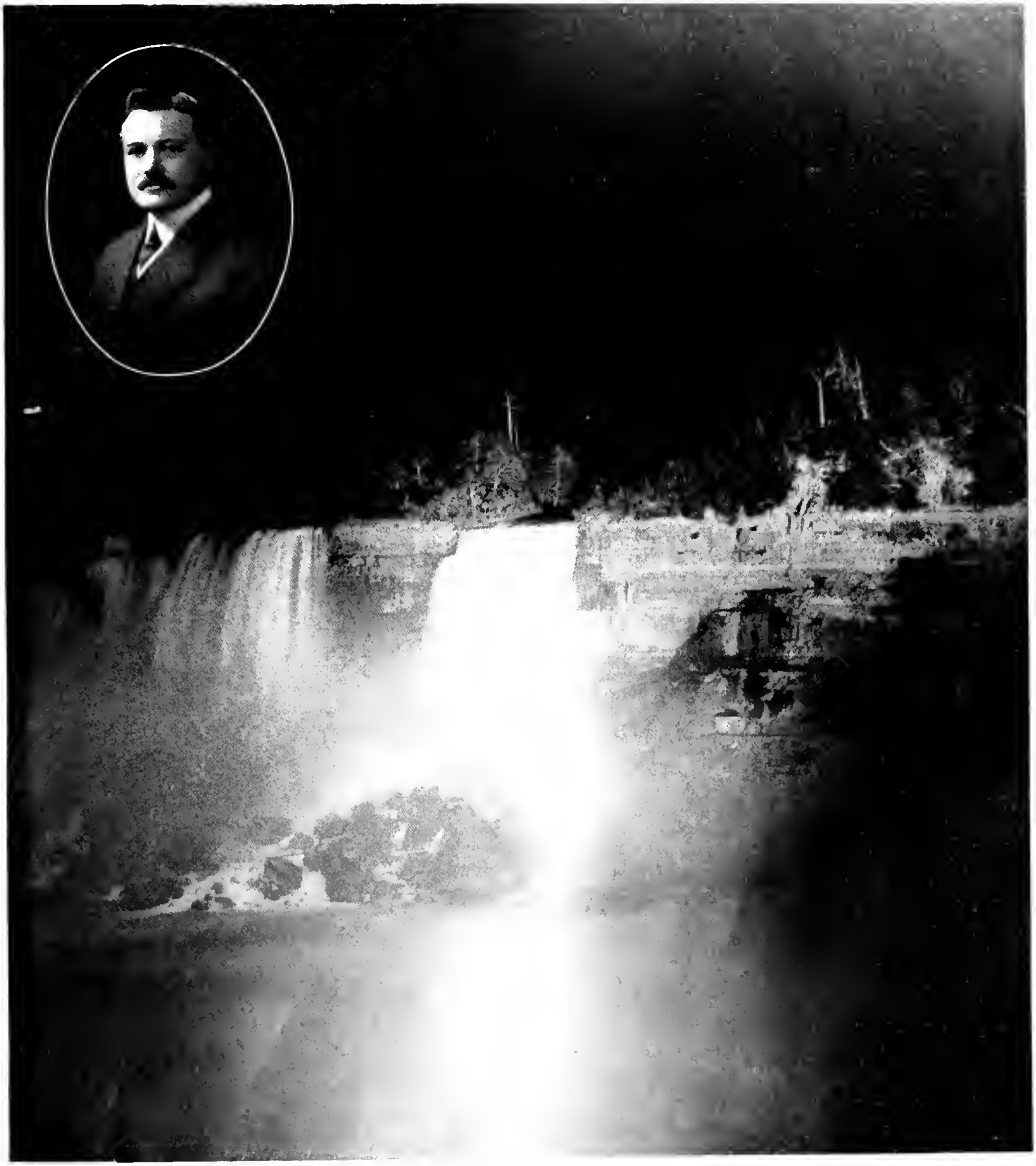
Fig. 7. Effect of Quality of Light on a Picture

Fig. 5. Effect of Distribution of Light on a Painting

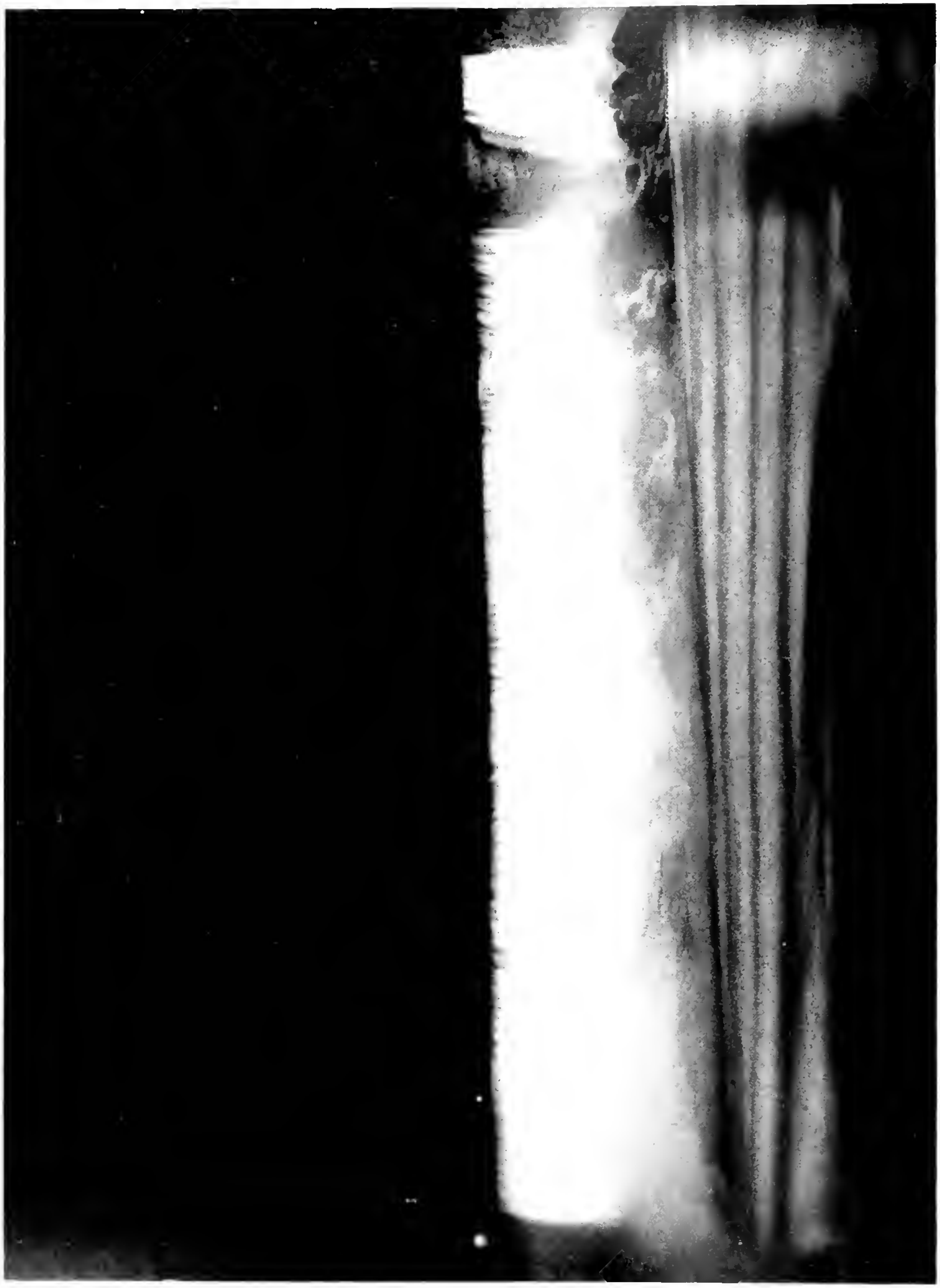
# SPECTACULAR ILLUMINATION

## A STORY WITHOUT WORDS

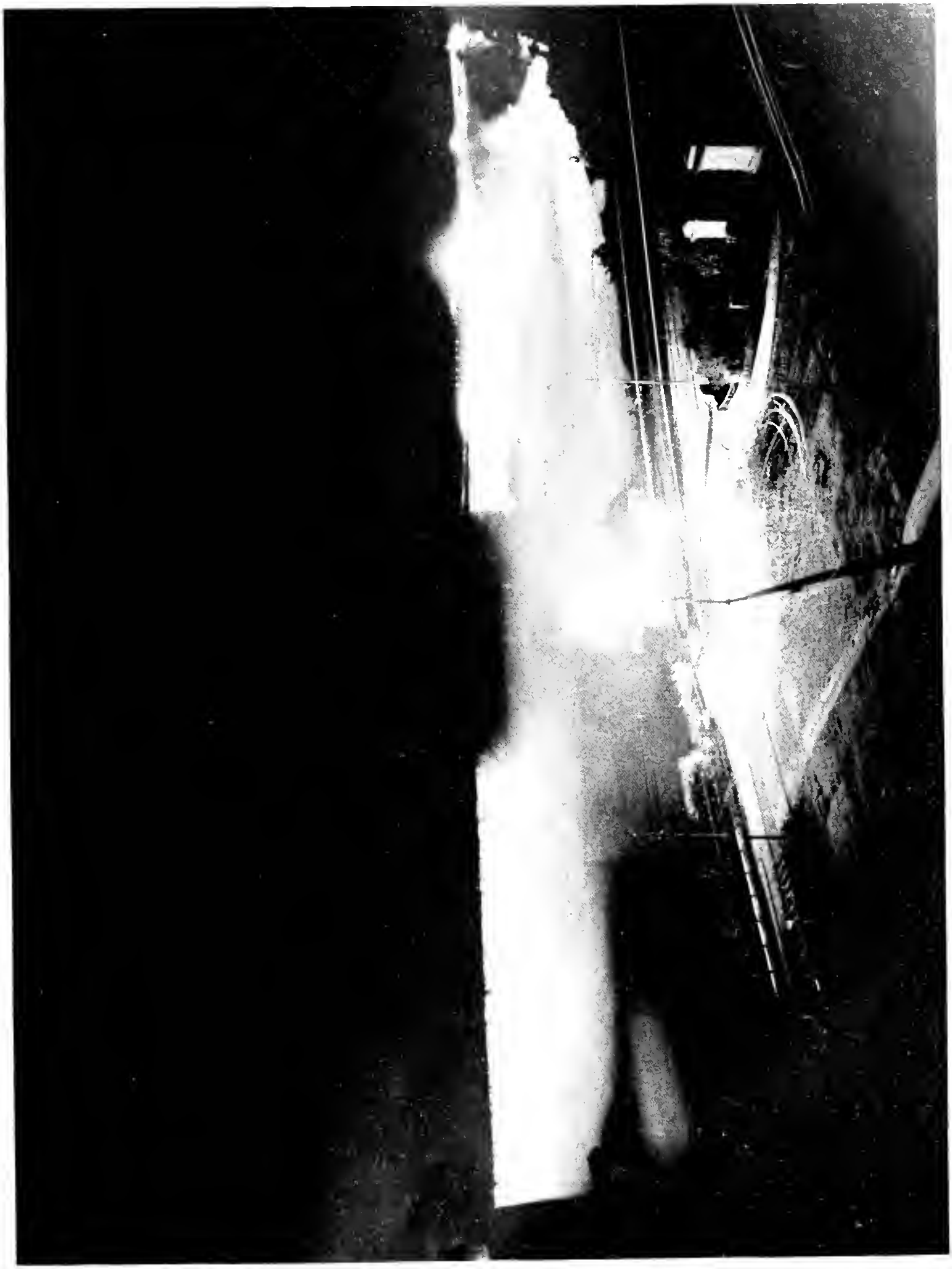
By W. D'A. Ryan
Illuminating Engineer, General Electric Company



Bridal Veil Falls, Niagara



The American Falls, Niagara

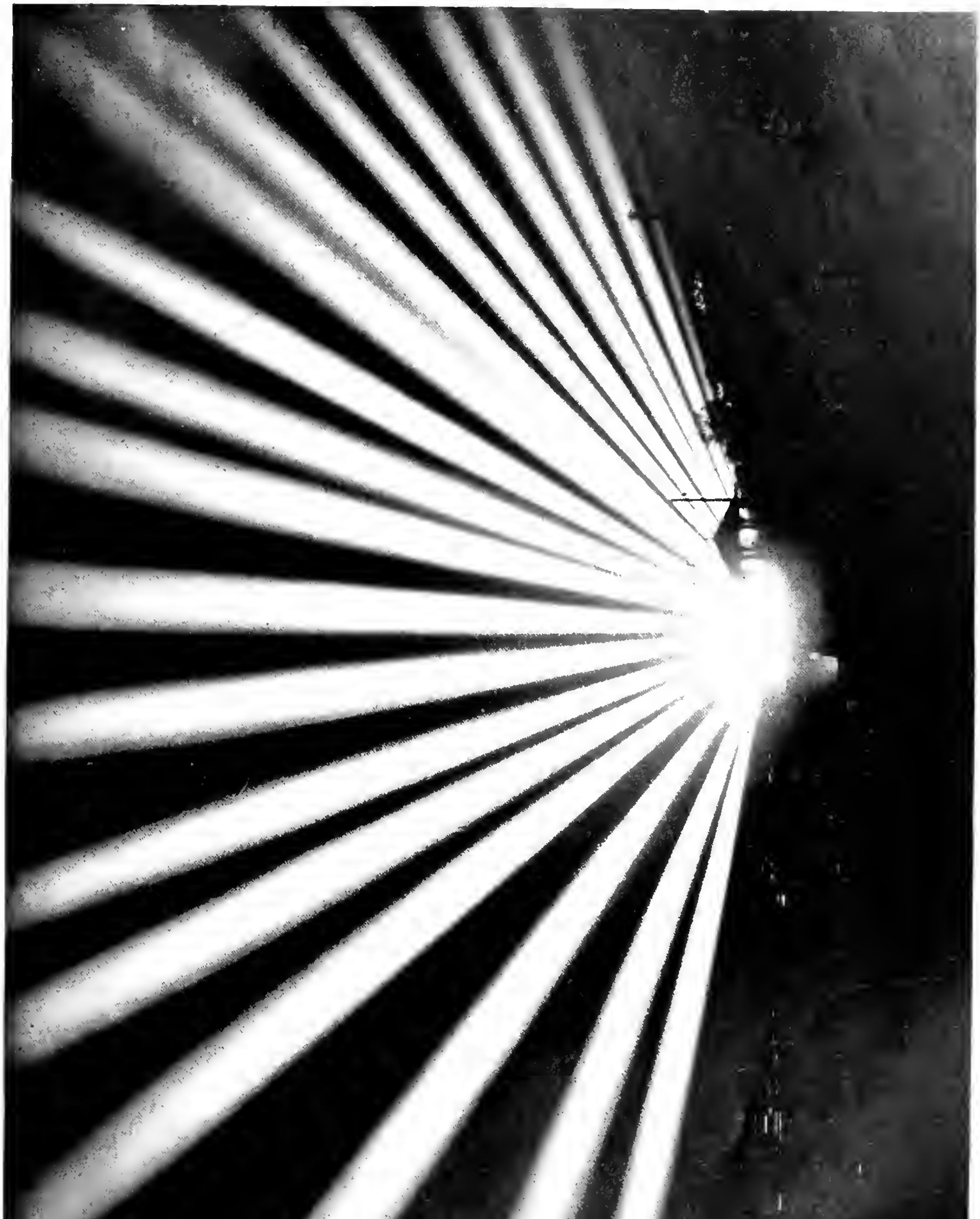


Niagara Falls

Hudson-Fulton Celebration

Hudson-Fulton Celebration

Night View, showing Illumination of South Gardens and Main Entrance, Panama Pacific International Exposition, San Francisco, 1915



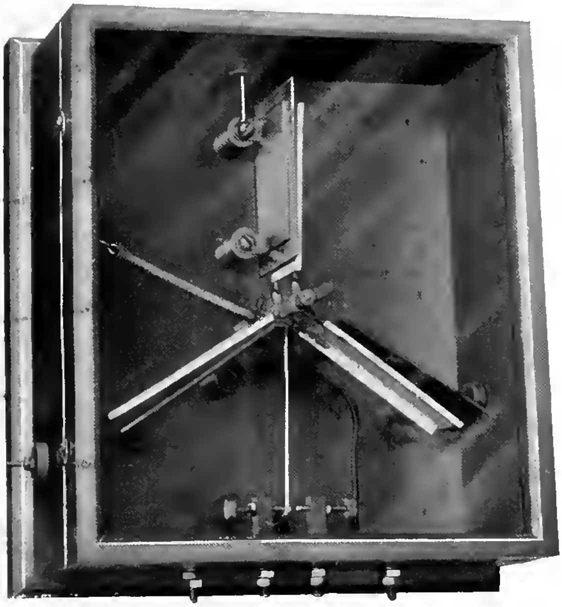
Hudson-Fulton Celebration

Singer Building, New York City

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## POTENTIAL INDICATING STATIC RELAY

The protective apparatus laboratory has developed a simple electrostatic relay for indicating potential on high tension circuits. It consists of three stationary brass plates separated by mica and air from three movable plates mounted on a common shaft which is grounded and carries a low voltage contact. The fixed plates are connected through the capacity of standard suspension insulators directly to the high voltage circuits, and by properly choosing the number of insulators the relay can be applied to any circuit above 10,000 volts. It is used either to close the circuit for an indicating device, such as a lamp or bell, or for operating one of the points of the multirecorder.



## VOLT-AMPERE CHARACTERISTICS OF THE VACUUM TUBE

The Geissler tube or luminous glow of the electric discharge in partial vacuum is the most fascinating of all the light sources, but although a vast amount of work has been devoted to it, we have not yet succeeded in developing it into an illuminant which can compete in efficiency with the high efficiency mazda lamp and still less with the high efficiency luminous or flame arc. However, everybody who has ever studied the vacuum glow thinks that there may be and probably are possibilities of efficiency in it which make it unwise to entirely abandon its investigation.

A large amount of study has been given by the Consulting Engineering Department, for a number of years, to the investigation of the electrical and luminous characteristics of the vacuum tube discharge.

The electrical characteristics in many ways differ materially from those of the arc, and of all other conductors. In the Geissler tube, at constant gas pressure and constant temperature, the voltage dissipated is, within a considerable range, approximately independent of the current, that is, the "effective resistance" is inversely proportional to the current.

The voltage dissipated by the Geissler tube, or Moore tube, very greatly depends on the gas pressure. With gradually decreasing gas pressure, that is, increasing vacuum, the voltage dissipated by the tube first decreases, then reaches a minimum, usually between 1 mm. and 0.1 mm. pressure, and then increases again, and the tube becomes unstable, i.e., shows a tendency to arcing.

The tube voltage consists of two components which vary with the pressure in opposite direction: the stream voltage, that is, the voltage consumed by the gas space between the terminals, is proportional to the length of the tube, and decreases with decreasing gas pressure; and the terminal voltage, that is, the voltage dissipated, mainly as heat at the terminals, is independent of the tube length, and increases with decreasing gas pressure. The sum of both voltages, or tube voltage, therefore reaches a minimum at some intermediate gas pressure; at higher pressures the stream voltage predominates, at lower pressures, the terminal voltage.

As the stream voltage is proportional to the tube length, and the terminal voltage independent thereof, the minimum point of the tube voltage, or total voltage, is not at a definite gas pressure, as sometimes assumed, but depends on the length of the tube; it occurs at a lower gas pressure with longer tubes, and at a higher pressure with shorter tubes.

At the minimum voltage point of the tube, with air and similar gases the terminal voltage is usually of the magnitude of about 1000 volts, and the stream voltage about 5 volts per cm. Much lower values are given by some of the noble gases, as argon, neon, etc.

J.L.R.H.

## QUESTION AND ANSWER SECTION

The purpose of this department of the Review is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the Review.

Second, it publishes for the benefit of all Review readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting subject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

### Announcement

This issue marks the first anniversary of the Q. and A. Section. At the time of beginning this department of the Review we adopted the policy which we believed would best fulfill the requirements of the service offered. We have held tentatively to this practice during the entire year, studying meanwhile how to be of greater benefit to all of our subscribers.

A careful review of the year's work confirms the fact that the original policy was fundamentally a satisfactory one, but we have decided, however, to make a greater distinction between the two functions of the department. An explanation of this new policy is given at the head of the section. It is not a radical departure from our previous practice but is a more definite and extensive one. It will enable us to improve the efficiency of the mail consulting service to the individual subscriber and to increase the attractiveness of the published answers. By including short reading articles or digests of such questions as are worthy, it is hoped that this section will be made one which is eagerly sought for at the coming of each issue.—Editor.

### MOTORS: DEFINITIONS

**(86) Will you kindly furnish definitions and give authority for the following terms?—Open motor, semi-enclosed motor, enclosed motor, totally enclosed motor. Would an induction motor with enclosed slip rings and dust-proof bearings be considered as an enclosed motor?**

We do not believe that at the present time there is any definite rule completely covering the various types. Our understanding in general is, that the open motor is one without any attempt at protection. The semi-enclosed motor is a very broad term and means anything from a partially protected motor to a drip-proof motor. However, we take it to mean more of a mechanical protection than anything else. Enclosed motors or totally enclosed motors mean one and the same thing, but as there are several different types of enclosed motors, each one would have to be specifically mentioned. For instance, there is the entirely enclosed self-contained motor without any external ventilation, there is the enclosed self-ventilated motor, and the enclosed motor with external pressure blower; both of the latter use a pure air intake pipe. There are also motors enclosed against dust and other motors enclosed for protection from moisture and dampness.

An induction motor with enclosed slip rings and dustproof bearings would not be considered an enclosed motor.

In any enclosed motor the rating depends entirely on the system of ventilation used. Therefore, the difficulty of making any simple classification of these various terms can be readily seen.

A.E.A.

### INDUCTION REGULATORS: OPERATION

**(87) Is it possible to operate three-phase, induction, revolving-armature, feeder regulators on single-phase lines?**

Three-phase feeder regulators may be operated on single-phase lines, in which case it is necessary to leave one secondary phase open circuited and to short circuit upon itself the corresponding primary phase, the other two phases, both primary and secondary, being connected in series. When operating single-phase the line current should not be more than about 75 per cent of that when operating three-phase, as otherwise the heating of the short-circuited coils may become excessive. The voltage of the single-phase line may be the same as that between phases of the three-phase line.

M.U.

### LIGHTNING ARRESTERS: DESIRABILITY

**(88) Are lightning arresters considered necessary on 2300-volt alternating-current lines running along steel mill buildings, either for protection against direct lightning or to take care of switching disturbances?**

The danger from lightning on short feeders for steel mill service has never been considered as being very serious. Potential surges, however, resulting from switching and sudden changes of load have frequently broken down apparatus. Since interruptions to steel mill service are of a very serious consequence, on account of the importance of continuous service, it is advisable to install aluminum lightning arresters at the generating stations and on the feeders of the more important mills.

V.E.G.

### ROTARY CONVERTER: 3-WIRE NEUTRAL

**(89) Is it possible to use the transformer or auto-transformer of a rotary converter for deriving the neutral of a three-wire machine, as shown in Fig. 1, instead of bringing out the neutral to slip rings and using a three-wire compensator? What will be the characteristics of the transformer and converter operating on an unbalanced load under these conditions?**

This method is entirely feasible and is commonly employed. It is, however, customary to use transformers rather than auto-transformers for the alternating-current side of rotary converters, as the ratio of transformation is usually too high to make auto-transformers economical. To derive the neutrals of three-wire generators, auto-transformers (sometimes called compensators or balancing coils, when used in this way) are used.

The direct current from the neutral wire divides equally between the three legs of the transformer. The transformer here spoken of is of the three-phase shell type, but three single-phase shell or core-type machines are equally applicable. The following statements apply to each of the preceding transformer installations.

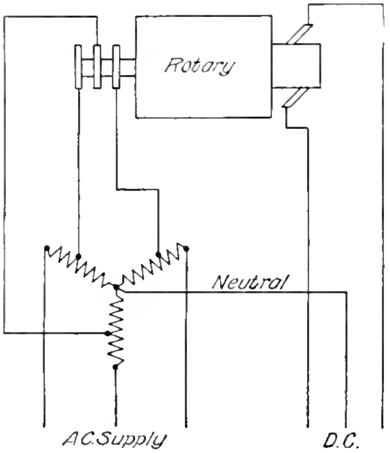


Fig. 1

When the transformer is Y-connected, the flow of direct current gives a biased magnetic condition, increasing the transformer exciting current with a change of wave shape. This increase in exciting current is roughly equal to the direct current (increasing, therefore, with the unbalancing). There is also some additional loss in the transformers due to the increased current density in the windings, and a small increase in iron loss due to the unsymmetrical cycle, since the maximum flux of one polarity is greater than normal.

To eliminate this increase in exciting current and core loss, one of the two following methods must be employed:

(a) The use of the so-called "zigzag" or distributed Y-connection (see Fig. 2). In this connection two separate windings are provided for each phase, one winding of each phase being connected to a similar winding in another phase to form a leg of the Y. The effect of the direct current in one winding is completely neutralized by the direct current in the other winding of the same phase, these currents being equal and opposite. With this connection, the exciting current and core loss are normal.

(b) The use of a three-legged (interlinked magnetic circuit) core-type transformer with a straight Y-connection. (See Fig. 3.) Here equal amounts of direct current flow in the same direction in the windings of the three legs and tend to cause equal fluxes in the same direction in the three legs. These fluxes cannot close in the iron circuit but must close in the air as leakage flux. On account of the high reluctance of the air, the fluxes are cut down to a very small value and therefore have a negligible effect upon the exciting current and core loss. Transformers for use in this service are never built with the straight Y-connection, except in the three-legged core type. For all other constructions, the "zigzag" winding is used.

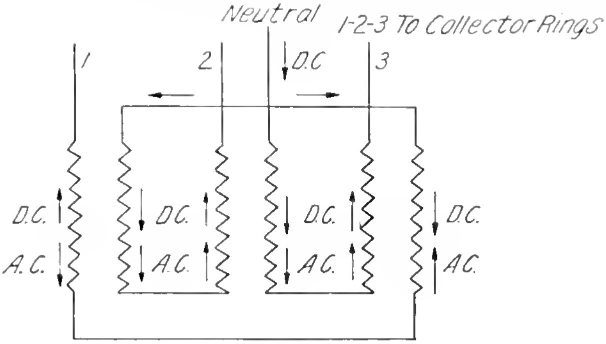


Fig. 3

One feature that may be considered a disadvantage to the use of auto-transformers in deriving the neutral is the fact that if either the a-c. neutral or the d-c. neutral is grounded both are grounded, and this is objectionable. If one side of the d-c. circuit is grounded instead of the neutral, it would successively ground the different a-c. phases.

W.W.L. & J.L.B.

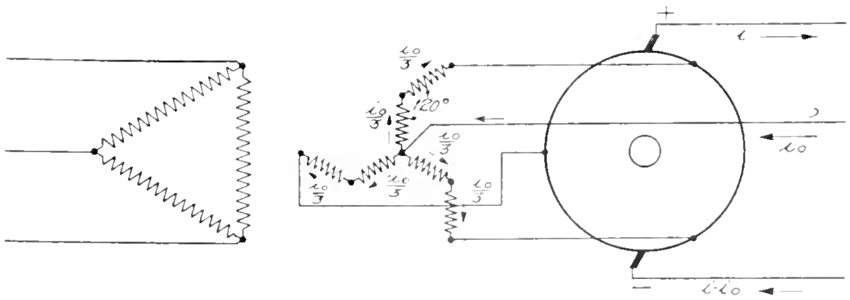


Fig. 2

### LIGHTNING ROD: PROTECTION

**(90) Is the application of a lightning rod to a brick chimney to be recommended?**

A lightning rod on a chimney or on a house is extremely useful in the case of a direct stroke of lightning. When used on a chimney, three small rods spaced 120 degrees, or four at 90 degrees apart are better than one for protecting the chimney from damage. Even an iron wire running down a wooden post gives a high degree of protection as a lightning rod against direct strokes.

E.E.F.C.

### ALTERNATORS: LINING UP

**(91) The revolving fields of two similar alternators are to be mechanically locked together and driven by the same prime-mover. The generators are to be run in parallel. What is the best means of determining the angular location of the fields (relative to each other) that the machines may give the most effective parallel operation?**

There are several methods whose results are indicative of the location desired. All of them require that the leads of one armature be connected through ammeters to the corresponding leads of the other machine; and, also, that there is some facility for shifting the rotative positions of the two rotors, or stators, relative to each other. Since it is more often the case that there is a coupling between the two machines, the methods which are most applicable to this condition will be first taken up.

*Stationary Method*

Assuming that the armatures of the two machines have been connected together as previously described, connect the two fields in series across a direct-current supply, having a quick-break switch in the circuit. When the current through the fields has reached its steady value, after closing the switch, there will be no tendency of the armature ammeters to register a deflection, their needles remaining stationary over the zero of the scale. Now suddenly break the field circuit. Unless the two rotors have been set correctly the first time, the ammeters will show a "kick." This indicates a flow of current in the leads, which is just the condition that it is desired to avoid. Make note, at this time, of the relative position of the two rotors, which is easiest done at the coupling, then shift one of them slightly and repeat the test. Being guided by the succession of positions and their corresponding ammeter readings, the zero-exchange-current position can soon be arrived at.

It is evident, of course, that an alternating-current excitation of the two fields in series will give readings equally as indicative as the direct-current. In the case of the use of alternating current, however, the armature ammeters will always give a deflection until the rotors are correctly placed, at which time they will read zero.

*Rotating Methods*

If undrilled couplings are used between the alternators, the adjustment can be made by drilling two diametral bolt holes in the one half and two corresponding slotted holes in the other half. If the couplings have already been drilled, two diametral holes of one half may be slotted. As a matter of precaution, wedges should be driven in the slotted holes beside the bolts to prevent the rotors from slipping relative to each other, because of the exchange current which will almost certainly occur at first. This construction will permit of the rotors, which should now be bolted together at the couplings, being shifted relative to each other. The machines should now be driven at some certain speed and be excited equally at some certain current. Read the exchange amperes armature, and, if not zero, shut down. Note the position of the two rotors to each other and then shift one a slight amount relative to the other. Drive the machines again, and repeat the test as many times as is necessary to reduce the reading of armature amperes to zero.

If for any reason it is inconvenient or inadvisable to slot the couplings or the rotors are pressed on the same shaft, or some equivalent condition making it impossible to change the position of one rotor relative to the other, the following procedure will furnish satisfactory results.

First, line up the two rotors on the shaft as accurately as possible, mechanically. Driving the machines with low field excitation, read the exchange current on these meters. It is possible that the precautions so far taken, in the lining up of the machines, will have been sufficient. There is, however, quite a possibility that the exchange current may be of such a magnitude as to render parallel operation impossible or inadvisable. This condition may have been caused by an inaccuracy in the mechanical lining-up of the two rotors on the shaft or by the stators not being located in exact similarity. It is always best, under the conditions last assumed, to rectify any irregularity by experimenting with the stator. This is permissible, so far as the results are concerned, for it is immaterial whether the rotor or stator is revolved.

By means of raising one side of the stator and lowering the other, inserting and withdrawing shims beneath the stator feet to accomplish this, the stator may be "revolved" a small amount. If the machine has many poles this small angular displacement will represent a considerable shift of phase, measured in electrical degrees, and may be sufficient to accomplish the purpose desired. It will be more expedient, in case a large movement is required, to entirely remove the sub-base of the generator under consideration and to support it upon a temporary adjustable one, so that greater travel can be accommodated. With these wider spread limits available, the stator may be revolved through a greater angular displacement. Care, at the same time, should be taken that the air-gap around the field is always held uniform. During all these trials, the measurements of armature exchange current should be made at the same field excitation and speed, in order that the value of exchange amperes may be indicative of the angular displacement of the machine. When the position of zero current, or minimum current in all three lines, is arrived at, the angular displacement of the stator, from its normal bed-plate position, should then be measured. This displacement may then be transferred to the rotor, which should now be located by a special offset key, cut for that purpose, and the stator returned to its normal position upon the bed-plate.

W.J.F.

# GENERAL ELECTRIC REVIEW

*A MONTHLY MAGAZINE FOR ENGINEERS*

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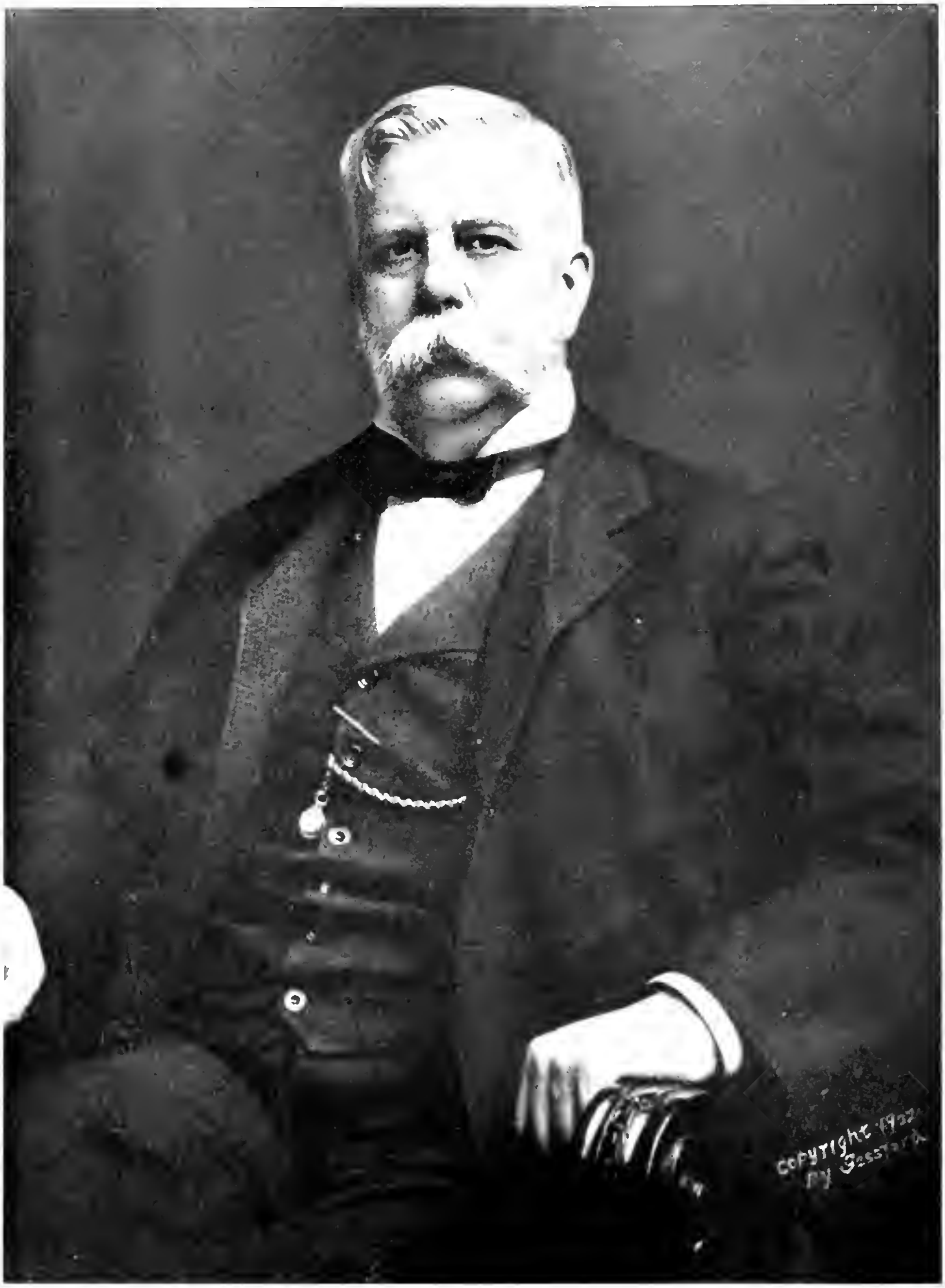

GEORGE WESTINGHOUSE

# IN MEMORIAM

George Westinghouse crowded the sixty-eight years of his life full of hard work, noble deeds and kind acts.

He constantly bent his energies to the solution of problems which meant progress to civilization and congenial and helpful employment for his fellow men. To his powerful intellect and well trained mind the most complex and difficult tasks yielded their answers in simple terms. To the achievements of this man in mechanical, electrical and scientific fields the industries of the world will pay homage for generations to come.

The attractiveness and charm of his personality rivalled his genius. His character was most interesting and fascinating because it combined with a powerful intellect and an indefatigable will, keen moral susceptibilities, a chivalrous manner, a quick sense of humor, deep rooted convictions of honor, cordial sympathies and an affectionate disposition.

Those who knew him but slightly admired his manifest genius; those who knew him intimately found their increasing admiration and respect outrun by their affection for him.

In his death mankind loses a benefactor, his industries a wise counsellor, the thousands connected therewith a considerate employer and his associates a loyal friend.

As one who has had the honor of a close friendship with him for more than twenty-five years and has felt the inspiration of his manly qualities, I deem it a great privilege to express in the pages of your journal this brief tribute to his memory.

Charles A. Terry

---

Mr. Terry's tribute will appeal to all who knew Mr. Westinghouse, for all who knew him admired and loved him. His versatility, courage, optimism and zeal for accomplishment were an inspiration to all workers, and his personal magnetism was irresistible. His life's work entitles him to a prominent place in constructive history, and his contributions to industrial progress will be of permanent benefit to mankind. The close of his splendid career will be universally regretted.

E. W. Rice, Jr.

GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

The paths of progress have been well trodden during the nineteenth century and the first decade of the twentieth. Many illustrious men have come and gone and left their mark; some as scientists, some as engineers, and some as organizers of mighty industries, each playing his part in our march of progress. As we go to press with this issue, we hear with the deepest regret that the unique career of one of these great men, Mr. George Westinghouse, is closed by his death, which occurred in New York City on March 12th. The work that he accomplished during his life will live for generations and the world at large will still continue to profit from the results of his fertile imagination and untiring effort although his labors have been brought to an end. Mr. Westinghouse was a man of remarkable capabilities, and by virtue of his force of character and indomitable courage, these capabilities brought a rich harvest of accomplishments.

It is as an engineer and organizer that he is best known to the world. The results of his labors in the invention, development and perfection of the air brake are known in every country, and the many industrial plants that he has built up and organized remain as a monument to his genius as an organizer of men. The breadth of his work is one of the most remarkable features of his career, he was an active worker in many branches of engineering, but we do not propose to cite examples of his activities, as these have been so thoroughly covered in the daily press.

The career of Mr. Westinghouse as an organizer is of special interest. His work in common with that of others in the same direction has played a very prominent part in the development of the electrical industry, which was born during his lifetime and which he lived to see become one of the greatest industries of modern times. For its present greatness the industry is largely indebted to those who in its early days saw the possibilities in it and had the courage and faith to spend their work and money in developing these possibilities until they became accomplished facts. A quarter of a century ago, most of our largest electrical factories were non-existent. The changes between then and now have resulted, very largely, from the labor of those who have organized and co-ordinated the work of many active men in one useful direction, and among these, one of the most prominent was Mr. George Westinghouse. Where the engineer uses material matter in accomplishing results, the organizer uses men, handling their brains and energy as the artisan handles tools. Without the organizer effective progress is almost impossible. It is the focusing of many different types of minds in one direction, the concentration of different species of skill in a harmonious effort to accomplish a desired result, that leads to efficiency and enables useful work to be done economically and thereby at a profit.

When the early pioneers had shown the rapidly extending scope of the electrical profession and had demonstrated that there was a tremendous field for the upbuilding of profitable undertakings, many more able men entered the field and the growth of the industry was phenomenal. The number of people employed in the manufacture of electrical apparatus and in its operation and maintenance forms no inconsiderable proportion of the industrial population. Most, if not all, of those people are working under conditions that are vastly superior to the ordinary industrial conditions that existed formerly. Mr. Westinghouse, as one of the organizers in the electrical industry, is responsible in a marked measure for its upbuilding. It is impossible to estimate exactly the extent of our indebtedness to an individual, because a great man's work always stimulates the efforts of others, and the influence of his power is felt far beyond his own immediate sphere of action. Mr. Westinghouse has passed beyond our ken, but his work lives on, and all of us, associates and competitors alike, feel that—losers though we are by his death—we shall still continue to be gainers by the example of one whose courage and perseverance has led to so many notable advances along the paths of progress.

# ELECTRIC LIGHTING OF STEAM PASSENGER EQUIPMENT

By C. W. Bender

Manager Commercial Department, National Lamp Works

The advantages of electric lighting for passenger service on trunk line railroads are well known, and the author does not attempt to present any arguments for its use. He has confined himself to a discussion of the systems in common use, which may be classified under three main headings, viz., straight storage, head-end, and axle generator. Each of these systems possesses advantages, and also disadvantages, over the other two systems, and these have been ably analyzed by the author. As adapted by different railroads, each system shows modifications that have been made to fulfill the needs of its special service, and each modified system is fully described and illustrated.—Editor.

The general public, who are continually demanding the use of electric lighting on all steam passenger equipment, do not realize the numerous difficulties to be encountered and overcome before any system employing electric energy as an illuminant can be considered wholly satisfactory.

It should be borne in mind that provision must be made for supplying light regardless of whether the train is in motion or at rest and, in the latter case, during stoppage of short or long duration. Another, though less obvious, difficulty is the necessity of providing means of automatically compensating for the various demands for light occasioned by the changes in length of the day at different seasons, of meeting the variation in conditions of service under which a car may be running and of providing against sudden dark weather at any time of the year. The problem has been studied by many authorities and attacked in many different ways, each of which has purported to eliminate some special difficulty of other methods, though not infrequently introducing drawbacks of equal or greater weight in some unforeseen direction.

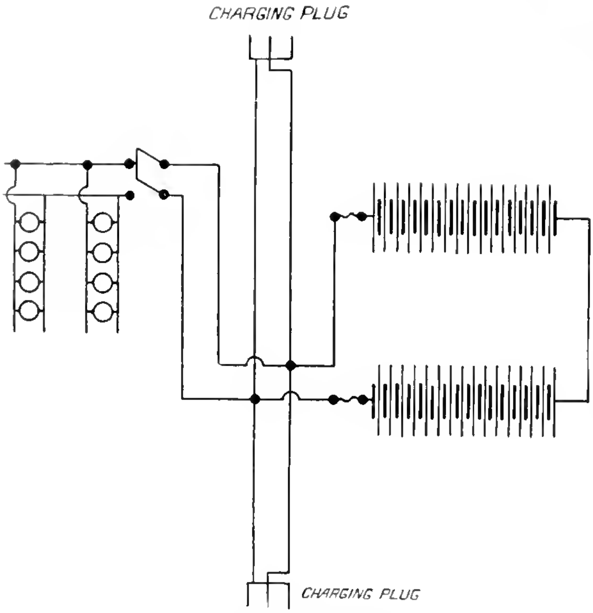

Fig. 1. Straight Storage System—Wiring Arranged for Charging and Discharging Batteries in Series

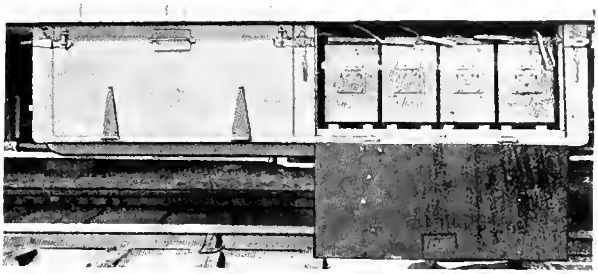

Fig. 2. Storage Battery Mounted on Car

Electric light has the advantage of eliminating open flames in the car, which vitiate the air and produce the unpleasant feeling of nausea. The heat given off from the incandescent lamp is very much less than with gas lighting. This is an item of special importance in the summer months. The discarding of the highly charged gas tanks is a point greatly in favor of electric systems. It is a step toward further safeguarding the traveling public, as statistics show that explosions have resulted disastrously in many wrecks.

Electric lighting lends itself more freely to combined scientific and artistic illumination of passenger equipment. A light source can be controlled by artistic and effectively designed reflectors to govern any condition from the baggage room to the parlor car.

Many engineers have worked on the railway lighting problem for the past 25 years and only within the past five years could it be stated that electric lighting was satisfactory. The improvement has been due not a little to the increased efficiency of incandescent lamps as well as improved train lighting apparatus, such as generators and regulators. The methods used for the electric lighting of passenger equipment today can be classified under three different heads: straight storage, head end, and axle generators.

The straight storage system, as ordinarily installed, consists of 32 cells of 300 ampere hour batteries, which are generally arranged in groups of two cells in double compartment lead lined tanks, the batteries being arranged under the car in special compartment boxes as shown in Fig. 2. It is impractical to change the batteries in a car at the end of each trip except in case of absolute necessity. The cars, therefore, must lay over in the terminal yard a sufficient length of time to charge the batteries. An elaborate and expensive yard wiring system is required in order that the charging circuit can be plugged to the batteries regardless of the position occupied in the yard. Another disadvantage is the fact that a lead storage battery is subject to temperature variations, the capacity dropping off approximately 5/8 per cent for every degree drop in temperature below 70 degrees. It is obvious, therefore, that in extremely cold weather the battery capacity may drop to such a point that sufficient capacity is not available to care for the lighting over a very long trip. With carbon filament lamps, the possibilities of the straight storage battery method of lighting were exceedingly limited, but the advent of the high efficiency mazda lamp, which requires approximately one-third the amount of current consumed by the carbon lamp, had the tendency of raising the number of straight storage battery equipments on the various railroads.

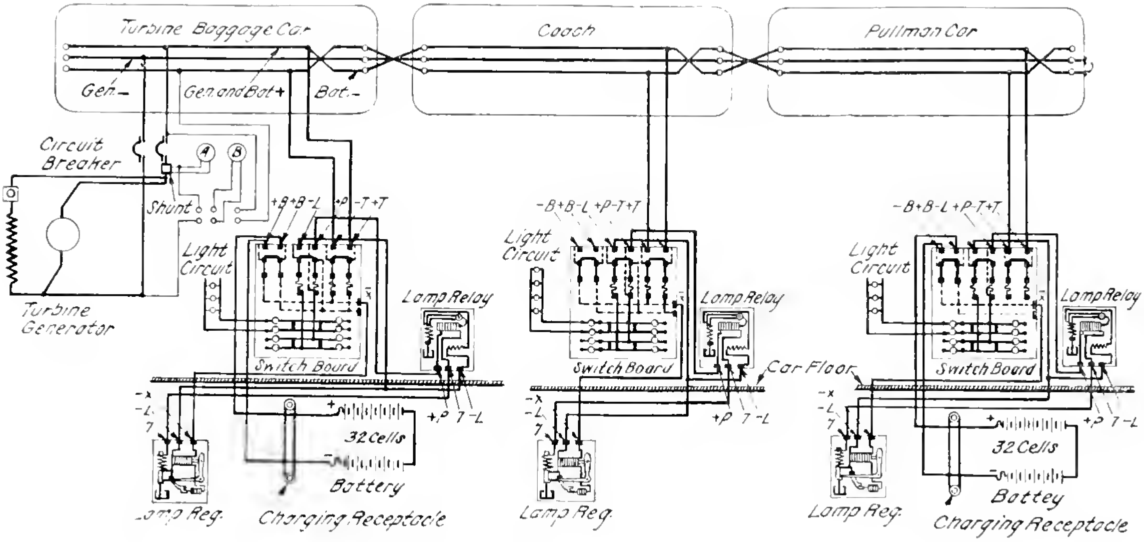

Fig. 3. Wiring Diagram—Baltimore & Ohio Head-end System

There are other disadvantages of the straight storage system, such as a car not being placed on charge at the terminal yard promptly, which introduces the possibility of leaving the batteries standing in a partially charged condition. Again a car going on to another road is subject to the possibility that it will not be properly charged or not charged at all, with the result that the battery is returned badly sulphated. Under these conditions it is often necessary to discard the plates altogether. Another disadvantage is that voltage variation on straight storage battery systems is considerable. A battery of 32 cells when fully charged will give a voltage of approximately 67. This greatly decreases during discharge until it has reached approximately 57 volts, but as the decrease is gradual it is seldom noticeable to the passengers.

## BALTIMORE AND OHIO HEAD-END SYSTEM

This system possesses the special feature of using automatic lamp regulators on each car to maintain a constant lamp voltage. The generator equipment consists of a 20 kw. 100 volt compound wound Curtis turbine generator operating at a speed of about 4500 r.p.m. at 80 pounds steam pressure.

Switchboards with the necessary instruments and overload no-voltage reverse current circuit breakers are provided which, with the generator equipment, are located in a separate compartment at one end of the baggage car. Steam piping is so arranged that either end of the turbine car may be operated towards the locomotive. The batteries consist of 32 cells of 300 ampere-hour capacity and are carried on all the cars of the train except the coaches and express cars. These generally average five batteries on a seven or eight car train.

Each car is provided with an automatic lamp regulator identical with that used for the Gould, Safety, and United States axle generators with a slight modification to adapt it to the larger voltage range met with in this service. The regulators are adjusted to maintain 63 volts on the lamp circuits, 63 volt mazda lamps being used.

The generators are operated at voltages varying from the lamp voltage to 90 volts, depending upon the amount of charging the batteries require. Normal train line voltage is maintained between 70 and 85 volts, thus insuring that the batteries are in a charged condition, or are being charged at all times. When turbines are operating during lighting hours with batteries in a fully charged condition, the voltage is reduced to about the floating point, thus carrying the lamp load entirely on the generators and at the same time preventing overcharging of the batteries.

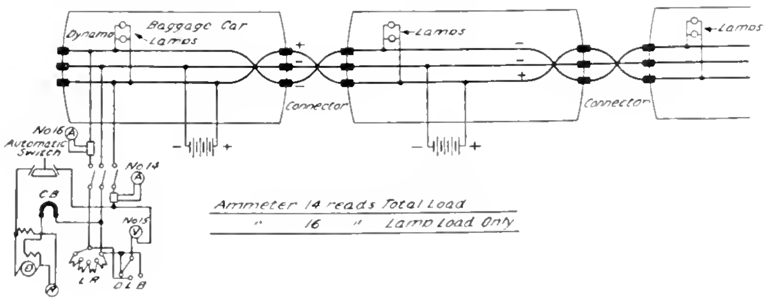

Fig. 4. Head-end System, C., M. and St. P.

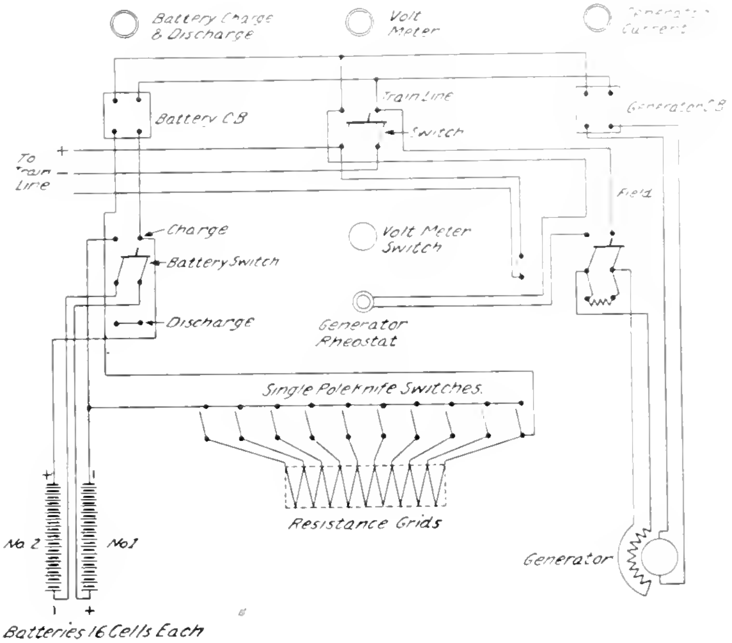

Fig. 5. Head-end System, Harriman Lines

Fig. 3 shows the wiring diagram of this system, from which it will be noted that the center diagram representing the center car is shown minus the batteries. It will also be noted that a pair of conductors are carried from the switchboard of this car to the main train lines, from which they obtain the necessary current for lighting the car.

## CHICAGO, MILWAUKEE & ST. PAUL SYSTEM

In this system the three-wire train line is so divided as to give two separate circuits, the one circuit carrying the batteries and the other carrying the lamps. This is effected by pulling down the loop at the rear of the train and closing the switch in the baggage car, the regular train wire being thus changed from the regular two-wire equipotential system as ordinarily operated, to the two separate two-wire systems having a common conductor, the positive of the three-wire system being used for the common conductor. Between this common positive and what is normally the generator negative, the batteries are connected, while the lamps are placed between the two outer wires and the train line, as is common practice on head-end systems.

A variable resistance is inserted in the lamp circuit, by means of which the electrician may maintain the lamp voltage constant, or the generator voltage may be varied to any desired value for the battery charging.

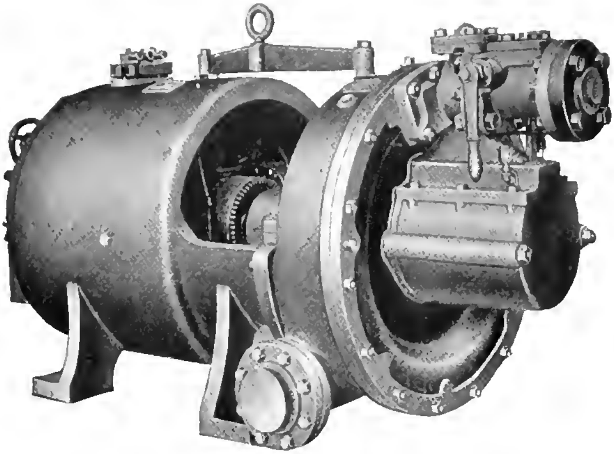

Fig. 6. 35 Kw. Curtis Train Lighting Turbine Baggage Car Type

## HARRIMAN SYSTEM

In the Union Pacific, or Harriman system of head-end lighting, the battery charging is done about midnight, when the lamp load is low. To do this the battery switch is thrown to the charging position. It takes 2.5 volts per cell to charge a battery to full capacity, and, while the train lighting voltage of 64 would not be sufficient to charge 32 cells in series when the battery switch is thrown to the charging position, the battery is cut into two halves of ten cells each and they can easily be charged with the standard lamp voltage of 64 by inserting an iron grid resistance in series with the batteries to keep the charging current from rising to such a high value that it might buckle the battery plates or overload the generator.

As the battery charging proceeds and the current tends to fall off, it may be boosted by cutting out a portion of this grid resistance and raising the impressed voltage of the battery by special single-knife switches located on the generator switchboard.

## HEAD-END SYSTEM

The head-end system of lighting was first attempted with a generator in the baggage car and no batteries, but, by reason of frequent lighting failures due to the train being parted and the locomotive being uncoupled from the train, it was found necessary to place storage batteries on the first and rear cars of the train. Such a system works out satisfactorily, provided the train is never parted and that when locomotives are changed at the division points the transfer is speedily made.

Another difficulty enters into this method of lighting through the possibility of a breakdown of the generator in the baggage car, which would cause a lighting failure of the entire train, and recourse must be had to some auxiliary lighting system; therefore the general practice today of having batteries on practically every car on the train.

Head-end systems are operated on the Harriman Lines, C. B. & Q., C. & N. W., Northern Pacific and Great Northern roads, where the runs are exceptionally long; while in the East the B. & O. is the only road that has continued to use this system.

The C. B. & Q. railroad are operating suburban trains out of Chicago, using a turbine generator placed on the top of the locomotive boiler. No batteries are used in these trains, but the runs are very short with sufficient lay-over at terminal points to properly care for the generator, the cars never being used in any other than this particular service.

All of the roads using head-end systems have adopted 63 volts as standard, i.e., 32 cells of 300 ampere-hour storage battery being used on the various cars.

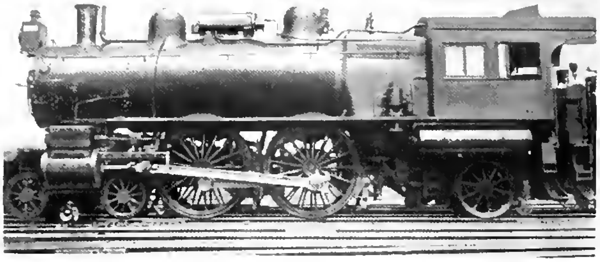

Fig. 7. Side View of Curtis Turbine Generator Mounted on Engine. Pennsylvania Locomotive

One of the difficulties to be overcome with such a system is the fact that to fully charge the 32 cells of battery requires 84 volts to be impressed across the battery, while on discharge in maintaining the lighting circuit the battery will return from 63 to 64 volts. Regulators must therefore be used on the various cars, or an excessive number of lamps will be burned out in the process of battery charging. This is overcome to a certain extent by operating the generator in the baggage car at 72 volts. With an equipotential system of wiring on the cars, and allowing for a drop in the train lines, this will impress approximately 66 volts across the lamps. At night, when very few lamps are burning, the generator voltage is raised to 78. This allows the batteries to be operated at a more nearly charged condition, with few of the lamps being subject to an excess current.

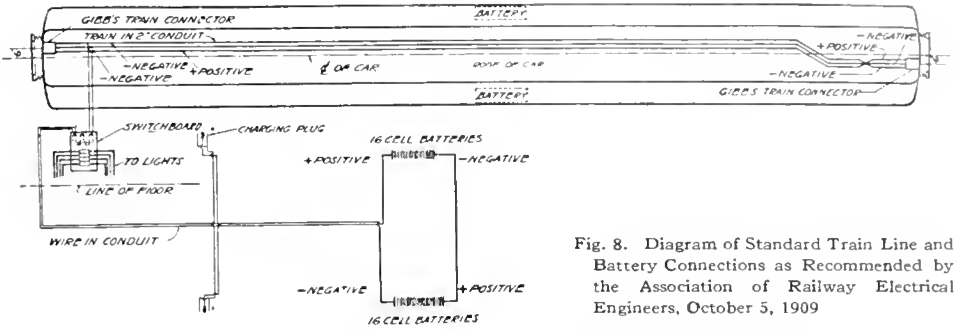

Fig. 8. Diagram of Standard Train Line and Battery Connections as Recommended by the Association of Railway Electrical Engineers, October 5, 1909

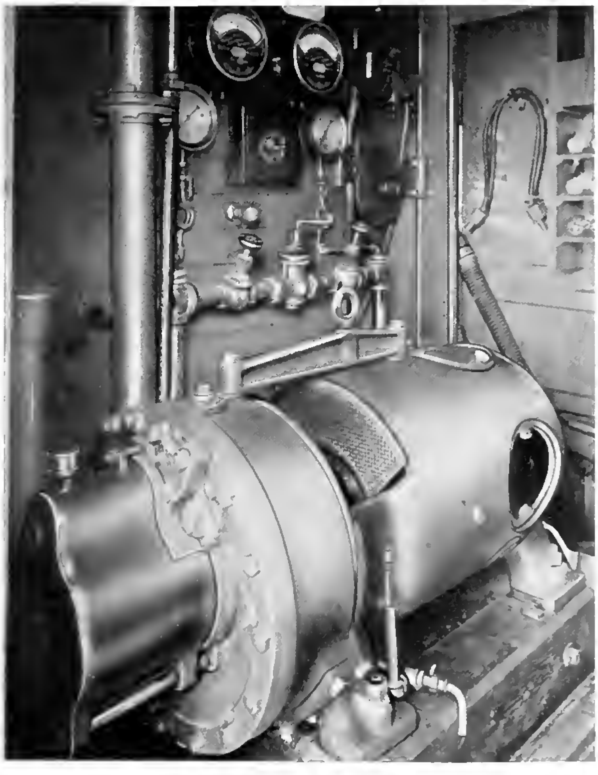

Fig. 9. 15-Kw. Curtis Steam Turbine Train Lighting Set Installed in Composite Car

The more general practice today, however, is to use a regulator on each car, which permits the generator to be operated at the proper voltage for charging batteries, while the resistance, generally a carbon pile affair, reduces the current to the proper amount for the lamp circuits.

### AXLE GENERATOR SYSTEMS

The axle generator system has been greatly improved in the last four or five years, and while still the most expensive system to install, by reason of a generator being required on every car, it has the advantage of being a self-contained unit and therefore the car can be operated on any road with small chance of a lighting failure, as practically all roads have train lighting men who understand the various systems and maintain not only their own but foreign cars passing over their lines.

Furthermore, the axle system does not require the elaborate yard charging facilities that are needed for cars operating on head-end systems, or specially straight storage systems. There are numerous axle-generator systems both in this country and abroad, but space will not permit a description of all of these various types. The following machines are among the most prominent and a description of each will probably be of interest: Consolidated, Gould, Safety, United States, Stone.*

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* Used in England and Colonies, as well as in some other countries of Europe.

## CONSOLIDATED SYSTEM

### Generator

The generator is of the four-pole, interpole, shunt wound type with cast steel frame, and has a rated continuous capacity of 45 amperes at 60 volts.

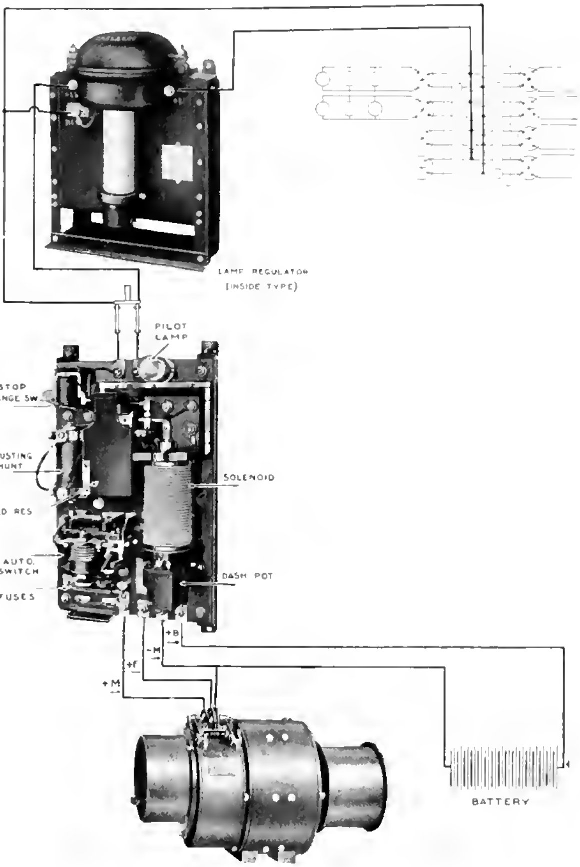


Fig. 10. Showing the Wiring for Connecting the Consolidated Axle Light System, Dynamo with Regulator

The bearings are of the ring oiling type and are carried in the heads, which are secured to the field frame by cap screws. Large oil wells are provided, which are fitted with overflow pipes to prevent overfilling. The armature coils are form wound, and the armature shaft is removable. The brushes, of which there are four sets, are carried in cast brass holders, which in turn are supported by the generator frame.

### Pole Changer

The armature shaft carries a worm operating a cam, which throws a switch when the direction of rotation of the armature is reversed, as is the case when the car is run in a reversed direction. The proper polarity is thus maintained for charging the batteries, regardless of the direction in which the car may be moving.

### Regulator

The Type L regulator consists of a solenoid connected in series with the generator. The solenoid core actuates a rocking contact arm, the contact operating over a series of bars connected to a continuous resistance consisting of metallic grids proportioned to suit the field of the generator.

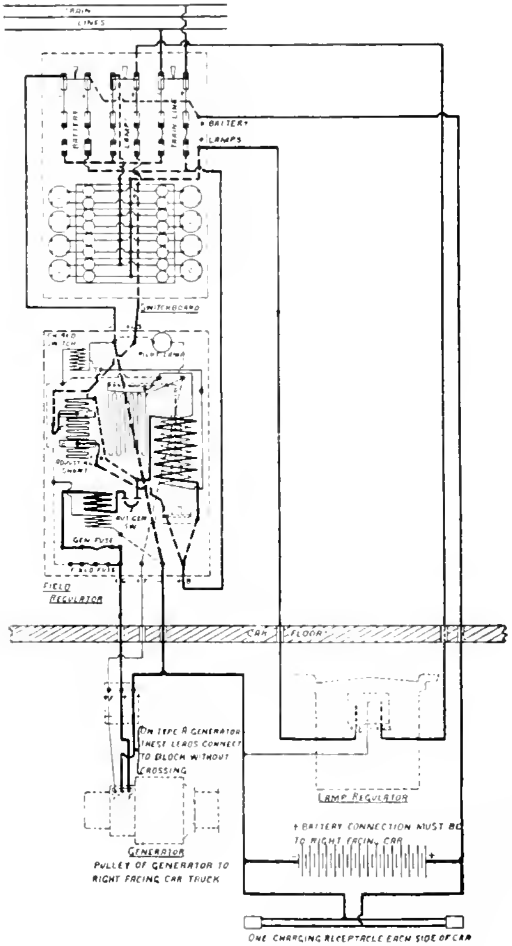


Fig. 11. Wiring Diagram of Complete Equipment with Pullman Switchboard, Dynamo with Regulator

An adjustable shunt is provided, by varying which the amount of current from the generator to lamps can be set at any desired value within the range of one-third to full lamp load. A stop charge switch is also employed for cutting off the generator current when the battery is fully charged. This switch may be adjusted by varying the air gap between the armature and its magnet by means of a graduated cam. The winding of the switch coil is connected across the generator leads, while a second shunt coil is added to the governing solenoid, so that when the first coil closes the switch at some predetermined value the second shunt coil adds additional strength toward drawing up the solenoid core and inserting additional resistance in the generator field, thereby reducing the generator output.

## GOULD SIMPLEX SYSTEM

### Generator

The generator is a multipolar shunt wound machine of the enclosed type, having a cast steel field frame with laminated pole pieces. The bearings are of bronze, the oiling being accomplished by packed oil waste or rings, as desired. The commutator end of the generator is provided with handholes and covers so that the branches are readily accessible.

The leads to the generator brushes and fields and the external leads from the generator are brought to a terminal block in the top casing of the commutator end of the generator. The pole changer is mounted on the shaft directly under the terminal block.

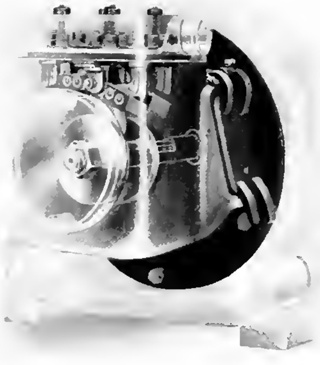
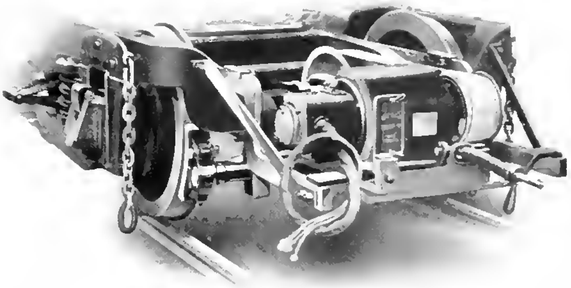
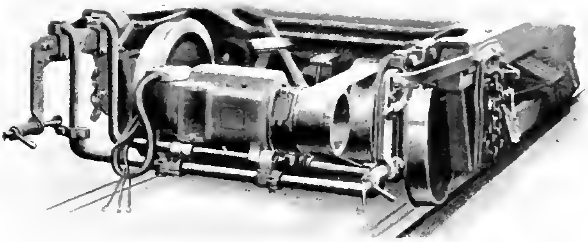


Fig. 12. Gould Pole Changer

### Pole Changer

The pole changer, a phantom view of which is shown in Fig. 12, is of the mechanically operated type, comprising a double-pole double-throw switch interposed between the brush leads and the external leads of the generator. The switch throwing mechanism comprises an eccentrically drilled weight pivotally mounted on a carrier, the latter being mounted on the armature shaft. The weights have forward and rear projections which act on the front and rear switch blades when the direction of rotation is reversed. When the switch is tripped the throw is completed by a spring toggle, which prevents further contact with the tripping mechanism when the direction of rotation is again reversed. In Fig. 12 the rear projection of the weight is about to throw the switch to a position corresponding to right-hand rotation; should the direction be reversed, the front projection of the weight, coming in contact with the lug on the front switch blade, would throw the switch in the opposite direction, thereby maintaining the proper polarity of the generator leads.





Figs. 13 and 14. Gould Drop Type Suspension

### Generator Suspension

This generator is suspended by means of the link type or the drop type suspension. Views of these are shown in Figs. 13 and 14, in either of which provision is made for alignment of the generator shaft with the car axle and the generator and axle pulleys, while the tension of the chain or belt drive after being set is regulated by springs.

### Automatic Switch

The automatic switch is of the laminated copper contact type with auxiliary carbon break, and is closed against the action of gravity by the lifting of its solenoid core. There are two windings on the solenoid, one a shunt coil across the generator mains, the other a heavy series coil connected in series with the generator mains. When the generator voltage reaches the proper value the shunt coil becomes sufficiently energized to raise the plunger and close the switch. The series coil is then energized and reinforces the action of the shunt coil, assisting in holding the contacts or switch closed. Should the generator speed be decreased and the voltage drop to that of the battery voltage, the latter will tend to discharge through the series coil in an opposite direction, thereby neutralizing the fall of the solenoid, and gravity, reinforced by the switch springs, will cause the switch blades and generator circuit to open. On top of the solenoid plunger are a metal disk and laminated copper brushes which serve to short circuit the series coil of the regulator simultaneously with the operation of the switch. This prevents the current due to the lamp load from exerting an effort to raise the solenoid plunger of the series coil of the regulator, which would increase the resistance in the field circuit and tend to prevent the building up of the generator.

### Generator Regulator

The generator regulation is effected through the compression of carbon pile disks in the generator field circuit. A variable compression of the disks is obtained by the movement of two lever arms, one of which is actuated by the solenoid plunger of a series coil in the battery branch circuit; the other being actuated by the plunger of a shunt coil connected across the generator mains. So long as the battery is not fully charged, the variable compression on the carbon disks, obtained through the lever actuated by the plunger of the series coil, maintains the generator current practically constant by increasing or decreasing the resistance of the carbon pile, should the current tend to increase or decrease from normal.

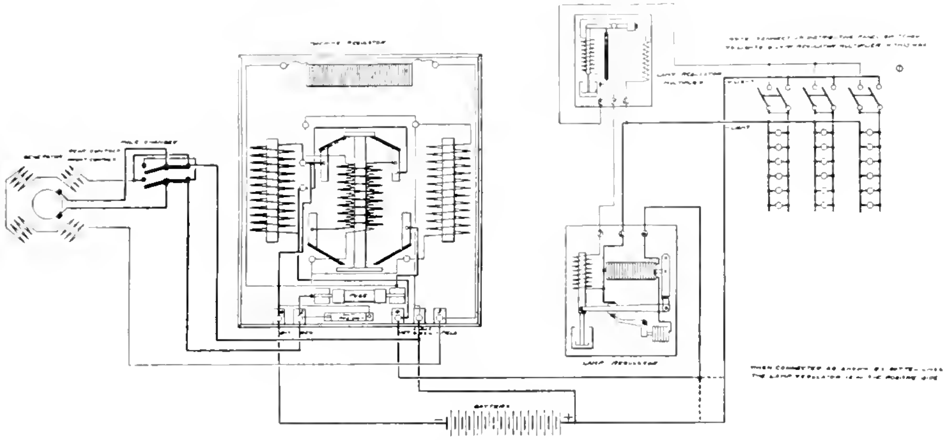


Fig. 15. Wiring Diagram, Gould System

When the battery becomes fully charged, as determined by its attaining a definite limiting voltage, the shunt coil of the regulator becomes sufficiently energized to lift its plunger, thus decreasing the compression of the carbon pile resistance through the movement of the other lever arm. Under this condition the plunger of the series coil is no longer sustained, as the current to the battery is reduced. The control of the field strength, and consequently the voltage, then results from the shunt coil. The current output of the generator is reduced to the value of the current required for the lamps that are burning, the voltage thus corresponding to that of the fully charged battery.

The shunt coil also acts as a prevention against excessive generator voltage, should the battery circuit be broken for any reason. In this event the generator supplies current for the lamps when the speed of the car is at or above the minimum limiting speed.

The solenoid plungers are restrained from oscillation by means of dashpots, while, to ensure the building up of the generator in case of loss of residual magnetism, a resistance unit is connected between the battery and armature circuit, which permits a small amount of current to flow across the armature, breaking down any resistance that may exist.

### Lamp Regulator

Lamp regulation is obtained by pressure exerted upon a series of carbon disks, this pressure being varied inversely with the voltage of the generator. The variable pressure is obtained by a lever arm actuated by a solenoid plunger, the current in the solenoid coil being controlled by an auxiliary regulator, also of the carbon pile type, acting as a multiplier. Thus a very slight increase in voltage of the lamp circuit results in a decided increase in lifting effort on the main plunger, thereby maintaining the lamp voltage and candlepower at approximately constant values, regardless of any variation in generator and battery voltage. The regulator is always in the circuit when the lamps are burning, but the carbon pile resistance is shunted gradually as the battery discharge proceeds.

## SAFETY CAR HEATING & LIGHTING CO.

### Generator

The generator, which is made in 2.6 and 4 kw. sizes, is a multipolar shunt wound machine, with a one-piece steel magnet frame and interchangeable cast iron heads for bolting to commutator or pulley end of the magnet frame. The bearings are of the bushing type, made of bronze, and are alike for both ends of the generator. The bearings are obtainable in either the waste-packed or ring-oiling type, the oil being added through a filling tube in the side of the head, which also acts as an overflow, the low lip of the filling tube determining the proper level of the oil.

The armature is form wound with fireproof insulated wire, the coils being held in slots by hard fiber wedges. The brushes are eight in number (two to each holder), each having a separate trigger with spring tension to maintain the contact with the commutator. Each brush has the usual copper shunt to maintain a good contact with the brush-holders.

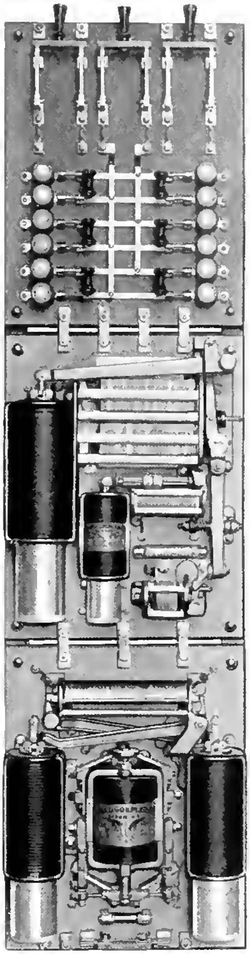


Fig. 16. Simplex Regulator and Distributing Panel

### Pole Changer

The current direction is maintained constant by rotating the brushes through an angle of about 90 deg. whenever the direction of rotation of the armature is changed. The four brush-holders are mounted on an insulated supporting ring which acts as an outer race of a ball bearing, and is slipped over a finished hub on the commutator head and held in place by a snap spring ring. The brush rocker has two stops about 90 deg. apart, with luggage projections cast on the head. While running, the friction of the brushes on the commutator holds the rocker firmly against one of these stops. Reversing the direction of rotation causes the brush rocker to be turned over against the other stop, changing the position of the brushes, but maintaining the same polarity as before.

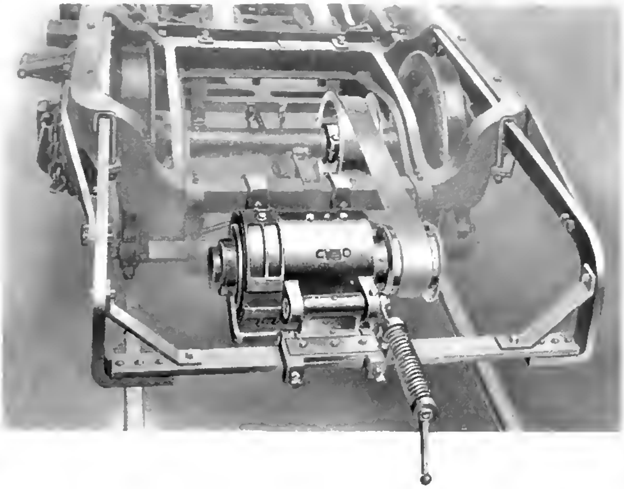


Fig. 17. Dynamo Suspended on Six-Wheel Steel Truck

### Generator Suspension

The generator is supported as shown in Fig. 17. The horizontal shafts by means of which the generator is suspended pass through holes in the projections cast on the field frame, these shafts in turn being supported by links carried by movable pieces resting on heavy horizontal bars. These bars in the case of steel trucks are passed through holes in the end of the truck frame and then bolted.

The dynamo is mounted on the car truck outside the end sill and is driven by a belt from a pulley on the car axle. Fig. 33 shows the general arrangement as applied to a standard form of cast steel truck. The heavy horizontal steel bars from which the dynamo is suspended pass through holes in the end of the steel frame of the truck and are bolted to the frame. The ends of these bars are turned down and securely clamped together by an angle iron, which serves as a brace and supports the tension rod. These bars are further strengthened to prevent lateral motion by braces bolted to the end of the truck. The dynamo is suspended on two horizontal shafts passing through two lugs on each side of the dynamo frame, the two lugs having a long bushing between them. These shafts are supported on each end by links carried by movable pieces resting on top of the horizontal bars. These pieces are adjusted by means of screw bolts to give proper alignment with the car axle, and are held securely, after being adjusted, by means of bolts passing through plates bolted to the supporting bars. A safety chain is attached to the dynamo and the end of the truck, and another safety chain to the dynamo and the angle iron which serves as a brace for the ends of the suspension bars. When the tension spring, which surrounds the tension rod, is compressed by the nut, it tends to pull the horizontal bars and generator away from the truck and give the required tension to the belt. As the vertical center line of the dynamo remains vertical with any movement of the dynamo, the belt tension is the same with either direction of drive.

### Automatic Switch

The automatic switch is of the closed magnetic type, having a fine, or shunt winding, connected across the generator circuit, and another winding connected in series with the circuit. When the generator voltage rises to the proper value, the shunt winding is energized sufficiently to raise the solenoid

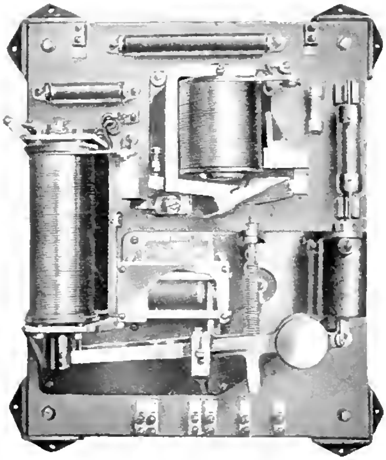


Fig. 18. Dynamo Regulator Panel

and close the heavy laminated contact, when the series coil maintains a firmly closed contact. When the generator voltage drops to that near battery voltage, the battery current, being in the reverse direction, causes the switch to kick out.

### Dynamo Regulator

When the dynamo is at rest the carbon disks in the field are tightly compressed by the pull of a spring so that the resistance is very low. As soon as the armature revolves, current is generated which flows through the field coils, energizing the lifting coil of the main switch. When the voltage is the same as the battery voltage, the main switch closes, connecting into the circuit a series coil which holds the switch firmly closed. As the current rises, a pull is exerted on the plunger of a solenoid magnet and the pressure on the carbons is decreased, thereby increasing the resistance in the field circuit.

## U-S-L SYSTEM

### Generator

This generator is of the multipolar type with a cast steel field frame. The armature is form wound. The bearings are of the ring oiling type. There are two brush-holders, which are accessible through a handhole with removable cover.

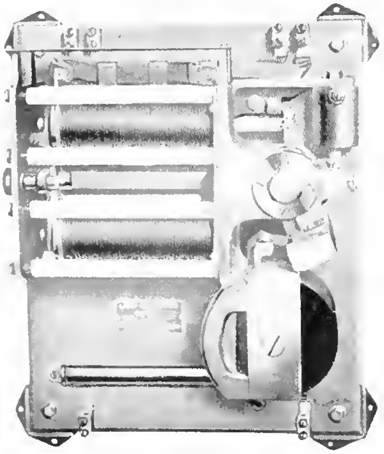


Fig. 19. Lamp Regulator Panel

### Pole Changer

The pole changer consists of a movable wrought iron ring carrying the current contacts, stationary contacts, and the steel plunger which is attached to the armature shaft. The function of the plunger is to engage the movable ring under a train speed of three miles per hour and rotate it so as to maintain the generator in proper relation with the battery. Above a speed of three miles per hour the plunger is disengaged by centrifugal force.

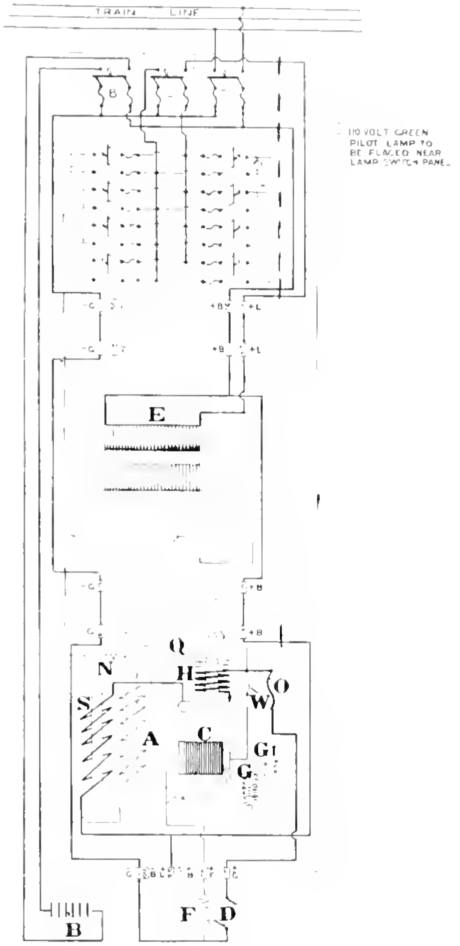


Fig. 20. Wiring Diagram Lamp Regulator in Car

### Drive

The generator is belt-driven, the proper tension being maintained by the use of helical springs attached to the under side of the generator and made adjustable with the suspension.

### Suspension

An overhung suspension is employed. The generator is supported from a $2\frac{5}{16}$ in. shaft which passes through two lugs, the latter being integral parts of the generator frame. Alignment of the machine may be made by shifting the bearings carrying the above mentioned shaft. The weight of the generator is taken directly by spring bars bolted to the truck. Cushion and recoil springs are inserted between these spring bars and a rigid "andle," which is also bolted to the truck.

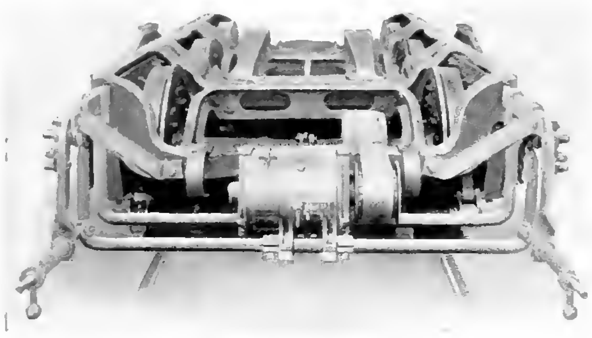


Fig. 21. Generator Mounted on Wide Non-Adjustable Parallel Link Suspension Applied to Steel Truck

### Generator Current Regulator

The current regulator consists of an iron-clad solenoid having a single heavy winding of edgewise wound copper bar connected directly in series with the armature of the generator, and through which the total armature current of the generator flows. The plunger of this solenoid is free to move in a vertical direction through a distance of about ⅜ inch. To the lower end of the plunger is attached a graphite piston which fits a cylinder or dashpot, which in turn forms a part of and is cast integrally with the frame of the solenoid. This dashpot is nearly air-tight and contains no liquids of any kind, the entrapped air and the small clearance between the piston and the walls of the cylinder affording all the damping action necessary to prevent sudden or jerky movements of the plunger. The upper end of the plunger engages a roller, which is attached to the forked end of the horizontal arm of a bell crank lever mounted upon a hub post attached to the panel. The end of the vertical arm of this lever is attached to a thrust plate and carbon terminal block, which latter engages one end of a horizontal pile of carbon disks. The other end of the pile abuts against a solid support. The pile of carbon disks constitutes a variable resistance under the control of the solenoid and is connected directly in series with the field of the generator. The arbor upon which the bell crank lever is mounted is carried through the hollow hub post and slate panel and then bent at right angles behind the panel. The initial pressure on the carbon pile is produced by a weight mounted on the rear horizontal arm of the bell crank. This weight is fixed in value, and its location on the horizontal arm determined in the factory and neither can be altered; but its effectiveness may be altered by changing the angular position of the rear arm of the bell crank lever by means of a knurled nut which, being directly pinned to the arbor passing through the panel and attached to the bell crank by a removable screw, enables one to rotate the arbor and engage the bell crank at different angles

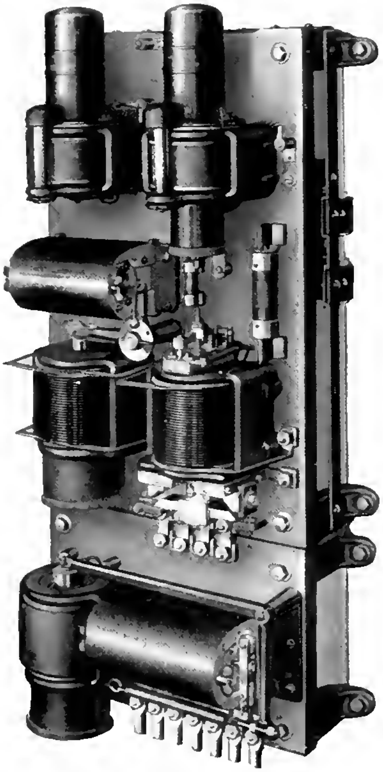


Fig. 22. Generator Regulator Panel with Lamp Regulator Panel Mounted Underneath

by shifting the screw in the knurled nut from one hole to the other.

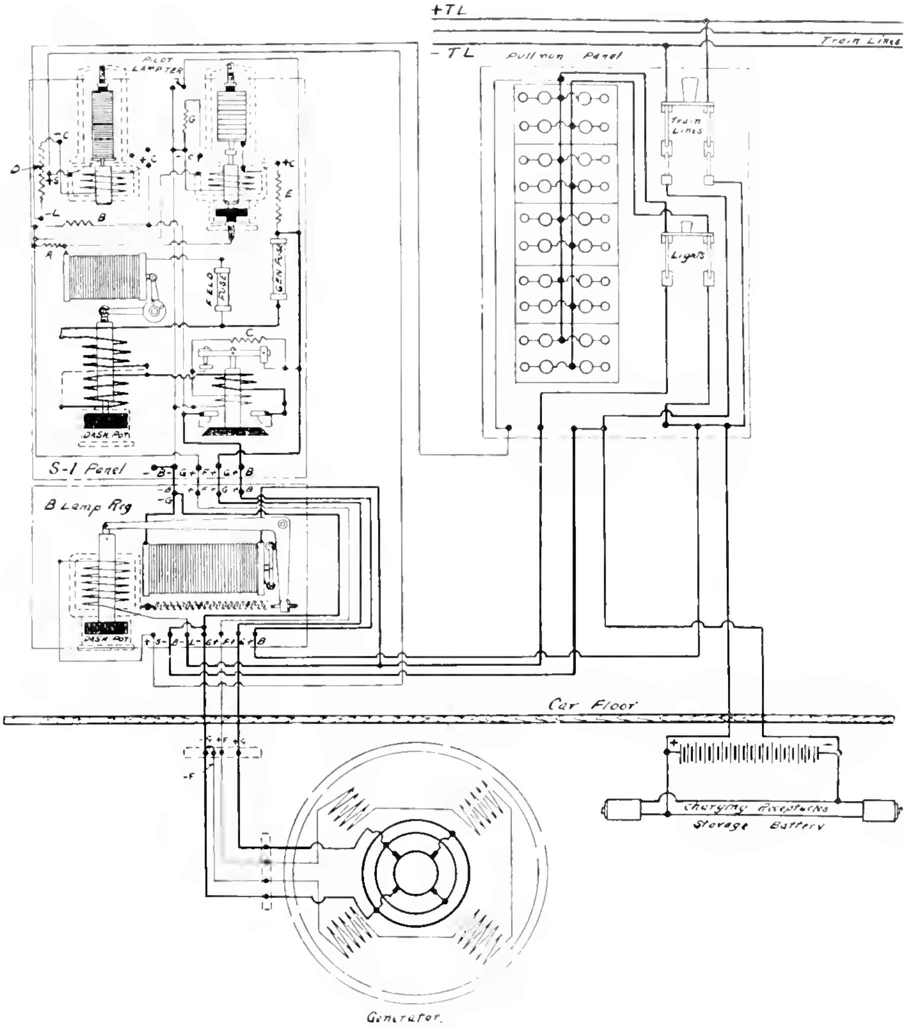


Fig. 23. U-S-L Panel with Lamp Regulator

**The Potential Regulator**

The construction of the potential regulator consists of an iron clad solenoid. It is provided with a single high resistance coil or winding wound on a copper tube, and is connected directly across the generator terminals which, after the automatic switch has closed, are the same as the battery terminals. Within the tube is an upper or fixed plunger and also a lower or movable plunger, the latter being mounted on a pair of parallel motion rods which permit of a frictionless vertical movement of the plunger within the tube. An air dashpot is formed integrally with the lower portion of the solenoid frame and a small graphite piston fitted therein, which is connected to the lower end of the movable plunger by means of a self-aligning connection. The dashpot serves to prevent sudden or jerky movements of the movable plunger. The bottom of the dashpot is made of molded insulating material, threaded and fitted into the dashpot. This insulating cover is provided with a carbon block terminal mounted on a screw, which is threaded through the cover and provided with a lock nut. The frame of the solenoid forms one terminal and the insulated carbon contact attached to the cover forms the other terminal of the resistance which is included in the field circuit of the generator and is normally short-circuited by the contact between the graphite piston and the lower carbon terminal. A brass tail rod is attached to the movable plunger and passes upward through a clearance hole in the stationary plunger. On the upper end of this rod is connected a cross bar, one end of which forms a rigid finger for the attachment of the helical adjusting spring, while the other is formed into a tapper which engages a roller on the end of a small multiplying lever. This lever is fulcrumed on a rigid support attached to the upper part of the solenoid frame. The lever engages a short vertical stud which passes up through the support to which the lever is attached, and supports the lower contact plate on which rests a vertical pile of carbon disks. The disks are confined within a cage whose vertical rungs are attached to the above mentioned support. The rungs are insulated with lava tubes, and thus the carbon pile is insulated from all metal parts with the exception of its lower carbon plate. A bonnet is attached to and insulated from the solenoid frame, and covers and conceals the carbon pile and its operating mechanism. In the top of the bonnet is mounted, by means of a steel adjusting screw provided with a lock nut, a carbon contact block which may engage the upper end of the carbon pile. A pressed cap fits over the top of the bonnet and covers and conceals the upper part of the carbon pile and the upper carbon contact.

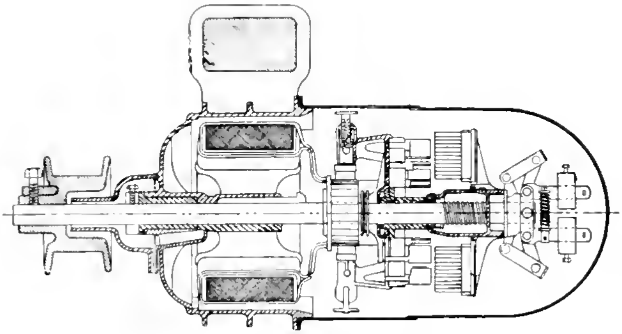


Fig. 24. Stone Axle Dynamo—Longitudinal Section

The action of the small lever provided with a roller is simply to increase the pressure exerted by the movable plunger of the solenoid upon the carbon pile, the dimensions of the lever being such that a multiplying effect of 2 to 1 is secured. The adjusting spring above mentioned is attached, as was stated, to one end of the cross bar fastened to the brass tail rod, and is enclosed within a brass tube mounted in lugs which are cast integrally with the frame of the solenoid. The magnetic pull of the coil is opposed by the weight of the carbon pile, the multiplying lever, and the movable plunger, and also by the tension of the adjusting spring.

## STONE SYSTEM

### Generator

The generator is of the two-pole shunt wound type with a rated continuous capacity of 18 amperes at 25 volts. The armature is of the old Gramme ring hand wound type. The bearings are of the ring oiling type and are carried by supports secured to the generator frame. The oil wells have an overflow pipe.

Two sets of brushes are carried in cast brass holders secured to the generator frame. The polarity is changed by means of a rocking arm and friction gear. Two plungers press against lignum-vitæ blocks on the rear end of the rocking arm by means of a spring engaging it and carrying it around to slots. After the arm is pushed home into the contacts, these plungers fly out free from the rocker arm when the centritugal force, due to the rotation of the armature shaft, is great enough.

The generator is suspended by means of an adjustable link in such a manner as to leave it free to swing. The belt is then adjusted to pull the generator out of the vertical position in which it would naturally hang, thus putting a tension on the belt sufficient to absorb power equivalent to the amount of current required at the speed for which the belt tension is adjusted. It is obvious, therefore, that increasing the speed will cause the belt to slip.

No regulator is used, as it is supposed that the cushioning effect of the batteries, in connection with a small resistance inserted in the lamp circuit and the slipping of the belt is sufficient to maintain the voltage within such limits that the variation in the candle-power of the lamps is not annoying.

The automatic switch is of the fly-ball type and is fastened on the generator shaft. As the speed is increased to a predetermined point, the weights are thrown out due to the centrifugal force and the contacts are made by knife blades being forced into the proper contacts.

Having attained the "cutting-in" speed, the centrifugal force on the governor weights will throw the pole changer to the proper position and cut in the automatic switch.

The generator is then supplying the current, any excess above that required for the lights going to the batteries. If the speed increases above the point at which the automatic switch is thrown in, the belt, if properly adjusted, will begin to slip as the generator is loaded, thus causing the voltage to drop, consequently decreasing the current

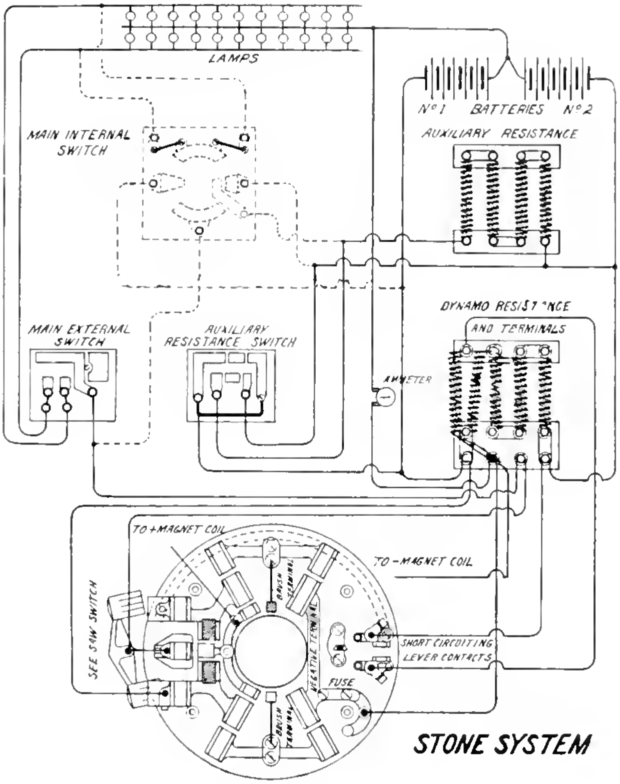


Fig. 25. Wiring Diagram

A question frequently asked is: "What particular system is best adapted to railroad work?" This question is difficult to answer from the fact that no one system is best for all cases; that is, by reason of train schedules, terminal lay-overs, organization, and the frequent interchange of equipment, no one system of lighting would give the most economical operation on all roads. For instance, a system that would be most economical for short runs, such as from Boston to New York and return, with the cars kept permanently on that run, would hardly prove to be the most economical when used in overland runs, such as from Chicago to the Pacific Coast.

Unfortunately, railroads which have adopted the head-end system of lighting are frequently handicapped by reason of the interchange of equipment with other roads, the cars of which do not have the same wiring system.

Where long runs are made, the cars of which are seldom if ever parted from one terminal to another, and no interchange of equipment with other roads is made, the head-end system with one generator taking care of the battery charging and the lighting for the entire train appears to be the most economical. The straight storage system appears to be the most economical for short runs and long lay-overs in terminal yards with no interchange of equipment. An equipment interchange is not troublesome with this system, as the lighting apparatus is a self-contained unit. Again, where cars are subject to transfer to another road, to be gone for some length of time, the axle generator system has proven the most satisfactory

# SOME ADVANTAGES OF THE ELECTRIC HOIST OVER THE STEAM OR AIR HOIST

By K. A. Pauly

Power and Mining Department, General Electric Company

In the introduction of this article the author points out the fact that since electricity can be far more economically distributed than can steam or compressed air it is best adapted to be the motive power in mining. This is especially true when the shafts are widely separated, for individual power generating stations at each shaft are to be avoided for obvious reasons. Attention is then called to the very low operating efficiency of steam and air engines when carrying such a fluctuating load as a hoist. A description of the steam hoist is omitted as it is so well understood, but a brief outline of the main features of the compressed air system is given. A full description of the systems of electric drive of hoists then follows; this covers the salient points of safety, reliability, cost of operation, and first cost. A table of calculated operating costs of the three kinds of hoist drive, covering a wide range of power and fuel costs, is furnished; and an analytical discussion of this table closes the article.—Editor.

As a result of efforts extending over many years, marked improvements have been made in many of the processes connected with the mining industry which have brought about either a reduction in the cost of mining or an increased percentage extraction or both. These advances, however, have been very largely confined to the methods of treating the ore after it has reached the surface. So great, in many cases, has been the reduction in the cost of treatment that the tailings from old concentrating plants and low grade ores from old waste piles, once considered worthless, now have a commercial value.

However, until a comparatively recent date almost no improvements were made in the methods of handling the ore from the face to the surface. This is due to two principal causes, first: the return on investments in improved methods of treating the ore is greater and more susceptible to more accurate determination in advance, and second: electricity affords the only means of making any considerable reductions over the old methods of handling the ore and, until recently, cheap electric power has not been available at most, if any, of the large mining districts. The early applications of electric power to mining were confined to driving locomotives, air compressors for supplying air for drills, small underground haulage engines, small and large pumps, ventilating fans, and the machinery used in treating the ore. The successes attending these early installations and the high cost of maintaining boiler plants for the hoists alone where power is purchased for the other operations have lead mining men, both owners and operators, to interest themselves in the possibilities of electric hoisting; and this article will present briefly some of the advantages of the electric hoist over other types, together with the more important factors which have a bearing on the choice of a particular system of electric hoisting to meet the more important special conditions obtaining at various mines. As the cost of developing power at the mines has an important bearing on the subject it will be discussed first, but in a very general and brief manner.

The conditions obtaining at mines are in general unsuited to the economical development of power. The shafts are scattered, requiring the installation of small steam plants supplying one or two shafts. In the latter case, the steam must often be piped from one thousand to three or four thousand feet. Fuel and labor, except at coal mines, are expensive and frequently of inferior quality. Water in sufficient quantities to supply the boilers is often expensive and frequently contains scale producing impurities, which reduce the boilers' efficiency and shorten their lives, thereby greatly increasing their cost of repairs and maintenance. Seldom is water available in sufficient quantities to permit the use of condensers even with the compressor engines and pumps, much less with the hoists.

These small plants, because of their low load-factor, are high in first cost and are inefficient, especially so when the mine is operated during only one or two shifts (8 hours each) as is frequently the case. In actual test, extending over several days, a boiler plant supplying a mine hoist alone showed the coal consumed during the idle period to be one-half the total coal consumed in generating steam for hoisting. In an effort to keep down the first cost of the boiler house, the boiler capacity is made so small that a large amount of water is carried over to the engines during the acceleration of the hoist, the engine taking steam full stroke for this period. Because of the first cost of piping steam into the mines and of the difficulty in taking care of it after exhausted, seldom, if ever, is any of the underground equipment steam-operated, except the large pumps. Small slope hoists and haulages take air from the drill-supply system and, because the air is necessarily used cold, are extremely inefficient, the useful work not representing over 15 per cent of the power consumed in driving the compressors.

On the other hand, the conditions which obtain in many districts, and which have a bearing on the power problem, are constantly undergoing changes that are favorable to electrification. There is a gradual consolidation of the larger mines into a few companies, which, in turn, absorb those smaller and weaker ones, resulting in a condition which makes the centralization of the development of power not only possible but highly commercial. Further, the increased stability of mining as an industry under these conditions renders a mining load an attractive proposition for investors interested in central station development. Only a very casual examination of the conditions existing, and the developments taking place in a few of the larger mining districts, is necessary to reveal this fact.

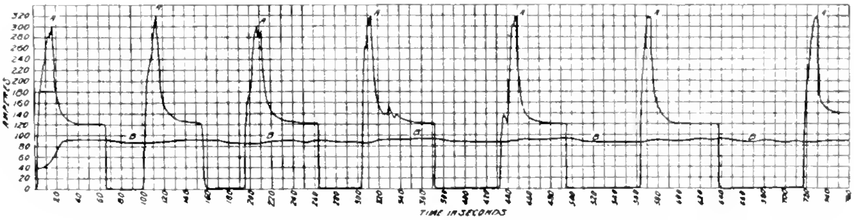


Fig. 1. Curve A, Current Input of Hoist Motor; Curve B, Current Input of Induction Motor of Motor-Generator Set

While these changes have an important bearing on the broad question of the electrification of mines, they affect the hoisting problem more than any other because of the intermittent character of this load. The two important competitors of the electric hoist are the steam hoist and the compressed-air hoist. The steam hoist is too simple to require explanation here, but for the benefit of those not acquainted with the air system a brief description is given.

In its operating characteristics the air hoist is similar to the steam hoist, compressed air from large steam or electrically driven compressors being substituted for steam. An ordinary steam engine may be used to drive the hoist, although the gain in efficiency by substituting a specially designed air engine usually warrants this expense. As a counterpart of the energy stored in the hot water of a steam boiler, large high-pressure storage tanks are provided with each hoist to reduce the momentary fluctuations in the demands for air, and where several hoists are driven from one central compressor plant a large central equalizer in the nature of an hydraulic accumulator is used. In order to improve the efficiency of the air system, which is otherwise very low, the air is reheated to as high a temperature as is practical just prior to admission to the engine. A modification of this system, known as the "dense air system," possesses certain theoretical advantages but, from a practical standpoint, it can seldom if ever be considered as a serious competitor of the simpler low-pressure systems and much less of the electric hoist. It will therefore not be considered here.

Although a great many systems of electric hoisting have been proposed, many of which are to meet special conditions existing at some particular mine, practically all of the installations are included by one of three systems. Of these, the simplest and usually the cheapest, and frequently the most efficient, is the induction motor hoist. In this type the drums are driven by an induction motor, usually through gearing, the speed control being obtained by the insertion of a variable resistance in the rotor circuit. Next in order from the standpoint of first cost is the system in which the hoist is driven by a direct-current motor, either geared or direct connected, the motor being controlled by varying the impressed voltage both in magnitude and polarity by varying the field of the supply generator. The third system is similar to the latter except that a flywheel is added to the motor-generator supplying power to the hoist motor, the speed of the motor-generator being automatically varied in such a manner as to store energy in the flywheel during the light load periods and return it during heavy loads, thereby reducing to a minimum the fluctuations in the central station load due to the hoist. The effectiveness of this system is well illustrated by the curves shown in Fig. 1, which are actual test curves.

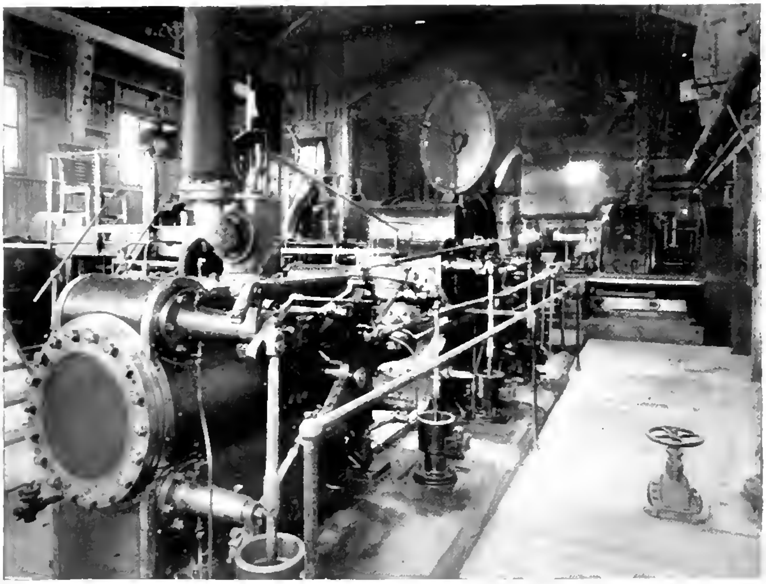


Fig 2. 900 h.p. Induction Motor Replacing Large Corliss Engine on Hoist

Because of the inherent characteristics of the reciprocating engine and the nature of a mine hoist load, an engine driven hoist is very extravagant in the consumption of steam or air. Each cylinder of the hoisting engine must be of sufficient size to handle the total unbalanced load under the most unfavorable position of the cranks, which requires that each cylinder be two times as large as would be necessary were the torque exerted by the engine uniform, as is the case with the electric motor. Steam or air is taken full stroke during acceleration while during the full-speed period the engine runs with a very short and uneconomical cut off. All losses of the engine are obviously high, as compared with its average load due to its large capacity. The steam consumption of a hoisting engine, as a result of these unfavorable conditions, seldom falls below 50 lb. per shaft horse power hour (actual work expended on the material hoisted) and often greatly exceeds this value. Combined with this extremely uneconomical use of steam, the low boiler efficiency due to the fluctuating demands often results in an overall efficiency which seems incredible, but which is confirmed by actual results obtained in practice. Coal consumption of 20 lb. and more per shaft horse power hour is not uncommon.

The consumption of the air engine is materially affected, in addition to the factors pointed out in connection with the steam engine, by the atmospheric temperature and the temperature to which the air is reheated and slightly by the elevation at which the hoist is operated. It is usually in excess of 10,000 cu. ft. of free air per shaft horse power hour.

On the other hand, the torque exerted by an electric motor is independent of the angular position of its rotating member which with its momentary overload capacity when designed for high efficiency at the average load of the cycle makes it especially adapted to meet mine hoisting conditions, advantage being taken of this overload capacity during the accelerating period. While with the systems using direct current motors power is consumed in driving the motor-generator light during idle periods, this is seldom a serious factor although it must be included in estimating the power consumption of an electric hoist driven by a direct current motor when the general supply system is of alternating current.

In discussing the relative merits of the various systems of hoisting, reference is frequently made to their respective efficiencies. Comparisons on this basis may be very misleading and may, unless care is taken, result in erroneous conclusions on the part of the purchaser who in reality is interested only in the relative economies of the several systems, efficiency being but one of several factors affecting economy, which is here used in its broadest sense. The most important factors affecting the economy of a proposed system for hoisting are, in the order of their importance, safety, reliability, cost of operation, and first cost.

Apart from humanitarian considerations an unsafe hoist is uneconomical. Continuity of service is of extreme importance, both because of the inconvenience to a large number of men who may be caught underground and the delay in production occasioned by a shut down, which would be the probable result owing to the small storage capacity that is usually provided. Too careful consideration can not be given these two factors in making a choice between competitive equipments.

The electric hoist has many characteristics which make for safety and reliability. Lowering unbalanced loads can be accomplished against the counter torque of the motor, insuring safe operation under these conditions and relieving the brakes of the severe strains to which they are frequently subjected in the case of the steam hoist. The electric hoist readily lends itself to the application of simple automatic protective devices, which increase the safety and reduce to a minimum the possible abuse of the hoist by carelessness on the part of the engineer. It is true that the electric hoist is liable to interruptions due to failures in the power supply, but little or no more so than is the air hoist depending upon electric power for driving the compressors. As a result of the recent improvements in power station and transmission protective devices and the precautions taken by power companies carrying a mining load, short interruptions are infrequent and long shut-downs seldom if ever occur.

An eminent American mining engineer, who is operating both types of hoists, confirms this in the following statement:

". . . . as to the relative merits of hoisting with electricity as compared with steam, I would say unqualifiedly that the electric hoists are more reliable than steam hoists, granting that you have, of course, a constant and reliable current. The electric hoists are more sensitive to handling, are much easier controlled, and it is easier to apply overwinding and other safety devices to them. The electric hoists give a steady pull on the rope during acceleration and, in fact, during the entire trip. There is none of the flopping of the rope which is apparent in the pull of the steam hoist. We find that for this reason our pulley stands which support the rope between the shaft house and the engine house can be set much farther apart and that the rope never jumps out of the grooves in the carrying sheave."

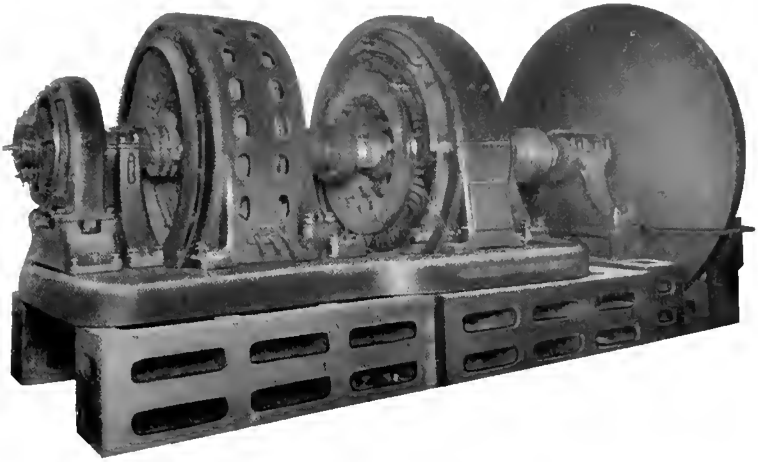


Fig. 3. 1000 kw. Motor-Generator Set with 18-Ton Flywheel for Mine Hoist

Next in order of importance is the cost of operation. Many factors entering into the cost of operating a steam mine hoist are so intimately related to the operating costs of other equipments at the mine that it is extremely difficult in most cases, and impossible in others, to properly separate the hoist costs from the total. The steam for the hoist is frequently taken from boiler plants supplying the air compressors, pumps, etc., which, as a result of a lowering of the boiler efficiency due to the excessive fluctuations in the steam as demanded by the hoist, are charged for at too high a steam cost. The oil waste and supply accounts are seldom segregated. However, the advantage obtained by the electrification of a hoist, because of the reductions in the cost of power made possible by centralization, are so great that a large saving can be shown in its favor even though the steam and repair charges against the steam hoist are somewhat under-estimated by reason of using corresponding costs from plants admittedly operating under more favorable conditions.

In general, the "Operating Cost" is the determining factor in the choice between the several electric systems although frequently the first cost plays an all too important part. A complete discussion of the relative operating costs of the various types of electric hoists is not feasible here, but a brief outline of the general conditions affecting the problem are in order. For long hauls and for slow-speed hoisting for shorter distances where the time required for acceleration is a comparatively small percentage of the total time consumed in making the trip and where the hoist is not required to run at reduced speeds to any considerable extent, the induction motor hoist will give the highest efficiency, but where the opposite conditions prevail the direct current hoist motor and motor-generator without flywheel will show the lower power consumption.

However, as previously pointed out the efficiency or its measure, the power consumption, is only one of the factors affecting the cost of operation for it is true that the most efficient electric hoist may be the most expensive to operate. With both the induction motor and direct current hoist motor and motor-generator without flywheel, all the fluctuations in power required to drive the hoist are reflected back upon the power system. As these variations may be equivalent in magnitude to 300 per cent of the rated load of the hoist motor, if the hoist load is a considerable percentage of the station or feeder load, a considerable excess capacity must be provided to prevent excessive voltage variations. Where power is purchased, provision is made in the rate to protect the power company against loss when supplying a load of this character. The method usually adopted is to base the power rate both on the maximum demand and the energy consumption. Under these conditions it is frequently advisable to install some form of equalizer, usually a flywheel operating in conjunction with the induction motor-generator supplying the hoist motor which, in this case, is of the direct-current type. By means of the flywheel, the speed of which is automatically controlled, the maximum demand is reduced to a minimum, with the result that the reduction in the "demand charge" for power will usually pay for the complete electrical equipment in from three to five years. Often where power is generated locally by the mine operator, the installation of the flywheel motor-generator system is warranted for the same reasons as when the power is purchased, although, of course, greater fluctuations in voltage are permissible

TABLE I

| | COAL AT $2 PER TON AT BOILERS | | | | | COAL AT $4 PER TON AT BOILERS | | | | | COAL AT $6 PER TON AT BOILERS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cost of Power per Kw-Hr. | | | | | | | | | | | | | |
| | $0.005 | $0.0075 | $0.01 | $0.015 | $0.02 | $0.005 | $0.0075 | $0.01 | $0.015 | $0.02 | $0.01 | $0.015 | $0.02 | $0.03 |
| ELECTRIC HOIST | | | | | | | | | | | | | | |
| Operating cost: | | | | | | | | | | | | | | |
| Maintenance and repairs | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| Electric power | 3740 | 5600 | 7470 | 11200 | 14950 | 3750 | 5600 | 7470 | 11200 | 14950 | 7470 | 11200 | 14950 | 22400 |
| Labor | | | | | | | | | | | | | | |
| Oil waste and sundries | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| Total | 4240 | 6100 | 7970 | 11700 | 15450 | 4240 | 6100 | 7970 | 11700 | 15450 | 7970 | 11700 | 15450 | 22900 |
| AIR HOIST | | | | | | | | | | | | | | |
| Operating cost: | | | | | | | | | | | | | | |
| Maintenance and repairs | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Electric power for driving compressor | 5630 | 8430 | 11250 | 16900 | 22500 | 5630 | 8430 | 11250 | 16900 | 22500 | 11250 | 16900 | 22500 | 33800 |
| Fuel for reheating | 750 | 750 | 750 | 750 | 750 | 1500 | 1500 | 1500 | 1500 | 1500 | 2250 | 2250 | 2250 | 2250 |
| Labor | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 |
| Oil waste and sundries | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Total | 9050 | 11850 | 14670 | 20320 | 25920 | 9800 | 12600 | 15420 | 21070 | 26670 | 16170 | 21820 | 27420 | 38720 |
| Saving with electric hoist | 4810 | 5750 | 6700 | 8620 | 10470 | 4560 | 6500 | 7450 | 9370 | 11220 | 8200 | 10120 | 11970 | 15820 |
| Saving with steam hoist | | 1710 | 2170 | 10180 | 15780 | | | 340 | 5990 | 11590 | | 1800 | 7400 | 8700 |
| STEAM HOIST | | | | | | | | | | | | | | |
| Operating cost: | | | | | | | | | | | | | | |
| Maintenance and repairs | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 |
| Fuel | 4940 | 4940 | 4940 | 4940 | 4940 | 9880 | 9880 | 9880 | 9880 | 9880 | 14820 | 14820 | 14820 | 14820 |
| Labor | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| Oil waste and sundries | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| Total | 10140 | 10140 | 10140 | 10140 | 10140 | 15080 | 15080 | 15080 | 15080 | 15080 | 20020 | 20020 | 20020 | 20020 |
| Saving with electric hoist | 5900 | 4040 | 2170 | | | 10840 | 8980 | 7110 | 3380 | | 12050 | 8320 | 4570 | |
| Saving with air hoist | 1090 | | | | | 5280 | 2480 | | | | 3850 | | | |

under these conditions than when power is supplied by a public service corporation.

Frequently, an otherwise objectionable hoist-load curve may be materially improved by using conical or cylindrical drums and slightly reducing the maximum rope speed or lengthening the period of acceleration, which may be done without seriously affecting the first cost of the equipment or reducing the shaft output. The high maximum running speed of steam hoists is due to the defect in the steam engine torque curve previously mentioned rather than to production considerations, and, unfortunately, these same high speeds are demanded of the electric hoist which is often looked upon as being inherently slow if a reduction in speed is suggested. It is appreciated that lack of underground storage capacity, or other important considerations in many cases, warrant as high a speed of hoisting as shaft conditions will permit, but frequently a material saving in first cost and operating cost can be made by reducing the speed of an electric hoist without harmful effect. Such a reduction is not possible with the steam hoist because of its irregular torque characteristics.

The determination of the shape of the drum can only be made after a careful investigation of all the special conditions affecting each individual problem, and it is dependent upon so many factors that no general recommendations can be made herein. For the same reason, neither can a complete analysis of the relative costs of operating hoists by steam, compressed air, or electricity be given. However, although the operating conditions vary widely in different localities, those affecting the operating costs produce in the majority of cases about the same relative changes in all of the systems. Bearing this in mind, the figures given in Table I may be taken as typical, although they are based upon hoisting an average of 650 tons per day from an average vertical depth of 1500 ft., assuming the non-productive work one-half the productive work. The estimates are made on the basis of 12,000 B.t.u. coal costing $2, $4 and $6 per ton delivered at the boilers, and power costing (including both demand and energy charge) from ½ c. to 3 c. per kw-hr. In preparing this table, it has been assumed that the particular type of electric hoist best adapted to meet the local conditions has been chosen, thus permitting the treatment of the electric hoist as a system. The air compressors supplying air for the hoists are motor driven, since the cost of so operating the compressors is less under the conditions assumed than if steam driven. The fixed charges are not included as the first cost of the hoisting equipment depends upon many local conditions which can not be taken into consideration. Including these charges will not materially affect the conclusions drawn as, in general, for new installations, the electric hoist can be installed for approximately the first cost of the steam hoist. This statement includes the cost of all of the items chargeable against the hoist, namely; the cost of the boiler plant, piping, additional cost of building to accommodate the steam hoist, for a larger building is required than would be for the electric hoist, etc., and 'it will be found less in all cases than the first cost of the air hoist including in this cost its proper percentage of the compressor plant, piping system, reheating equipment complete and building to house the same, air engine, receivers, and pressure-equalizing equipment. Where the problem is one of replacement, the first cost of the equipment may differ somewhat for the different systems, but the resulting difference in the fixed charges will but slightly affect the results as given.

From an examination of the table, it will be found that only when the cost of power is very low and the cost of fuel high is the compressed air hoist cheaper to operate than the steam hoist; and that in all cases the electric hoist is cheaper to operate than the compressed air hoist and, except where the cost of power is high and the cost of fuel is low, the electric hoist is cheaper to operate than the steam hoist

In summing up it may be stated that the air hoist possesses no advantage over the steam hoist except where fuel is high and power is extremely cheap, and possesses no advantage over the electric hoist under any conditions; that the steam hoist has no advantage over the electric hoist except where fuel is cheap and power is high and then only the advantage of a lower operating cost, while the electric hoist has the advantages of greater safety and reliability, longer life of ropes and brakes, more delicate control under all conditions, and, under practically all actual operating conditions, is operated at a lower cost.

# THE SELECTION OF STEAM TURBINE CONDENSERS

By A. R. Smith

Construction Engineering Department, General Electric Company

In this article the author gives an impartial discussion of the three common types of condensers, viz., the surface condenser, the low jet condenser, and the barometric condenser, and to afford a ready comparison of the different types, has arranged a table which shows at a glance the advantages and disadvantages of each. The question of the best form of drive for the auxiliaries is discussed, with a recommendation for motor drive from an auxiliary non-condensing turbo-generator set. The several types of air pumps, circulating pumps and hot well pumps are described and the merits of each pointed out. The data found in the text and in the form of curves will be of great service in determining the best type of condenser for a given set of conditions.—Editor.

To limit the scope of this article it has been necessary to assume that condensing water is available so as to avoid reference to cooling towers, cooling ponds, spray nozzles, evaporative condensers and the like, which naturally have considerable bearing on the problems as presented.

There are few instances where the installation of condensers is not justifiable. Two common conditions met with in practice which may at first appear to be strictly non-condensing propositions are: first, where a considerable quantity of exhaust steam is required for heating, and second, where the station is purely a "standby" station and economy is of little importance. That a careful investigation of the conditions should be made in such cases will be evident after studying the two following examples.

Let us take a small station containing two 1000 kw. turbines designed for steam extraction for heating, with a condensing water rate of 16 lb., or two non-condensing turbines with a water rate of 34 lb. per kw-hr. Let us further assume that the maximum heating requirements are 34,000 lb. of steam per hour. Now, for a climate requiring seven months heating, the average daily steam required for the coldest month would be about 60 per cent of that for the coldest day and the average for seven months would be 80 per cent of that for the maximum month, or 48 per cent of that for the coldest day.

The curve shown in Fig. 1 is of a typical daily load for a manufacturing plant. The daily load factor here is 54 per cent and the yearly load factor 45 per cent. Because of the entirely different characteristics of the electrical load from that of the heating load, it is obvious that at certain times the electrical output exceeds that which could be obtained as a by-product of the heating, and if condensers were installed 28 per cent of electrical load during the winter, or heating months, could be generated with a turbine water rate of 16 lb. per kw.-hour. Therefore,

$$7 \text{ mo.} \times 30 \text{ days} \times 24 \text{ hr.} \times 45\% \times 28\% \times 1000 \text{ kw.} = 630{,}000 \text{ kw-hr.}$$

$$5 \text{ mo.} \times 30 \text{ days} \times 24 \text{ hr.} \times 15\% \times 1000 \text{ kw.} = 1{,}620{,}000 \text{ kw-hr.}$$

$$\text{Total yearly} \quad 2{,}250{,}000 \text{ kw-hr.}$$

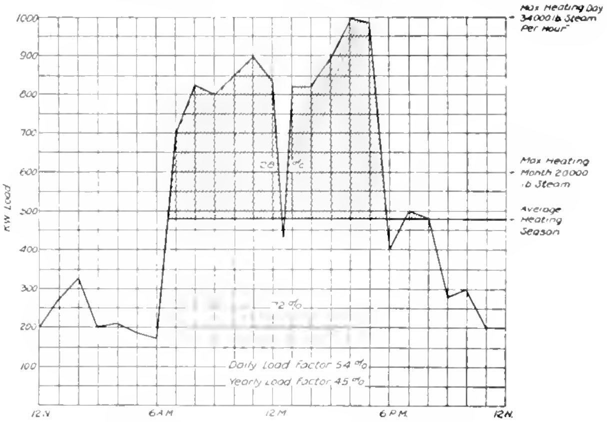


Fig. 1. Characteristic Factory Load Curve Showing Relation Between Electrical Load and Heating Requirements

Now, 34 lb. − 16 lb. = 18 lb. saving per kw.-hr. by running condensing, or 18 × 2,250,000 = 40,500,000 lb. of steam. If steam costs 25 cents per 1000 lb., the yearly saving will be $10,100.00. The steam consumption of the auxiliaries should not exceed 10 per cent of the main turbine steam or 1600 lb. per hour and 87½ per cent of this can be charged to heating the feed water. Therefore,

$$8760 \text{ hr.} \times 12\tfrac{1}{2}\% \times 1600 \text{ lb. per hr.} \times \frac{25 \text{ cts. per 1000 lb.}}{1000} = \$438.00$$

yearly cost of power for auxiliaries. Two condenser equipments installed and including piping would cost approximately $7.50

per kw., or $15,000.00, and the additional building space would cost about $3000, or a total of $18,000. With interest at 6 per cent, depreciation at 4 per cent and maintenance at 2 per cent, the fixed charges would be $2,160.00 a year. The net saving would then be $10,100.00−($438.00+$2,160.00)=$7,502.00.

Considering now the second case, viz., that of a standby station where the yearly output would be so small that the saving in coal due to condensing operation would be negligible: The operation of a turbine condensing practically cuts the water rate in half and proportionally reduces the necessary boiler capacity. It is then a question of balancing the investment for condensers with the investment for boilers.

If condensers were installed, the boiler h.p. would be

$$\frac{1000 \text{ kw.} \times 16 \text{ lb.}}{30 \text{ lb.} \times 1.33\% \text{ rating}} + 50\% \text{ spare} = 600 \text{ h.p.}$$

and if condensers were not installed, the boiler h.p. would be

$$\frac{1000 \text{ kw.} \times 34 \text{ lb.}}{30 \text{ lb.} \times 1.33\% \text{ rating}} + 50\% \text{ spare} = 1280 \text{ h.p.}$$

An increase of 680 boiler h.p. at $20.00 per h.p. installed, would be $13,600.00 against two condensers at $6.50 per kw., or $13,000.00. It is thus apparent that condensers can be installed for practically the same price as additional boilers, when neglecting the extra cost of the building, stack, piping and tunnels, which should ordinarily be in favor of the condensers.

### Types of Condensers

The three common types of condensers are the surface condenser, the low jet condenser, and the barometric condenser. Various trade names are applied to cover modifications in construction, but the merits of the different designs on the market will not be considered here. The essential difference between the low jet and barometric condenser is that the water is pumped away from the former and is pumped to the latter, as will be seen in Figs. 5 and 7.

The one all-important advantage of the surface condenser is that the condensate is saved for re-use as boiler feed. This is really the first consideration in selecting a condenser, unless the available boiler feed water is exceptionally good. With surface condensers it should be possible to re-use 90 per cent of the water evaporated by the boilers, and as the scale-forming matter is deposited during the first evaporation, the only accumulated scale in the boilers will be from the remaining 10 per cent make-up, that is, the amount of boiler scale should be but one-tenth of what would be deposited if surface condensers were not used.

### Surface Condensers

Surface condensers are by far the most commonly used for steam turbines, principally because of the salvage of the condensate. Surface condensers used with sea water will give perfect satisfaction, unless the water is contaminated. Two power houses obtaining circulating water from different parts of the same salt water inlet may show entirely different maintenance costs.

Foreign matter can usually be screened from the water even if it becomes necessary to resort to mechanically cleaned screens. In shallow salt water inlets barnacles, mussels, and shell fish will sometimes spawn after passing the screens and give considerable trouble. Such obstacles can usually be overcome by properly designing the plant.

Besides the reduction of boiler scale due to the re-use of the condensate, there is a small saving in heat. For example, a 28 in. vacuum should give a condensate of about 95 deg. F. which, compared with city water at a temperature of 50 deg. F., means a saving of 45 deg. F. on 90 per cent of the water evaporated, or roughly, 3½ per cent saving in heat. And again, if city water is purchased at a rate of 10 cents a 1000 gal., there is an additional cost of 1.2 cents per 1000 lb. of steam produced.

There are two kinds of surface condenser equipments, one known as the wet vacuum and the other the dry vacuum system. The distinction between the two is that in the former the air pump removes the air and the condensate, and in the latter the air pump removes the dry air, and the hot well pump removes the condensate.

At first glance the wet vacuum system appears to have the advantage, but this is not always true. While the hot well pump is eliminated, the discharge head on the wet air pump is limited and usually a second pump is necessary to lift the water up to the feed water heater, or make-up tank. To make the air pump effective at high vacua, it is essential to lower the temperature of the air below the temperature of the vacuum before removing it from the condenser; but the air and condensate must necessarily be of the same temperature when handled by a single pump, which means a loss of from 5 to 10 deg. F. due to the lower temperature of the condensate. And again, the returned condensate contains more air, which has to be freed in the open feed heater, or in the reboiler if condensate is used for making ice. It is very doubtful if the feed water heater removes all of the air, and the dry vacuum system should have the benefit of the doubt.

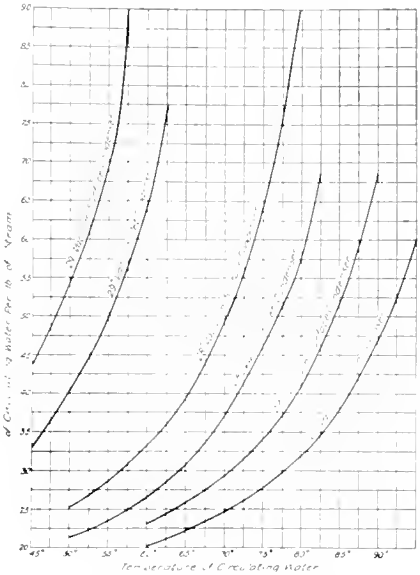


Fig. 2. Curves showing Quantity of Circulating Water Necessary to Produce 27 In., 28 In. and 29 In. Vacuum, Based on Water Leaving Surface Condenser 10° F. Below Temperature of Vacuum and 3° F. Below for Jet Condensers

The above mentioned disadvantages of the wet vacuum system are more or less trivial and for small stations this system is very simple to operate and maintain and has proved in general very satisfactory.

### Barometric and Jet Condensers

A jet condenser whether of the low or barometric type is essentially a chamber where the steam and water come in direct contact. There are many forms on the market, such as horizontal, ejector, injector, eductor, counterflow, etc. and some barometric condensers are arranged so that the sweeping action of the water removes the air and thus makes the air pump unnecessary. Such condensers naturally have restricted water passages to obtain high velocities and generally require some means of opening up such passages to free the condenser of leaves and other material that may accumulate. The pumping head also exceeds that of the type where the cooling water falls over trays.

In choosing between a condenser with an air pump and one without, the merits of each manufacturer's apparatus has to be given consideration. In choosing between a low jet and a barometric condenser, it is largely a question of water levels and design.

### Choice of Condenser as Regards Pumping Head

The amount of circulating water required by a jet or barometric condenser is less than that required by a surface condenser because of the more efficient heat transfer from the steam direct to the water. In the former it is common practice to figure that the outgoing water will be within 3 deg. of the temperature of the vacuum. In the case of the surface condenser it has been customary to figure 13½ deg. F., but the many advances recently made in condenser design indicate that 10 deg. F. is a conservative figure to use. It will be noted from the curves in Fig. 2 that the surface condenser requires considerably more water than the jet condenser as the temperature of the circulating water approximates the temperature of the vacuum sought. However, the power re-

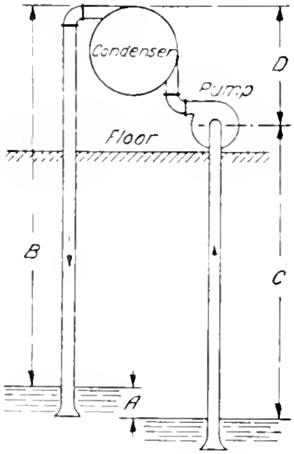


Fig. 3. Diagram of Typical Surface Condenser Installation, where C does not Exceed 22 Ft.

quired for pumping is proportional to the product of the quantity and head, and the following will illustrate how the pumping heads vary.

Referring to Fig. 3 which shows a diagram of a typical surface condenser installation: Dimension C should not exceed 22 ft. (this may be increased slightly by reducing to a minimum the pipe friction) because of the inability of the pump to lift water to a greater height. Should the incoming water level be lower, then the scheme shown in Fig. 4 should be resorted to and the pump may then, if possible, be located so as to be below the water level, to save priming. The pumping head in Fig. 3 will be (A + condenser friction + pipe friction) and the suction lift and static head on the pump are balanced by the siphon formed by the condenser discharge so long as B does not exceed 25 ft. Should B exceed 25 ft., then the pumping head would be

(A + cond. friction + pipe friction + B − 25 ft.)

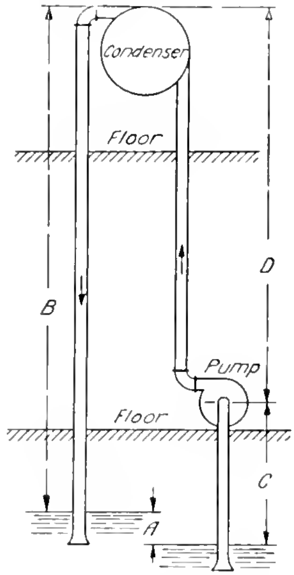


Fig. 4. Surface Condenser Installation for Cases where C is greater than 22 Ft.

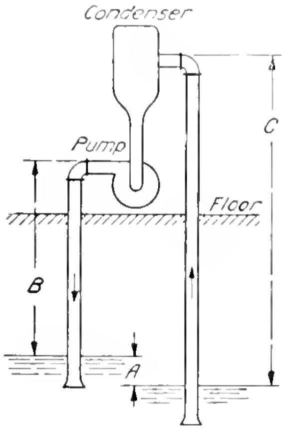


Fig. 5. Diagram of Typical Low Jet Condenser, where C does not exceed 25 Ft.

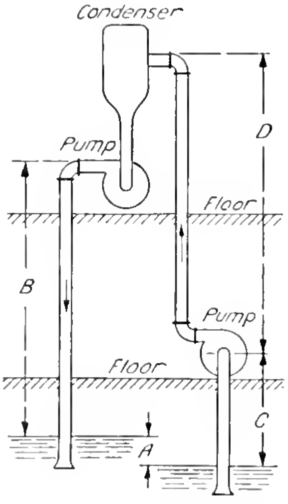


Fig. 6. Diagram of Low Jet Condenser for Cases where C is greater than 25 ft.

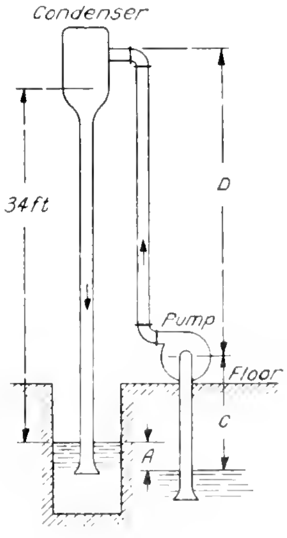


Fig 7. Barometric Condenser in which all the Pumping is Accomplished on One Side with One Pump

Assume a common condition as in Fig. 3, with A = 3 ft., C = 15 ft., cond. friction = 10 ft., pipe friction = 6 ft. Then, the total normal pumping head is 19 ft. Now, if 29 in. vacuum is desired and 50 deg. F. water is available, there would be required 55 lb. of water per lb. of steam (see Fig. 2), or 19 × 55 = 1045 ft. lb.

Now, referring to Fig. 5 showing a diagram of a typical low jet condenser, it will be observed that the dimension C is also limited as the water is lifted by the vacuum in the condenser. Dimension C should not exceed 25 ft. Should this be considerably less than 25 ft. more pumping head is required because the discharge leg on the pump is correspondingly reduced, and the friction in C is increased by the throttle valve to maintain constant flow of water. Therefore, in comparing the jet with the surface condenser under the following assumptions, the conditions are favorable to the jet condenser.

A = 3 ft. C = 25 ft. B = 10 ft. Pipe friction = 6 ft.

Then the total pumping head with 29 in. vacuum is: (29 in. mercury, or 32.8 ft. water − 10 ft.) = 22.8 ft. For a 29 in. vacuum and 50 deg. F. water, 40 lb. of water per lb. of steam is necessary. Therefore, 40 × 22.8 = 912 ft. lb.

Should C be more than 25 ft. and an additional pump be required, as shown in Fig. 6, the problem of regulating the output from two pumps in series is encountered and the barometric condenser shown in Fig. 7 is immediately suggested, where all pumping is accomplished on one side and with one pump.

Let us now compare the power required for the barometric condenser with the foregoing.

Assume A=3 ft., D=30 ft., C=10 ft., pipe friction=10 ft. and 29 in. vacuum in condenser. Then, we have a static pumping head of 30 ft. + 10 ft., or 40 ft.; but this is partly overcome by a vacuum of 29 in. or equivalent 32.8 ft. lift. Still it is not safe to use this without discounting it for leaks and we will credit 28 ft. lift to the vacuum. Therefore, 40−28 ft.=12 ft. static head + 10 ft. friction, or 22 ft. total head. 40 lb. of water × 22 ft.=880 ft. lb.

It is thus apparent that the surface condenser can be used under any conditions of water levels, whereas the low jet condenser is somewhat restricted to a low lift, and that there is little to choose as regards pumping head. The barometric condenser can be adapted to varying water levels and shows a low pumping head; but the conditions on which the calculations are based are rarely met because of high and low water levels at different seasons of the year, which will increase A accordingly, and therefore materially increase the pumping head.

The foregoing examples are given to illustrate the fact that the prevailing and varying water levels are important factors in selecting the type of condenser to be purchased, and it is necessary to make a study in each case of these conditions, providing other considerations do not preclude the use of the jet or barometric condenser.

### Comparative Costs of Condensing Equipments

To show the approximate costs of condensers, including their auxiliaries f.o.b. the factory, curves in Fig. 8 have been made up from average costs of some 150 equipments. The averages for each capacity of turbine are compiled from costs without regard to amount of surface, quantity of water, vacuum maintained, and steam or electric drive. They therefore represent the masses.

It should be borne in mind that the cost of a condenser and its auxiliaries may be considerably more or less than shown on the curves, depending on local conditions and other special considerations.

### Steam *vs.* Electric Auxiliary Drive

Steam driven condenser auxiliaries have been universally recommended in preference to motor drive because any disturbances on the electrical end will not affect the auxiliaries. For example, suppose a short circuit occurs on some outside feeder and the speed and voltage is reduced sufficiently to let the condenser auxiliaries drop out. First, the loss of vacuum on the turbine will necessitate the immediate generation of double the amount of steam; but the boiler room is not prepared for this emergency, and the only alternative is to reduce the load. Second, the vacuum pump has to be started, and third, the circulating pump started and primed. These operations consume considerable time, especially with chaotic periods of interruption. Should there be two turbines on the line, the duration of the interruption is doubled.

The dry vacuum pump and hot well pump can conveniently be made motor driven because the motors are small and can be self starting. An interruption of half an hour of the vacuum pump, or one minute of the hot well pump ought to show but little effect on the vacuum.

It is not an uncommon occurrence to lose the station excitation. With steam driven auxiliaries this does not result in so long an interruption as with motor driven auxiliaries, where the machines not only have to be re-synchronized, but also changed from non-condensing to condensing.

Motor-driven auxiliaries are very desirable in that they are cheaper in first cost and maintenance; they obviate the use of considerable steam and exhaust piping and the expense of maintenance and radiation incident thereto; the motor speeds are conducive to high pump efficiencies, and they are easily started and require little attention when running. To enjoy these advantages without sacrificing continuity of service is possible by feeding the auxiliaries for each turbine off a separate auxiliary turbine driving an exciter and a-c. generator. This may seem like an additional complication, but investigation will show that this auxiliary turbine can be operated at a speed of highest economy and each pump can be operated at the most efficient speed.

The auxiliary turbine can be exhausted into its own feed water heater, thus evolving a comprehensive unit plan station as follows:

| | |
|---|---|
| Main turbine unit (operated condensing) | Supplying all outside load |

Aux. turbine unit (operated non-condensing)
- Exhausting to individual heater
- Supplying excitation to main unit
- Supplying power to
  - Boiler feed pump
  - Circulating pump
  - Air pump
  - Hot well pump

Unless an auxiliary turbine is employed, or steam driven auxiliaries used, there is usually a shortage of exhaust steam for heating the feed water. Take, for example, a case where the turbine is running at half rated load: the steam driven exciter and boiler feed pump would be taking about 5 per cent of the total steam, which would heat the feed water from 75 deg. F. (29 in. vacuum) to 125 deg. F. If the main turbine were carrying full rated load, the condition would be worse as the auxiliary steam would represent only about 3½ per cent and the increase in feed water temperature would be only 35 deg. F. Now, if the condenser auxiliaries are steam driven, the total exhaust steam would be about 15 per cent at half load, and 9 per cent at full load, and the feed temperature in the former case would be 210 deg. with a waste of 1½ per cent of the steam, and at full load it should be 165 deg. F.

## ADVANTAGES OF DIFFERENT TYPES

| Surface | Jet | Barometric |
|---|---|---|
| Re-use of condensate for boiler feed. | Least expensive type of condenser. | Condenser proper not costly but piping to it is expensive. |
| Re-use of condensate for ice production. | Requires less building space. | No possibility of flooding turbine as in the case of a low jet condenser. |
| Readily adapted to the weighing of condensate for tests. | Equipment simpler because hot well pump is not necessary. | Maintenance low. |
| Slightly better vacuum obtainable. | Requires less circulating water than surface condenser. | The use of acidulated water possible. |
| Advantage of low pumping head through siphon action. | Maintenance low. | Requires less circulating water than surface condenser. |
| Less chance of losing vacuum because a drop in vacuum does not affect water supply. | The use of acidulated water possible. | Requires little building space. |
| | | Equipment simple. No hot well pump necessary and in some forms no vacuum pump is required. |

## DISADVANTAGES OF DIFFERENT TYPES

| | | |
|---|---|---|
| First cost high. | Failure of removal pump would flood turbine. Protection is provided by a vacuum breaking float valve. | Long exhaust pipe line to condenser which entails high initial cost and greater possibility of air leaks. |
| Maintenance high. | Waste of condensate. | Loss of vacuum between turbine and condenser which may amount to ½ in. or even more. |
| Requires considerable building space to remove tubes. | | As condenser cone generally extends above roof, it does not lend itself to economical station design when boiler room and turbine room are parallel and contiguous. |
| Acidulated water or water containing foreign matter in large quantities may preclude the use of surface condensers. | | Waste of condensate. |
| More head room necessary to obtain sufficient head on hot well pump. | | |

**Amount of Condensing Surface**

There is at present a wide disparity between the amount of surface recommended for a given condition by the different manufacturers, both here and abroad, and inasmuch as the cost of the surface represents about half of the total cost of the condenser equipment, it is manifestly unfair to compare bids covering different amounts of surface without compensating for it in the prices.

The amount of surface necessary for condensing 1000 lb. of steam at 29 in. vacuum is

$$S = \frac{1000 \text{ lb.} \times \text{latent heat in steam at } 29'' \text{ vac.}}{U \times \left(T - \frac{T_2 + T_1}{2}\right)}$$

where:

$S$ = surface in square feet.

$U$ = B.t.u. transmission per sq. ft. per degree per hr.

$T$ = temp. of vacuum, Fahrenheit.
$T_1$ = temp. of incoming circulating water.
$T_2$ = temp. of outgoing circulating water.

The two uncertain items are $T_2$ and $U$. Now, $T_2$ may vary from 5 deg. to 15 deg. F. below the temperature of the vacuum. It is not safe to figure on 5 deg., although this has been obtained in practice, and it should not reach 15 deg. A temperature of 10 deg. below the vacuum is common and in the writer's opinion can safely be used for the calculation of surface.

On the other hand, it may be better to circulate more water and thereby lower $T_2$ and consequently reduce the amount of surface, but this will be discussed under the subject "Circulating Pumps." The fact remains that "U" is the uncertain quantity, and the one on which the condenser manufacturers disagree.

It has been found that with ordinary condenser tube materials of usual thickness, a transmission of 455 B.t.u. could be obtained with a water velocity of 1.6 ft. per second, and this is materially increased by increasing the water velocity. But the average transmission in a condenser under operating conditions depends on the distribution of steam, the amount of surface used for cooling the air to the pump, the amount of air in the steam, which acts as an insulator, and the condition of cleanliness of the tubes. In the past, the practice has been to figure on an average heat transmission of 350 B.t.u. and now some manufacturers claim that they have in their new designs eliminated most of the idle surface, and can obtain at least 500 B.t.u. transmission. There is no doubt that a perfectly designed condenser will raise the rate of transmission; but it is a question if this increase should not be taken in smaller doses, and it is the writer's opinion that 400 B.t.u. might be safely used until experience has demonstrated that it is safe to take another step forward.

Of course, the purchaser is interested in the guaranteed vacuum, but more particularly in the vacuum that can be maintained in regular service. There are many loop holes, such as air infiltration, moisture or superheat in the exhaust steam and quantity of circulating water, that the purchaser might easily be convinced that the performance was well within the guarantee; but far better results might have been attained with more surface. It is therefore well, in comparing prices, to give due consideration to the amount of surface included, which may readily be done by adding to the lowest price the cost of the additional surface included in the bid containing the greatest amount of surface.

### Air Pumps

There are three general types of air pumps used in connection with condensers. They are the rotative reciprocating pump, the rotary positive displacement pump, and the hydro-centrifugal pump. The reciprocating pump is most commonly used, and is best fitted for steam cylinder drive, although it can readily be adapted for motor drive. The rotary pump is particularly adapted for motor drive and is used almost exclusively on wet vacuum systems. The hydro-centrifugal pump, or one where the impeller projects successive sheets of water, each entrapping a certain amount of air, is best adapted to turbine drive but may also be used with motor drive.

The reciprocating pump, commonly known as the rotative dry vacuum pump, can be used for a wet or dry vacuum system, and requires only about half as much power as a hydro-centrifugal pump. When steam driven the speed can be varied at will, but if motor-driven it may as well be operated at full speed at all loads.

The rotary pump, of which there are many makes, requires water sealing and is therefore best suited for wet vacuum service. The motor drive makes this pump a very compact and simple outfit for moderate size turbines.

The hydro-centrifugal pump is now manufactured in many types, most of which are importations from Europe. It is comparatively new and sold at present largely because of its simplicity. Although it takes about twice the power of a rotative pump, its speed corresponds closely with that of the circulating pump, and thereby makes possible a combination unit of air pump and circulating pump, driven by either a motor or a turbine. Like a circulating pump, it requires priming in starting and some makes are likely to drop the suction when the condenser vacuum gets very low.

The volumetric capacity of the air pump cannot be figured from any theoretical formula, because the amount of air in the steam and the air infiltration are very uncertain quantities. It is quite common to make the volumetric capacity in cubic feet per minute fifty times the cubic feet of condensate per minute, and this represents very good practice. The curves in Fig. 10 show air pump displacement in cubic feet per minute based on 100 r.p.m. for all capacities of turbines. The horizontal line represents the factor "50 times condensate" and various points on both curves show the averages of some fifty condensing outfits.

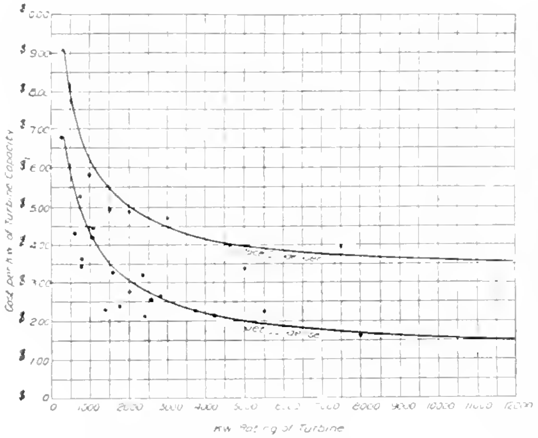


Fig. 8. Curves showing Approximate Cost of Condenser Equipments per Kilowatt of Turbine Capacity

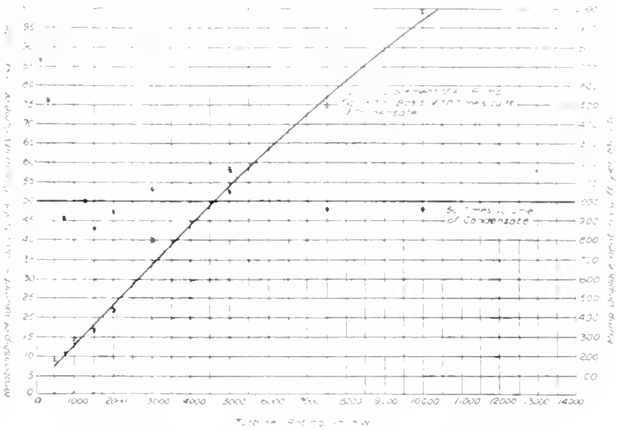


Fig. 10. Curves showing How the Average of Fifty Condenser Propositions Check with Customary Rule of Figuring Air Pump Capacity Fifty Times the Volume of Condensate

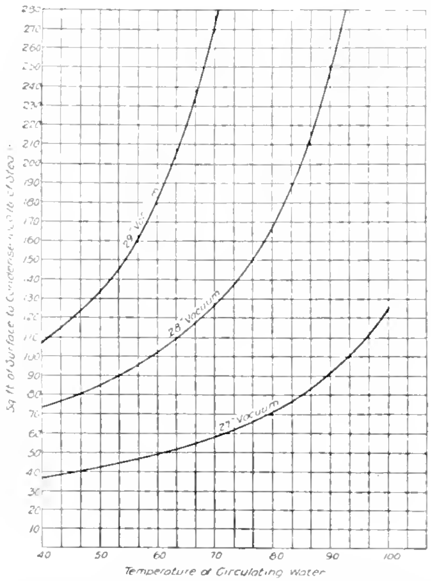


Fig. 9. Curves showing Amount of Surface Necessary to Condense 1000 Lb. of Steam, Based on Transmission of 400 B.t.u. and Water Leaving Condenser at 10 Deg. Below Temperature of Vacuum

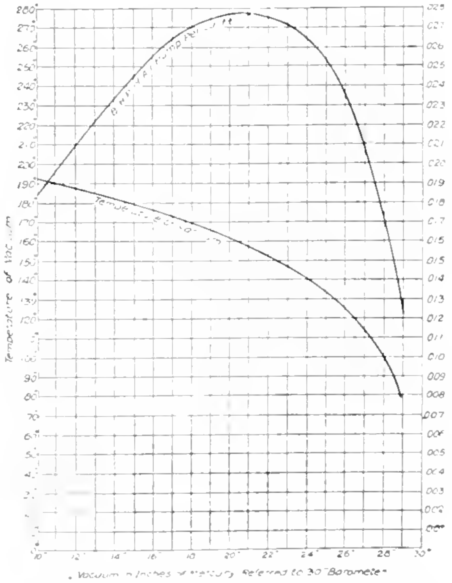


Fig. 11. Curves showing Correspondent Temperature of Vacuum and Brake Horse Power of Air Pump Working Against Vacuum

The power required by different air pumps varies so widely that no curve or tabulation has been worked out showing the horse power for motor drive or steam consumption. The curve shown in Fig. 11 gives the theoretical b.h.p. per cubic foot of air for different vacua, and the actual horse power can be estimated by assuming an efficiency for the pump.

### Circulating Pumps

Circulating pumps are now almost exclusively of the centrifugal type. The volute or turbine form and single or multi-rotor and single or multi-stage developments make these pumps suitable for almost any quantity of water, head and speed. The pumps can advantageously be driven by engines, turbines or motors, although the wide choice of motor speeds often gives the best pump efficiency.

The quantity of circulating water of various temperatures to produce a given vacuum is shown in Fig. 2. As has been pointed out under "Amount of Surface," the surface can be reduced by increasing the quantity of water, but no general rule can be made to show when it is cheaper to pump more water or to increase the surface because of so many factors entering into the cost.

These factors are:

1st. The capacity factor of the turbine. The increased surface represents a fixed charge whether turbine is in operation a part or the whole of the time, while the pumping cost is proportional to the time the turbine is in operation.

2nd. The cost of pumping the water. This is dependent on the head and the cost of motive power.

The cost of motive power is determined by the cost of steam and on the main turbine water rate if motor drive is used.

3rd. The average number of days during the year when the circulating water will reach the temperature on which the calculations are based.

It is apparent that if the condensing equipment is proportioned to give 29 in. vacuum for the highest water temperature, cooler water may produce no higher vacuum because of air leaks, and that less surface and water might have produced the same results. In general, it is well to take the highest average water temperature for about six consecutive weeks during the year and proportion the surface and quantity of water to attain the highest vacuum which appears economical to strive for. One inch increase in vacuum usually means over one pound reduction in the turbine water rate.

The power required by the circulating pump is the largest item of the condenser auxiliaries, and therefore every effort should be made to reduce the pumping head to a minimum. Pump efficiencies as high as 75 per cent are attainable with certain combinations of quantity, head, and speed, and 65 per cent is commonplace. The brake horse power necessary is then:

$$\frac{\text{Head in feet} \times \text{g.p.m.} \times 8.3}{33{,}000 \times 0.65 \text{ eff.}} = \text{b.h.p.}$$

**Hot Well Pump**

The centrifugal pump is now quite universally used for pumping the condensate from surface condensers. The power required to drive the pump would be

$$\frac{(34 \text{ ft. suction} + 25 \text{ ft. discharge}) \times \text{lb. condensate per min.}}{33{,}000 \times .50 \text{ eff.}}$$

Thirty-four feet being equivalent to 30 in. vacuum.

Twenty-five feet discharge being the usual head figured on until actual conditions are known

Fifty per cent efficiency is low due to the small size of the pump.

# THE MISSISSIPPI RIVER HYDRO-ELECTRIC DEVELOPMENT AT KEOKUK, IOWA

## Part II

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The first part of this article, published in the February, 1914, issue of the Review, consisted of a brief description of the dam, power house, ship canal, hydraulic equipment, and portions of the electric equipment, including generators, exciters and transformers. The present instalment completes the description of the electrical apparatus of interest in the power house at Keokuk, and then deals in considerable detail with the construction and main features of the five transmission lines, of which the Keokuk-St. Louis line is by far the most important. The St. Louis substation is well described and illustrated and the location of other substations shown by a wiring diagram of the complete system.—Editor.

### Power Limiting Reactances

Power limiting reactances are, as before mentioned, inserted between the low-tension busbar sections to limit to a safe value the rush of current in case of short-circuit. There are twelve reactances in four sets, each having a nominal rating of 240 kv-a., or 8 per cent in terms of the rating of one of the 9000 kv-a. generators. In other words, when the normal current of one generator flows through the reactance, it causes a drop in voltage of 8 per cent of the generator star voltage across the terminals of the reactance coil. As the generators themselves are designed for a high inherent reactance, limiting their short-circuit current to about five times normal full load current, it is obvious that the total current input into a short-circuit somewhere on the low-tension bus will be limited to about 40 times the full load current of one generator. In case of a short-circuit on any of the outgoing lines, the current rush will be still less, owing to the intervention of the transformer reactance in series with the sectionalizing reactances. In any case not more than two sections on either side of the short-circuited one will be affected, and the voltage of these will not fall below 75 per cent of the normal voltage. By means of these sectionalizing reactances it is therefore possible to confine troubles to one section and thus maintain an uninterrupted operation of the other parts of the system.

The reactance coils are provided with tap terminals, so that either 6 or 4 per cent reactances can be obtained when desired. These taps are, however, not used at the present time. The winding consists of one inch copper cable, wound so that both ends of the coil are brought to the outside in order to facilitate their connection to the busbars. The core is of hollow concrete and the winding is mounted on specially selected, kiln dried, resin treated maple sup-

Fig. 17. Reactance Coils in Low Tension Switch Room

ports, fastened to the concrete core by brass studs. The winding is insulated from all metal parts and the concrete core to withstand an insulation test of 33,000 volts for one minute. The temperature rise is limited to 40 deg. C. at normal operating conditions and to 300 deg. C. with fifteen times full load current for one minute. No iron or other magnetic material is used in the construction of these reactances, and furthermore they are sufficiently removed from such materials to maintain a straight voltage characteristic. The spacing between centers of coils is 78 in. and the magnetic clearances 72 in. from the center point and 26 in. from the ends. The reactances are 98 in. high, 56 in. in diameter, and weigh about 9000 lb.


Fig. 18. Completed Section of West High Tension Room, Fourth Floor

## Switching Equipment

The arrangement and sectionalizing of the busbars was described in the February issue of the Review, and a clear understanding of the switching equipment and the system of connections can best be obtained by reference to the general wiring diagram reproduced in that number.

All the switches, with exception of those for sectionalizing the low-tension busbars, are of the non-automatic type. On account of the double busbar arrangement, double generator and transformer switches, as well as line switches, are provided. The generator switches have a capacity of 500 amperes, and the low-tension transformer switches 800 amperes.

The automatic low-tension bus-section switches, which have a capacity of 2000 amperes, are opened by definite time limit relays actuated from current transformers in the outgoing lines and by inverse time limit relays in the main transformer leads. In this manner trouble on one section merely opens the two section switches and thus confines the trouble to the affected section. The relay settings, however, are adjusted to limit currents to values below those which would injure transformers, and also to limit the time during which line currents can supply an excessive arc. An arrangement is also made whereby the opening of the section switches will cause resistance to be inserted in the fields of the exciters for the short-circuited section, reducing the generator voltage to less than half of its normal value. This result is accomplished by special relays which open short-circuits across extra exciter field resistances. By this arrangement a certain class of troubles, such as arcing ground, etc., may be cleared through lack of potential without even causing the synchronous machinery on the system to fall out of step.

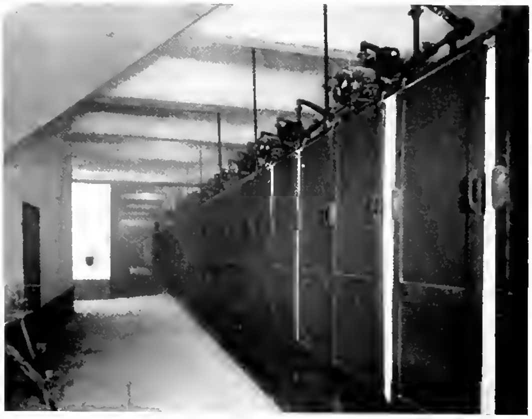


Fig. 19. Looking North Through Low Tension Switch Room

There are in all 74 low-tension oil switches, which are of the H-6, motor-operated type, with 10 in. pots mounted in concrete cells. Disconnecting switches are provided on both sides of every oil switch. These switches are mounted in sub-cells below the oil switches, and are equipped with locking devices to prevent accidental opening. The disconnecting switches for the reactances are mechanically interlocked with the sectionalizing oil switches so that they cannot be opened or closed until the oil switch is first opened.

The high tension switches, of which there are 21, are of the K-15 solenoid-operated type. Each switch has a capacity of 400 amperes, weighs 24,400 lb., occupies a floor space of 6 ft. by 17 ft., and has a height of 10 ft. The tank contains 1375 gallons of oil. Each switch is tested at 330,000 volts. A piping system is provided so that the oil can readily be drawn off to the oil storage tanks in the basement. By means of a track which runs the full length of the high-tension bus room floor, the handling of these switches, in case of repair, is greatly facilitated. All the switch tanks are thoroughly grounded, and a complete ground system with four ground plates is provided throughout the station.

High-tension disconnecting switches are also provided, as indicated on the wiring diagram. The blades of these switches have a length of about 4 ft. They are opened by long wooden rods, which are provided with grounded rings placed above the hand of the operator. When in use these rings are to be connected to the nearest ground bus, thus protecting the operator from danger of static shocks.

Fig. 21. View of Low Tension Bus Compartments

The generator leads consist of 600,000 c.m. single conductor cable, insulated with $\frac{3}{8}$ in. of varnished cambric and with a double braid flameproof covering. They are installed in fiber ducts.

The low-tension buses consist of $\frac{3}{8}$ in. by 3 in. copper bars, mounted on insulator supports and installed in an enclosed bus structure. This structure is built up of $2\frac{1}{2}$ in. molded concrete slabs set on 4 in. concrete barriers. The inside dimensions of each bus compartment are 15 in. by 15 in. and the total length of the compartments is over one mile, requiring over three thousand slabs.

Fig. 20. Looking South Through Low Tension Bus Room

Special provisions for expansion and contraction have been made in the construction of the buses, on account of their length, which is nearly equal to the full length of the station.

Fig. 22. Chief Operator's Room, showing Control Board and Switchboards

The connections from the low tension bus to the step-up transformers are similar to the generator leads, and are also run in fiber conduit.

Each of the two sets of high-tension buses are installed in a separate room. They consist of 2 in. standard iron pipes, bronze painted and spaced 6 ft. apart without any barriers between. They are suspended from the ceiling by 7-unit, 10 in. suspension insulators, dry tested at 440,000 volts. The connections from the high-tension bus to the transformers consist of $1\frac{1}{4}$ in. bronze painted iron pipe, and from the bus to the outgoing lines of $1\frac{1}{4}$ in. copper pipe. The pipes are supported by 6-unit post insulators, and large vertical air shaft passages are provided for the transformer connections.

The roof bushings are of the compound-filled type, tested at 440,000 volts dry and 330,000 volts wet. From these bushings the lines run through the lightning arrester choke coils to disconnecting switches. These switches are of a rotary double-break type, with 12 ft. blades spaced 24 ft. apart. They are opened from the roof by means of a lever, and provided with horns at both ends for breaking the charging current. By means of separate ground switches the lines can readily be grounded when repairs are to be made. Both the choke coils and disconnecting switches are mounted on a roof structure of steel, which also serves as anchor tower for the long river spans.

All the apparatus and their groupings are distinctly labeled throughout the station to avoid as far as possible accidents and mistakes in operation. The piping is painted in different colors to clearly indicate to what class it belongs.

### Operating Room and Control Switchboard

All the apparatus in the station is controlled electrically from an operating room, which is at present located on the fourth floor at the south end of the present building, but which will be in the middle of the station when the extension is completed. The generator room is not visible from the operating room, but by descending a few steps to an inspection balcony a good view is obtained of it.

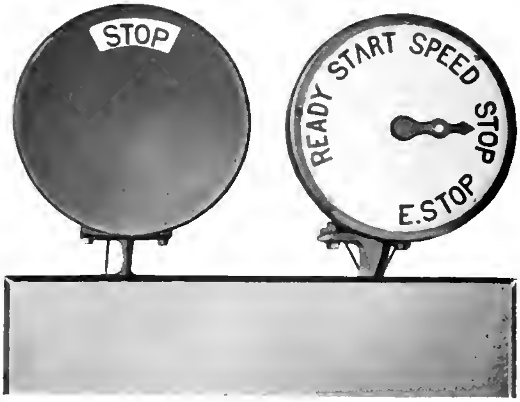


Fig. 23. Receiver and Transmitter for Signalling between Control Board and Generator Room

The operation of the station is completely controlled by a chief dispatcher, who is in telephonic communication with all parts of the system. A special desk is provided for him, on which is mounted the telephone switchboard, while in front of this desk a miniature arc-shaped switchboard is installed which contains a set of mimic busbars showing by means of small indicating lights the open or closed position of all the switches in the station. It also contains graphic voltmeters and ammeters for recording the voltage on each bus section and the current in each of the outgoing lines.

The main control switchboard is divided into six sections corresponding to the bus sections, with an additional section for the auxiliary equipment. The arrangement of these boards is at the present time in the form of an L, although ultimately it will be in the form of a U, with the despatcher board in the center.

The different sections comprise a total of 25 panels, with one panel for each generator and transformer unit and one for the section equipment and each outgoing line. The boards, which are made of black slate, are of the bench-type, with the control switches, indicating lamps, etc., mounted on the bench; while the instruments, generator voltage regulators, etc., are mounted on vertical panels back of the benches. The instrument equipments are as follows:

Fig. 24. Pedestal Containing Transmitter and Receiver, Located near Generator

### Generator and Transformer Panels

3 ammeters, 1200 amp., generator leads.
1 indicating wattmeter, 15,000 kw.
1 watthour meter.
1 wattless component indicator, 7500–0–7500 kv-a.
1 field ammeter, 600 amp.
3 ammeters, 2400 amp., transformer leads.

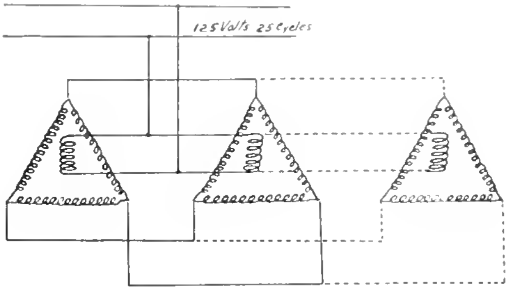


Fig. 25. Diagram of Connections of Transmitter and Receiver

### Section and Line Panels

1 synchronism indicator.
2 voltmeters for buses, 175 volts.
1 voltmeter for generators and transformers, 175 volts.
1 frequency indicator, 25 cycles.
1 generator field voltmeter, 350 volts.
1 transformer neutral ammeter, 600 amp.
1 exciter transformer ammeter, 1000 amp.
3 line ammeters, 1200 amp.
1 exciter transformer watthour meter.

Current and potential transformers are installed in the bus and wiring compartments. Of particular interest are the large 110,000 volt current transformers inserted in the outgoing lines. Transformers are provided with a spark gap to protect them against high voltage surges, etc.

The system for transmitting signals between the switchboard and generating room is quite novel. It is similar to that which will be used on the Panama canal to indicate the position of the lock machinery. The signals will be transmitted by "position indicators," which resemble to some extent small induction motors; these devices being provided with three-phase stator windings and single-phase rotor windings of the shuttle type. For operation, two position indicators are connected in multiple, the rotors being excited from a single-phase 125 volt, 25 cycle source, and the stators by induction. To send a signal, the rotor of one of the indicators is turned to any desired position, and the rotor of the connected machine or machines will assume a like position.

One transmitter and one receiver for each generator are provided on the switchboard, and also on a pedestal, similar to that shown in Fig. 24, located conveniently near each generator. The transmitter on the switchboard is operated through a cable and pulley arrangement by a handle located on the front of the board concentric with the handwheel which operates the field rheostat of the generator. This controlling handle is provided with a pointer which moves over the face of an indicating dial. The dial at the right in Fig. 23 is the receiver. The dial shown at the top of the pedestal is operated by the receiver end of the position indicator, which, as has already been stated, is controlled from the switchboard transmitter. The handle and pointer just below this dial are mechanically connected to the transmitter (located in the pedestal) which controls the receiver at the switchboard. On both the pedestals and benchboard, at each side of the transmitter handle, are located double push button switches which are employed for operating signal lamps, whistles and bells.

The method of signalling is as follows: When the switchboard operator desires to send a signal he turns the handle of the transmitter until its dial indicates the signal he wishes to send. This signal will be indicated on the dial of the receiver in the generator room. He then pushes the button on the right of the handle. This lights a lamp on the generator and blows a whistle in the generator room to attract the attention of the man in charge of the particular machine. As soon as the attendant has read the signal on his receiver, he will turn the handle of the transmitter on the pedestal to the same signal. He will then push the button at the right of the handle, which will extinguish the lamp and cut out the whistle. Next he will push the button at the left of the handle, which operation will light a lamp in the switchboard room and also ring a signal bell indicating to the switchboard man that the generator attendant has received the signal and also just what signal he received. The switchboard operator, after having seen this returned signal, will push the button at the left of the transmitter handle, which will extinguish the lamp and cut out the signal bell. This completes the cycle of sending and receiving a signal.

Double emergency cut-out switches are installed near all the generators, one on the main floor and the other on the exciter gallery. In case of trouble to one of the units it is only necessary to break the glass cover of the cabinet and pull the switch, which operation will close the gates and open both the main generator switch and the field switch, thus entirely disconnecting the unit.

The panels containing the circuit breakers and switches for the auxiliary generators, lighting, and other station service are located on the exciter gallery in the bays opposite the auxiliary generators.

Power for the electrical control of all the oil switches, etc., is obtained from two storage batteries, each consisting of 68 cells having a rating of 320 ampere-hours. For their charging two 15 kw., 750 r.p.m. motor-generator sets are provided.

Feeder regulators are used on several of the local and station circuits. The largest of these are the two three-phase water cooled induction regulators which control the two 3000 kw., 11,000 volt Burlington lines. These regulators have a range of 20 per cent, and their operation is by motors automatically controlled by contact-making voltmeters used in conjunction with line drop compensators. A number of smaller, self-cooled, automatically operated, single-phase regulators are also used for maintaining a constant voltage on the station lighting circuits.

A very complete telephone system has been installed. Nearly one hundred instruments are provided at various points in the station alone, and many others are installed in the substations and in telephone booths along the transmission lines.

### Lightning Arresters

Two sets of electrolytic lightning arresters are provided for the two outgoing 110,000 volt lines. These arresters are installed on the fourth floor, in separate rooms with fire doors, while the choke coils and horn gaps are mounted out-of-doors on the roof structure. The taps for the arresters are taken off between the choke coils and disconnecting switches, and bushings similar to the line entrance bushings are provided for passing the connections through the roof.

Each arrester consists of four tanks, three of which are connected to the line wires through the horn gaps, while the fourth tank is connected between the other three and ground. The arrester gaps are of the double-horn type with charging resistances. The auxiliary horn is mounted above and insulated from the regular horn in such a manner as to intercept the arc if it rises on the regular horn. Enough resistance is connected in series with this auxiliary horn so that the current flow and arc across this gap are always limited to a moderate value. Such a device has several advantages: Since the mechanism is so arranged that the charging is always done through the auxiliary horn, the current rush is limited during the charging and thus troubles from carelessness or ignorance are avoided. It also gives a more uniform charging current. Lightning discharges will pass across the auxiliary gap through the series resistance to the cells. If the discharge is heavy, the resistance offers sufficient impedance to cause the spark to pass to the main horn. This is accomplished with only a slight increase in potential, because the gap is already ionized. If the cells are in a normal condition the spark at the gap is immediately extinguished without any flow of dynamic current. If the cells, through either negligence or some untoward condition, are in poor form, the dynamic current may follow the discharge across the main gap and the arc will rise to the safety horn and be extinguished through a resistance.

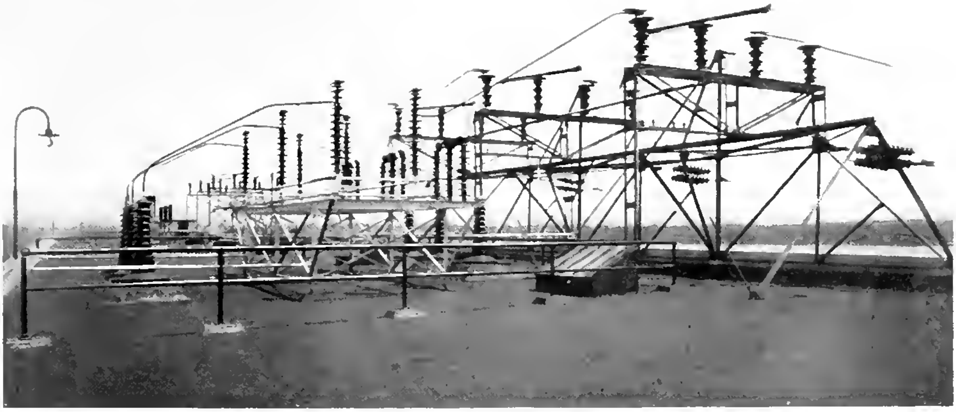


Fig. 26. Roof Structures for 110,000 Volt Line Entrance

Electrolytic lightning arresters are also installed for each of the 11,000 volt bus sections.

### Station Lighting and Service Equipment

The lighting in the generator room is done entirely by 500-watt tungsten lamps, other parts of the station being illuminated by tungsten lamps varying in size from 25 to 500 watts. The current for the lighting is normally taken from the 440 volt a-c. exciter bus, from which it is stepped down to 250/125 volt by means of three 75 kv-a. transformers. Arrangements are also made so that the current may be supplied from the 11,000 volt buses through three 75 kv-a. step-down transformers. Each of the lighting feeders is provided with a 7.5 kv-a. induction regulator for maintaining a constant voltage.

As a protective measure, about one-third of the lights, well distributed in the station, are arranged so that in case of trouble to the supply system they will be automatically switched over to one of the control batteries, which has sufficient capacity to operate them for about one hour.

Diffused illumination in the control room is provided by means of a skylight, which forms the entire ceiling. In order to prevent glare on the instruments it also became necessary to provide amber-colored glass in the windows. At night a diffused illumination is accomplished by tungsten lamps, which are mounted back of the skylight panes.

A complete steam heating system with water tube boilers is installed, and in connection with this there is a steam cleaning plant for waste, which necessarily is used in large quantities in a station of this magnitude.

The auxiliary power for driving the numerous pumps, cranes, etc., in the station is also ordinarily taken from the 440 volt exciter bus; but it may also be supplied from the 11,000 volt main bus through a 500 kw. three-phase, step-down transformer which is provided for this purpose.

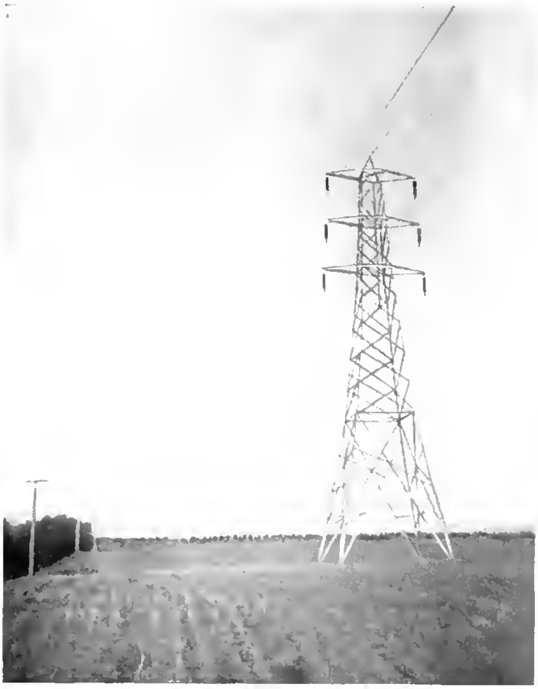


Fig. 27. St. Louis Transmission Line. Cable Strung on Line of Standard Towers

Two 150 ton travelling cranes are installed in the generating room and a 75-ton crane in the gate house.

A complete repair shop is located in the north end of the building, and ample store rooms are provided on both the main floor and the upper floor. Both freight and passenger elevators are provided, and spacious offices are located near the control room in the south end of the building.

There are locker and modern toilet rooms in several parts of the building, and both a vacuum and air pressure system for cleaning. Two complete water systems are installed, one for the transformer cooling, utilizing a pair of 5 in. duplicate headers extending the full length of the building, and the second for the house service.

### Transmission Lines

The bulk of the power is, as before mentioned, transmitted at 110,000 volts to St. Louis, a distance of about 144 miles from Keokuk. Several substations are, however, installed along this line for tapping off branch lines through which power is transmitted to other communities at lower voltages. For local consumption and for the territory north as far as Burlington, a distance of about 37 miles from Keokuk, the power is transmitted at 11,000 volts. A map illustrating the territory served by the various transmission lines was shown on page 86 of the February General Electric Review, while the above table gives the respective lengths and transmission voltages.

| Line | Length in Miles | Voltage |
|---|---|---|
| Keokuk-St. Louis | 143.6 | 110,000 |
| Meppen-Alton | 28.7 | 66,000 |
| Hulls-Ilasco | 8.3 | 33,000 |
| Hulls-Quincy | 19.3 | 33,000 |
| Keokuk-Burlington | 37.0 | 11,000 |
| Keokuk-Mooar | 5.8 | 11,000 |

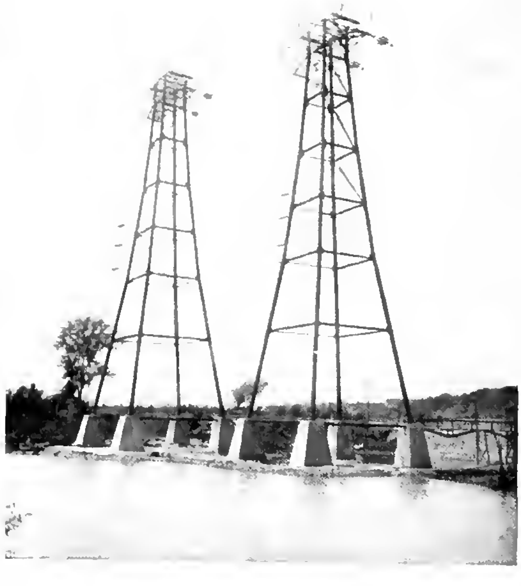


Fig. 28. St. Louis Line, 135 Foot River-Crossing Tower

**Keokuk-St. Louis Line**

This is a double-circuit steel tower line built on a 100 ft. private right-of-way, providing room for another future line. The normal span is approximately 800 feet, while the longest span, which is across the Missouri river, is 3180 ft. Strain towers are used at all angles, on both sides of railroad crossings, and for approximately every tenth tower on tangents.

The towers are all of the four-legged construction, the standard type having a total height of 79 feet and a base measurement of 20 by 20 ft. Its weight is 6800 lb., and it is designed to withstand the weight and side strain of all the conductors under the most severe weather conditions, besides the unbalanced pull caused by the breaking of two of the conductors.

The strain towers, to which the conductors are dead ended, have a total height of 74 ft., a width at the base of 24 by 24 ft., and a weight of 10,500 lb. These towers are designed to withstand the unbalanced pull caused by the breaking of all the seven wires.

Fig. 29. River-Crossing Insulator on Entrance Structure on Power House Roof

The line conductors consist of a 19-strand medium-drawn copper cable having a diameter of 5/8 in. and an area of 300,000 c.m. The three wires of each circuit are arranged in nearly a vertical plane at elevations of respectively 50, 60 and 70 ft. above the ground; the two circuits being suspended on opposite sides of the towers, with a spacing of about 18½ ft. The top wires are slightly closer together than the bottom ones.

Fig. 30. 66,000 Volt Line to Alton, Looking Towards Illinois River Crossing

The cable has an ultimate strength of 14,000 lb., which gives a factor of safety of two under the worst load conditions, which are assumed to be a one-half inch coating of ice, a 60-mile wind, and 0 deg. F. For an 800 foot span, this corresponds to a load of not more than 7000 lb. The corona voltage is approximately 150,000, which gives a wide margin above the normal operating voltage.

The suspension insulators on the standard towers consist of single strings of seven 10 in. disks in series, while at the anchor towers each conductor is fastened rigidly to the structure by two parallel strings, each consisting of eight 10 in. disks. The conductors are looped under the crossarm of the anchor towers. The suspension insulators have been subjected to a rain test of 330,000 volts and a dry test of 440,000 volts.

The ground wire, which is a ½ inch 7-strand galvanized Siemens-Martin steel cable, is mounted at the apex of the towers. Its ultimate strength is 11,000 lb. with a factor of safety of two.

All towers are provided with heavy reinforced concrete foundations. Those for the standard towers extend 6 ft. below ground and weigh about 2 tons per leg, while strain tower foundations extend 8 ft. below ground and weigh approximately 7½ tons per leg.

The transmission line crosses the Mississippi River twice and the Missouri River once, the spans varying from 1950 to 3180 feet, with a minimum clearance to the water surface of 70 feet. At each crossing the two circuits are separated and each circuit, together with a ground wire, is carried on separate towers. The first crossing is at Keokuk, where the span has a length of 2820 feet, extending from the roof structure on the power house to strain towers on the opposite shore, each having a total height of 145 feet and a weight of 88,300 lb.

The second crossing is at Brussels, where the river divides into three channels. Each circuit is carried across on three 160 ft. towers located on islands, the span varying from 1950 to 2400 feet. These towers, which weigh 76,400 lb. each, are only of an intermediate type, and the lines are dead-ended by means of lower anchor towers on the river banks.

The crossing of the Missouri River necessitates one span of 3180 feet and another of 2350 feet. The highest tower, which is located on an island at the midpoint of the crossing, has a total height of 230 ft., while the tower on the higher south bank of the river is 190 ft. high. The former tower weighs 107,400 lb. and the latter 84,700 lb. Both towers are of the intermediate type, the lines being dead-ended to the next ones, which are 60 ft. high and of the anchor type. All these river crossing towers are set on massive concrete foundations resting on bed rock, piles, or earth.

The conductor used for all these long spans consists of a ⅝ in. 19-strand core of special high-tension steel, with an outer stranding of 20 No. 10 B.&S. hard drawn copper wires, making a total diameter of ⅞ inch. They are rigidly fastened to the tower structures by a group of six parallel insulator strings, each consisting of eight 10-inch disks. A system of equalizing levers is provided for dividing the strain equally among the six strings. The ultimate strength of the conductor is 52,000 lb. and of the insulator banks 60,000 lb., which, under the worst load conditions of 24,000 lb., gives a safety factor of more than two. In order to prevent the swinging together of the wires, the conductors are spaced 20 ft. apart in a horizontal plane, with the ground wire above. These ground wires, which are similar to the steel core of the line conductors, serve as supports for the telephone wires and also as runways for the cable cars which are used for the inspection and repair of the spans.

For railroad crossings the conductors are dead-ended at the first two towers on each side of the track, the outside ones of which are of the anchor type. The conductors in these three spans are strung only at half normal tension, and in other respects the N.E.L.A. recommendations for railroad crossings are followed.

Each of the transmission circuits has a capacity of 45,000 h.p., with a voltage drop of 10 per cent and an energy loss of approximately the same amount.

A telephone line parallels the transmission line for the entire distance from Keokuk to St. Louis. It is built on one side of the right-of-way and consists of two No. 8 telephone conductors and a ground wire mounted on 30 ft. cedar poles with a spacing of 125 ft. Houses for the patrolmen are provided every 18 miles and telephone booths every 4 miles. Special precautions have been taken to insulate the telephone lines, and the protective equipment for the telephones consist of drainage coils, vacuum and multigap arresters, and fuses and insulating transformers.

### Meppen-Alton Line

This is a single circuit 66,000 volt line branching out from the main line at the Meppen substation and running as far as Alton, a distance of 28.7 miles. The conductors are supported on H-frame wood structures spaced 300 ft. apart. The structures consist of two cypress poles 6 in. in diameter at the top and 45 ft. high, and a wooden crossarm of two pieces 2 in. by 8 in. by 16 ft. Three No. 2 stranded copper conductors are supported in a horizontal plane by 4-disk suspension insulators and the two $\frac{5}{16}$ inch Siemens-Martin galvanized steel stranded ground wires are carried on the top of the poles. The two No. 8 copper clad telephone wires are supported on brackets on the sides of the poles.

This line crosses the Illinois River, necessitating four spans from 1160 to 1800 ft. in length. Five steel towers are used for these, having a height of 104 ft., a width of 34 by 34 ft. at the base, and weighing 36,800 lb.

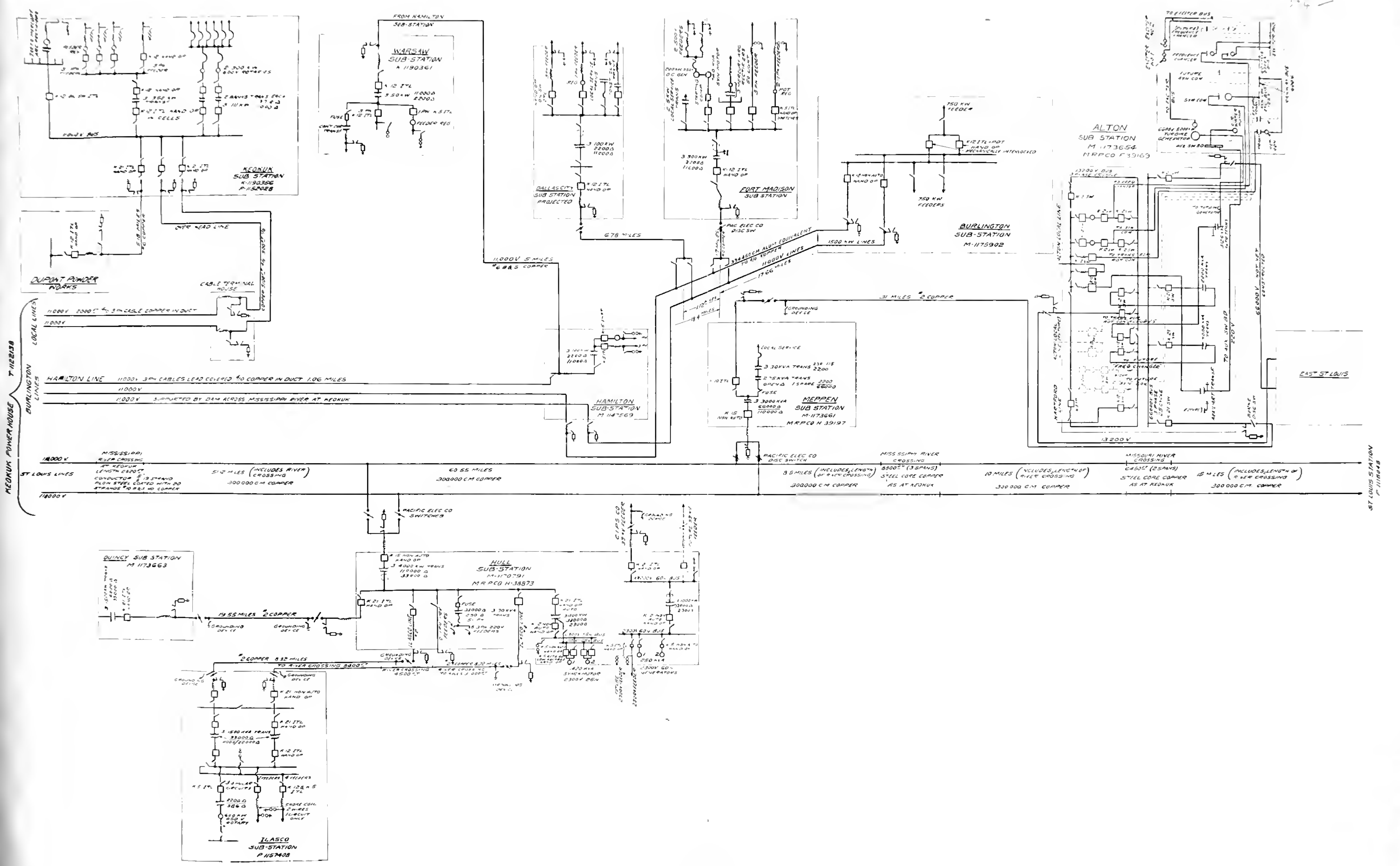


DIAGRAM OF TRANSMISSION LINES AND SUBSTATIONS, KEOKUK HYDRO-ELECTRIC DEVELOPMENT

The line conductors here consist of 5/8 in. Monitor steel strand, supported from the middle crossarm by three parallel 4-disk insulators. The ground and telephone wires are of 3/8 in. high-tension steel, the former being supported from the upper crossarm and the latter from the lower crossarm by two parallel 4-disk strings.

### Hulls-Ilasco Line

The length of this line is 8.3 miles and the transmission voltage 33,000. The line consists of two single circuits of three No. 2 B.&S. stranded hard-drawn copper conductors mounted on pin type insulators on 40 ft. Idaho cedar poles spaced 140 ft. apart. A 1/4 in. galvanized stranded steel ground wire is mounted on the top of the poles, and two No. 8 B.W.G. galvanized iron telephone wires are carried on a crossarm below the two crossarms carrying the line conductors.

This line also crosses the Mississippi River in two spans of 1650 and 2850 ft. lengths. Three steel towers are used for these spans: a 60 ft. tower on the Illinois shore, and two 190 ft. towers, one on King's Island and the other on the Missouri shore. The latter tower is of the anchor type with a base 50 ft. square and a weight of 122,870 lb., while the other 190 ft. tower is of the intermediate type with a base of 42.5 ft. square and a weight of 96,260 lb. The line conductors, which consist of 5/8 in. stranded Monitor steel cores surrounded by twenty No. 10 copper wires, are rigidly supported by 6-string 8-disk insulator groups, as were the river spans of the St. Louis line. Similarly, the two ground wires are of 5/8 in. Monitor steel and serve as supports for the two No. 8 telephone wires.

### Hulls-Quincy Line

This is also a 33,000 volt single circuit branch line with a length of 19.3 miles. The three No. 2 stranded copper wires are carried on pin type insulators on 40 ft. Missouri cypress poles, spaced 140 ft. apart in the country and 125 ft. inside the Quincy city limits. A 1/4 in. Siemens-Martin steel strand ground wire is carried along the top of the poles, except inside the city limits, where it is supported above the poles on a channel iron support.

Two No. 8 hard drawn bare copper wires are used for the telephone circuit, which is carried on crossarms below the conductors, except on the stretches where the line parallels the St. Louis line, in which case it is carried on the telephone poles of that line.

### Keokuk-Burlington Line

This line extends northward from the substation in Hamilton, to which power is fed from the generating station through lead-covered cables carried across the dam in fiber ducts. The distance to Burlington is 37 miles and the transmission voltage is 11,000. The line conductors consist of six 19-strand, 4 0 equivalent aluminum cables carried on pin insulators which are mounted on 40 ft. Idaho cedar poles spaced 140 ft. apart. These poles are provided with three crossarms, two of the line conductors being mounted on the upper and four on the middle while the lower serves for supporting the two No. 8 B.&S. copper wires constituting the telephone circuit. A ground wire of 5/16 in. Siemens-Martin galvanized steel strand is carried above the tops of the poles by 3 in. steel channels. The line is grounded every fifth pole.

### Keokuk-Mooar Line

Power for local distribution in the vicinity of Keokuk is also carried through lead-covered cables from the power station to a cable terminal house on the west side of the railroad tracks. In this building the lead-covered cables are terminated and the lines conveyed overhead from this point.

The Mooar line, for supplying power to the DuPont Powder Works, is of single circuit, 11,000 volt construction and has a length of 5.8 miles. Where it passes through the country, the poles, which are Missouri cypress, have a height of 35 ft. and are spaced 140 ft. apart, while through the city alleys they have a height ranging from 40 to 60 feet with a spacing of 125 ft. The three No. 2 copper conductors are all carried on one crossarm 5 ft. below the No. 6 galvanized steel ground wire, which is carried along the tops of the poles.

No transpositions are made on the 110,000 and 66,000 volt transmission lines, but the 33,000 and 11,000 volt lines are transposed every third mile. All telephone circuits are transposed every fifth pole.

## SUBSTATIONS

### St. Louis Substation

This station, which is by far the largest on the system, was built and is owned and operated by the Electric Company of Missouri, formerly known as the Mississippi River Power Distributing Company. The station has a capacity of 60,000 kw., and the power is distributed to two large customers, the Union Electric Light & Power Company and the United Railways Company. It is a brick structure laid out in the form of a T, with a length of 219 ft., a maximum width of 150 ft., and a height of 60 ft.

Fig. 31. Cooling Basin for Transformer Circulating Water. St. Louis Substation

There are four 110,000 volt incoming circuits, as each of the two Keokuk lines are split up into two circuits about a $^1{}_4$ mile from the station. These circuits enter through roof entrance bushings and connect through line switches with a high-tension bus, which is divided in four sections separated by oil switches, each circuit feeding one section. The low-tension bus is similarly divided into four sections, with an additional connection forming a ring bus. Four transformer banks are provided, one for each section.

The high tension bus is normally sectionized in the middle, while the low tension bus has all the sectionalizing switches open so that there are four separate groups of feeders on the low tension side. Two of these supply the Union Electric Light & Power Company and two the United Railways Company. One group in each pair is tied together on the high-tension bus to one transmission line, so that both these companies have two separate sources of supply all the way back to the generating station. Furthermore, as either line is capable of transmitting the full load of the station, no interruption to service will result in case one line is temporarily out of service.

All the outgoing feeders for the United Railways Company are three-phase, 25 cycle, 13,200 volt circuits. In addition this Company has installed in the substation two 2000 kw., 375 600 volt rotary converters with air blast step-down transformers for supplying power to the territory nearest the substation, and additional space is provided for two future units.

A number of the outgoing lines of the Union Electric Light & Power Company are also three-phase, 25 cycle, 13,200-volt circuits. This Company has, however, installed a 5000 kw., 25 60 cycle frequency changer set with step-down transformers, and space is provided for a future set. The 25 cycle motor is wound for 6600 volts and the 60 cycle generator for 4400 volts, with the neutral brought out. The generator is connected to a double set of 4-wire buses, which supply power to a number of 60 cycle, single-phase outgoing feeders provided with induction regulators. A group of three 3000 kw., single-phase, 60 cycle, 4400 13,200 volt step-up transformers are also provided for supplying 60 cycle power to the territory farthest away from the station.

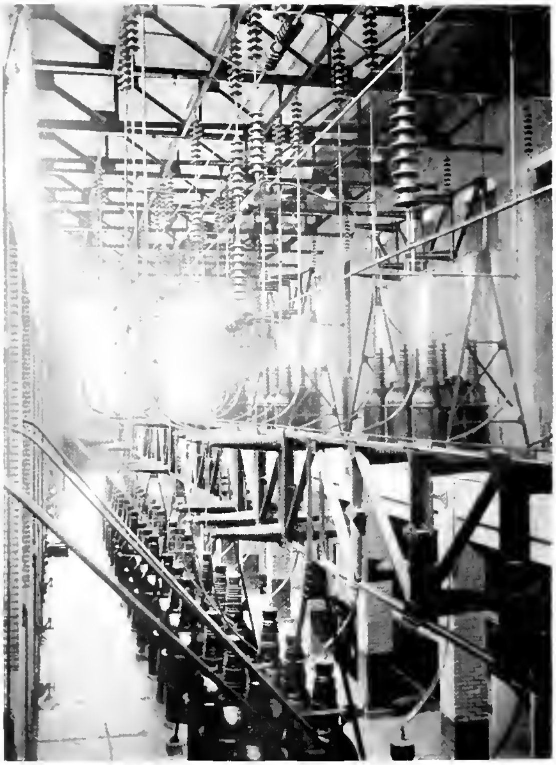


Fig. 32. High Tension Oil Switch Gallery St. Louis Substation

The high-tension apparatus is located in that portion of the building corresponding to the stem of the T, and the rotating machinery in the transept. The four incoming line switches are installed on a gallery, while the high-tension transformer and section switches are placed on the main floor and below the busbars, which are suspended from the roof trusses.

The transformers are placed in compartments along the west side of the high-tension room. These compartments are provided with rolling sheet iron doors in the outside walls, so that in case of repairs the transformers may be carried outside and placed on a transfer truck which runs to the end of the building, where they are taken into the repair room.

Fig. 33. 5000 Kv-a. Transformer in St. Louis Substation

The low-tension oil switches are installed underneath the gallery in the high-tension room, and the buses beneath in the basement, while the control board is located on the gallery facing the machine room.

There are four main transformer banks, each consisting of three 5000 kw., 95,000 13,800 volt, delta-delta connected, single-phase, water-cooled transformers. Each transformer requires about 5000 gallons of oil and weighs complete about 57 tons. A large cooling basin is provided a short distance from the station. It has not been found necessary to use spray, and provision is made simply for the radiation of the heat from the water to the air. Approximately 36 hours is required for the water to circulate through the cooling basin, two motor-driven pumps being provided for pumping the water. The oil drain is piped through a quick-opening valve to an oil tank in the basement. There is one tank for each transformer bank. These tanks are installed in the basement in fireproof compartments provided with iron doors. In order to make sure that these compartments are kept clean, and to obtain better ventilation, their doors are normally held open by weighted chains. These chains are provided with a fusible link which melts in case of fire and closes the door. A filter press is provided for cleaning the oil.

The incoming circuits are anchored to a structural steel roof, which also supports four line disconnecting switches. These switches are of the motor operated type, controlled from the switchboard in the station. Provisions are also made on the roof for grounding the lines by special pull-type grounding switches.

All the high tension switches are of the solenoid-operated type, and the low-tension switches of the motor-operated type. The equipment provides two parallel reverse energy relays in the low-tension leads of every transformer bank. One of these relays, which is of the instantaneous type, trips the middle sectionalizing switches of both the high- and low-tension buses, while the other relay, which has a time element, trips the high-tension line switches. In case of a short-circuit in one of the lines, power will be fed into this both from the generating station at Keokuk and from the Union Electric Light & Power Company's 20,000 kw. steam station in St. Louis. In such a case the bus sectionalizing switches will open first, due to the instantaneous action of their relays, and thereafter the line switch of the faulty line, thus cutting out this line without disturbing the operation of the other. As usually operated, however, the high-tension bus is normally sectionalized in the middle and all the low-tension section switches are open.

The effectiveness of this protective system has been fully demonstrated. During the only case of line trouble which has occurred, a dead short-circuit on the line was handled by the automatic equipment without any interruption whatever in the delivery of the full amount of power being taken at the time by each receiving company.

Disconnecting switches are provided for isolating all the oil switches. The low-tension type is of the ordinary switch blade design, but the high-tension switches are of a special plug-type design, making it possible to reduce the width of the switch room about 36 feet.

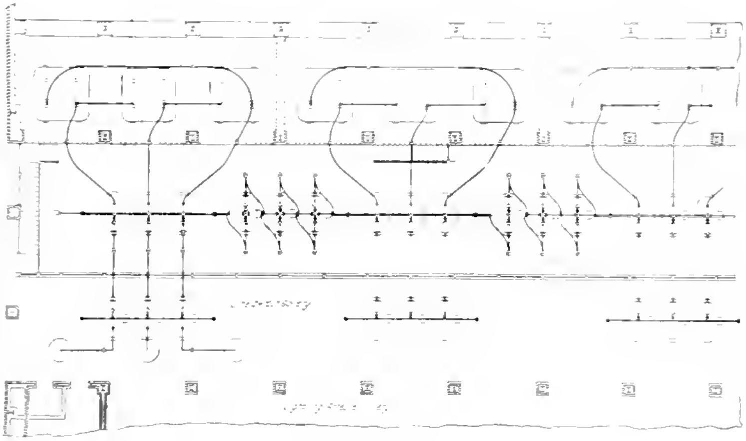


Fig. 34. Partial Plan of St. Louis Substation

These plug-type switches consist of vertical sliding rods with concentric spring contact blocks similar to those of the familiar H-3 oil switches. The rod can be firmly locked in the closed position by means of a bayonet joint.

The high tension busbars consist of 1 in. copper tubing, supported in a vertical plane from the roof trusses by means of suspension insulators comprising eight 10-in. disks, the different sections being separated by strain insulators consisting of ten 10-in. disks. All the high-tension connections are also of 1 in. copper pipe, except the leads from the transformer switches to the transformers, which are of iron pipe.

The low tension main and group buses consist of copper bars mounted on insulators in concrete compartments in the basement. The ring connection for the main bus consists, however, of cables drawn through fiber ducts in the wall back of the bus compartments, this arrangement resulting in a considerable saving of space. All the low-tension connections, furthermore, consist of cable run through fiber ducts in walls and floors, and provided with fireproof coverings in the manholes. The low-tension connections in the transformer compartments are encased in concrete columns, as seen in Fig. 33. This serves both as a support for the leads and as a protective feature. All the outgoing feeder circuits for the city service leave the station through underground lead-covered cables while the county service is supplied through both overhead and underground circuits.

The control switchboard is of the ordinary benchboard construction. In addition to this there are four terminal or meter boards, one for each bus section. These boards are located in the low tension switch room adjacent to the feeder circuits which are to be measured, and graphic-recording and integrating meters are mounted thereon instead of on the benchboard. This reduces the running of a considerable amount of instrument leads to the main switchboard, and results in a great saving in both control wire and conduit. Interconnections are also made between the terminal boards, so that if it is desired at any time to record the output of one board on the meters of another board, this can readily be accomplished.

All the transformer and switch banks, etc., are thoroughly connected to the ground system, which consists of pipes driven into the ground under each building column, with bare copper wires carried around to various parts of the building.

Current for the oil switch operation is obtained from a storage battery, a small motor-generator set being used for charging the battery.

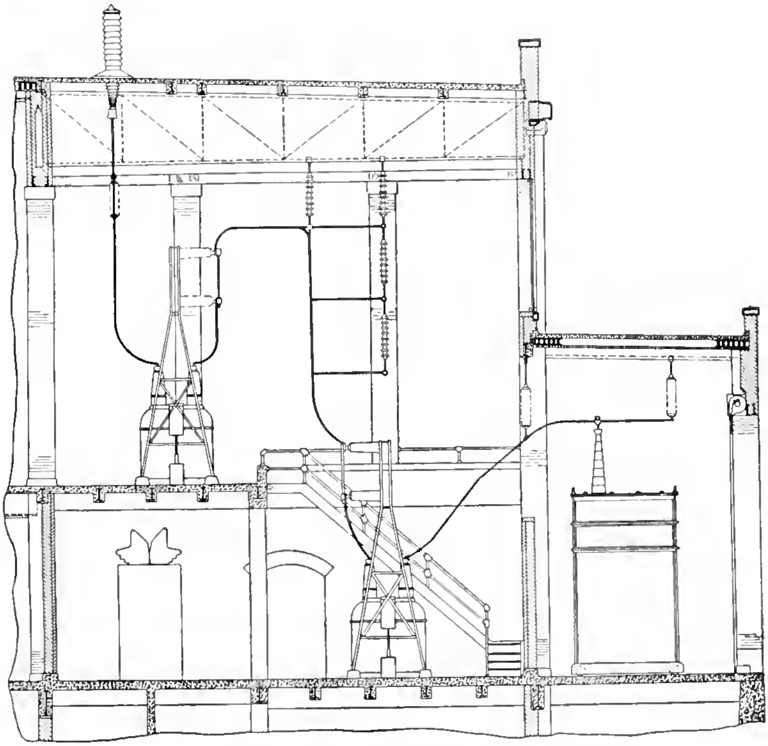


Fig. 35. Sectional Elevation, St. Louis Substation

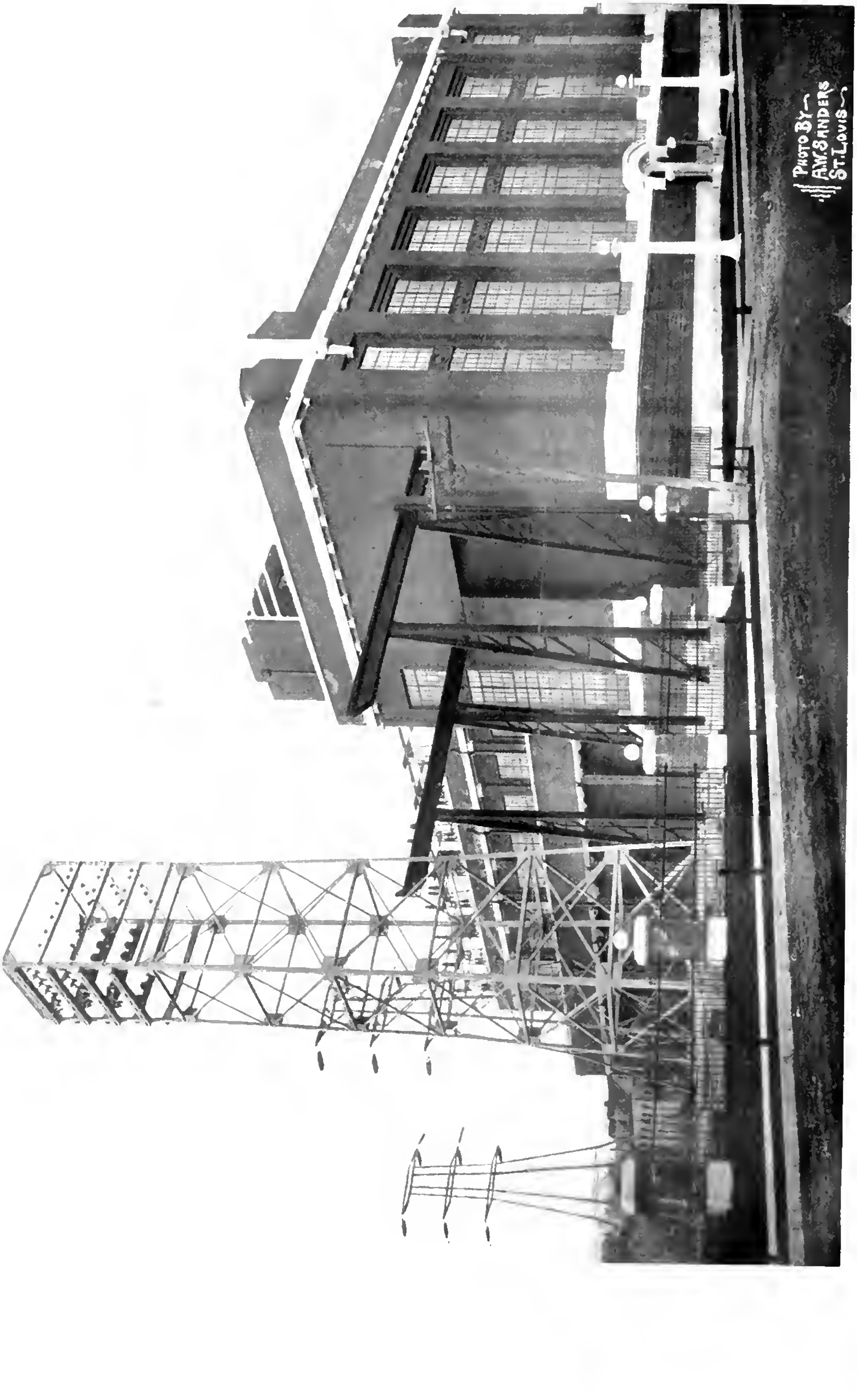
Four electrolytic lightning arresters are provided for the incoming lines. They are of the same design as those for the generating station; the tanks being placed indoors, while the horn gaps and choke coils are mounted on the roof. Each of the four low-tension bus sections is also equipped with an arrester of the electrolytic type.

The auxiliary equipment in the station is very complete. A bank of three 50 kv-a., 13,200-200/110 volt transformers, with one spare unit, is installed for supplying current to the light and power circuits in the station. A large crane is provided for handling the heavy machinery in the low-tension machine room. It can be run out of the building onto a steel trestle, and is also used in connection with the tracks and turntable outside the building to move the large transformers with block and tackle and to pull the transfer trucks along the track. Pumps are provided for draining the basement in case it should get flooded, and a compressed air system is provided for cleaning purposes. This system is quite novel in that the compressed air is carried around the station through the iron pipes which are used for railings in the various rooms and galleries. This has resulted in a material saving in the amount of pipe used.

The design of this station has been carried out under the supervision of Mr. C. S. Ruffner, General Manager of the distributing company.

### Other Substations

There are a large number of other substations which have been built and which are operated by either the Mississippi River



St. Louis Substation

Power Company or their customers. These are located at Meppen, Alton, Hull, Ilasco, Quincy, Hamilton, Warsaw, Fort Madison, Dallas City, Burlington, Keokuk and Du Pont. The equipments and system of connections of these stations are clearly illustrated in the diagram facing page 384.

The construction of this entire plant, with the exception of the St. Louis substation, has been carried out by the Mississippi River Power Company and no work has been contracted for. All the hydraulic design and construction in connection with the dam, lock and power house have been under the personal supervision of the Company's Chief Engineer, Mr. H. L. Cooper, while the Stone & Webster Engineering Corporation has had charge of the installation and erection of all the electrical equipment, including the power station, substation and transmission lines. The plant is now being operated by the Stone & Webster Management Association. With the exception of the transmission line material and a few other minor apparatus, the entire electrical equipment was furnished by the General Electric Company.

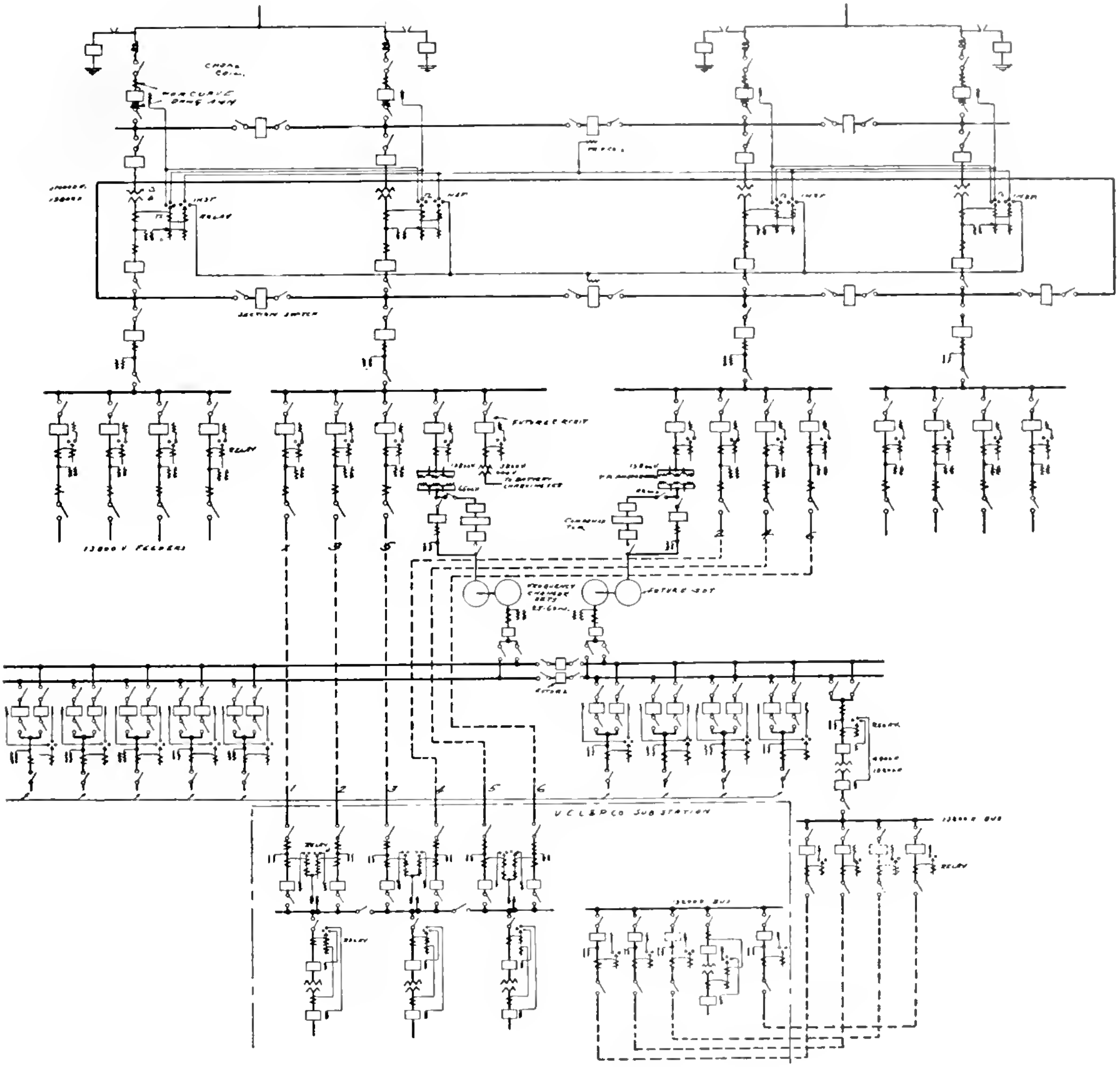


Fig. 36. Wiring Diagram, St. Louis Substation

# EFFECT OF ELECTRICAL ENGINEERING ON MODERN INDUSTRY

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

This article is divided into two parts. The first section makes prominent the fact that, while the two forms in which energy is transported, viz., in chemical form and in electrical form, are both commercially practical so far as transportation is concerned, electricity alone permits of facile conversion of the energy into those other forms in which it is usually used. Among the examples brought out in the discussion following, to exhibit the influence of this feature upon modern industry, are some which show that, while it is true that the use of electricity adds convenience to all previously existing processes, the manufacture of many products would be commercially impossible without it (this being due to its property of high energy concentration). An exceedingly clear exposition of "load-factor" and "diversity-factor" concludes this section. The second part of the article shows that our modern civilization, and consequently our industries, has been brought about by the transportation of both materials and energy. The former is carried on by railroads and steamships, the latter by electrical distribution systems. The influence of electricity upon our industries is then outlined. This article appeared in the *Journal of the Franklin Institute*, February, 1914.—Editor.

## I.

The use of electricity in modern civilized life is rapidly increasing: in lighting our homes, factories, streets; in industrial power applications; in domestic service, from the fan motor to the electric bell or the heating and cooking device; in transportation: and while no great inroads have yet been made into the field of the steam locomotive, an entire system of electric railroads has sprung up all over the country, fully comparable in size and power demand with the steam railway system; large new industries have developed in electro-chemistry and electro-metallurgy, supplying us with materials unavailable before—as aluminum—or improving the production of other materials—as in copper refining, etc.

All these applications are uses of *energy*. In nearly all, electrical energy is replacing some other form of energy used heretofore: chemical energy of fuel, or mechanical energy of steam or gas engines, etc.

To understand the reasons which enable electrical energy to compete successfully with other forms of energy, which are longer and more familiarly known, we have to look into its characteristics.

Electrical energy can be transported—or, as we usually call it, transmitted—economically over practically any distance. Mechanical energy can be transmitted over a limited distance only, by belt or rope drive, by compressed air, etc.; heat energy may be carried from a central steam heating plant for some hundred feet with moderate efficiency, but there are only two forms of energy which can be transmitted over practically any distance, that is, which in the distance of transmission are limited only by the economical consideration of a source of energy nearer at hand: electrical energy, and the chemical energy of fuel. These two forms of energy thus are the only competitors whenever energy is required at a place distant from any of Nature's stores of energy. Thus, when we study a problem in electric power transmission and consider whether it is more economical to transmit power electrically from the water power or the coal mine or to generate the power by a steam plant at the place of demand, both really are transmission problems; and the question is whether it is more economical to carry energy electrically over the transmission line, or to carry it chemically, as coal by the railroad train or boat, from the source of energy supply to the place of energy demand, where the energy is converted into the form required, as into mechanical energy by the electric motor or by steam boiler and engine or turbine.

Electrical energy and chemical energy both share the simplicity and economy of transmission or transportation, but electrical energy is vastly superior in the ease, simplicity, and efficiency of conversion into any other form of energy, while the conversion of the chemical energy of fuel into other forms of energy is difficult, requiring complicated plants and skilled attendants, and is so limited in efficiency as to make the chemical energy of fuel unavailable for all but very restricted uses: heating and the big, high-power steam plant. Pressing the button turns on the electric light and thereby starts conversion into radiating energy: with chemical energy as source, either special fuels are required—in the candle, kerosene lamp—or a complex gas plant. Closing the switch starts the motor, whether a small fan motor or a 1000-horse power motor supplying the water system of a city or driving the railroad train. With fuel as the source of energy, the boiler plant, the steam engine, or turbine, with their numerous auxiliaries, and skilled attendants, etc., are necessary, and the efficiency is low except in very large units. To appreciate the complexity of the conversion of the chemical energy of fuel, compared with the simplicity of electrical energy conversion, imagine the domestic fan motor with coal as the source of energy: a small steam engine, with boiler and furnace, attached to the fan: to start the fan, we have to make a coal fire and raise steam to drive the engine. This illustrates how utterly unavailable the chemical energy of fuel is for general energy distribution. General energy distribution, therefore, may justly be said to date from the introduction of electric power.

Equally true is the reverse: the conversion of mechanical or other energy into electrical is simple and economical, while the conversion into chemical energy is not. Hence, one of the two large sources of Nature's energy, the water power, was, before the days of electrical engineering, useless except to a very limited extent, since the location of the water power is rarely such that the energy could be used at its source. The water powers thus have really been made available only by the development of electrical transmission.

It is a characteristic of electrical energy that it can be concentrated to an energy density higher than any other form of energy, and results can thus be produced by it which no other form of energy can bring about, or do directly by the brute force of energy, as we may say, which formerly had to be brought about in a roundabout way.

Thus iron can be reduced from its ores by the chemical energy of coal in the blast furnace, but aluminum and calcium can not, as their chemical affinity is higher, and require the higher energy concentration available with electric power. Iron reduced in the blast furnace combines with carbon to cast iron. So calcium combines with carbon in the electric furnace to carbide, the starting material of acetylene, and of cyanamid and the modern fertilizer industry. Platinum can just be melted, and quartz softened, in the hottest flames of combustion: the oxy-acetylene flame and the oxy-hydrogen flame. But in the electric arc platinum and quartz and every existing substance, even tungsten and carbon, can be melted and distilled or sublimed. Thus mighty industries have grown up and many new materials made available to man, as aluminum, silicon, calcium, chromium, the carbides, cyanamid, acetylene, etc.; others produced in a cheaper manner, as alkalies, hypochlorites, phosphorus, magnesium, sodium, etc.

Electricity as such is the most useless form of energy: it is not found in Nature in industrially available quantities, and finds no industrial use as electrical energy, but it is always produced from some other form of energy, and converted into some other form of energy: light, mechanical energy, chemical energy, heat, etc. That is, electrical energy is entirely the connecting link, the intermediary, by which energy is brought from the place where it is found to the place where it is used, or changed from the form in which it is found to the form in which it is used. Thus, on first sight, it appears a roundabout way, when, for instance, in modern electrical ship propulsion an electric generator is placed on the steam turbine, and a motor on the ship propeller, a few feet away, though it is not different from practically every other use of electric energy: a transmission link, superior to any other transmission by the flexibility given by the simplicity and economy of conversion.

The most serious disadvantage of electrical energy is that it can not be stored. It is true, there exists the electric storage battery, and it is used to a large extent as a stand-by battery in high-grade electric distribution systems to give absolute reliability of service, or as a battery floating on a railway circuit to equalize fluctuations of power, or in special applications, as electric automobiles. It does not really store electrical energy, but stores energy by conversion of the electrical into chemical energy, and by reconversion, in discharge, of the chemical into electrical energy.

The economic efficiency of the storage battery—using the term in the broad sense including interest on the plant investment and depreciation—is so low that the storage battery does not come into consideration in the industrial storage of energy—that is, in making the rate of electrical energy consumption independent of that of energy production. We can best realize this by comparing electrical energy with the chemical energy of fuel: the latter can be stored with perfect economy. Thus, when using fuel as the source of energy—in a steam plant—no serious difficulty is met by the industry even if the fuel supply is interrupted for months, as in the case of a supply by water, through the closing of the navigation by ice: we would simply bring in a sufficient coal supply to last until the navigation opens again in spring. But with electrical energy from a water power we could never dream of storing energy by storage battery to last over the two or three months during which the river runs dry and the water power fails.

This means that electrical energy must be consumed at the rate at which it is produced, and the cost of electrical energy thereby becomes dependent on the rate of the energy used. This is not the case with most other forms of energy, as, for instance, the chemical energy of fuel. The price of a ton of coal, as determined by the cost of supplying it, is the same whether I dump the coal into a furnace all at once, or whether I use it up at a uniform rate in a small stove, lasting for weeks. If I consume 2400 cubic feet of gas per day, its cost and thereby its price is the same whether I use the gas at a uniform rate throughout the day, of 100 cubic feet per hour, or whether I use the entire 2400 cubic feet in one hour, nothing in the remaining 23 hours: the gas is produced at whatever rate is most economical, stored in the gas holders and supplied from there at whatever rate it is required for consumption. If, however, I use 240 kilowatt-hours of electrical energy per day, it makes a very great difference in the cost of supplying this energy whether I use it at a uniform rate of 10 kilowatt-hours per hour, or whether I use the entire 240 kilowatt-hours in one hour, nothing in the remaining 23 hours. In the former case, 10 kilowatts of generating machinery are necessary in the steam or hydraulic station producing the electric energy, 10 kilowatts capacity in transmission lines, transformers, substation and distribution lines, to supply the demand. In the latter case, 240 kilowatts of generating machinery, 240 kilowatts of line and transformer capacity are absorbed, and that part of the cost of supplying the electric energy, which consists of interest in investment in the plant, of depreciation, etc.—in short, the fixed cost—is 24 times as high in the latter as in the former case. If the fixed cost approximates half the total cost in a steam plant, or is by far the largest part of the total cost in a hydraulic plant, it follows that in the case of concentrated energy used during a short time the cost of electric energy—and with it the price—will be very much larger—many times, possibly—as in the case of a uniform energy consumption.

Thus, due to the absence of storage, the cost of electrical energy essentially depends on the uniformity of the rate of its use—that is, on the load factor, or the ratio of the average consumption to the maximum consumption.

If I use 240 kilowatt-hours of electrical energy in one hour, nothing during the remaining 23 hours, that part of the cost which is the fixed cost of plant investment and depreciation is 24 times as great as if I used the same amount of energy at a uniform rate throughout the day. In the former case, if somebody else uses 240 kilowatt-hours, but during another hour of the day, the same plant supplies his energy, and the fixed cost thus is cut practically in two—that is, the cost of energy to both of us is materially reduced. Thus, again, the cost of electrical energy, and with it its price, depends on the overlap or not overlap of the use of the energy by different users, the so-called "diversity factor." The greater the diversity factor—that is, the less the different uses overlap and the more their combination, therefore, increases the uniformity of the total energy demand, the "station load factor"—the lower is the energy cost. The cost of electrical energy for lighting, where all the demand comes during the same part of the day, is inherently much higher than the cost for uniform 24-hour service in chemical works, and with the increasing variety of load, with the combination of energy supply for all industrial and domestic purposes, the cost of energy decreases.

Thus, unlike other forms of energy, due to the absence of energy storage, electrical energy can have no definite cost of production, but, even supplied from the same generating station, its cost varies over a wide range, depending on the load factor of the individual use and the diversity factor of the different uses.

This feature, of necessity, must dominate the economical use of electrical energy in industrial, domestic, and transportation service.

## II.

Civilization results in the complete interdependence of all members of society upon each other. Amongst the savages each individual, family, or tribe is independent, produces everything it requires. In the barbarian state some barter develops, followed by trade and commerce with increasing civilization. But up to a fair state of civilization—up to nearly a hundred years ago—all necessities of life were still produced in the immediate neighborhood of the consumer, each group or territory still independent in its existence, and commerce dealing with such things only which were not absolutely necessary for life. All this has now changed, and in our necessities of life, as well as in our luxuries, we depend on a supply from distances of hundreds and thousands of miles: the whole world contributes in the supply of our food, clothing, building materials, etc.

That means, our existence is dependent on an efficient and reliable system of transportation and distribution of all needs of civilized life. Such has been developed during the last century in the system of steam railroads, which, in taking care of the transportation and distribution of commodities, have made modern civilization possible. Civilization means separation of production, in time and in location, from consumption, to secure maximum economy.

The necessities of civilized life consist of two groups: materials and energy. Our transportation system takes care of materials, but can not deal with the supply of energy, and the failure of an efficient energy supply has been and still is the most serious handicap which retards the advance of civilization. The transportation system could deal with the energy supply only in an indirect manner, by the supply of materials as carriers of energy, and when our railroads carry coal it is not the material which we need, but the energy which it carries. But this energy is available only to a very limited extent, as heat, and as mechanical power in big steam units; most of the energy demands of civilized life could not be satisfied by it In any country village far away from the centers of civilization we have no difficulty to have delivered to us any material produced anywhere in the world; but even in the centers of civilization we could not get the energy to run a sewing machine or drive a fan without *electric power*. Thus, just as our steam railways and express companies take care of the transportation and distribution of materials, so civilization requires a system of transmission and distribution of energy, and our electric circuits are beginning to do this; and just as fifty to seventy-five years ago in the steam railroads, steamship lines, etc., the system of transportation and distribution of materials was developed, so we see all around us in the electric transmission systems the development of the system of the world's energy transmission in progress of development When we see local electric distribution systems combining, the big electric systems of our capital cities reaching out over the country, transmission lines interconnecting to networks covering many thousands of square miles, this is not merely the result of the higher economy of cooperation, of mass production, but it is the same process which took place in the steam railroad world some time ago, as a necessary requirement of coordination to carry out their function as carriers and distributors of materials in the case of the railroads, of energy in the case of the electric systems.

We must realize this progress, and the forces which lead to it, so as to understand what is going on, and to assist in the proper development, in avoiding, in the creation of the country's electrical network, whatever mistakes have been made in the development of the country's railway network.

Electricity, thus, is taking over the energy supply required by civilization as the only form of energy which, by its simplicity and economy of conversion, combined with economical transmission, is capable of supplying all the energy demands, from the smallest domestic need to the biggest powers. As we now begin to realize, the economic function of the steam engine is not the energy supply at the place of consumption, from the chemical energy of coal—it is too complicated and inefficient for this—but it is the conversion of chemical energy of coal into electrical energy in bulk, for transmission and distribution to the places of consumption.

If, then, electric power takes the place of steam power in our industries, etc., it is not merely the substitution of the electric motor for the steam engine or turbine. Such would rarely realize the best economy. The method of operation in all our industries, and especially those requiring considerable power, is largely—more than usually realized—determined by the characteristics of the power supply, and what is the most economical method with the steam engine as source of power may be very uneconomical with electric power supply, and electric power supply often permits a far more economical method of operation which was impossible with steam power. Thus the introduction of electricity as the medium of distributing the world's energy demand means a reorganization of our industrial methods, to adapt the same to the new form of power.

For instance, the steam engine requires skilled attendance, and with its boiler plant, auxiliaries, etc., is a complex apparatus, is economical only in large units. Thus, when operating a factory or mill by steam power, one large engine is used, driving by shafts and counter-shafts, by pulleys and belts, and possibly wasting half or more of its energy in the mechanical transmission to the driven machines. But we could not economically place a steam engine at every one of the hundreds of machines in the factory. Substituting electrical power by replacing the engine by one large electric motor would be very uneconomical, as we can place a motor at every driven machine, and these small motors are practically as efficient—within very few per cent—as one big motor would be, and all the belting and shafting, with its waste of energy, inconvenience, and danger, vanishes. With the steam engine as source of power, to run one or two machines only, to complete some work, requires keeping the big engine in operation, and therefore is extremely wasteful. With individual electric motors the economy is practically the same whether only one or two motors are used, or the entire factory is in operation. On the other hand, with the steam engine, it makes no difference in the cost of power whether it is in operation from 8 A.M. to 6 P.M., or from 6 A.M. to 4 P.M. With electric power, in the former case the power demand would overlap with whatever lighting load the same supply circuit carries, but would not in the latter case, and the latter case thus would give a better load factor of the electric circuit, and thereby a lower cost of power. Again, with electric power, if very large power demands could be restricted to the period of light load on the electric supply systems, this would reduce the cost of power. Nothing like this exists with the steam engine.

Electrical energy thus makes the power users economically more dependent upon each other, and thereby exerts a strong force toward industrial coordination—that is, cooperation.

Another illustration of the industrial reorganization required to derive the full benefit of electric power is afforded by the traction problem. Very often a study of the electrification of a railway shows no economical advantage in the replacement of the steam locomotive by the electric locomotive, even when considering only passenger service. At the same time, an electric railway may parallel the same steam railway, offer better service at lower price, and show financially better returns than the steam railway. But so, also, in the early days of steam, the steam engine in place of the horse in front of the stage coach was no success, and still the stage coach has gone and the steam locomotive has conquered; but it did not by replacing the horse, but by developing a system suited to the characteristics of the steam engine. The same repeats now in the relation of steam traction and electric traction. The steam engine is most economical in the largest units, and the economy of steam railway operation depends on the concentration of the load in as few and as large units as possible: therefore, the largest locomotive which can pass through bridges and around curves. Exactly the reverse is the condition of economy of electric traction: the economy depends on the distribution of the load as uniformly as possible in space and in time—that is, small units at frequent intervals—and therefore, while steam traction has gone to larger and larger units, in electric traction even the trailer car, so frequently used in the early days, has practically vanished. Obviously, then, the electric motor can not economically compete with the steam engine under the conditions of maximum economy of steam and minimum economy of electric operation, and electric traction under steam traction conditions shows marked economy only in the case of such heavy service that the maximum permissible train units follow each other at the shortest possible intervals—that is, give maximum uniformity of load—and thus the economic requirements of both forms of power coincide. These two instances may illustrate the changes in industrial operation which the introduction of electric power requires and which are taking place today.

To conclude, then: Electric energy is the only form which is economically suited for general energy transmission and distribution. Civilization depends on the supply of materials and of energy as its two necessities. The supply of materials is taken care of by the transportation system of the world. The supply of energy is being developed by the electrical transmission system, which with regard to energy becomes what the railway system is with regard to materials. Introduction of electric power in place of other forms of power rarely can be mere substitution, but usually requires a change of the methods of power application, a reorganization of the industry, to secure maximum economy.

# THE SMALL OUTDOOR SUBSTATION

By E. B. Merriam

Assistant Engineer, Switchboard Department, General Electric Company

The central stations of the country, in co-operation with the manufacturers of electrical apparatus, have from time to time conducted campaigns for the education of the farmer and the rural resident to the convenience of electricity; but, before any returns can be realized from these efforts, it becomes necessary to supply them with a source of electric power, and at a cost for equipment that will insure a fair return upon the investment. This has been a problem for the manufacturer, and in this article the author describes some of the apparatus that has been developed for tapping off small amounts of power from medium and high voltage transmission lines. Such substations are usually installed out-of-doors to save the cost of a special building, and the designer is confronted with the problem of producing an inexpensive piece of apparatus which at the same time will insure reliable service under severe conditions. More information on the same subject will be found in an article by Mr. Merriam in the August, 1913, issue of the Review.—Editor.

The present rapid increase in the use of small amounts of electricity for purposes of lighting and power in locations heretofore too far distant from the central station and isolated electric plant to be economically feasible, is almost wholly due to the development of the comparatively inexpensive outdoor substation, by which means transmission lines of moderate voltage can be tapped at desired points to obtain the power required. The householder, the owner of farm machinery that has hitherto been operated by hand, and the manager of the small industrial plant outside the previous bounds of central station service insist on those comforts and advantages which can be obtained only through the medium of the electric current. The central station has shown a desire to extend the geographical limits of its activities and obtain additional revenue from the sale of current for such purposes.

The whole question is now, as heretofore, one of installation and upkeep against obtainable revenue, with the added fact that the outdoor substation as now developed cuts down these two latter items to a point sufficiently low to lead one to believe that the use of such substations will greatly increase within a very few years. The mass of data which have been collected and published on this subject proves the point without question.

To the central station this load is highly desirable, adding as it does considerably to diversity and tending to raise the load factor of the system. It may be even said that in many cases a large demand for power can be created by establishing pioneer lines to some few customers at a loss at first. Again it is often possible to create in the minds of some sparsely settled community a co-operative feeling which prompts the citizens to band together and pay some or most of the expense of the installation. This burden will not as a rule be heavy, because one of the underlying principles in the development and construction of outdoor substations is the necessity for producing them at a low price, and also to construct them so that the installation charges will be small. This is one reason why they have not generally been placed on the market sooner, because it has taken considerable time and effort by the manufacturers to produce equipment which, while being low in price, would also be of sufficiently high quality to give continuity of service, and to avoid the introduction of trouble on the transmission line itself.

The equipment has been reduced to the smallest amount consistent with good service; keeping in mind, however, the fact that very seldom will labor skilled in the employment of electrical devices be at hand, and that the apparatus must as a rule perform its functions satisfactorily for a long time with no attention whatever.

The idea of reliability is well brought out by the adaptability of these stations to mining industries where the power is used to drive ventilating fans which require infallible operation or a serious loss of life.

The table on page 398 gives a list of services to which outdoor stations are well adapted.

## Equipment

The wide field just outlined has been opened to operating companies by the development of efficient, reliable and inexpensive outdoor substation equipments. They include outdoor transformers, fuses, switches and other devices recently placed upon the market by electrical manufacturing companies. The equipments, which are shipped complete, permit supplying power from transmission lines operating at pressures up to and including 110,000 volts, the minimum economical sizes of installations for various line voltages being as follows:

| Line Pressure in Volts | Rating of Smallest Economical Substation in Kv-a., Three-Phase |
|---|---|
| 2,300 | 3 |
| 4,600 | 3 |
| 6,600 | 3 |
| 11,000 | 10 |
| 16,500 | 25 |
| 22,000 | 25 |
| 33,000 | 25 |
| 44,000 | 50 |
| 66,000 | 100 |
| 88,000 | 250 |
| 110,000 | 400 |

In general, the equipments consist of the following groups:

1. Primary disconnecting switches, fuses, choke coils, and other protective apparatus.
2. Step-down transformer.
3. Secondary switching and measuring apparatus.
4. Suitable supporting structure.

### Disconnecting Switch

The switch which has been especially adapted for outdoor service under extreme weather conditions is a modified lever switch design. (Fig. 1.) It is provided with a mechanism for raising and lowering the blade in a vertical plane by the rotation of a handle, thus permitting minimum spacing between

### APPLICATIONS OF THE SMALL OUTDOOR SUBSTATION

| Consumers | Applications | Character of Load | Type of Substation |
|---|---|---|---|
| Small towns | Street lighting<br>Commercial lighting<br>Water supply<br>Power<br>Railway<br>Household devices | Similar to urban service | Semi-portable |
| Farms | Outlined in previous papers | Regular intermittent cyclic load | Semi-portable or portable |
| Ice harvesting | Hoists<br>Cutters | Intermittent | Portable |
| Mines and quarries | Cable ways<br>Compressors<br>Crushers<br>Drills<br>Hoists<br>Lighting<br>Locomotives<br>Pumps<br>Ventilating fans | Regular flat load | Semi-portable and portable |
| Pumping installations | Irrigation<br>Refrigeration<br>Water supply | Regular flat load | Semi-portable |
| Manufacturing plants | Heat<br>Power<br>Light | Regular day load | Semi-portable |
| Contract jobs | Cable ways<br>Compressors<br>Concrete mixers<br>Cranes<br>Dredges<br>Drills<br>Hoists<br>Lighting<br>Locomotives<br>Pumps<br>Shovels | Irregular<br>Intermittent<br>Day and night load | Portable |

the poles, and easy operation. It is equipped with horn type arc deflectors and is designed to permit the operation of one, two or three poles as single-, double-, or triple-pole units. The operating handle, which may be located at any convenient point, is connected to the switch mechanism by bell cranks and gas pipe. It may be locked in either open or closed position by a padlock in a manner similar to that employed for railway track switches and signals.

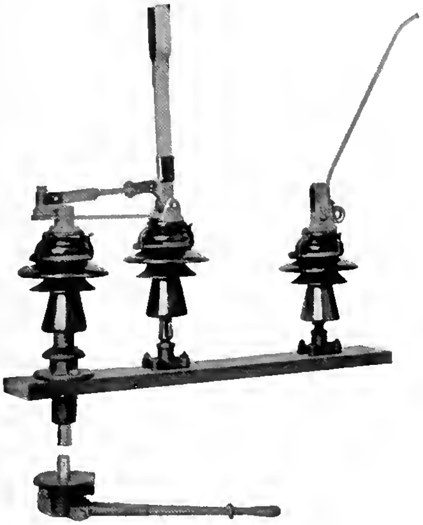


Fig. 1. Single-pole Disconnecting Switch for Outdoor Service on 35,000 Volt Lines

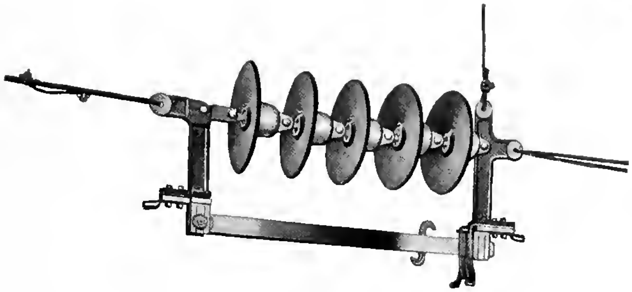


Fig. 3. Disconnecting Switch with Strain Insulators, 300 Amperes, 90,000 Volts

In order to fill the demand for a disconnecting switch that could be mounted outside the power station and operated from the station itself, a motor-operated switch of the above type was developed. (Fig. 2.) Other disconnecting switches suitable for outdoor installations are shown in Figs. 3, 4 and 5.

### Primary Fuses

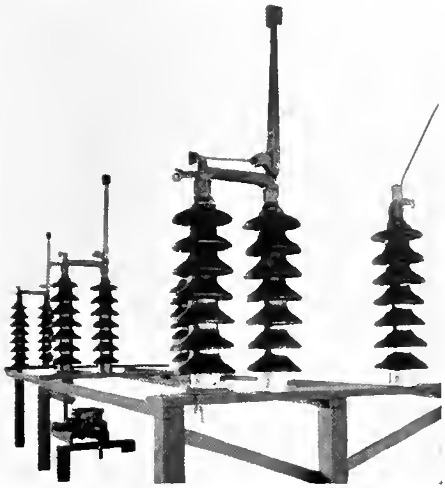


Fig. 2. Triple-pole Disconnecting Switch with Motor-Operating Mechanism for Outdoor Service, 400 Amperes, 100,000 Volts

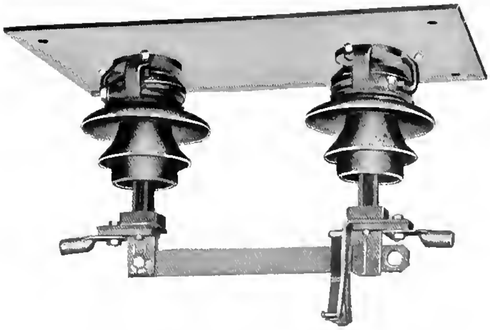


Fig. 4. Disconnecting Switch Underhung on Steel Base for Outdoor Service, 300 Amperes, 35,000 Volts

For vertical mounting, the fuse that is recommended is arranged to swing in clips and operate as a disconnecting switch (Fig. 6) while for horizontal mounting a fuse similar to the above, but without the disconnecting switch feature, is available. These fuses are a modification of the well-known tube expulsion fuse and consist of a holder protected by a weather-proof housing. The holders are closed at one end by a readily removable cap to which is attached the fuse wire. The latter is stretched through the interior of the holder and fastened to the outside at the open end. When overloaded, the fuse wire melts and forms a gas under high pressure which expands rapidly and blows the arc out of the holder. This design is the result of considerable experimental work and practical experience covering a long period of time.

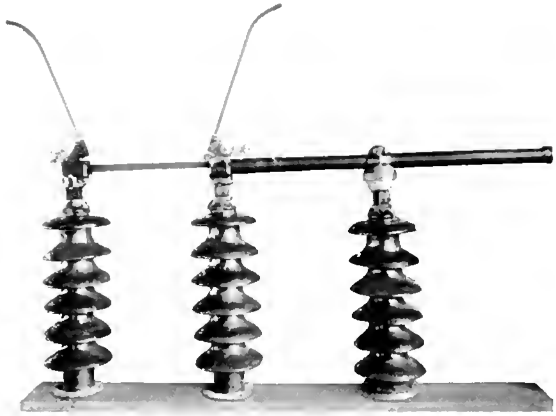


Fig. 5. Single-pole Bolt Type Disconnecting Switch for Outdoor Service, 400 Amperes, 90,000 Volts

Fig. 6. Expulsion Fuse Block showing Fuse in Open Position, 50 Amperes, 15,000 Volts

The vertical fuses can be made up in double or triple-pole units as a disconnecting switch so arranged that all the poles of the unit can be operated at once from the ground by means of a pole, operating rod, or rope. A station layout having this feature is shown in Fig. 7. The vicious and dangerous arcs characteristic of the horn gap render such apparatus unsuitable for fuse protection.

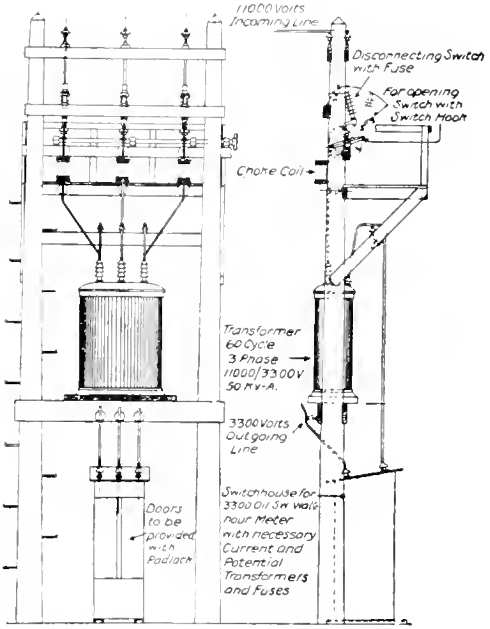


Fig. 7. Arrangement of Switching and Protective Apparatus for Supplying 50 Kv-a., Three-phase, at 3300 Volts from 11,000 Volt Transmission Line. Wooden Pole Construction

### Transformers

The transformers supplied with these equipments are single-phase or three-phase units, oil-insulated and generally self-cooled. They are especially designed for outdoor service under the most severe climatic conditions and are provided with special insulation in order to withstand the arduous character of the service demanded.

Transformers below 25 kv-a. capacity are placed in smooth cast iron tanks. From 25 kv-a. up to 750 kv-a., self-cooled transformers are supplied with corrugated sheet steel tanks, as the largest of these sizes, if made of cast iron, would be too heavy and bulky. From 750 kv-a. to about 2500 kv-a., the necessary radiation surface for self-cooled transformers may be obtained by compounding the corrugation, i.e., by welding together two plain corrugated sheets to form one large corrugation. Another construction, known as the "tubular" or "pipe" tank, consists of a boiler-plate tank having the ends of a double row of vertical steel tubes welded into it at the top and bottom. Transformers above 1500 kv-a. are usually water-cooled.

Transformers for pressures below 17,500 volts have their leads brought out through porcelain bushings set in or underneath the rim around the top of the tank. For pressures above 17,500 volts, the leads are carried vertically upward through the cover and are protected from the weather by petticoated porcelain coverings.

### Choke Coils

Two types of choke coils are available, the hour glass type, which is usually mounted as shown in Fig. 8 and used for stations of 22,000 volts and above, and the suspension type (Fig. 9), which is adaptable for use on small capacity moderate voltage stations.

### Instrument Transformer and Watthour Meter Housing

It is sometimes either desirable or necessary to measure power delivered over lines whose voltage is higher than 6600 volts. Heretofore, where the station is an outdoor one, the general practice has been to use two outdoor weatherproof current transformers and two outdoor potential transformers, and then provide a suitable housing for the outdoor meter.

In order to provide a more compact arrangement, the combined metering and transforming outfit shown in Fig. 8a has been designed. Here the current and potential transformers and watthour meter are arranged in one weatherproof housing, which can be handled as a unit. Only three entrance leads are required. Two of these have two entering cables for the current transformers, which are connected in the outside line of the transmission system. One terminal of each of the two potential transformer primary coils is connected to the incoming current transformer line. The other two terminals are tied together and connected to the necessary wire on the transmission line, which is entered through the third bushing.

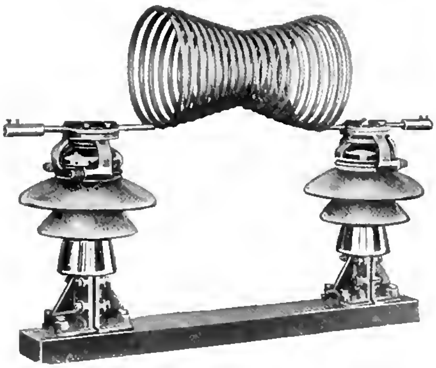


Fig. 8. 200-Ampere Choke Coil, 45,000-Volt Circuit

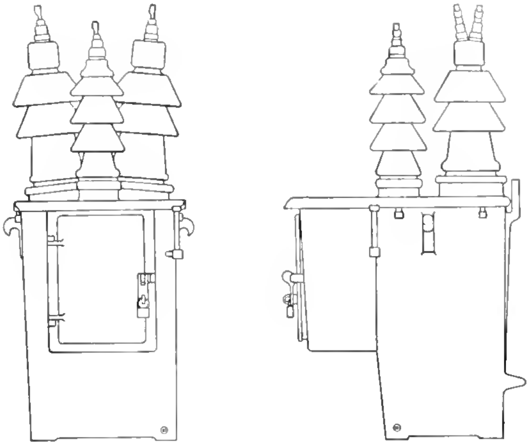


Fig. 8a. Instrument Transformer and Watthour Meter Housing

The secondary equipment is made up from the following elements:

### Secondary Equipment

1. Weatherproof housing.
2. Disconnecting switches.
3. Automatic oil switches or fuses.
4. Watthour meters.
5. Current and potential transformers.
6. Pole type regulators

The oil switches, watthour meters, current and potential transformers require no description, as they are of a standard design. They may be mounted on a steel or slate switchboard and enclosed in a wooden or preferably steel switch house. When no measuring apparatus is required, no housing

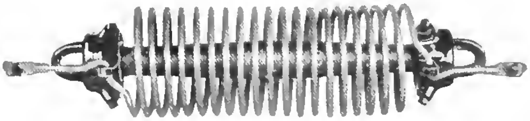


Fig. 9. Suspension Type Choke Coil, 50-100 Amperes, 25,000 Volts

for secondary apparatus is necessary, the load being handled by a pole-type switch and outdoor disconnecting switches.

### Switch Houses

Two types of switch houses have been designed, one for distributing voltages not exceeding 440 volts, where oil switches, current and potential transformers are not necessary, and the other for pressures not exceeding 2300 volts, a service which requires them. The switch house shown in Fig. 10 is for use on the lower voltage distributing circuits. It may be readily mounted at any convenient point. The incoming and outgoing leads pass through bushings fixed in the sides, and the box is provided with a door and padlock for securing the contents against marauders. A lever switch with enclosed fuses mounted on a slate base furnishes both disconnecting facilities and overload protection to the secondary circuit. A watthour meter connected directly to the circuit, without the intervention of current and potential transformers, measures the current supply.

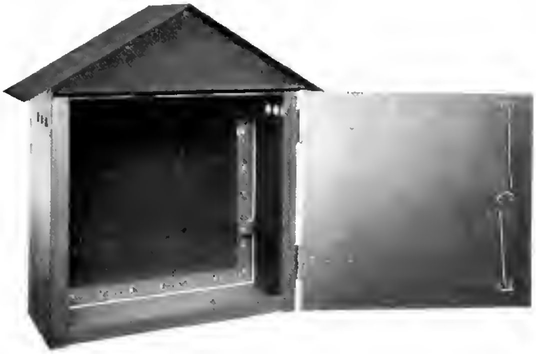


**Fig. 10.** Sheet Steel Switch House for Use on Distributing Circuits of 440 Volts and Lower

The switch house for 2300 volt secondary distribution is shown in Fig. 11. This house is built of sheet steel secured to a structural iron framework mounted on skids to facilitate transportation and provide a foundation. It is provided with padlocked doors at both the front and the rear, which give ready access to all parts. It contains a slate panel on which are mounted the disconnecting switches, automatic series trip oil-switch, and the watthour meter, the latter being provided with conveniently located test terminals. The necessary current and potential transformers are mounted on one of the interior side walls. Ammeters or voltmeters can be easily added to this equipment. The house is also provided with busbars which are fastened to the roof, and to which all of the interior apparatus is connected. Switch houses are shipped completely equipped and wired; in order to place the house in commission it is therefore necessary only to place oil in the oil switches, when they are part of the equipment, and attach the incoming and outgoing lines to the exterior terminals. Switch houses are designed for various standard forms of panels, to provide for single and three-phase commercial lighting, street lighting, three-phase power, and many other standard distribution circuits.

**Fig. 11.** Sheet Steel Switch House for Distributing 25 Kv-a., Three-phase, at 2300 Volts from High Voltage Transmission Line

### Pole Type Regulators

In connection with these equipments, the recently developed pole-type regulators, Fig. 12, may be used to considerable advantage, particularly for constant pressure lighting circuits. The regulator is of the induction type, automatic, entirely self-contained, and has no arcing contacts. It is operated by a small single-phase motor kept in continuous operation and connected to the regular shaft by mechanical means. It is controlled by a voltage relay which operates without the use of arcing contacts. This design of regulator is at present on the market in the 2.3 kv-a., 2300 volt, 60 cycle size only, although other sizes are now being developed. It will control the pressure of a 10 ampere feeder, from 10 per cent above to 10 per cent below normal voltage. The voltage relay is designed for 115 and 230 volt, 60 cycle circuits, and its series resistance is provided with several taps so that any voltage up to 15 per cent above or below normal may be used. It is not designed for line drop compensation, but may be used with a standard external compensator.

### Supporting Structure

The equipments which can be furnished may be divided into three classes, portable, semi-portable and permanent.

Portable equipments for supplying power to contractors, farmers or other consumers, whose apparatus is continually being moved from place to place, may be mounted on wagons, railway cars, floats or drags.

The semi-portable stations are usually of small capacity, where all the apparatus can be placed on a single pole, or a modification where the necessary secondary switching devices, either because of the voltage or current, are elaborate enough to necessitate a housing larger than that adapted to attachment to the pole. In this case a portable house is used.

The permanent structures are used where the size of the outfit requires a framework for the primary switching equipment, or a platform for supporting the transformers, or both. In cases of this kind, the supporting structure may consist of a steel tower, or two or more wooden poles.

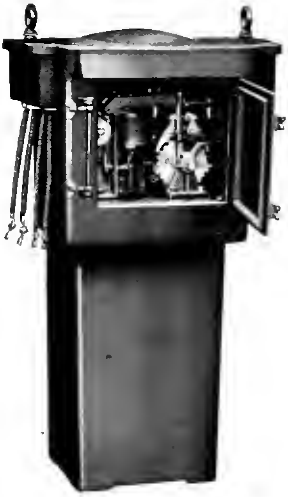


Fig. 12. Small Automatic Feeder Voltage Regulator

Fig. 13. 25 Kw. Transformer and Switching Equipment after Snow Storm. An Installation for Supplying 110-220 Volt Service from a 16,500 Volt Transmission Line

### Arrangement of Apparatus

For single or three-phase stations having a voltage of 6600 to 16,500, with 110 to 440 volt secondary, either two or three-wire, and of a capacity not exceeding 25 kv-a., the apparatus can be arranged as shown in Fig. 13*. In these stations the high tension lines first come to combined disconnecting switches and fuses and then through the transformer. The secondary wiring runs to a small switch house attached near the base of the pole containing a watthour meter and a suitable lever switch with enclosed fuses mounted on a slate panel. In order to adapt stations such as these for 2200 volt secondary distribution, it is only

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* Also Figs. 1, 2, 3, pages 550 and 551, GENERAL ELECTRIC REVIEW, August, 1913.

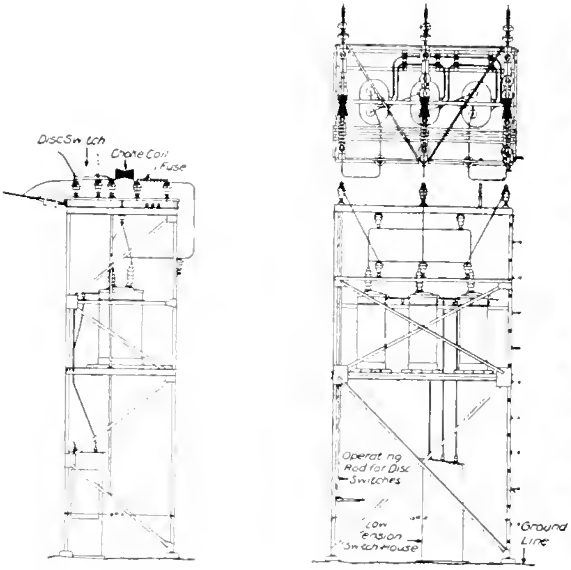

Fig. 14. Arrangement of Switching Apparatus and Three Single-phase Transformers for Supplying 150 Kv-a. at 2200 Volts, Three-phase, from 35,000 Volt Transmission Line. Steel Tower Construction

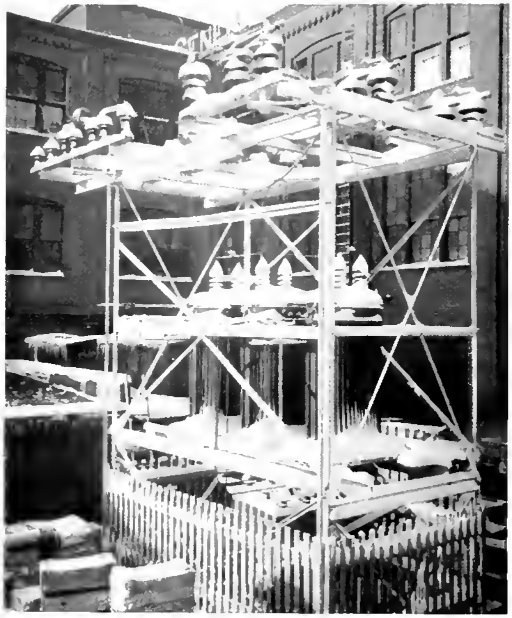

Fig. 15 Outdoor Substation showing Switch House Located Under Transformers, with the Lower Portion of the Tower Structure Enclosed by Picket Fence

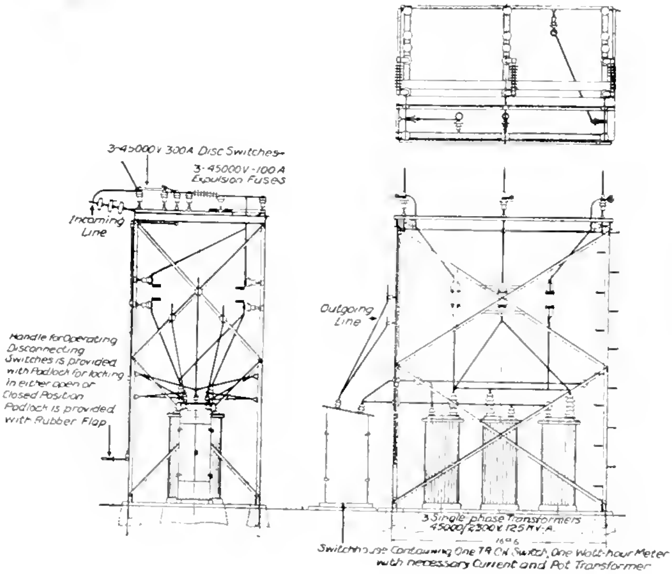

Fig. 16. Arrangement of Switching Apparatus and Three Single-phase Transformers for Supplying 375 Kv-a., Three-phase, at 2300 Volts from 45,000 Volt Transmission Line. Steel Tower Construction

necessary to substitute for the smaller house the 2300-volt switch house shown in Fig. 11, which contains an automatic oil switch and watthour meter with necessary current and potential transformers. Such stations are classed as semi-portable.

For stations larger than 25 kv-a., where a two or four-pole wooden structure or steel tower is required, a double or triple-pole combined fuse and disconnecting switch unit can be supplied. This unit, as previously described, differs from the single-pole

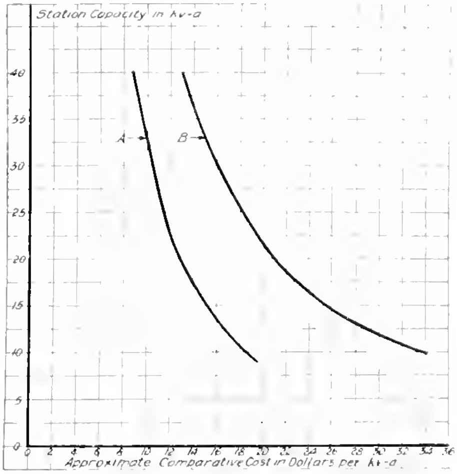

Fig. 17

APPROXIMATE COST OF STATIONS

A—Transformer Cost per Kilovolt-ampere.
B—Station Equipment Cost per Kilovolt-ampere.
16,500 Volts Primary
Single-Phase
110-220 Volts Secondary
Pole Mounted

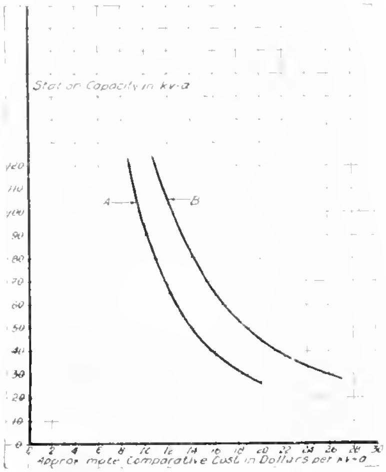

Fig. 18

APPROXIMATE COST OF STATIONS

A—Transformer Cost per Kilovolt-ampere
B—Station Equipment Cost per Kilovolt-ampere
Wooden Pole Mounting
Three-phase
Three Transformers
16,500 Volts Primary
110 or 220 Volts Secondary

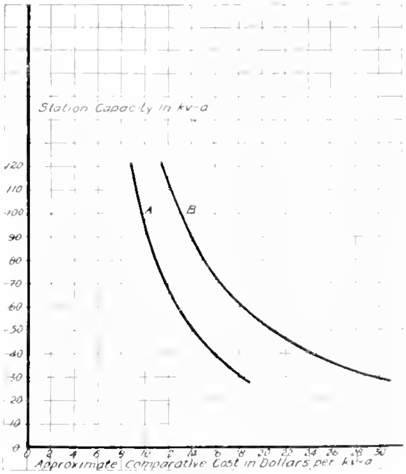

Fig. 19

APPROXIMATE COST OF STATIONS

A—Transformer Cost per Kilovolt-ampere
B—Station Equipment Cost per Kilovolt-ampere
Wooden Pole or
Tower Mounting
Three-phase
16,500 Volts Primary
2200 Volts Secondary
Three Transformers

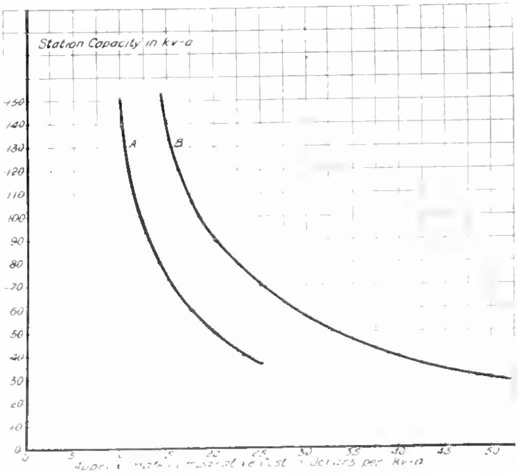

Fig. 20

APPROXIMATE COST OF STATIONS

A—Transformer Cost per Kilovolt-ampere
B—Station Equipment Cost per Kilovolt-ampere includes Steel Tower
Steel Tower Mounted
Three-phase
Three Transformers
35,000 Volts Primary
2200 Volts Secondary

fuses in that all the fuses can be pulled out at the same time by means of a hook or an operating rod, or a rope running to the foot of the supporting structure. The single-pole units are removed with a hook.

For some stations, where the capacity and secondary voltage render the amount of power greater than that easily handled by a lever switch, it is sometimes necessary to substitute the larger steel house with an oil switch in place of the small switch house attached to the pole. In cases where the voltage does not exceed 440, watthour meters not requiring current transformers can be supplied. Choke coils of the suspension type can, if desired, be supplied for such stations.

Where cheapness is especially desirable, stations up to 150 kv-a. can be constructed for voltages up to and including 35,000, single or three-phase, by using the double or triple-pole vertical type combined disconnecting switch and fuse unit. The arrangement for a two-pole structure is shown in Fig. 7. Secondary distribution can be arranged for either 110, 220, 440 or 2200 volt distribution as described for the 16,500 volt outfits.

For a more substantial layout for installations of a capacity greater than 75 kv-a., with three-phase distribution at 22,000 or 35,000 volts, steel tower mounting is to be preferred. Fig. 14 shows the arrangement of apparatus for such stations. The primary equipment consists of a disconnecting switch, shown in Fig. 1, an outdoor choke coil and a horizontal type fuse. The switch, fuse and choke coil can be supplied as a single unit mounted on a channel iron. This permits one insulator to support the ends of two pieces of apparatus, thus making a very compact unit.

When desired, the switch house can be placed underneath the transformers and the whole lower tower structure enclosed. (Fig. 15.)

It is to be noted that in these installations a low tension bus is provided. The secondary distribution is made through the 2200-volt steel switch house, which has already been described. When the size of the transformers becomes so large that platform mounting would be inadvisable, they can be mounted on the ground as shown in Fig. 16. In all these cases no low tension bus has been provided, for the necessary wiring can in most cases be more advantageously carried on the insulators attached to the steel supporting structure. These layouts are shown in the illustrations, with delta connection on both primary and secondary sides.

The steel tower structures supplied are thoroughly galvanized after all labor is finished. They are easily put together with bolts and nuts that have been sherardized.

### Portable Generating Equipments

There is a wide range of permissible designs of stations for portable use. For supporting or containing the necessary apparatus, wagons, floats, drags, railway boxes, flat cars, or sleds have been used.

In addition to the stations described, which depend for their supply of electricity on a permanent power installation at some convenient point, there has been placed upon the market a line of portable generating equipments. These consist of a gasolene-engine driven generator mounted on a wagon which may be drawn by horses to the point at which power is desired. These equipments are particularly adapted for the following classes of service:

Breakdown auxiliary service.
Temporary peak loads.
Construction work.
During rehabilitation of old stations.
Assisting in new business solicitation.

They should form an efficient and useful auxiliary to all transmission line operators.

### Costs

Approximate costs per kilovolt-ampere of equipments compared with like costs of necessary power transformers are shown in the curves of Figs. 17, 18, 19, and 20. In these are included single and three-phase pole mounted stations for a primary voltage of 15,000 and a distributing voltage of 110, 220 or 2300; and also three-phase wooden and steel tower mounted stations for 35,000-volt lines and 2300-volt distribution.

### Conclusion

The stations described in the above article indicate some of the permissible arrangements of apparatus developed. As the apparatus is adaptable to a multiplicity of combinations for various services, the central station manager is given an opportunity to devise safe and reliable stations, which will permit him, even in isolated communities, to profitably realize on the rapidly awakening tendency to "do it electrically."

# THE EVOLUTION OF RAILWAY MOTOR GEARING

By W. G. Carey

Manager, Railway Supply Sales, General Electric Company

The author traces the development of railway motor gearing from the time that gears and pinions as used on stationary apparatus (where plenty of space was available to permit the use of cast iron) were applied to railway motors, up to the modern gearing which has been developed to meet the severe conditions of up-to-date railway practice. Most of the early part of this work resolved itself into devising means and ways of increasing the life of the pinion to approximate that of the gear. The different methods adopted to produce a harder and more durable pinion are described. The life factors necessary to determine the maintenance cost of different types of pinions are given.—Editor.

The design of the gear equipment of the first small electric railway motors was adapted from established practice in the construction of gear trains in stationary apparatus. Abundant space was available for adequate cast iron gears. With increase in size of motors it became convenient to substitute cast steel for cast iron in order to secure increased strength while conserving interchangeability on existing trucks; and thereafter for many years cast steel gears with machine steel pinions continued to be used in universal practice. The speed reductions from the armature shaft to the axle ranged from about 3 to 1 to 4.78 to 1, and pinions and gears wore out in about these ratios. The obvious advantage of increasing the life of the pinion to approximately that of the gear in order to improve average conditions of mesh and to reduce the cost of frequent renewal of pinions led to early experiments in case-hardening of pinions. In applying this process, practice satisfactory in other arts was followed and little attempt was made to modify, for the special conditions, the process as usually carried out. The first case-hardened pinions exhibited consequently a considerable measure of warping from the heat treatment, which fact involved high cost in rejections in manufacture. Also, this warping and other results of the treatment caused in many cases destructive wear of the companion gear, and the net results were such that no really great interest in any form of heat treatment of gearing was felt until increased size of motors, for which an active demand was arising, made imperative an increase in the strength of materials. The pitch of teeth and width of gear face had been increased to the limit allowed by available space on the trucks, and the strongest cast steel practicable for machine operations was found inadequate; therefore, to meet the severest conditions resort was had to alloy steels with partial success in keeping equipments in service. Experiment to determine the alloy steels best suited for the purpose required, however, a long time and involved heavy expense, and heat-treated carbon steels tried out at the same time afforded excellent results. Painstaking study by manufacturers of railway apparatus, aided by the broad minded co-operation of operating engineers, soon resulted in the determination of suitable material and the development of methods in heat treatment adequate for the severest conditions in present normal practice.

Incidentally, the modification of the material and its heat treatment, together with increased strength, produced considerable increased hardness, and, at least for city service where the strength of untreated gears was still adequate, the old idea of a pinion harder than the gear, tending to equalize the life of the two, was in a measure realized, and within a very short time the untreated pinion was entirely discarded, even for service in which the strength of the heat-treated steels was entirely unnecessary.

Only experiment could determine certainly the effect of the hard pinion on the untreated cast gear, and some curious results developed in special cases. In one of the first installations on a considerable scale the hardened pinions wore out completely in about half the life of the old untreated machine steel pinions, and this proved to be due to the presence in the gear grease of considerable quantities of very hard sand prevalent in the neighborhood, which, getting into the gear case, became embedded in the surface of the soft gear teeth, forming a lap for the rapid destruction of the pinion teeth. On the whole, however, with good methods of lubrication and maintenance of equipment, heat-treated pinions having a hardness not exceeding approximately 300 in the Brinnell scale appear to afford greatly increased life without measurable reduction in the life of an untreated companion gear.

Continued experiment in case-hardening developed means of avoiding most, if not all, of the original trouble of warping in treatment, and the process was applied experimentally on a considerable scale to the cast gears as well as to pinions; and increased life, altogether out of proportion to the increased cost, was immediately obtained. Split gear castings, however, still gave some trouble from warping on account of their irregular sections. At that time split gears were in considerable demand, although the use of solid gears had already commended itself strongly for many reasons. Split gear bolts had always given trouble and it was easier to obtain sound castings in the more regular sections in the solid gear, and these considerations had begun to have a considerable influence in hastening the provision, in repair shops and inspection barns, of wheel presses and other facilities for handling solid gear equipments. In the present state of the art of case-hardening pieces of such size and shape as motor gears, this matter of warping is not so serious a matter, as its control has been greatly improved; but at that time a general readiness to substitute solid gears greatly facilitated the trial of case-hardened gearing on an extensive scale in service.

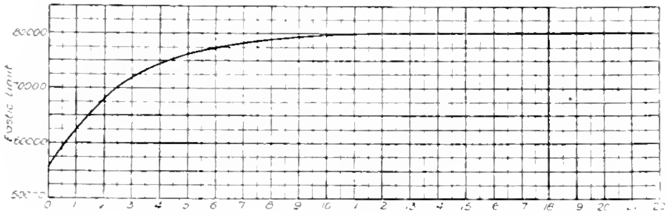

Fig. 1

This material is essentially a low carbon steel with the surface impregnated with additional carbon and heat-treated. The usual practice is to shroud portions not required to be hardened so that only the tooth surfaces are exposed to the "cementing" process, as the incorporation of additional carbon is called. Therefore, only the carburized portion hardens in quenching. It is usual practice to carry the depth of impregnation of carbon in the tooth surface to about the limit of allowable wear, which, in three-pitch gearing, is approximately 1 10 in. This, however, is subject to very definite control and is varied within limits for various conditions.

The surface of case-hardened gear and pinion teeth shows hardness about 95 in the scale of the Shore schleroscope. It is not practicable to measure this material with the Brinnell instrument for the reason that the uncemented core will not stand up under the pressure necessary to effect an indentation, and such pressure also causes deformation of the pressure ball. The schleroscope is also to some extent misleading, as different conditions, such as size of parts tested or method of their support in test, give rise to considerable inaccuracies. In experienced hands the most reliable comparison of hardness of specimens of materials of this class is a file test, though this may be entirely misleading in comparison of different alloy steels. Modern case-hardened carbon steel which gives a schleroscope reading of 95 can just be scratched with a very fine Swiss file.

This class of gearing, because of the price at which it could be marketed, was manifestly a great improvement in economy of operation, wherever it might be found sufficiently strong to withstand the shocks of service. No test, other than that of service, has been devised for determining its resistance to service stresses, but that the limit of its strength is below the requirements of the heaviest modern service appeared probable and has since been demonstrated. In the first days of its use much virtue was attributed to the toughness of the low carbon core, but this toughness cannot manifest itself under stresses on the whole tooth, and a tooth strained beyond its strength breaks short. It is evident that substantially the entire tooth strength must be found in the hardened case, and the factor of safety, even with the enormous elastic limit of this high carbon case, promised to be too low for safety in the heaviest equipments throughout the very long period of its probable service. Although this gearing has been used very conservatively on motors of over 125 h.p., and then only in the light of careful study of operating conditions, the original estimates of strength have been closely borne out. Breakage has occurred in certain carefully watched test equipments after two years of service where wear had hardly begun. This has in some cases undoubtedly been due to fatigue of the case from repeated shocks closely approaching the elastic limit, and in other cases to subsidence of the soft tooth core resulting in cracking of the case.

It is therefore known today that, while with motors of less than about 100 h.p. this type of gearing is sufficiently strong to resist fatigue until worn out in service, its application with heavier equipments can only be advised in the light of a very definite understanding of the conditions of operation. With such heavier equipments, especially in high speed service with rapid acceleration and liability to abnormal shocks such as are produced by commutator flash-overs or line breaks at the collector, the case-hardened gearing appeared and has already been proved to have an inadequate factor of safety.

Attention was then turned to a modification of the homogeneous heat-treated gearing with a view to increasing its hardness to attain increased life and a greater elastic limit, which was essential in order to defer fatigue beyond the extended limit of wear. The physical characteristics of heat treated steels depend upon a considerable number of variable factors in the constitution of the steel, the manner in which it is worked, and methods of treatment. The constitution of the material can only be definitely controlled within certain limits which are well recognized in steel manufacture, and variations in the constitution affect final physical characteristics, though the variations may be corrected in a measure by corresponding variations in treatment. Such methods, if carried to too great a refinement, are prohibitively expensive, and the development of the desired new type of gearing involved a method of analysis and an adjustment of treatment which would be commercially practicable.

The type of heat-treated gearing which had become recognized as a heavy service standard showed elastic limit varying in regular production from eighty to ninety thousand pounds per square inch, although occasionally specimens showed still higher values and certain other specimens with elastic limit varying down to 70,000 lb. per square inch were put into service in the earlier days of this development. Throughout several years a record was kept of mileage and physical characteristics of all specimens broken in a service of known character, and the curve in Fig. 1 shows relation between elastic limit of broken specimens and the time required for fatigue to the breaking point in normal service.

This shows that maximum stresses on the gear teeth, which could be determined in no other way, are equivalent to about 70,000 lb. per square inch in the teeth, since all specimens broken early in service show approximately this value. Higher values are shown to afford longer life, until the specimens broken toward the limit of wear invariably show an elastic limit of approximately 80,000 lb. per square inch, and in no cases have specimens showing higher values broken in service.

With a lower ductility, it was assumed—and it is in all probability true—that a larger factor of safety would be necessary to defer fatigue beyond the limit of wear, and a composition was selected and methods of working and treatment determined which would give an elastic limit of 140,000 to 150,000 lb. This steel shows a hardness approximately 500 in the Brinnell scale, and, while no very definite comparison with hardness of case-hardened gearing is possible, such rough comparison of the Brinnell and schleroscope scales as is possible and the file test indicate the hardness to be approximately 85 per cent of that of case-hardened gearing.

Commercial application of this type of gearing has been made with the greatest care, and it has not yet been trusted in the heaviest service, although since its first commercial use two years ago about 7000 equipments of this gearing have been installed with motors of all power up to 150 h.p. and there is no record of breakage of a single tooth within the limit of wear.

It has been pointed out that various factors had contributed to a marked tendency to substitute solid for split gears. This tendency was manifest in all classes of service, and its wide spread made possible the realization of an old idea of using forged blanks in place of castings for axle gears.

The manifest advantage of forgings in entirely eliminating shrink strains and other faults not altogether avoidable in castings was important, but not all of the desired end. It was practicable to machine steel of a higher carbon content, and the strength and toughness could be greatly enhanced by the operation of forging the blank. The very great diversity of combinations of shape and dimension required involved an enormously expensive development cost and it is probable that this would have long deferred the general substitution of forged for cast solid gears, were it not for the fact that the development of the homogeneous heat-treated types absolutely required forgings, since the desired physical characteristics were unattainable in castings. The cost of manufacture is so far a little higher, but the difference would probably be justified by the certain and invariable integrity of the blank, even with the same life factor. In addition, however, the untreated forged gear shows approximately 20 per cent higher elastic limit and nearly 25 per cent greater hardness, and these characteristics afford an increased life approximately proportional.

Fig. 2
Forged Gear

There are then available in the art today three modern types of gearing, each of which may have its appropriate field, although there may be some difference of opinion as to where and to what extent these fields overlap. The first essential in the selection of a type is adequate strength for positive assurance against breakage within the limit of wear.

There are thousands of motors in operation which are destined to be superseded by more modern machines within the expected life of heat-treated gearing, and in such cases no advantage can be gained by the use, at higher cost, of a type which cannot be worn out within the life of the apparatus; and therefore the untreated forging is clearly the only type to be considered.

Also, many important systems have been completely equipped with case-hardened gearing, and the problem of changing over to another type, unless the two types can be successfully operated together, is a difficult one, and such a change must be effected gradually. Both of these considerations must be taken into account, although in the end practice will be standardized on the basis, first, of safety and then of annual cost of maintenance.

In the meantime, in substituting complete gear equipments of the modern heat-treated steels for untreated gears with heat-treated pinions having hardness of about 250 to 300

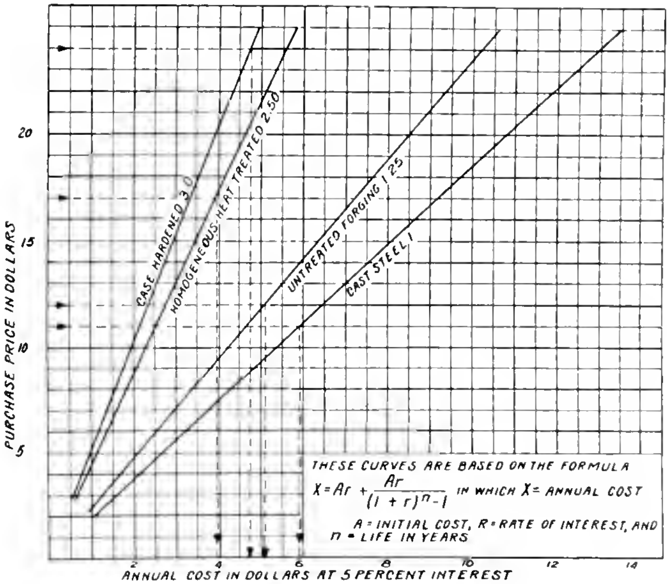

Fig. 3

in the Brinnell scale, it is evident that some trouble will be involved in attempting to maintain the proper combinations, and the result of combining gears and pinions of widely differing hardness under all service conditions is very uncertain. While occasional instances of successful operation of even case-hardened pinions with untreated gears are reported, it is certain that such combinations will generally result in reduced life of the softer member, and in effecting changes in their practice most operators are taking the trouble to provide pinions of only moderate hardness for use with their untreated gears and meshing all new gears of more modern types with pinions of the same types.

For the purpose of estimate of maintenance cost, life factors of different types must be assumed and the following are based upon records of service under widely varying conditions:

| Grade | Life Factor |
|---|---|
| Untreated cast steel | 1 |
| Untreated forged steel | 1.25 |
| Homogeneous heat treated | 2.25 |
| Case hardened | 3 |

These estimated life factors, with cast steel taken as 1, are about proportional to the relative hardness of the respective types, which factor should, and apparently does, reflect fairly closely the average life in service. Based upon these factors and an assumption of 5 per cent interest on investment, the curves in Fig. 3 show a comparison of the respective maintenance costs of the four types here considered, at the prevailing market prices of a representative gear for city service.

The market prices of this gear in the four different types are, respectively: cast steel, $11.00; untreated forging, $12.00; homogeneous heat-treated, $17.00; and case-hardened, $24.00. Following the dotted lines as indicated by arrows from these purchase prices in the ordinates, the respective annual costs will be found to be $5.90 for untreated casting; $5.10 for untreated forging; $3.95 for homogeneous heat-treated, and $4.75 for case-hardened gears.

It has been said that the heat-treated carbon steels now available have proved adequate for the severest conditions in present normal practice. It is known, however, that we are already near the limit of strength of this material, and the added demands of apparatus already projected, and of at least one existing application of somewhat special character, call for an additional factor of safety to maintain strength requisite for service to the limit of wear. Experiment on an extensive scale is being conducted with various alloy steels and various treatments, and encouraging results are promised, particularly with chrome-vanadium. Owing to its narrower base, the strength of the pinion tooth is measurably lower than that of the teeth of its companion gear, and there will undoubtedly be a wide range of applications in which alloy steel pinions may be used with carbon steel gears, and by virtue of an elastic limit of something like 170,000 lb. per square inch, which appears attainable, will equalize the difference and take us another long step in the development of this art in which we are so circumscribed by the fixed dimensions of the trucks.

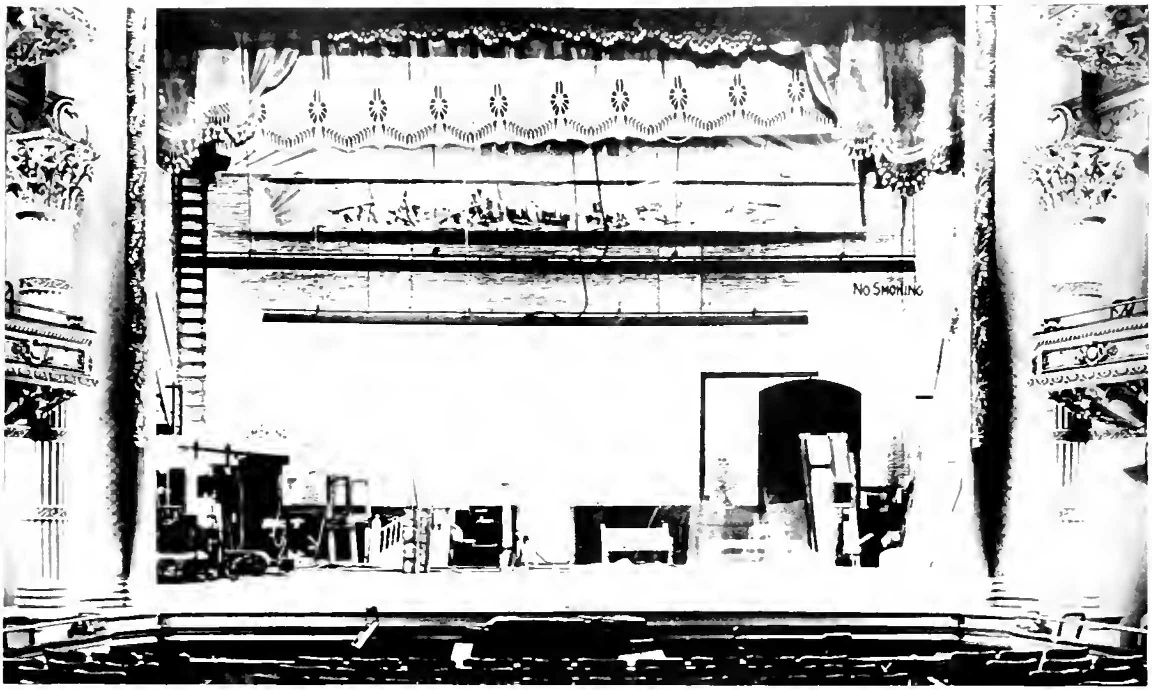

Fig. 1. View of a Stage from the Auditorium. Curtains and Suspended Scenes Raised showing Border-light with Concert-border Beneath

Fig. 2. Partial View of Stage and Auditorium Including Border-light, Double-row Footlight, Stage Switchboard, Boxlight Lens Lamp, Dimmer, Magazine Panel, Company Service Switch and Portable Strip-light

# CONSTRUCTION AND INSTALLATION OF STAGE LIGHTING EQUIPMENT

By H. H. Reeves

Supply Department, General Electric Company

In the October, 1913, issue of the Review there appeared an article on "The Requirements of Theater Lighting." This article dealt mainly with the various types of lighting required in the different parts of the theater building, with the lamps which are employed to secure those effects, and with the locations of the lamps. The present article describes in detail the best practice in the construction and installation of the equipment which supplies and controls the electricity furnished the lamps. The usual layout of the stage equipment is clearly pictured, and particular attention is directed to those locations for the electrical equipment which produce the most effectiveness in presenting a performance. Wiring diagrams of the main circuits and of convenient arrangements for wiring the switchboard are given. One of the strong points of the article is the suggestion to connect the motion-picture machine to the secondary service lines. In the event of the blowing of the main fuses a possible panic may thus be easily averted, for the audience can be entertained with pictures until normal conditions can be restored.—Editor.

## Introduction

It is not intended that the description of the construction and installation of electrical stage equipment as given in this article is to be regarded as the final word on this subject, for new apparatus is being developed every day and different methods of installation follow each other in rapid succession. However, there are standard types of construction and systems of arrangement of the various pieces of apparatus about the stage in general use today, and the following has been written after a careful study of the situation and represents what the writer believes to be the best practices that are employed in theater construction at the present time. The ideas are not adaptable to theaters of special character, such as hippodromes, etc., but were incorporated with the type of theater in mind which is suited to the average production.

## General

The producing of a play of several acts and scenes, in this day of realism and elaborate detailed settings, necessitates for example the erection and furnishing of an elaborate apartment in a very few minutes. It is no longer an imitation but an actual habitable apartment with real properties, furnishings, etc., and consequently requires specially constructed scenery and equipment. The appliances must be specially designed to be available for instantaneous use and, at the same time, be so constructed as to withstand the necessarily rough handling they experience when in use. The equipment is further taxed by the fact that when it is sent on the road it is subjected to continual shipping and handling by inexperienced and irresponsible parties, and is used on foreign stages under unusual and varied conditions.

The modern theater is equipped with all of the latest mechanical contrivances which tend toward expediency. This has been carried out so far at the Century Theater in New York City that four stages are arranged on a pivot and can be presented to the audience successively. As the stages revolve and one goes behind the proscenium wall the next is brought before the audience. The average theater, however, depends upon movable scenery rather than a movable stage. To facilitate the handling of this scenery, as much of it as possible is kept suspended in a loft above the stage and can therefore be quickly dropped into place and be as easily pulled up out of sight again. This is accomplished by ropes running over pulleys or sheaves fastened to a gridiron structure and then down to a fly gallery on the side wall.

The gridiron (Fig. 3, GI) consists of parallel steel bars ($\frac{3}{4}$ by $2\frac{1}{2}$ inches) spaced approximately two inches apart. Wooden beams are sometimes used where the local ordinance permits. The gridiron should be placed at a height exceeding twice that of the proscenium arch by at least three feet in order to allow the suspended scenes to clear those in use on the floor and in order to allow the free operation of the asbestos curtain. For a standard equipment this should not be less than 65 feet. A greater height than this is advantageous but not necessary for ordinary purposes. Sufficient head room must be provided over the gridiron to conveniently adjust sheaves, ropes, etc.

There is a fly gallery (Fig. 3, FG) on each side of the stage running from the proscenium wall to the rear wall of the theater. These flies are vertically located about halfway between the stage floor and the gridiron, being on a level or a little below the proscenium arch. For standard usage the fly floors should not be less than 27 feet above the stage floor. Their width varies according to the conditions which govern the size of the building, but for standard work they should on no account extend nearer than 4 feet to the

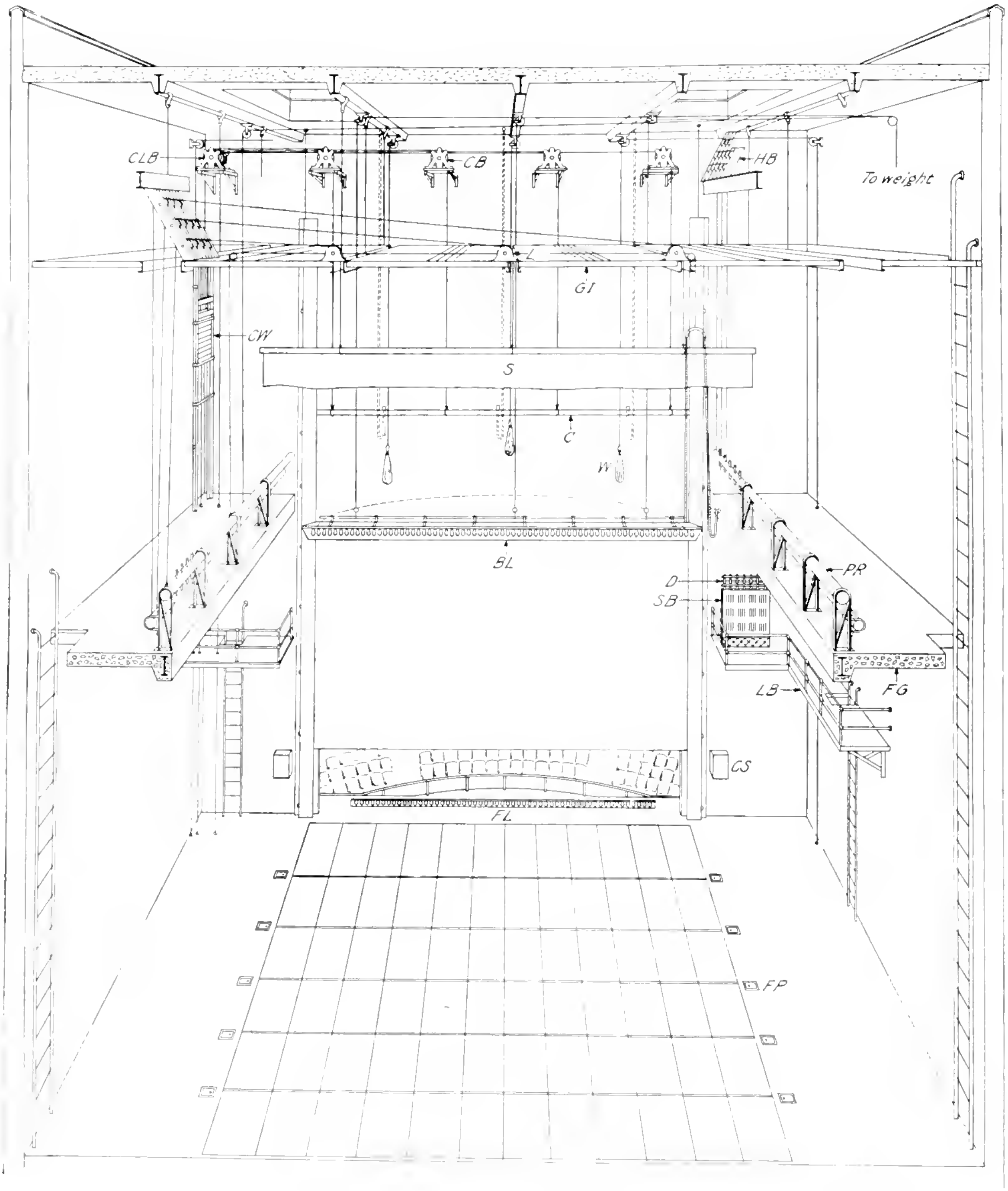

Fig. 3. Diagram of a Stage showing Rigging and Stationary Equipment, and the Relative Locations of the Various Parts

**KEY**

FP —Floor Pocket
FL —Footlight
CS —Company Switch
LB —Lighting Bridge
FG —Fly Gallery
PR —Pin Rail
SB —Switchboard
D —Dimmers
BL —Border-light
W —Weight
GI —Gridiron
CW —Counter-weight
HB —Head Blocks
CB —Curtain Blocks
L —Loft Block

proscenium opening and be less than 50 feet between rails. These fly floors should ordinarily extend to the side walls of the theater but should not be less than 8 feet in width, greater width being desirable.

Along the edge of the fly galleries and at about the height of a man's waist the pin rails are placed (Fig. 3, PR). It is around the pins in these rails that the free ends of the ropes, which suspend the scenes and borders, are tied. Since the pin rails bear the weight of all the suspended pieces, they are subject to considerable strain and should be carefully designed. It is customary to have two lines of pins, one above the other, on the rail with the pins spaced on 8-inch centers in each and staggered so that those on the lower rail come between those on the upper rail. When one tier of flies does not afford sufficient working space it sometimes becomes necessary to introduce a second tier above the first.

All theaters for general productions should have a "paint bridge." This is usually placed at the rear of the stage at a distance of at least one foot from the rear wall so as to permit the "paint frame", on which scenes are mounted to be painted, to pass the bridge upon being raised or lowered. For standard construction the floor of this bridge should be at the height of the fly galleries, and should extend across the stage from fly to fly.

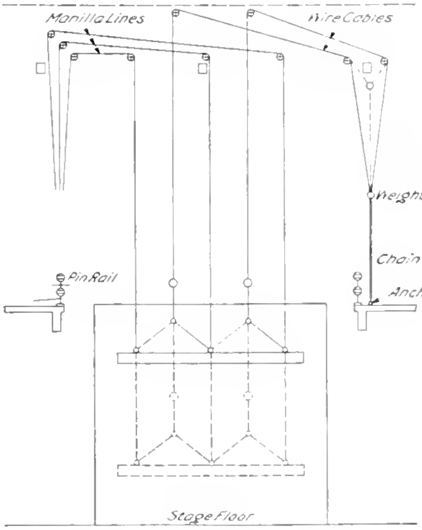

Fig. 4. A Method of Border Suspension

Spot-light bridges (Fig. 3, LB) are used in a large number of modern theaters and extend along the side walls underneath the fly galleries. Lens lamps and similar portable lighting units are operated from these bridges.

### Footlight

A general distribution of light over the stage is obtained by means of footlights (Fig. 3, FL), border-lights, and proscenium-lights, the footlight being the most efficient because of the greater horizontal component of its light distribution. The reflector-hood of the footlight should not project more than 4 or 4½ inches above the stage floor, or it will interfere with the line of sight of that portion of the audience on the lower floor. The reflector should also be designed so that the lamps cannot be seen by those sitting in the back row of the gallery. It is preferable to set the footlight in a concrete trough built in the stage floor as it makes a much more substantial installation and eliminates vibration to a large extent.

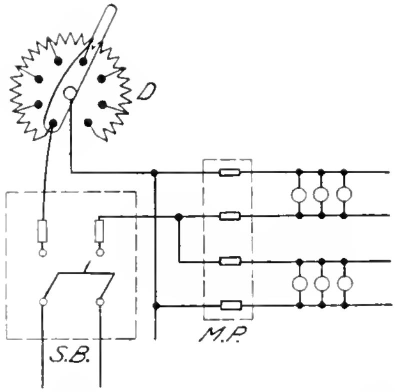

Fig. 5. Diagram showing Multiple Lamp Circuits Separately Fused in the Magazine Panel and Connected to a Dimmer and Switch

The single-row type is used only in the smaller theaters. Of the two forms of double-row footlight, the inverted is much superior to the upright for both electrical and mechanical reasons, the illuminating efficiency being about the same.

The axis of the lamps in both rows should be inclined at an angle of 20 degrees to the vertical, as in this position the maximum of useful light is obtained. The filaments of all the lamps should be as high above the stage level as possible, being limited only by the height of the reflector hood.

The color of the lamps used in the footlight depends largely upon the character of the plays produced, and has been discussed in a previous issue of the Review*.

For standard dramatic use a stage opening 40 feet wide has proved most advantageous, and as this opening is further reduced by the "masking in" of "returns" and "tormentors" the actual working space of the stage is reduced to about 36 feet. On this account the footlight does not necessarily have to extend the full width of the proscenium opening.

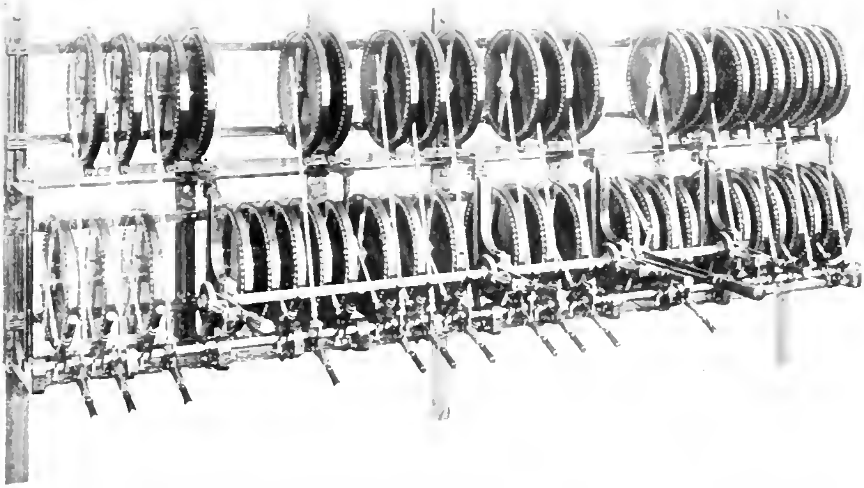

Fig. 6. A Standard Dimmer Controlled by Individual Handles or Master Handle. The Resistance Disks are Units, and may be Quickly Removed and Replaced or more Added

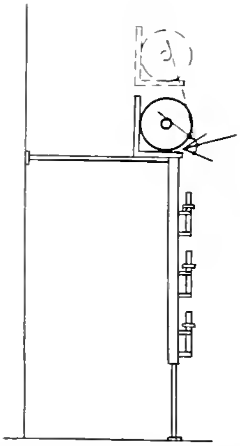

Fig. 7. Diagram showing Dimmer Located Above Horizontal Pipe Supports. Operating Handles at Top of Switchboard

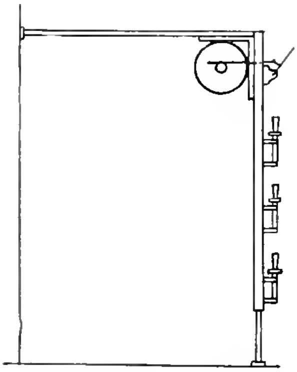

Fig. 8. Diagram showing Dimmer Located Immediately Below Horizontal Pipe Supports. Operating Handles at Top of Switchboard

The splicing box is generally located at the end of the footlight nearest the switchboard.

Very few curved footlights are installed today. This is on account of the difficulties of construction and the poor light distribution obtained, as compared with the straight footlight; and also on account of the difficulty in designing the seating of the auditorium so that the lines of sight from certain sections, viz., the boxes and sides of the balconies, do not bring the lamps of the footlight into view. In case more illumination is required in the

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*See "The Requirements of Theater Lighting," by Messrs. Rose and Mahan, General Electric Review, Oct. 1913, page 745.

first "entrances" or "tormentor entrances" than is afforded by the footlight the proscenium-light mentioned later can be brought into play.

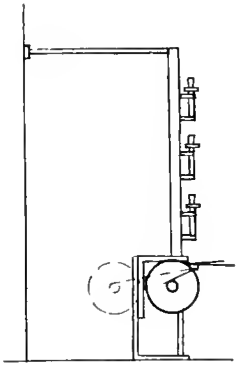

**Fig. 9.** Diagram showing Dimmer Located Between Bottom of Switchboard and the Floor. Operating Handles at Bottom of Switchboard

### Border-lights

Border-lights (Fig. 3, BL) should be suspended from the gridiron by steel cables in such a manner that they can be raised nearly to the gridiron or lowered to within a few feet of the floor according to the position of the scenery and effect desired. Strain insulators should always be used with steel supporting cables. A very good method of suspension, and one which conforms in every respect to the National Electric Code rule, is shown in Fig. 4. The border may be raised and lowered entirely by the manila ropes, while the steel cables, weight, and chains act as a counter-balance and will hold the border in place in case the ropes break. The method shown in Fig. 3 seems simpler, however, and is the one more generally used at the present time. The suspension cables are here carried across and fastened to a counter-weight which slides up and down the side wall in a

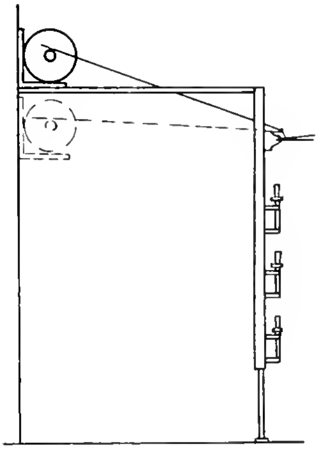

**Fig. 10.** Diagram showing Dimmer Located on Proscenium Wall. Operating Handles at Top of Switchboard

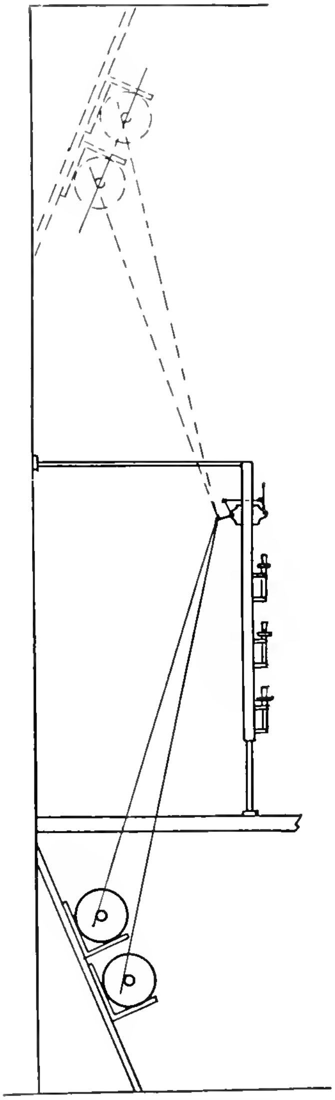

**Fig. 11.** Diagram showing Two Available Locations for Remote Controlled Dimmer, One Below the Floor, the Other Above on the Wall. Operating Handles at Top of Board in Either Case

"track." A manila rope is then used to run back to the pin rail and holds counter-weight and border in place. These are so nearly balanced that there is very little weight on this rope. A simple method of supporting the border-light without the expense of a counter-weight track is to run the three (or four) border lines over the loft and head blocks to a "curtain clew" from which is hung a counter-weight (sand bag) and a manila rope line is run from this to the pin rail. A border with two rows of lamps will weigh in the neighborhood of ten pounds per foot and the cable should be selected to give at least a 200 per cent factor of safety.

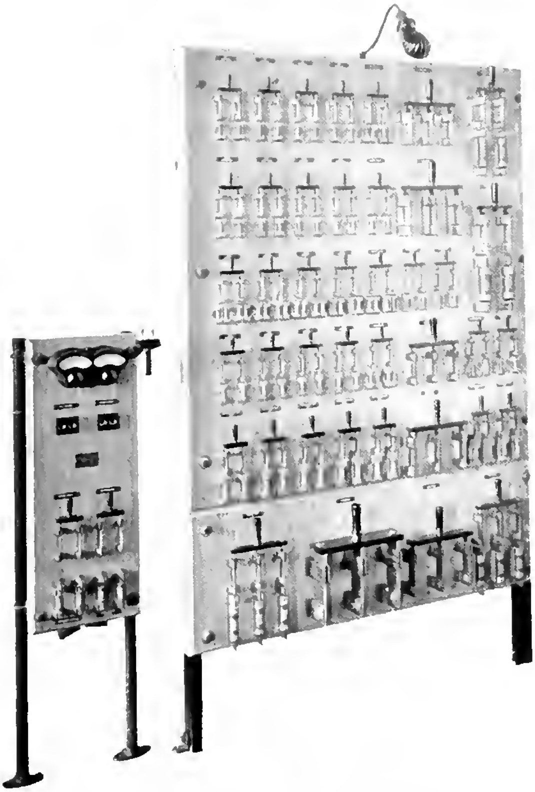

Fig. 12. Front View of a Live-front Stage Switchboard. Small Board at the Left Enables the Mercury Arc Rectifier to be Thrown Onto Either the Moving Picture Machine or Storage Battery for Emergency Lights

The number of borders and whether they are single or double row depends largely upon the size of the theater. In the average theater with a stage 30 to 40 feet deep and a proscenium opening of 30 feet three or four borders of double row construction, spaced 5.5 to 6 feet apart, should be used. In addition to the four borders it is advisable to use a concert border wired in two circuits each having 12 clear 32 c.p. lamps. This concert border (or ceiling strip, as it is sometimes called) is used with small interior sets and for rehearsals. When the interior of a room is shown on the stage, the scenery is often arranged so that it is impossible to lower the long borders, consequently a short ceiling strip is not only advantageous but necessary, especially in large theaters. A paint border is very often hung in the rear of the stage. This is near the paint bridge and is used by the artist in painting scenery.

The arrangement of white and colored lamps used in the footlight is generally followed in the border-light.

The border-light should be two feet longer than the proscenium opening. This does not apply to the first border which should be the same length as the footlight for the same reason.

The splicing boxes are often located on the ends of the borders nearest the switchboard. This arrangement makes it possible to reach readily either the cable or box from the fly galleries and saves a considerable amount of wire and conduit. Sometimes, however, the boxes are placed at the center of the borders in order to keep the cable from interfering with side sets. Inaccessibility is a disadvantage of this arrangement. The position is often determined by local requirements. If the splicing box is at the center of the border, the cable should be run in conduit from the magazine panel to a splicing box or gridiron interconnection box located in the gridiron. This box is used in some installations on account of the convenience of testing the border circuits afforded by an intermediate point between the border and switchboard fuse panel. It is often placed ten feet from the center towards the side of the stage on which the switchboard is located. The cable from this box should be of sufficient length that the border can be lowered to within a few feet of the stage floor. The slack cable is taken up by running it over an inverted U-cradle which is fastened to an extra border line, the latter being run through a sheave set in the gridiron approximately five feet off center. This rigging allows the cable to hang evenly and provides for the working of the cables and borders together. In some localities the requirements call for the cable to be continuous from magazine panel to border splicing box. In this case it is advisable to place pull boxes at suitable distances

(50 to 60 feet). These boxes often have three porcelain knobs so placed that the cable can be run over and between them in such a manner as to prevent its slipping in the conduit.

The most advantageous arrangement, however, seems to be as shown in Fig. 3. The splicing box is on the end of the border nearest the switchboard and the cable runs from here to a splicing box on the edge of the fly floor, being supported near the middle by the cradle. From this box the cable runs in iron conduit along the edge of the fly floor to the proscenium wall and then down to the magazine panel. This arrangement, while saving very little cable if any, removes the weight of all cable from the splicing box and places it on the supporting cradle and attached line. This has an important bearing in eliminating loose connections in the splicing box and is also a much more accessible position for the latter.

### Proscenium-lights and Portable Strip-lights

Proscenium-lights (one on each side of the proscenium opening) are used as an aid to the footlight and first border-light. They are generally of single row construction and are of a length of about one-half the height of the proscenium opening, the lower end being three feet above the stage floor.

Portable strip-lights are used for increasing the local intensity during a scene, and are always wired in one circuit for white lamps.

### Floor Pockets

Every play requires more or less portable lighting apparatus, and to facilitate its use there are, in the floor of the stage, pockets which are connected to the switchboard by means of the permanent theater wiring. The receptacles on the stage are installed on either side opposite the ends of the various borders, but from four to five feet back of the proscenium line towards the side wall. The pockets should, however, be at least three feet from the side wall as scenery is usually stacked against these walls. The Underwriters specify that "plugs for arc and incandescent pockets must not be interchangeable," and consequently it is advisable to install one single arc and one double incandescent pocket opposite each end of each border. Two double pockets should be installed about two feet from the rear wall near the center line.

### Wall Pockets

Wall pockets serve the same purpose as the floor pockets. There is usually one double pocket on each side of the stage mounted on the proscenium wall at a height convenient to the switchboard gallery (about 12 feet above stage floor). There should also be four single pockets on each spot-light bridge, two or three feet above the floor of the bridge. These are frequently mounted along the side wall although sometimes they are placed on the bridge rail.

### Company Service Switches

There are times when the floor and wall pockets are not sufficient to accommodate some certain production and then provision must be made for additional portable lighting units. This is done by using a portable plugging box, or "spider" as it is familiarly termed in stage parlance. If some provision is not made it is perfectly natural to connect the cables from this box directly to the busbars at the back of the board, which is not only a dangerous practice but is harmful to the equipment. This can be obviated by providing company service switches to which the "spider" may be attached. There should be one of these on each side of the proscenium wall at a convenient height from the floor (see Fig. 3, CS). Each should consist of a double-pole single-throw 200 ampere switch mounted on a panel and enclosed in a steel cabinet.

### Magazine Panel

The cables from the footlight, borders, pockets, etc., are brought back to the switchboard fuse panel, or "magazine panel" as it is often called. While all of the switches on the switchboard are fused, the fuse panel is necessary as each switch generally controls several circuits. For example, there is one switch controlling all of the white lights in the first border but, as the National Electric Code states that no set of lamps requiring more than 1320 watts shall be dependent upon one cutout (or fuse), it is necessary to divide the white lamps in the first border into several circuits, fusing each (see Fig. 5). Plug, link, or enclosed fuses may be used, depending upon the local requirements or the preference of the architect. The enclosed fuse can be easily and safely replaced in case of emergency and on this account is more practical from the operator's point of view.

The switchboard fuse panel should be mounted in close proximity to the switchboard, so that the operator or electrician can replace a blown fuse without leaving the vicinity of the board.

**Dimmers**

Dimmers are merely variable resistances which can be inserted in the various lamp circuits for the purpose of varying the intensity. Fig. 6 illustrates one of these. The resistances are usually embedded in soapstone or some kind of insulating compound which is formed in the shape of a disk. Leads are brought out to contact buttons on the surface of this material, and a rotating arm operated by the dimmer handle makes contact on these buttons thus inserting the proper amount of resistance in the lamp circuit. Fig. 5 shows the diagram of connections of a switch, a dimmer, two lamp circuits and their fuses in the switchboard fuse panel

The dimmers are usually mounted above or below the switchboard. Occasionally the

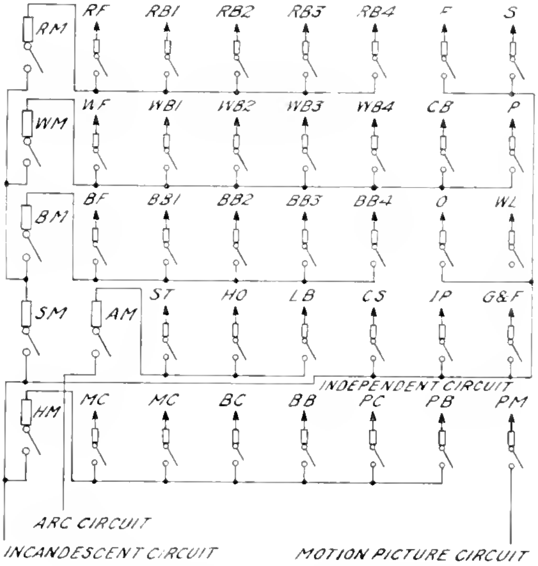

Fig. 13. Arrangement of Switches on a Three-color Switchboard. Master Switches at One Side

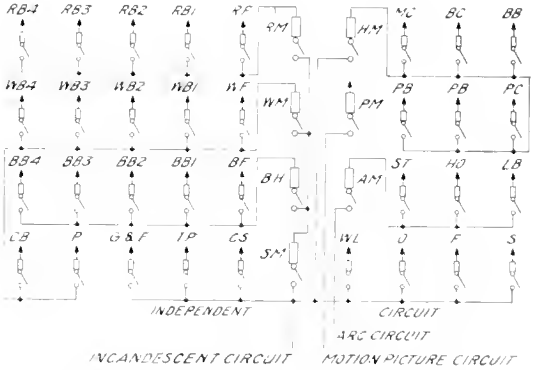

Fig. 14. Arrangement of Switches on a Three-color Switchboard. Master Switches in Center

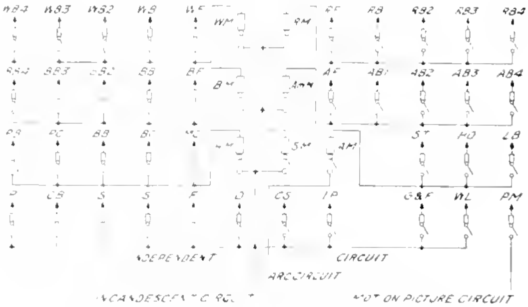

Fig. 15. Arrangement of Switches on a Four-color Switchboard. Master Switches in Center

### KEY TO FIGS. 13, 14 AND 15

### MAIN AND MASTER SWITCHES

SM —Stage Main or Incandescent Main.
AM —Arc Main.
HM —House Master
RM —Red Master
WM —White Master
BM —Blue Master
AmM—Amber Master
PM —Motion Picture Machine.

### SWITCHES CONTROLLED BY MAIN OR MASTER SWITCHES

RF —Red Foot
RB1 —Red Border No. 1
RB2 —Red Border No. 2
RB3 —Red Border No. 3
RB4 —Red Border No. 4
WF —White Footlight
WB1 —White Border No. 1
WB2 —White Border No. 2
WB3 —White Border No. 3
WB4 —White Border No. 4
BF —Blue Footlight
BB1 —Blue Border No. 1
BB2 —Blue Border No. 2
BB3 —Blue Border No. 3
BB4 —Blue Border No. 4
AF —Amber Footlight
AB1 —Amber Border No. 1
AB2 —Amber Border No. 2
AB3 —Amber Border No. 3
AB4 —Amber Border No. 4
ST —Stage Arcs
HO —House Arcs
LB —Lighting Bridge Arcs
P —Proscenium Lights
CB —Concert Border
MC —Main Ceiling
BC —Balcony Ceiling
BB —Balcony Brackets
PC —Parquet Ceiling
PB —Parquet Brackets

### SWITCHES ON INDEPENDENT CIRCUIT

CS —Company Switches
IP —Incandescent Pockets
G & F—Gridiron and Fly Floor
WL —Working Lights
O —Orchestra
F —Fans
S —Spares

dimmers are mounted on a separate panel at one side of the switchboard. This arrangement, however, has rarely been used except in cases where it was impossible to mount them above or below the board. Other arrangements which are sometimes used are shown in Figs. 7, 8, 9, 10, and 11. The dimmer handles are usually mounted in a row above or below the board, depending on the position of the dimmers. In some cases they have been alternated with the switch handles, but this is decidedly poor practice from the standpoint of construction and the majority of stage electricians prefer the segregation of dimmer and switch handles, so far as the operation is concerned.

### Switchboard

The switchboard (Fig. 3, SB) is the vital point of the theater lighting system as it is from here that control is exercised over all the lights of the theater. It is generally located parallel to the proscenium wall, and may be on either side of the stage. The National Electric Code requires 18 inches of clear space between the apparatus on the back of the board and the wall. More space is desirable. It seems to be better practice to mount the board in a switchboard gallery eight to ten feet above the stage floor as this prevents any accidental contact with the board on the part of players or others.

The majority of theater switchboards are made of black slate approximately 72 inches high and of width suitable to accommodate the switches. If the dimmers are mounted beneath the board its top will be somewhat more than 72 inches from the floor. The board is mounted on pipe or angle iron supports, and its bottom should be at least ten inches from the floor.

Switchboards are classified into "live front" and "dead front" types depending upon the position of the switches. Fig. 12 illustrates a live-front board. In the live-front type the switches are located on the front of the board with the fuses in conjunction with the switch clips. In the dead-front type the switches and fuses are mounted in the rear of the main switchboard panel with only the operating mechanism on the face of the board. A "quick make and break mechanism" should be specified with this type of board, otherwise the switch may be held in an arcing position for some time without the operator knowing it.

Almost every conceivable arrangement of switches can be found on existing boards. It seems advisable to group the switches in accordance with their respective functions and in a manner most convenient to the operator, particular attention being given to the symmetry of the layout. Figs. 13, 14 and 15 show ideal arrangements suitable for any theater. When three colors of lamps are used and the master switches are desired along one side of the board, the grouping in Fig. 13 has been used to advantage. This is for a board on the right-hand side of the stage and for one on the left-hand side the arrangement should be reversed in order to bring the master switches nearest the stage. Fig. 14 shows a three-color arrangement with the master switches in the center of the board, and Fig. 15 a similar scheme for four colors. The question of placing the master switches at the side or in the center of the board is one of preference on the part of the operator. The foot and border-light switches, being the ones most often used, are given the preference in laying out a board, and the switches controlling the arc, independent, and house circuits, are then placed in the most consistent manner. The above arrangements followed as closely as possible seem to produce the most successful results.

### Panelboards and Cabinets

Panelboards are located in various parts of the theater for controlling certain sections of the theater lighting. In the majority of theaters a panelboard is located in the box office for controlling all the emergency lights and for the miscellaneous lighting in the front of the theater, such as lounging rooms, smoking rooms, etc. Many theaters constructed recently have offices in the same building, and numerous panelboards are required for the various lighting circuits but this has nothing to do with the theater proper.

### Picture Machine Outlet

Whenever picture-machine booths are installed a picture machine outlet is necessary. This is simply a panel on which is mounted a set of main busbars with main lugs and generally two 100-ampere fused branch switches, the panel being enclosed in a steel cabinet. It is strongly recommended that this be connected to the independent service as the picture machine can then be started in case of any accident to the regular service and the audience thus kept in ignorance of any irregularity and perhaps a panic averted.

### Plugging Cabinets

Plugging cabinets are often installed in the gallery where lens or spot-lamps are used and have as many outlets as the maximum number of lens lamps which will be used at the same time. The capacity should never be less than six arc lamps on account of the wiring, although a four-way plug box is generally sufficient. The receptacles should be similar to those used in the regular floor or wall pockets. The cabinets should conform in construction to the standard panelboard cabinet.

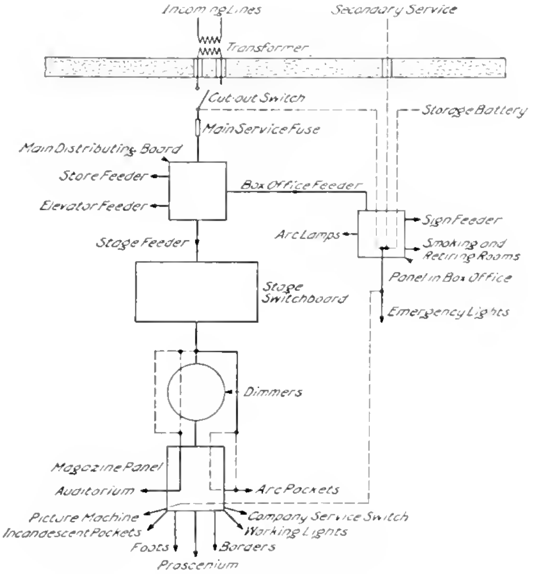

Fig. 16. Complete One-line Diagram of the Lighting Circuits in a Theater

### Service Panel

The service panel is usually located in the basement of the theater and the main incoming lines are brought directly to the fused side of a main switch, the meter loops being provided inside this switch. In the average theater there are two branch circuits from this panel, one to the stage switchboard and the other to the box office panel.

### Control of Theater Lights

Fig. 16 is a one-line diagram giving a general idea of the layout of the various lighting circuits of a theater and the location of the controlling devices. The service is generally brought in at the rear from the secondary of a transformer located on the outside of the building or on an adjacent pole. It then passes through the cutout switch and main service fuse to the main distributing board where it divides, one feeder going to the stage switchboard and the other to the box office. As shown in Fig. 16 the auditorium lighting circuit may be arranged to pass through or around the dimmers as preferred. Also the stage arc light circuit may or may not pass through the magazine panel.

The Board of Underwriters require the installation of a second service, that it may be available to keep the emergency lights burning should some accident cause the blowing of the main service fuse. This second service may take the form of secondary service, a reserve storage battery, or a tap on the main feeder located outside of the main service fuse. All of these circuits are shown in Fig. 16 as dotted lines entering the box office. Local conditions determine which of these schemes will be used. The storage battery is of course to be preferred from the standpoint of safety (although more expensive than either of the other schemes) for the reason that it will furnish light even in the extreme case of the failure of all external power supply. The source used for charging the storage battery is a rectifier, which may be used at any other time for supplying the moving picture machine.

Good practice to-day strongly recommends that the moving picture machine, which is ordinarily supplied from the main switchboard, be fed from the same source as the emergency lights. Then, in case the main service fuse is blown, throwing out all the lights in the theater (except the emergency lights), the picture curtain can be lowered and the audience kept in ignorance of any irregularity and thus a possible panic averted. In the intermission thus gained the trouble can be removed and the interrupted performance continued, thus avoiding the creating of dissatisfaction among the ticket holders.

# NOTES ON INVISIBLE LIGHT

By Dr. W. R. Whitney

Director of the Research Laboratory, General Electric Company

Dr. Whitney prepared these brief notes on invisible light to answer a few of the most frequently asked questions about the radiations given by X-ray tubes and radio-active material. Some of the more important characteristics of the electron are cited and its behavior in different media is stated briefly. The similarity and difference between the emissions from radium and X-ray are touched upon. We hope to publish a longer article dealing more fully with this subject in the near future.—Editor.

The object of these notes is to cover very briefly some of the points of interest in modern electrical theory, particularly with reference to such radiations as are given by X-ray tubes or radioactive material. It may help to review the conceptions of atoms, electrons and ether waves, for the subject is intimately connected with the constitution of matter and of electricity. Formerly the chemical atom was considered the ultimate indivisible particle. While this still has a significance for positively charged matter, another single and much smaller mass has been discovered in the electron. This consists of a negative electrical charge which is always the same in magnitude and to which a mass is attributed of about one eighteen-hundredth that of the hydrogen atom. This magnitude, the sign of the charge, its velocity, etc., have been determined from measurements of the effects of electrostatic and magnetic fields upon it. It is to the motion of these negative charges or electrons through metals that we attribute the flow of current. More is known about their flow across various spaces and within gases than elsewhere. They move with velocities varying with the potential gradient through which they fall. In such places as so-called "hard" X-ray tubes the velocity of the electrons is already known to exceed half that of light. The electrons are capable of passing through thin aluminum foil and even when this is earthed they emerge with their original charges. Material is in general, however, opaque to these electrons.

There seems to be no positive electrons corresponding exactly to the negative ones. The smallest positively charged masses yet known are the atoms of elements from which the negative electrons have escaped. These heavy positively charged particles of matter are well known and they act about as one would expect. They move in electrostatic fields with a velocity much lower and in the opposite direction to the negative. Ponderable matter of the atoms accompany them or constitute them. They do not pass through ordinary matter and are easily filtered out of gases.

Thus we see a differentiation of great importance which we express by saying that electricity exists in ultimate units which are negative charges. Their inertia, i.e., the property which by definition determines mass, make them out to be much smaller than any other particles of which we know.

When these moving negative electrons are stopped by contact with material, then X-rays are set up. It is believed that these light waves are set up by the impact of the electrons on the atoms of matter. These are exceedingly short waves in the ether, otherwise very like light waves. They possess greater penetrability, however, but also affect photographic plates.

These three things, positively charged atoms, negative electrons, and ether waves, are common to radium also; so while no attempt is being made here to cover entirely the properties of either, or the similarity or differences between radium and an X-ray tube, the following rough statements may be of help.

There are three kinds of emissions from radium, viz., alpha, beta and gamma rays. The positively charged atoms of matter from radium are the alpha rays. In the vacuum tube these correspond to the so-called canal rays and were discovered by studying the rays which passed through holes in the cathodes into the space behind the cathode. This is what we would expect if there were any such positively charged particles in a discharge tube.

The negative electrons of radium constitute beta rays and have been well studied. They correspond to the electrons which are shot off from the cathode in an X-ray tube. By their impact upon the anti-cathode or target, the X-rays are produced. Similarly the impact of the beta rays of radium are apparently the cause of the gamma rays of radium, as it is known that the impact of beta rays on solids produces gamma rays. These correspond to the X-rays. Both the gamma rays and the X-rays are ether vibrations of high penetrating power. Their velocity is in each case that of light. It is true that the penetrating power of the gamma rays is greater than that of the ordinary X-rays; but X-rays are of widely different penetrating power, though of the same velocity. The penetrative power should now be under control as it depends on the voltage across the X-ray tube. The hardness of an X-ray tube corresponds to the electromotive force necessary to produce and maintain the current of negative electrons through it, so that if this is made greater the hardness is raised. The greater the hardness the more penetrating are the X-rays produced. Evidently then the application of higher voltages to suitable X-ray tubes should give continually increasing penetrating power of the rays.

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# FEEDER REACTANCES

By F. C. Barton

Lighting Engineering Department, General Electric Company

The introduction of the following article presents those reasons which show that feeder reactances should be included in many station equipments to assure the furnishing of an uninterrupted and high-quality service. Their purpose and consequently their advantages, having been covered thus in a general way, the remainder of the article is devoted to a detailed discussion of their disadvantages. These it shows are of a far less serious nature than has been often supposed.—Editor.

Articles on reactances which have appeared in former numbers of the Review have dealt chiefly with those for generators and busses. This type of reactance is certainly a very valuable, in fact, almost a necessary adjunct to the large central station in which the inherent reactance of the generators is comparatively low or in which the total kv-a. generated is very high. At the present date, however, practically all large 60-cycle generators are built with sufficiently high inherent reactance to limit the current on short circuit to not more than ten times normal. In these cases the need for the external generator reactance disappears except for the protection of the generator in case of an internal short circuit, and the need for the bus reactance is diminished, but the demand for a device which will protect the station against the effect of a short circuit on a feeder becomes if anything more pronounced, as where the generators have high inherent reactance it is essential that the currents due to short circuit be held as low as they can be efficiently, because of the effect of such heavy currents on the generator voltage regulation.

The merits of feeder reactances as a step toward that continuous service for which all central station companies are striving are rapidly becoming appreciated, and in modern central stations the practice of installing these protective reactances in feeder circuits is becoming a recognized necessity. Feeder reactances as a contributing factor toward continuity of service fully justify the space they occupy, the losses which they entail, and their cost, for not only do they protect the system of which they are a part from shutdowns due to short circuits in the feeders, but, also, they limit the short circuit current to a point where switching on the short circuited feeder ceases to be a menace. They possess certain disadvantages, which, however, are not as serious as they appear at first sight and which are usually magnified beyond their true proportions. These are:

First. The space required for their installation. Where the reactances are to be installed in the station already built, this is apt to present a rather serious problem; however, if the maximum space available for the installation of reactances is known, it is in most cases possible to design coils which will accommodate themselves to local conditions. The most efficient coil, and also the most economical from a manufacturing standpoint, is one whose diameter is fairly large in relation to its height, but where space limitations prohibit the use of such a coil there remains the alternative of accepting a coil of very slightly lower efficiency and possibly slightly increased price, which will fulfill the space requirements. A three-phase feeder naturally requires three single-phase reactances. These may be installed in any of three general methods, as best suited to the conditions, viz., in the form of a triangle the coils having vertical axes, in a row of coils side by side with the axes vertical, or with coils mounted one above the other with a single common vertical axis. Regardless of which method of mounting is adopted, it is advisable to install the groups of coils in cells or compartments similar in general to the compartments commonly provided for oil switches. Consideration must be given in the layout of such cells or compartments to the dissipation of heat resulting from the energy losses, dealt with later, in the coils. To take care of this heat adequate ventilating facilities must be provided.

Second. The effect on line voltage regulation. The rating of a reactance is based on its apparent watts or kv-a., for example: a single-phase reactance having a rating of 50 kv-a. would have approximately 191 volts drop across its terminals in a circuit carrying 262 amperes, or 3 per cent reactive drop in a 6350 volt circuit of 262 amperes, 6350 volts being the phase to neutral voltage of an 11,000 volt three-phase circuit. This voltage drop is at quadrature with the impressed e.m.f., therefore, the station voltage to overcome the reactive drop will be the $\sqrt{6350^2+191^2}$ or 6352.8 volts, or a rise of 2.8 volts. Expressed in terms of a three-phase circuit of 11,000 volts, the station voltage will have to be raised 4.4 volts to overcome the reactive drop produced by a 3 per cent reactance. The effect of reactances on the regulation of circuits carrying lagging currents is much more pronounced than when carrying current at unity power-factor, as that portion of the total current comprising the wattless component produces a reactive drop or counter e.m.f. which is at right angles to the wattless current or directly opposing the impressed e.m.f. In other words, the drop or counter e.m.f. of the reactance due to the energy current is 90 degrees behind the impressed e.m.f. The resultant station voltage necessary to overcome the effect of the reactance on the regulation being represented by the hypothenuse of a right-angle triangle, the sides of which are the line voltage and the reactance counter e.m.f. whereas the drop or counter e.m.f. due to the wattless component of a current of less than unity power-factor is 90 degrees behind that current or 180 degrees behind the impressed e.m.f., the resultant station voltage necessary to maintain constant line voltage being the straight addition of the drop due to the wattless current and the impressed e.m.f. The problem may be most simply expressed by saying that the voltage drop due to a feeder reactance is at quadrature with the line current, this line current being the resultant of the energy and wattless components, for example: in a circuit carrying power at 70 per cent p-f., the current will be lagging behind the impressed e.m.f. approximately 45 degrees, making a wattless component equal to the energy component. This will produce a drop in phase with the impressed e.m.f. equal to the drop at quadrature with the impressed e.m.f., or a resultant drop of 45 degrees behind the impressed e.m.f. This will be 90 degrees behind the resultant or actual line current. The relations of the various voltages affecting the line regulation and the resulting generator voltages are shown in Fig. 1 in which

$I$ equals actual current.
$I_e$ equals energy component.
$I_w$ equals wattless component.
$E_L$ equals line volts.
$E_{xe}$ equals reactive volts drop due to $I_e$ flowing over the reactance.
$E_{xw}$ equals reactive volts drop due to $I_w$ flowing over the reactance.
$E_x$ equals resultant voltage drop at quadrature with $I$.
$E_g$ equals station voltage.

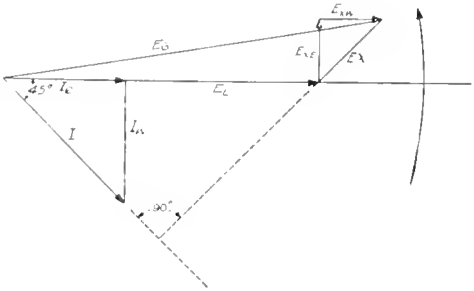

Fig. 1. Vector Diagram of the Voltage and Current Relations as Influenced by the Line, Generator and Reactance Coil

In the foregoing the drop due to resistance is ignored as this quantity is almost negligible.

Third. The energy loss due to resistance and to eddy currents in the copper conductors comprising the coils. These losses vary as the square of the kv-a. transmitted through the reactance, or in the case of the 50 kv-a. referred to above, represent about 2 to 3 kw. per coil when the feeder is carrying 5000 kv-a. or full load. This is equivalent to 0.18 of 1 per cent.

The reactance described, viz., one which produces 3 per cent reactive drop in a 5000 kv-a. feeder operating at 11,000 volts three-phase, will limit the current in a short circuit to 33.3 times normal or 8724 amp. This amount of current represents sufficiently high kv-a. to cause serious disturbances in any but the large systems. Reactances of 5 to 10 per cent are generally recommended for feeders. Such a low value as 3 per cent would be used only in large capacity stations where the ratio of generator capacity to feeder capacity is very large or in conjunction with generator and bus reactances in smaller capacity stations, or when a mixed load of low power-factor makes the voltage regulation of importance.

The preceding paragraph leads to points which must be given consideration when contemplating the installation of feeder reactances. The function of feeder reactances differs from that of generator reactances in that the generator reactances are intended to limit the instantaneous rush of current from a generator on short circuit to a point which will protect it from mechanical injury due to magnetic strains, and also protect the station apparatus and switches in the event of a short circuit occurring inside the station. This current, for the first few cycles following a short circuit, may reach as high as ten times normal in a generator having 10 per cent inherent reactance. If the inherent reactance is but 5 per cent the current may reach a maximum of twenty times normal, which might set up sufficient mechanical strains to destroy the generator windings, or, in the event of several generators feeding a bus which is short-circuited, might produce strains sufficient to destroy the bus structure. After the first few cycles the short circuit current will fall due to generator reaction to from 2 to 4 times normal. With the feeder reactance the impressed potential is maintained and the reactance must be such as to limit the current in a short circuited feeder to a point where it will not produce undue disturbances in the generating station. In other words, it must limit the current to such a point that the station will carry the short-circuited feeder until it is cut off the system without interfering with other feeders or causing the synchronous apparatus in the station and on other feeders to drop out of step. From the foregoing it will be seen that the per cent reactance which is placed in feeder circuits is governed chiefly by the capacity of the generating station to which the feeder is connected, and it must be high enough to prevent excessive voltage drop in the station due to short circuit, but should not be much higher than this point because of the effect as already outlined, upon space requirements, line regulation and energy loss, all of which increase as the per cent reactance or kv-a. capacity of the coil increases.

A secondary function of feeder reactances is to protect the feeder oil switches from the effects of extremely high currents resulting from short circuits. As modern oil switches may be considered as having a rupturing capacity limit of about 500,000 kv-a., it will be seen from this that a reactance of 1 per cent in the 5000 kv-a. feeder previously referred to would limit the short circuit to 500,000 kv-a. or a value sufficient to protect the oil switch against possible injury; therefore, with the 3 per cent reactance, selected for illustration, the kv-a. on short circuits would be limited to approximately 166,000 which gives a large safety factor insuring positive and safe action.

A feeder in some cases may be used as a tie line between generating stations. Tie line reactances perform the same function as bus section reactances, and will usually have a magnitude intermediate between feeder and bus reactances, as the ohmic resistance of the tie line is available, in quadrature with the reactance, to limit the current transferred. The protection of a system will usually be best obtained by a combination of generator bus and feeder reactances.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## HIGH FREQUENCY MEASUREMENTS

A method has been developed for making energy measurements at high frequency and high voltage, and the apparatus employed involves the use of only hot-wire ammeters and voltmeters. The energy measurements are made by a process of tuning, whereby the wattless components are eliminated so that the energy is represented by the product of the volts and amperes that are measured. In this way, energy measurements have been made as high as 100,000 volts and 100,000 cycles and, in insulation materials, as low as a few watts can be measured at potentials of 20,000 to 30,000 volts. Though the voltages applied to the sample are high, the energy measurements are made at the low-tension end of the oscillation transformer and at voltages within the range of the ordinary hot-wire voltmeter.

It is expected that this measuring apparatus, in combination with the high-frequency alternator, will contribute valuable knowledge of insulation material under high-tension. The results obtained with measurements at high frequency are in many cases startling. Insulators break down at voltages much lower than those for which they are designed and at which they are used at ordinary frequency. Arc-overs occur in air over distances which for ordinary purposes are considered to have an ample margin of safety. For instance, a static voltmeter calibrated for use at 50,000 volts arcs over between the plates at 30,000 volts with 100,000 cycles. Destructive corona discharge appears under circumstances which ordinarily would be no source of trouble. At first there seemed ground to believe that totally different laws apply for dielectric strength at high frequency, but further investigations have shown that the apparent departures are due to secondary phenomena accompanying the high-frequency field. The principal cause is heat generated by dielectric hysteresis and corona. An ordinary insulator breaks down on account of the heat of the corona discharge at the edges of the metallic terminal, and the arc-over in air over long distances is due to corona discharge reaching out in streamers until the whole gap is bridged. Evidently the greater heating of the brush discharge enables it to maintain its conductivity over longer distances, though there is a variety of evidence that indicates that the dielectric strength of air, as well as insulating materials, is substantially the same at high frequency.

It is very difficult to establish a condition under which this can be demonstrated. In order to test insulators at high dielectric strain, they must be immersed in oil to avoid corona at the terminals and even then the heating due to dielectric hysteresis is so great that the insulator is apt to break down before the dielectric strength of the material is reached. Dielectric strength of air was measured between polished spheres of 5 inch diameter and it was found that a gap of 3 inches breaks down at 100,000 volts, which is practically the same as the values found with low frequency. On the other hand, the gap between the two plates 5 inches apart breaks down at 30,000 volts.

Measurements of corona loss at 100,000 cycles have been made and the results agree with the law of corona derived in the investigations of F. W. Peek, Jr. A corona loss of $\frac{1}{2}$ kilowatt at 30,000 volts was found on two wires 0.01 inch in diameter and 40 inches long.

A series of investigations are in progress to measure the dielectric losses and breakdown strength of various insulation materials, as well as parts of finished apparatus.

E.F.W.A.

## QUESTION AND ANSWER SECTION

The purpose of this department of the REVIEW is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the REVIEW.

Second, it publishes for the benefit of all REVIEW readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting subject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

### ALTERNATOR ARMATURE RECONNECTIONS

**(92) Given an a-c. generator, 1000 kv-a., 2300 volts, three-phase, 60 cycles, 80 poles, 720 slots, armature Y-connected, to reconnect it so as to give the same output at 440 volts, which of the two following methods would be the more practical in regard to its regulation of a load having a power-factor of 0.85: first, to connect the armature in triple parallel △ since there are 240 coils per phase $\frac{2300}{3 \times 1.73} = 440$ or, second, to parallel the three coils per pole per phase and connect the armature △? If this same generator had only 480 slots, that is, only two slots per pole per phase instead of three, what would be the most feasible way of changing its terminal e.m.f. from 2300 to 440 volts?**

It is doubtful if either of the methods suggested for reconnecting the generator for operation at 440 volts would be satisfactory. In the first case, a three-circuit connection on an 80-pole machine is not a very simple matter to accomplish and obtain a properly balanced winding between the three phases of the machine. The other method of connection would result in a heavy circulating current between the three circuits, since the three slots per phase under each pole are 30 electrical degrees out of phase with one another. To make a proper connection and obtain a balanced winding, the machine should be connected Y five circuits per phase for 440 volts, if it is now Y one circuit per phase for 2300 volts. The actual potential obtained with the same field excitation would be 460 volts, but the slight difference would not affect the operation of machine materially. The connection should be made in the same way whether the machine had two or three slots per pole per phase.

T.S.E.

### INDUCTION MOTOR CHARACTERISTICS AT HALF VOLTAGE

**(93) What are the characteristics of an induction motor when running on one-half normal voltage?**

Since the breakdown horse power of an induction motor varies as the square of the applied voltage, the breakdown point with only 50 per cent voltage will be but one-fourth as great. The average motor is designed with a maximum horse-power output of from 2 to $2\frac{1}{2}$ times the normal rating, and to keep this same factor of safety on half voltage the rating would be reduced to one-quarter that of normal.

The starting torque with a squirrel-cage or short-circuited rotor also varies as the square of the voltage, and, in some cases where the static friction is great, the one-fourth torque resulting from the half voltage may be only sufficient to start the machine, therefore allowing no load to be applied at this period.

The efficiency at one-fourth horse power and one-half voltage will be lower than that at normal rating by from 5 to 10 per cent. The friction is the primary factor in thus lowering the efficiency. Since the friction loss is of a constant value, its percentage loss at one-quarter the horse-power rating will be four times that at normal rating. The core loss varies as the 1.6 power of the voltage, which will reduce the core loss watts at one-fourth the horse-power rating to about one-third that at normal. This will therefore give at one-fourth normal load a higher percentage core loss than at normal rated load. With one-half the line voltage at one-quarter the horse-power rating, the line current would be expected to be one-half of normal. Then the percentage copper loss which is $\frac{IR}{E}$ would be the same as at normal. It slightly exceeds this, however, due to a lower apparent efficiency (eff. × p-f.). Therefore, all tendencies are for lower efficiency.

Since the per cent slip varies as the rotor copper loss, the slip at one-half voltage and one-quarter horse-power rating will be slightly greater than the normal full-load slip.

The power-factor is dependent upon the reactance and magnetizing current. With the motor operating at one-half voltage, the percentage reactance will be slightly greater than normal and the percentage magnetizing current will be less. Therefore, the resulting power-factor will be about equal to normal full-load power-factor.

The heating under the condition given will amount to less than one-half load under normal voltage, since the current is one-half normal and the excitation losses less than one-half. However, on a heating basis it will be possible with a 50 per cent drop in voltage to operate the motor up to nearly one-half the normal horse-power rating. The efficiency and speed, however, will fall rapidly, but the power-factor will keep up until the breakdown point is reached, when it will drop off rapidly.

These statements only apply in general, and there may be a variation from them on large and high-torque motors.

C.B.H.

### OIL SWITCH: CONNECTIONS OF CIRCUIT-OPENING EQUIPMENT

**(94) Various methods have been used for connecting the series transformers, relays, and trip coil of an oil switch in order to make it open the line circuit when the load on the line becomes excessive. Direct or alternating current is employed for energizing the trip coil. Please explain the actions which take place when using alternating current for tripping in each type of auxiliary circuit as the result of a single-phase and a three-phase short circuit on the line; also discuss the merits of the different connections.**

There are, it is true, a number of different methods of connecting the tripping device of an oil switch which opens on overload, but only a very few of these afford complete protection. There are several which have been tried with more or less success, and there are others that have been proposed but which have never been adopted because of practical difficulties of application or because of theoretical faults. The following discussion will take up the connections which seem to be most worthy of consideration.

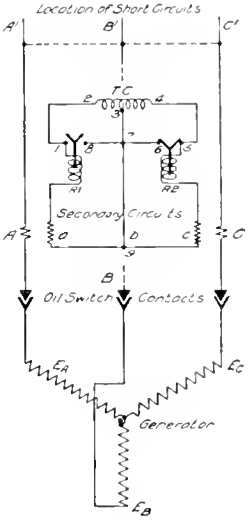

Fig. 1

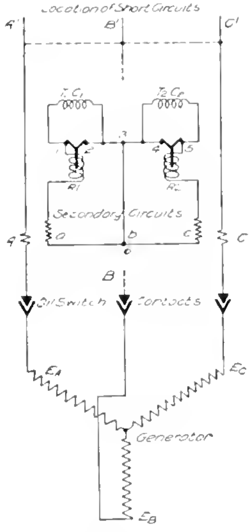

Fig 2

### First Method

The arrangement which at first sight would seem to be the simplest that could be applied is illustrated in Fig. 1. Here the relays are shown closed which is their position during normal operation. In this, and in all the following diagrams, the letters *A*, *B* and *C* will be used to represent the high-tension lines of which *A* and *C* act as the primaries of the series transformers; *a* and *c* the corresponding secondaries of these transformers and *b* the middle secondary wire; $R_1$ and $R_2$ the circuit-opening relays; and *TC* the trip coil when only one coil is used and $T_1C_1$ and $T_2C_2$ the coils when two are used.

This method of connection will fulfill the requirements perfectly in the case of any single-phase short circuit on the line. For instance, in the event of a short circuit at *A'-B'*, the heavy current flowing in *A* and *B* will induce a correspondingly excessive current in *a*, the secondary of the affected series transformer. This current passing through the circuit *a-$R_1$-1-7-6-8-a*, which is the one of lowest resistance and reactance open to it, will cause the solenoid of relay $R_1$ to lift, thus opening that circuit. This action of the relay now forces the entire current to flow through the trip coil *TC*, the circuit being *a-$R_1$-1-2-TC-3-4-5-6-8-a*. The trip coil now being energized opens the oil switch. A short circuit across *B'-C'* would act in a manner corresponding to the one across *A' B'*.

If the short circuit had been across *A' C'*, both relay solenoids would have gone up on account of the heavy current sent through them by the secondary coils *a* and *c* of their respective series transformers. These two secondaries then acting in series will force their entire current through the trip coil *TC*, using the circuit *a-$R_1$-1-2-TC-3-4-$R_2$-c-8-a*. The oil switch is then of course opened by reason of this current through *TC*.

The fault of this method of connections, however, is in the operation of the series transformers under the condition of a three-phase short circuit on the line, i.e., across *A'-B'-C'*.

At this point it will be well to note that the effect on the series transformer secondaries by a single-phase short circuit across *A'-C'*, is by no means the same as that caused by the three-phase short circuit across *A'-B'-C'*.

The difference lies in the phase relation of the currents induced in the secondaries *a* and *c*.

In the case of the single-phase short circuit at *A'-C'*, the voltages $E_A$ and $E_C$ impressed on this single primary circuit combine into a single-phase voltage $E_{A+C}$, which causes a single-phase current $I_{A+C}$ to flow around that circuit, *A-A'-C'-C*. This being the current that flows in the primaries of both series transformers, the e.m.f.'s induced in the secondaries *a* and *c* are in phase and therefore add together directly to cause a single-phase current to flow through the relays and trip coil. Under these conditions, no apparatus is unduly stressed.

When a three-phase short circuit takes place at *A'-B'-C'*, however, the e.m.f.'s $E_A$ and $E_C$ cannot combine to form the single phase e.m.f. $E_{A+C}$ as before, to apply to the circuit *A-A'-C'-C*, for they are maintained individually in their normal relation of 120 degrees apart. This is the result of the short circuit being three-phase, which holds all three primary e.m.f.'s $E_A$, $E_B$ and $E_C$ symmetrically 120 degrees apart.

As a consequence of the primary e.m.f. in *A* being 120 degrees displaced from that in *C*, the induced e.m.f. in *a* is 120 degrees displaced from that in *c*. Therefore, the secondary e.m.f.'s not being in phase, they can never unite to produce a single-phase current in that circuit without a stress at some point.

Previous to the opening of the relays no trouble is experienced, for the two 120-degree-displaced currents of the secondaries flow in independent circuits, viz., *a-$R_1$-1-7-6-8-a* and *c-$R_2$-4-5-6-8-c*. At the moment the relays open, however, the two secondaries of the transformers are restricted to the single circuit *a-$R_1$-1-2-TC-3-4-$R_2$-c-8-a*.

The primaries being 120 degrees apart, whereas the corresponding secondaries form a single-phase circuit, electrically forces the secondaries 30 degrees away from the primaries. The maintaining of this condition, even though it is but momentary, places the series transformers under excessive magnetic strain, since magnetism alone is the connecting link between the primary and secondary circuit.

This excessive magnetic stress on the cores of the series transformers is apt to seriously change their magnetic characteristics and the ratio of the transformers, which will render further operation unsatisfactory. This detrimental action is especially dangerous if high-accuracy instruments and meters are connected to these transformers in addition to the relays.

### Second Method

It has been proposed to overcome the bad features of the first method by using two separate trip coils as shown in Fig. 2. In this case the secondary of each series transformer acts independently of the other upon its own relay and trip coil. When a short circuit occurs across $A'$-$B'$, the secondary $a$, the relay $R_1$, and the trip coil $T_1C_1$ unite in their action to open the switch; in the case of a short circuit across $B'$-$C'$, the corresponding elements $c$, $R_2$ and $T_2C_2$ open the switch; and if a short circuit takes place across $A'$-$C'$, both sides of the secondary circuit act in unison, as in the First Method, to release the latch of the switch. For single-phase short circuits, then, the operation is satisfactory and it remains but to examine the action taking place when a three-phase short circuit takes place.

In the case of the three-phase short circuit, i.e., across $A'$-$B'$-$C'$, the same primary conditions as described in the First Method are, of course, produced. That is, the e.m.f.'s in $A$ and $C$ are 120 degrees apart. Until the relays open, the resulting 120-degree-displaced secondary currents flow independently in their separate relay circuits $a$-$R_1$-$1$-$2$-$3$-$6$-$a$ and $c$-$R_2$-$5$-$4$-$3$-$6$-$c$. Since each series transformer has its own trip coil, their secondaries are not restricted to a single circuit when the relays open. Their two individual circuits are preserved. Therefore, the two separate single-phase currents, one from each secondary, still flow independently of each other, a condition which eliminates the objection found in the first method.

This scheme of connections, therefore, is thoroughly satisfactory so far as its theory of operation is concerned, for it operates as intended in the case of short circuits on any or all the phases. It has not been adopted, however, on account of the cost involved in using two trip coils instead of only one and because of the difficulty of mounting the additional coil in the limited space available on the oil switch.

### Third Method

It might be thought that the objection to the two-coil arrangement could be overcome by the use of a single trip coil having a tap in the center of its winding as shown in Fig. 3. This method does give satisfactory operation when a three-phase short circuit occurs across all the lines or a single-phase short circuit across $A'$-$C'$, for under this condition the tapped coil acts as do the two coils in the Second Method. But, it will not furnish reliable service in the event of a single-phase short circuit either across $A'$-$B'$ or $B'$-$C'$. For example, assume the lines $A$ and $B$ tied together. The excessive current induced in $a$ raises the relay $R_1$, in which position it is shown in Fig. 3. The left-hand half of $TC$, i.e., $2$-$3$, then carries the total current from the secondary $a$. The resulting pull of this half of the trip coil, however, may be insufficient to operate the latch of the oil switch because of the dampening action of the right-hand side, $3$-$4$, of the same coil. Since the two halves of this coil are mounted on the same core, they are linked together magnetically and bear the same relation to each other as the primary and secondary of a transformer. Thus, the current flowing in section $2$-$3$ induces an e.m.f. in section $3$-$4$. This e.m.f. applied to the low resistance and low reactance circuit $4$-$5$-$6$-$7$-$3$, causes a heavy current flow in that circuit. (The action is the same as that of a short-circuited secondary of a transformer.) This current flow partially demagnetizes the core of the trip coil $TC$ and therefore the effective pull of the active section of that coil, i.e., $2$-$3$, is materially reduced. The service rendered by the trip coil in opening the switch is therefore unreliable. The actions taking place in the case of a short circuit across $B'$-$C'$ are similar to those just described.

This feature of unreliable service prohibits the use of this method of connections.

### Fourth Method

In order to secure a construction in which the preceding difficulties would be avoided and which, at the same time, would be sufficiently inexpensive to warrant its adoption, another arrangement has been developed. This is shown in Fig. 4 in diagrammatic form for the sake of clearness. There is but one trip coil and it has a center tap as was used in the Third Method. This construction differs from that of the preceding in the fact that the operation of either or both relays open but one contact, that being $5$-$7$-$6$. This is accomplished by a mechanism of toggle-joints and levers.

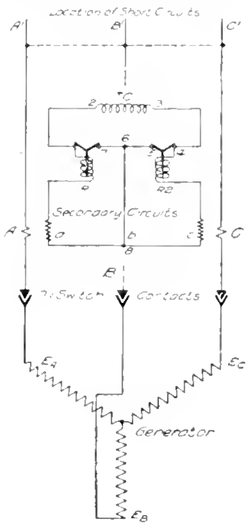

Fig. 3

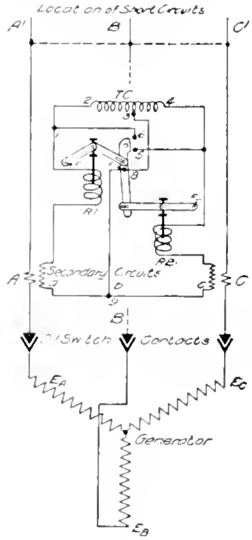

Fig. 4

The only fixed points of the lever system are $F$, and the action of either or both of these relays in opening the contact $5$-$7$-$6$ opens the short circuit around the trip coil.

In the event of a single-phase short circuit between $A'$-$B'$, the relay $R_1$ breaks the links above it upward and opens the contact $5$-$7$-$6$, as shown in Fig. 4. The oil switch is then tripped by the action of the current flowing in the circuit $a$-$R_1$-$1$-$2$-$TC$-$3$-$8$-$9$-$a$. There is no dampening action by the remaining part of the trip coil $3$-$4$, as occurred in the Third Method which also used a tapped trip coil, for this remaining section is not short circuited by a low resistance and therefore cannot act as the short-circuited secondary of a transformer. A short circuit across $B'$-$C'$ has the correspondingly same effect.

A short circuit across $A'$-$C'$ causes the entire trip coil to be used, the single-phase current induced flowing in the circuit $a$-$R_1$-$1$-$2$-$TC$-$4$-$R_2$-$c$-$9$-$a$.

After the relays have operated under the effect of a three-phase short circuit across $A'$-$B'$-$C'$, the conditions existing in the secondary circuit are exactly the same as for the same circumstance in the Third Method and therefore this method is of course equally satisfactory.

This arrangement, fulfilling all the requirements for which it was intended and being cheaper and more convenient of application than the only other satisfactory type, is the one generally used.

D.B.

### OIL SWITCH: USE OF BAFFLERS

**(95) What are the reasons for using bafflers in the oil vessels of motor-operated oil switches?**

The primary reason is to increase the rupturing capacity of the switch. Another reason is to reduce the tendency of the oil to be expelled from the oil vessel on opening the circuit under conditions of heavy overload or short circuit.

Fig. 1

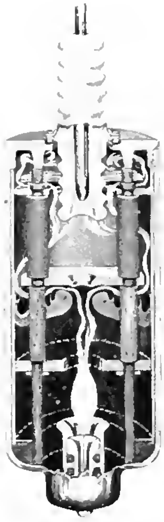

Fig. 2

In detail, the lower or circular section of the baffler tends to prevent the oil in that chamber from leaving, thus assisting in smothering the arc. The only oil exit from this lower chamber being the small hole in the lower baffler plate, the oil which leaves is forced into the path of the arc, thereby cooling it.

Fig. 2 pictures the course of the escape of the generated gases from the oil-filled vessel, as influenced by the baffler, Fig. 1.

The second or triangular baffler and the upper bafflers, by forcing the oil and gases traveling upward around a long and tortuous path on their way to the vent at the top, tend to reduce the velocity of the oil and turn it downward. At the same time, the action permits the gases to escape, which reduces the tendency of the oil to be thrown out of the tank under severe conditions and also prevents high pressure in the upper portion of the tank.

At the same time, the oil is forced back under pressure into the region of the arc which shortens the time of breaking the arc and confines the violent disturbance or explosive effect on short circuit. Consequently, it eliminates to a great extent the flashes due to hot gases and the ejection of the oil from the oil vessels.

E.H J

### INDUCTION GENERATORS: OPERATION

**(96) Are there any induction generators in use in this country? Are there any such machines driven by exhaust-steam turbines. If so, please state some of their operating details.**

Yes. For instance, the Interborough Rapid Transit Company, New York City, has six or seven of these low-pressure steam-turbine-driven induction-generator sets of 7500 kw. each. Two good points have been claimed for this type of generator. First, it acts somewhat as a storage battery floating on the line, delivering no load when the primary generators are capable of carrying the station demand. This produces a higher station efficiency, for since but a few generators are actually carrying the load they are operating at a high efficiency. Second, it somewhat lowers the impetus or flywheel effect which the generators throw into a short circuit occurring on the line; this because the induction generators depend upon the synchronous generators for their excitation, and with the lowering of the voltage delivered by the synchronous generators the induction machines lose their excitation. Some of the unfavorable points of the induction generator are lower efficiency, poorer regulation, and a larger size machine for the same output.

E.C.S.

### INDUCTION MOTOR: KNOCKING OF ROTOR

**(97) A certain $\frac{1}{8}$ h.p., 60-cycle, 104-volt induction motor produces a knocking sound when running under current. This sound disappears when the current is switched off, although the motor runs at nearly full speed for some time. The bearings are in good condition and the rotor does not rub the stator at any point. A test shows no reversed coils. What is the cause of the sound?**

It is suggested that the operation of the rotor be carefully noted when it is running supplied with current. It would appear that the knocking is due to the rotor and shaft violently oscillating between the bearings, the sound resulting from the shoulders of the shaft bumping against the shoulders of the bearings. Such an action would be quite possible if the rotor is not mounted at the correct position on the shaft.

The correct position of the rotor on the shaft is that at which the action of the field upon the rotor will hold the latter in such a position that the shaft will run freely without its shoulders coming in contact with the shoulders of the bearings. If the rotor is not set in this position, it will seek one bearing when current is applied, bump up against that bearing and be sent to the other bearing. This oscillating action increases in magnitude until it becomes violent. The remedy, of course, is to shift the rotor along the shaft until it becomes central with the field set up by the stator, at which time the knocking will be eliminated.

E.C.S.

# INVESTIGATION TO DETERMINE THE EFFECT ON THE PROPAGATION OF ELECTRIC WAVES OF THE TOTAL ECLIPSE OF THE SUN, AUGUST 21, 1914

British Association for the Advancement of Science

The forthcoming total eclipse of the sun affords an exceptional and important opportunity of adding to existing knowledge of the propagation of electric waves through air in sunlight and in darkness, and across the boundaries of illuminated and unilluminated regions. The eclipse will be total along a strip extending from Greenland across Norway, Sweden, Russia and Persia to the mouths of the Indus. In Russia the duration of totality will be little more than two minutes.

There are two main points calling for investigation during the eclipse. In the first place, the propagation of signal-bearing waves through air in the umbra and penumbra will probably obey laws different as regards absorption and refraction from those obeyed in illuminated air. In the second place, the strength, frequency and character of natural electric waves, and of atmospheric discharges, may vary. The variations may occur either because the propagation of natural waves from distant sources is facilitated or impeded by the eclipse, or, possibly, because the production of natural electric waves or atmospheric discharges is for some unknown reason affected by the eclipse.

These points have previously been investigated to only a slight extent. The observers of signals during the solar eclipse of 17th April, 1912, nearly all agreed that the strength of the signals was greater during the eclipse than an hour before or after. There was only one special observation of strays during the same eclipse, when very pronounced and remarkable variations were recorded during the passage of the shadow-cone across Europe.

To investigate the propagation of signals across the umbra it will be necessary to arrange for wireless telegraph stations on either side of the central line of the eclipse to transmit signals at intervals while the umbra passes between them. This transit of the umbra occupies about two minutes. It is thus very desirable that the Scandinavian and Russian stations should transmit frequently throughout several minutes before, during, and after totality. But stations other than those favoured by their proximity to the central line should endeavor to keep a complete record of the variations of signals during the eclipse. Stations in Europe west of the central line and stations in the Mediterranean and in Asia Minor may find noticeable changes in the strength of signals, particularly long distance signals, between the hours of 10 a.m. and 3 p.m., Greenwich time; and it is probable that the stations of India and East Africa, and ships in the Indian Ocean, may feel the effect of the penumbra in the afternoon. On the other hand, ships in the Atlantic, and fixed stations in eastern Canada and the United States, will probably be affected by the penumbra in the early morning. At Montreal the eclipse (partial) is at its greatest phase at 5.52 a.m. Standard Time. It is possible that the eclipse may have some influence even when it is invisible.

The investigation of strays is of as great interest as that of signals. So far as is yet known, the natural electric waves reaching wireless telegraph stations in latitudes higher than 50 deg. appear to travel mostly from the south. Thus the greatest changes produced in strays by the eclipse will probably be experienced at stations in Scandinavia and Russia, to reach which the waves must cross the path of the umbra. At the same time changes of some kind are to be expected in other districts than these, and it is therefore desirable that statistical observations of natural electric waves be made all over the world, and especially at places within an earth quadrant of Southern Russia. It is also desirable that meteorological observations, including those of atmospheric ionization and potential gradient, should be at the disposal of the Committee when considering the records of strays and signals.

The Committee proposes to prepare and circulate special forms for the collection of statistics of signals and strays, especially within the hemisphere likely to be affected by the eclipse; they will endeavor to make provision for the transmission of special signals at times to be indicated on the forms; and they will offer for the consideration of the authorities controlling stations near the central line a simple programme of work. The discussion of the observations, and the comparison with meteorological data, will be carried out by the Committee; and digests of the statistics, together with the conclusions drawn from the analysis, will be published in due course.

# GENERAL ELECTRIC REVIEW

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This striking picture illustrates forcefully the conditions that exist on the mountain divisions of many of our trunk line railways. Such sections on the right-of-way act to throttle the traffic in each direction, with much loss in time and revenue, and it is the ability of the electric locomotive to cope with the difficulties involved in the expeditious handling of trains on these grades that forms one of the strongest arguments for main line electrification. The reader is referred to the article, "**The Development of Electric Traction**" on page 462.

GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

The cost of power is one of those subjects of vital importance that is attracting considerable attention just at present. That electric power should be generated and sold as cheaply as possible is essential, as under modern industrial conditions the wheels of industry are getting more and more dependent upon this form of energy every day. But this subject of the cost of power is one which the public can very easily be misled on and fooled into believing that they are paying more for than they ought. There is nothing easier in the world than to deceive people by figures. The bare statement that electrical energy can be produced for less than one cent per kw-hr. at the central station busbar is telling only a very small part of a truth, and immediately makes the uninformed on technical matters wonder why they are paying so much more than this figure for the energy they are consuming. The difference between the cost of production at the central station bus and substation bus and between the cost at the substation bus and at the customer's meter means nothing to the average lay mind. The load factor and the cost of the distributing system are items that are entirely disregarded by those unfamiliar with the subject.

As a rule, the figures cited when talking of the cost of power are based upon very large stations operating under the most favorable conditions which rarely exist. The cost of power is vitally affected by the nature of the load factor, and fortunately, owing to the rapidity with which the use of electric energy is spreading, we may look for an improvement in this direction, but the cost of distribution must under any circumstances always be high.

It would be an interesting study to take a certain number of the best typical central stations with distributing networks of normal dimensions and calculate the cost of power to the consumer at his meter, calculating the cost of energy at the station busbar at zero. Such a set of figures would be a liberal education to some people. The cost of constructing and maintaining a system of energy distribution for a large city is enormous, and these costs are likely to increase rather than decrease since the demands on the public service corporation for a higher class of workmanship are incessant. The fact of whether the light and power wires are carried on poles in our city streets or are laid in expensive conduits under ground must have a marked effect upon the cost of energy delivered.

An appreciable portion of the distributing system and especially that part feeding the residential lighting circuits is only doing active work for a small proportion of the 24 hours, while the heavy overhead charges are working continuously. In spite of the high cost of distributing electrical energy to the consumers, it is immensely cheaper than the transportation of any other form of energy. The cost of electrical energy as paid by the consumers includes the cost of manufacture and transportation, and all the consumer has to do is to turn a switch. If electricity were of such a nature that the consumer could call at the central station and take it away in buckets full, then he could buy it at a figure approaching one cent per kw.-hour, but owing to the service rendered to the consumer by the power company, which includes the manufacture, transportation, metering and controlling of the energy, it is unlikely that rates much lower than those prevailing in many districts at present can be looked for. As a matter of fact, the decrease in the charges for electrical energy that have already been brought about at a time when all the other necessities of life have been increasing at a rapid rate shows what marked progress has been made in the industry of generating and supplying electric power.

# THE LATEST AND LARGEST ELECTRICALLY-OPERATED GOLD DREDGE

By W. H. Gardner and W. M. Shepard

The methods now employed in gold dredging are widely different from those in vogue in the early days, principally because almost all of the gold-bearing surface deposits which have not already been worked out give so low an assay value that the work can only be carried on profitably on a very large scale. The author shows the rapid growth that has been made in the size of the dredges designed for this work, and describes and illustrates in detail the construction, equipment, and operation of the latest dredge—the all-steel electrically-driven Yuba No. 14.—Editor.

## Introduction

Gold dredging is the class of mining that involves the least risk. A dredgable property can be prospected by pits or shafts, if there is not too much water, or by the usual method of drilling. This work, if done under expert supervision, gives with remarkable accuracy the total gold contents of the placer deposit. If the building of the gold dredge is entrusted to a responsible and capable concern, its first action is to study carefully the physical and climatic conditions of the property; and the completed dredge, especially designed to operate efficiently under these conditions, will have an operating cost that can be calculated with reasonable exactness. The value per cubic yard and the cost of recovery per cubic yard thus being known, the profits become practically a known quantity. Were this not the case dredging operators would not so readily spend up to a third of a million dollars for a dredge before actual returns commenced. There is no uncertainty regarding the extent of the vein, nor a continual outlay for exploration and development work, as in a quartz mine. The "ore" is always in sight.

Unfortunately, however, deposits which will lend themselves to the successful operation of a gold dredge are becoming scarce. The richest placers of New Zealand and California are rapidly being worked out. Alaska is a rich and promising field, but inaccessibility and short seasons preclude the successful exploitation of anything but comparatively rich deposits. In South America, Columbia offers a promising field, but difficult prospecting conditions render its development slow. Siberia and the Philippines will eventually prove valuable fields. The whole world is being combed for dredgable deposits, prospecting parties are investigating wild and unexplored regions, but suitable placers are becoming increasingly hard to find. This is largely due to the fact that conditions must be fairly favorable for dredging. Inaccessibility means increased cost; ground running 9 cents per cubic yard being workable at a profit in California, while in some sections of Alaska the costs alone run to 30 cents per cubic yard. The bed rock must be soft, for the heaviest dredge yet built or likely to be built cannot dig hard and massive bedrock, nor recover gold that is highly concentrated in its crevices. Clay is exceedingly difficult to handle, large boulders render operations exceedingly expensive or impossible. As a result, the large dredging companies have turned much of their attention to the problem of handling the extensive low grade properties of more accessible regions, which have favorable conditions. Huge and powerful dredges, having a capacity of 10,000 cubic yards or more per day, have thus been evolved, with their consequent exceedingly low operating cost. Of this type of dredge, the Yuba No. 14 stands to date as the largest, most powerful, and most modern.

The gold dredge is essentially a hull or scow on which is mounted excavating machinery, screening and washing appliances for the recovery of the gold, and an arrangement for depositing the waste material sufficiently far behind the dredge as not to interfere with its flotation and operation. The dredge excavates material at its front end, extracts the gold and deposits the waste material behind it, continually moving forward and carring its own pond with it, thus working any fairly level deposit independent of its elevation or proximity to the river or stream. A continuous influx of fresh water through a ditch, varing from 40 to 200 miner's inches* depending on the kind of ground and the size of the dredge, counterbalances the losses through seepage or evaporation, and serves to settle the suspended clay and silt.

The excavating is done by means of an endless chain of heavy buckets, revolving

---

* A miner's inch is approximately estimated at 1½ cu. ft. per min.

A View of the Yuba Gold Dredge No. 14 in Operation

A View of the Yuba Gold Dredge showing the Digging Ladder Raised over two tumblers mounted at the extremities of a long ladder, the upper tumbler being six sided and acting as a positive driving sprocket for the bucket chain. In modern installations the lower tumbler is round, acting as an idler or sheave. The ladder is suspended at its lower end from a heavy gantry on the bow of the dredge hull, the raising and lowering of the ladder controlling the digging depth. The elevation of this ladder is controlled by a winch, called the ladder hoist winch, situated on the port side of the dredge. The lateral motion of the buckets is secured by swinging the entire dredge on one of the "spuds" as a pivot. This is done by means of lines run from two drums, the "swing winch," on the starboard side, connected through sheaves on the port and starboard bow to "dead men" on the banks. The continuously revolving bucket line is thus swung across the face of the bank for a width of from 190 to 300 feet, and at the extreme lateral limit of the swing the ladder is dropped and the side swing repeated. The revolving buckets thus terrace away the bank until bedrock is reached, when the ladder is raised, the dredge stepped forward by swinging on alternate spuds, and the whole operation recommenced. These spuds, which are single sticks of lumber on the smaller dredges and of structural steel on the larger and more powerful dredges, are at the stern of the dredge and suspended from the stern gantry. On Yuba No. 14, for instance, these spuds weigh over 40 tons each, and are 60 feet long. By alternately raising and dropping these two spuds as the dredge swings, it is stepped ahead much as a stiff-legged man might walk.

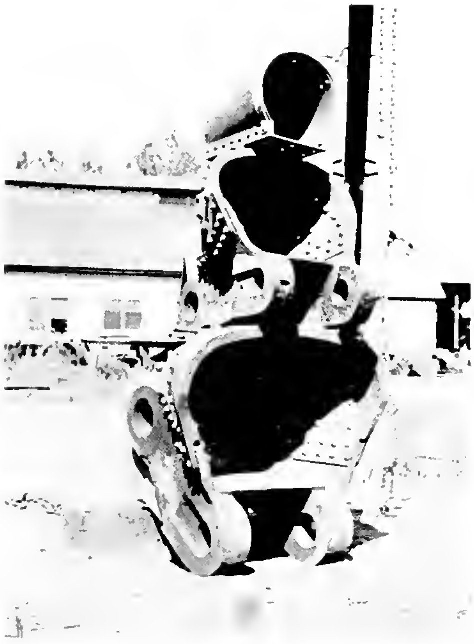


Fig. 1. A Comparison of:
Bucket of First Dredge on Yuba River
7 Cubic Foot Bucket of Early Dredges
15 Cubic Foot Bucket of Yuba No. 13

The ascending buckets, full of gold-bearing material, are dumped over the upper tumbler into a hopper, lined with heavy wearing bars, where it is subjected to high pressure sprays of water. The gravel is then delivered to the screen, a revolving cylinder sloping toward the stern and lined with perforated steel plates, in which it is continuously played upon by jets of water and is completely disintegrated. The sand, fine gravel, and gold particles are washed through the perforations into the distributor under the screen which serves to properly distribute the mass onto the gold saving tables. These are in two banks, an upper and a lower, and are composed of fore and aft and thwart ship sluices, lined with steel shod sugar pine riffles, where the gold is caught and amalgamated by mercury. The waste sand is delivered from the tail sluices at the stern of the dredge, some of it being deposited around the spud points to enable them to obtain a firmer hold, and the remainder dumped at some distance behind the dredge. The boulders and heavy gravel, which do not pass through the perforations, fall from the rear end of the screen into a chute and are thence delivered onto the stacker belt. This endless belt carries the material up a long stacker, which is hung from the stern gantry of the dredge, and is finally dumped far to the stern, forming the extensive "rock piles" characteristic of a dredging field.

All these operations are controlled by three men. The winchman, in the "winch" or operating room above the swing winch, commands a view of the line of buckets and controls the principal motions of the dredge. Two oilers are employed, one of whom attends to the control of the screen and stacker, and they complete the necessary crew for a shift.

The gold dredge became an accredited machine for recovering gold in this country soon after its success in New Zealand. The Continental Dredge, built by Mr. W. P. Hammon in Oroville in 1899, first proved the tremendous possibilities of this method of low-cost extraction. The first dredges were small, although the necessity for using special steels and high-grade material due to the terrific wear and tear on the bucket line was early recognized. At that time a dredge equipped with 9-cubic-foot buckets was considered impossible, and a 16-cubic-foot dredge was undreamed of. Fig 1 shows an old bucket of one of the earliest California dredges, a 7-cubic-foot bucket of the wonderfully successful Yuba Consolidated Gold Fields Company's dredges of a later period, and a 15-cubic-foot bucket of a modern dredge, Yuba No. 13, the immediate predecessor of Yuba No. 14.

The Yuba River, draining a region from which the early output of California gold was largely derived, was considered as a dredging field as early as 1900. While good values were found, the ground was thought too deep to dredge, and it was several years before it was considered possible to construct dredges that could dig deep enough to handle this ground. Yuba No. 1 and No. 2, 7-cubic-foot dredges, were then constructed to dig to a depth of 65 feet. Six more dredges of improved design followed rapidly. The ground was very rich, one of the dredges alone once clearing more than four hundred thousand dollars profit in a single year. Later, four more dredges having somewhat larger hulls were built and added to the fleet. In August, 1911, Yuba No. 13, a 15-cubic-foot dredge with wooden hull, started work and handled an average of 280,000 cubic yards per month at an average operating and maintenance cost of a little over $3\frac{1}{3}$ cents per cubic yard. On the Feather River at Oroville, and on the American River at Folsom, fleets of gold dredges were operating by this time, but in point of extent and value the Yuba River was unequalled.

In 1912 the construction of Yuba No. 14, at present the last word in modern gold dredge construction, was first projected. It was determined to build this dredge entirely of steel, the longer life and practically negligible fire risk being the determining factors. The life of a dredge is limited by the life of its hull, and the steel hull while more expensive increases the life of the dredge from ten years, with a wooden hull, to fifteen years or more. Steel housing and steel gold saving tables were provided to decrease risk of loss by fire and for other reasons. Buckets of 16-cubic-foot capacity each were designed, the expected yardage being 10,000 cubic yards per day. A [illegible] ladder was planned, to enable the dredge to dig 70 feet below water level and reach the deepest bed rock. The latest improvements in electrical equipment and control were incorporated in the plans of the dredge, to help reduce the operating cost to a minimum. An increased area of gold saving tables was provided, to secure the maximum gold recovery. While no experimental features were introduced in the design, the machinery was strengthened in many places. As a result Yuba No. 14 stands as the largest and most advanced gold dredge in the world.

Yuba No. 14 was designed and constructed by the Yuba Construction Company of Marysville, California. It was built on the Yuba River a little further up river than the other dredges operated by the Yuba Consolidated Gold Fields Company, at a total distance of about 14 miles from Marysville. Fig. 2 shows the dredge under construction. A brief description of the engineering and mechanical points of this dredge follow.

### Steel Hull

Perhaps the most important and interesting feature of Yuba No. 14 is its steel hull. This hull is 155 ft. 6 in. long, 58 feet wide with an additional overhang of 5 feet on each side to increase the deck area, and is 11 ft. 6 in. deep. It is made entirely of steel, and is the first steel-hull dredge to have a deck of steel plating. Particular attention has been given to the design of the hull. It has been so constructed that all of the heavy stresses are distributed over a series of fore and aft and transverse trusses. The vertical sides of the hull form the girders which carry the concentrated loads near the edges of the main deck. The bottom of the hull is framed in such a way that the upward pressure of the water is carried to the main fore and aft trusses and to the sides, allowing the hull to be as light as possible and yet giving it at the same time ample strength to withstand the stresses incident to the operation of the dredge. Following out this same scheme, the spuds are directly in line with the fore and aft trusses.

The bow gantry, the truss from which the ladder is suspended, is of particularly heavy steel construction, and the weights of the bow and stern gantry, added to the weight of the hull, show a grand total of 1,562,546 pounds.

The housing, carrying out the general plan of the dredge, is also of steel fireproof construction. It is made up of two sheets of 22 gauge steel between which is a $^1_4$ in. sheet of millboard. This insures absolute fire protection, and gives a maximum insulation, keeping the dredge interior warm in winter and cool in summer. This is an important item, for warm weather in the field is particularly torrid owing to the gravel and sand bars along the river.

### Digging Ladder

The digging ladder, of the plate girder type, is one of the heaviest yet designed, and to enable the dredge to dig 70 feet below water level has a length of 133 ft. 6 in. between tumbler centers. This girder is 10 feet in depth. Not counting the ladder rollers or bucket line, this ladder weighs 125 tons.

### Bucket Line

The bucket line is composed of 87 buckets, connected in an endless chain. The bucket bottoms are of a special nickel-chrome steel, cast with the hoods integral. The lips and bushings are of manganese steel, and the bucket pins are of a specially heat-treated oil-tempered nickel-chrome steel. The wear on the bucket line of a deep digging dredge is very great, and hence only the highest grade steels can be used in its construction. This bucket line complete weighs very nearly 203 tons, a weight of over 4600 lb. per bucket.

### Ladder Hoist Winch

The ladder hoist winch, Fig. 3, is operated by the main motor through a pulley shaft on the main deck, this shaft being also belted to the main bucket drive above. The main digging motor, which is of 400 h.p., is thus used to raise and lower the ladder, and to drive the bucket line.

### Main Drive

The main drive, consisting of the upper tumbler shaft with its two 12-foot-diameter gears, the intermediate shaft which is made in two separate lengths to allow room for

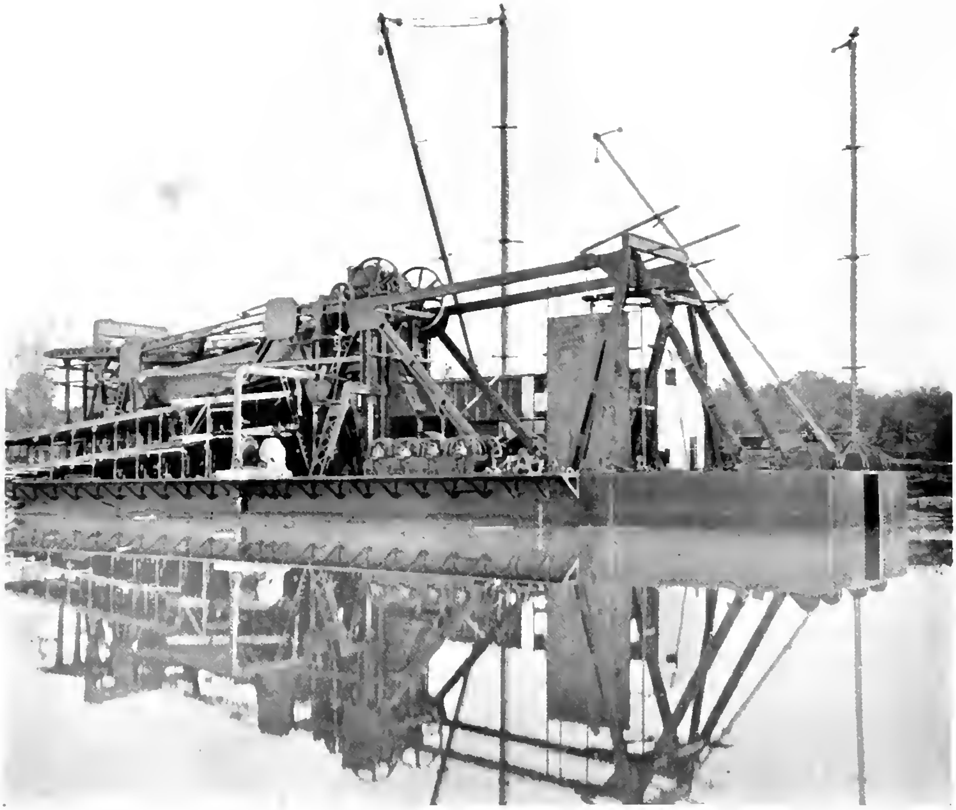


Fig. 2. Yuba Gold Dredge No. 14 Under Construction

the long hopper, and the pulley shaft with its two differential pinions and 12-foot-diameter pulley, is rigidly supported by the steel main gantry and the upper chords of the fore and aft main trusses, this rigidity serving to hold the gears accurately in mesh and to preserve the alignment of the shafting.

### Screen

The screen, a revolving cylinder of perforated high carbon steel plates, is 50 ft. 6 in. in length and 9 ft. in diameter and is stiffened by heavy longitudinal steel angles extending between the supporting tread rings at each end. Fig. 4 shows a part of the drive.

### Gold Saving Tables

The gold saving tables and supports are made entirely of steel, and divided into two separate banks 6 feet apart. In each bank there are fourteen transverse sluices on each side of the dredge. The three upper sluices extend through the side of the house where each one discharges into separate outboard longitudinal sluices that extend to the stern. The other eleven cross sluices discharge into seven inboard longitudinal sluices, the discharge from which is carried about 25 feet astern by overhanging steel tail sluices, or delivered back of the spuds as may be required. The total table area is 7540 square feet.

### Spuds

The two spuds are built up of structural angles and plates, have a cast steel point, are 30 in. by 60 in. in section and 60 feet long, and weigh together 160,800 lb.

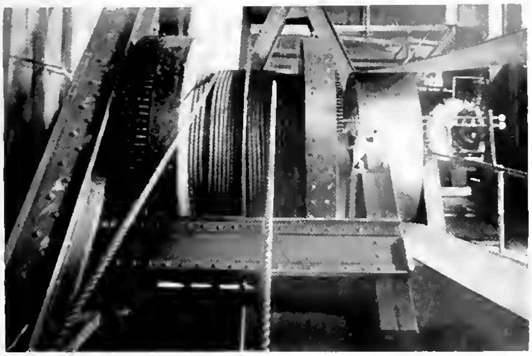


Fig. 3. Ladder Hoist Winch

### Stacker

The stacker is exceptionally long, measuring 137 feet between pulley centers, for when digging to the maximum depth of 70 feet the boulders have to be stacked very high. As is usual, it is of the lattice truss type.

### Swing Winch

The swing winch, Fig. 5, is an eight-drum winch, two of the drums being for spares (lines which are used for repair work and miscellaneous purposes), two for the bow swinging lines, two for the lines that raise the spuds, and two for the stern lines. This winch weighs 41 tons. The design of winches of this type has been worked out particularly well, and in spite of continuous use and hard wear, repairs on such a winch are wonderfully small.

Fig. 4. Screen Drive

### Pumps

Since Yuba No. 14 will not dig with a high bank, as do some of the Natomas Consolidated Dredges, no monitor pump is carried. There are, however, three Yuba construction pumps, one a 14 in. high-pressure horizontal centrifugal pump used for supplying water to the screen, one a 14 in. low-pressure pump used for supplying water to the tables, and

Fig. 5. Eight-Drum Swing Winch

the third, a 6 in., two-stage pump supplying water under a 125-foot head to the dump hopper.

### Operating Levers

By a system of levers the motion of the drums on the swing winch, the speed change on the same winch, and the operation of the main drive clutch, the ladder hoist clutch, the ladder hoist brake, and the main drive brake are all controlled from the winch room, requiring a total of 23 levers (Fig. 6). These are in addition to the control of the main drive and swing winch motors. From the winch room the bucket line can be raised or lowered, stopped or set in motion, the spuds can be raised or lowered, and the dredge moved by either the bow swing, head or stern lines.

Fig. 6. Operating Levers in Winch Room

### Electrical Equipment

The electrical equipment of Yuba No. 14 is of interest in that it represents something of a departure from the equipment heretofore considered standard for California gold dredges. This departure from former practice was made in the light of experience gained in the operation of four dredges of the largest type which were built by the Yuba Construction Company for the Natomas Consolidated of California and one similar dredge built for the Yuba Consolidated Gold Fields.

### Power Supply

Power is supplied by the Pacific Gas & Electric Company and is three-phase, 60 cycle, 4000 volt.

### Shore Cable

The power is brought on board the boat through 750 ft. No. 0 B.&S. gauge, 3-conductor cable, each conductor being stranded and insulated with $\frac{5}{32}$ in. 30 per cent para rubber, conductors twisted together, rounded out with jute and covered with a layer of $\frac{1}{8}$ in. varnished cambric. Over this is a layer of jute and the cable is armored with No. 10 B.W.G. armor put on with short pitch. This cable is insulated for 4500 volts working pressure. The shore cable is brought aboard the dredge on pontoons and enters a switch house on the upper deck near the stern of the dredge, where there is installed an automatic 300 ampere 7500 volt oil switch with hand-operated remote control. The switch is mounted on pipe framework away from the panel carrying the operating lever. There are installed in this switch house two 4400/110 volt, 200 watt potential transformers with fuses and two 150 ampere current transformers. The secondaries of these transformers are connected to indicating instruments mounted in the winch room. From the switch house the current is fed through triple conductor varnished cambric cable in conduit to the primary side of the main transformers. These consist of three 200 kw. oil-cooled transformers, 4000-volt primary and 460/230-volt secondary. In addition to the main transformers, there is installed one 15 kw. 4000-volt primary 230/115-volt secondary oil-cooled transformer to supply lights. From the secondary side of the main transformers various feeder circuits supply the different motors, triple conductor varnished cambric being used in iron conduits.

The control panel for the main drive or digging motor, and for the winch motor, is located in the winch room, as is also the instrument panel. The instrument panel contains the following instruments, which are supplied, as mentioned above, from the instrument transformers located in the entrance switch house: One 5-ampere alternating current ammeter with 150 ampere scale, one 175-volt alternating current voltmeter with 8 point potential receptacle and plug, one alternating current polyphase indicating wattmeter with 1200 kw. scale. The readings of these instruments give the total input to the dredge.

The double-circuit control panel for main drive and winch motors has the following equipment: One 60-ampere alternating current ammeter (winch motor); one 5-ampere alternating current ammeter, 800 ampere scale (main drive motor); one 200 ampere automatic oil switch with double coil series trip (winch motor); one 600-volt 800-ampere automatic oil switch with double coil trip (main drive motor); and two 800-ampere current transformers in main drive motor circuit.

The panels for the pump motors are located on the lower deck, the starting compensators for the pump motors being mounted alongside the panels. These compensators are all provided with inverse time-limit relays. The pump motor panels consist of the following: Two 3-phase 2-circuit motor panels, each panel mounting two 500-volt 200 ampere lever switches controlling the high-pressure, the low-pressure, the 6 in. two-stage, and the vertical pumps.

The stacker and screen motors are controlled from independent panels located in the stern of the dredge, each panel having the following equipment: One 200-ampere automatic oil switch, with 2-coil series trip, and mounting on the front of panel for one reversible type controller. The oil switch operating lever is directly above the controller.

All of the panels are natural black slate mounted on pipe supports.

### Digging or Main Drive Motor

This motor, which is shown in Fig. 7, operates the digging mechanism. It is a 400-h.p., 514 r.p.m., 3-phase, 60-cycle, 440 volt, slip ring, variable-speed induction motor with three bearings, pulley and sliding rails with a master controller and contactor panels, and is provided with resistance good for continuous operation at all speeds from 50 per cent normal to normal.

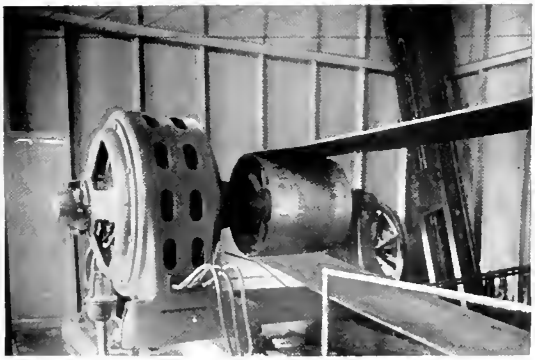


Fig. 7. 400 H.P. Induction Motor Operating Buckets

The contactor equipment, which is shown in Fig. 8, is provided with current limiting relays, which limit the maximum load that the motor can take and so protect both the motor itself and the complete digging mechanism that it drives. This is of considerable importance in keeping down the cost of repairs and preventing loss of time incident to repairs. The digging mechanism is subject at times to sudden and excessive loads and without the current limiting feature provided by the contactor control the only protection would be given by the overload oil switch. Due to the annoyance of having this switch tripping out frequently it is usually set so high as to afford little protection. The current limiting relays also protect the motor and digging mechanism when starting. The winchmen can throw the master controller to the full "on" position and the motor will come up to speed at a predetermined rate, which will not impose excessive stress on any part of the mechanism.

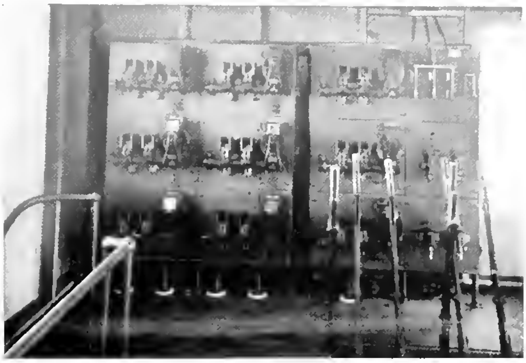


Fig. 8. Contactor Panel for Motor of Fig. 7

### Winch Motor

This motor operates the winch, raises the spuds, and swings the boat, and consists of one 35-h.p., 600-r.p.m., 3-phase, 60-cycle, slip ring, variable-speed induction motor with a controller and resistance for continuous operation at from 50 per cent to full speed. The motor is provided with pulley and base. In a few instances on smaller dredges, motors of intermittent rating were furnished for operating the winch. These motors, however, have not been found suitable for this service, as the winch operates almost continuously.

### Pump Motors

All the pump motors are squirrel-cage motors, the high-pressure pump having a 150-h.p., 600-r.p.m. motor, the low-pressure pump a 75-h.p., 600-r.p.m. motor, the 6 in. two-stage pump a 50-h.p., 1200-r.p.m. motor, and the vertical pump a 10-h.p. vertical motor. These motors are all direct connected to the pumps and, with the exception of the 10 h.p. motor, are all provided with welded end-ring construction in the rotor.

### Screen and Stacker Motors

These motors are of the slip ring, variable-speed type, provided with resistance for continuous operation at from 50 per cent to full speed and with reversible controllers. They operate at 600 r.p.m., the screen motor being 75-h.p. and the stacker motor 60-h.p. In most of the former gold dredges these motors were of the constant-speed squirrel-cage type. However, in the more recent large dredges, due to difficulties sometimes experienced with squirrel-cage motors on account of the heavy starting conditions and the desirability at times of running for short periods at reduced speeds, slip-ring motors with resistances for two-minute starting duty were used. In heavy work, however, these were found too light and for Yuba No. 14 resistances for continuous operation were installed and reversible controllers used.

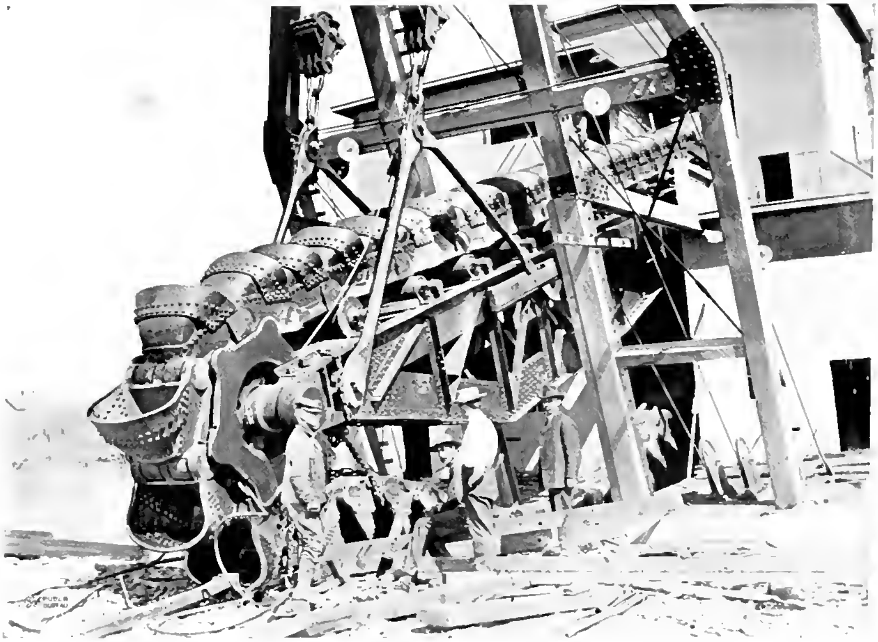
### Tool Motors

There is provided a 2-h.p., 1800-r.p.m. 3-phase motor with pulley and base for the repair shop on board the dredge.

### Power Consumption

The operating time of a gold dredge is between 85 and 88 per cent of the total time. The dredge operates night and day with three shifts. The load-factor varies from 62 per cent to 80 per cent, depending on the character of the ground, and as the dredge operates practically every day in the year throughout its life, except the Fourth of July and Christmas, it represents an excellent load for the power company.

Yuba No. 14 was built in four months and four days from the driving of the first rivet, a remarkable time considering the enormous total weight of the dredge. All material was transported 14 miles from the railroad over uncertain roads by means of power tractors and trailers, by no means a small job when it is noted that the completed dredge weighs very close to 1994 tons.



The Bucket Line of an Earlier Electrically Operated Gold Dredge

# PATENTS

By Chas. L. Clarke

Consulting Engineering Department, General Electric Company

## Part I

Mr. Clarke writes on patents from the standpoint of the technical and practical man in the field of engineering, to which has been added long experience as an expert in patent suits. Two articles on Patents, by Mr. Albert G. Davis, Head of the Patent Department of the General Electric Company, were published in 1908 in the June and July numbers of the Review, and represent the presentation of the subject by the patent lawyer. The engineer reader will do well to consider both series of articles together.—Editor.

### Introduction

It is our purpose broadly to consider the nature and effect of the exclusive right or monopoly, termed a Patent, as granted by the United States.

We shall endeavor to present the subject in its fundamental aspect, and in a manner directed to the understanding of engineers, rather than for the consideration of those versed in the law, whom we naturally disclaim qualification specially to interest and much less instruct. The subject is of particular interest to engineers because favoring opportunity in the practice of their profession frequently leads to invention, or to utilizing with premeditated understanding the inventions of others.*

### THE LAW

The power to grant patents was vested in the Congress by Article I Section VIII, of the Constitution, 1787, whereunder:

> The Congress shall have power—Clause 8. To promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries.

The exclusive right of authors to their writings, referred to in the Constitution, and otherwise termed a copyright, has been, and is still secured under laws separate and apart from the laws relating to the granting of patents to inventors.

The first statute law on patents was enacted by the Congress in 1790, and entitled, "An act to promote the progress of useful Arts," which authorized the issue of "letters patent" to any person or persons that have:

> * * * * * invented or discovered any useful art, manufacture, engine, machine, or device, or any improvements therein not before known or used, * * * * * granting * * * * * for any term not exceeding fourteen years, the sole and exclusive right and liberty of making, constructing, using, and vending to others to be used, the said invention or discovery.

At that time there was no Patent Office with a Commissioner and staff, as now, to investigate the rights of applicants and issue patents, when justified.† Application was made to the Secretary of State, the Secretary of the Department of War, and the Attorney-General; and they, or any two of them, could cause letters-patent to be made out, which were examined by the Attorney-General, who certified thereon that they were conformable to law, if he found such to be the case, and the President then set his hand, and caused the seal of the United States to be affixed thereto.

The law now in force relating to the conditions controlling the granting of patents for inventions or discoveries, is embodied in Section 4886 of the Revised Statutes, March 3, 1897, as follows:

> Any person who has invented or discovered any new and useful art, machine, manufacture, or composition of matter, or any new and useful improvements thereof, not known or used by others in this country, before his invention or discovery thereof,

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* In the preparation of this article, Walker on *The Patent Laws*, 1904, and Renwick on *Patentable Invention*, 1893, have freely been consulted. These works have mainly been relied upon because the former expounds the patent laws from the standpoint of an eminent, practicing lawyer, and writer of acknowledged reputation; while the latter, although now of somewhat early date, was written by one of the most talented experts in this country, who, after an experience of forty-three years, became so much in sympathy with the efforts of inventors, that he was inclined somewhat impatiently and controversially to view the patent situation, in regard to the question as to what should constitute patentable invention, more as he thought it ought to be answered, rather than as determined by the Courts in some very important respects, although his well-trained mind led him accurately to state in his book the actual condition of affairs from the legal point of view. We find expounded in these works, respectively, the legal side, and the inventor's side of the case. We purpose in this article to confine our attention to the patent situation as it exists by virtue of the statutes and decisions of the Courts.

† The first United States patent was issued, on July 31st, 1790, to Samuel Hopkins, of Philadelphia, for pot and pearl ash manufacture. Three patents were issued in that year. *Annual Report of the Commissioner of Patents*, 1891, page XX. By contrast, it is of interest to note that 33,941 patents for inventions and 1683 patents for designs were issued during the year 1913. The Patent Office was established by law in 1836, and a systematic examination into the novelty of inventions for which patent application was made was then begun for the first time. An interesting historical account of the Patent Office and earlier offices relating to patents, from 1790 to 1877, when the office was partially destroyed by fire, may be found in the *Official Gazette of the United States Patent Office*, Vol. XII, 1877, as a separately paged publication between pages 588 and 625 of the regular *Gazette* issue.

and not patented or described in any printed publication in this or any foreign country, before his invention or discovery thereof, or more than two years prior to his application, and not in public use or on sale in this country for more than two years prior to his application, unless the same is proved to have been abandoned, may, upon payment of the fees required by law, and other due processes had, obtain a patent therefor.

The monopoly granted by a patent is expressed in Section 4884, as "the exclusive right to make, use, and vend the invention or discovery throughout the United States, and the Territories thereof, referring to the specification for the particulars thereof." And the Courts have said that this monopoly likewise conveys the right of refusing to make, use, or sell the patented thing, or allowing others so to do; in other words, the owner may lock up his patent, so that the public can derive no benefit from the invention during its life.

In 1842, a law was enacted providing for the grant of patents of another sort, known as "design patents." The law in force from 1874 until 1902 was embodied in Section 4929 of the Revised Statutes, and read:

> Any person who, by his own industry, genius, efforts, and expense, has invented and produced any new and original design for a manufacture, bust, statue, alto-relievo, or bas-relief; any new and original design for the printing of woolen, silk, cotton, or other fabrics; any new and original impression, ornament, patent (obvious misprint for "pattern"), print, or picture to be printed, painted, cast, or otherwise placed on or worked into any article of manufacture; or any new, useful and original shape or configuration of any article of manufacture, the same not having been known or used by others before his invention or production thereof, or patented or described in any printed publication, may, upon payment of the fee prescribed, and other due proceedings had the same as in the cases of inventions or discoveries, obtain a patent therefor.

And in Section 4933:

> All the regulations and provisions which apply to obtaining or protecting patents for inventions or discoveries not inconsistent with the provisions of this title, shall apply to patents for designs.

Section 4929 was amended May 9, 1902, the law now in force relating to the grant of design patents reading as follows:

> Any person who has invented any new, original, and ornamental design for an article of manufacture, not known or used by others in this country before his invention thereof, and not patented or described in any printed publication in this or any foreign country before his invention thereof, or more than two years prior to his application, and not in public use or on sale in this country for more than two years prior to his application, unless the same is proved to have been abandoned, may, upon payment of the fees required by law and other due processes had, the same as in cases of invention or discoveries covered by Section forty-eight hundred and eighty-six, obtain a patent therefor.

## MEANING OF THE WORD "DISCOVERY"

### Laws of Nature not Invented

Under the Constitution, as we have seen, an exclusive right may be secured by law to an "inventor" for his "discoveries." By the law of 1790 this right, by letters-patent, was granted for an "invention or discovery." Today a patent is also granted for the same thing, and for designs.

The question naturally arises in the mind of the layman, say, the engineer who has not inquired into the subject and consulted the books: What is the difference between an "invention" and a "discovery"; the Constitution mentions the "discoveries" of "inventors," but says nothing about their "inventions"; the first patent law and the present law refer to an "invention or discovery" that has been "invented or discovered" by a "person" or "persons," but make no mention of an inventor, or of a discoverer?

The answer is that in the Constitution and in the law the word "discovery" means invention, and thus where the words "discovery" and "invention" are used, they are two names for the same thing. The "discoveries" of inventors are inventions.

According to amended Section 4929 and Section 4933, a design may not, however, be classed as an "invention," or as a "discovery," which are names of one meaning appropriated to arts, machines, manufactures, and compositions of matter. A design is simply a design (for an article of manufacture), and nothing else, although for patent purposes it must have been "invented."

It will be perceived that the word "discovery," in the Constitution and in the law, does not have the broad meaning in the dictionaries. A man may invent a machine (which may also be called a discovery, although this word should not be used in patent specifications in the sense of invention, but only in respect to a new fact ascertained), and he may also discover a comet, or a "law of nature" also spoken of as a "principle," a "scientific principle," a "scientific fact." For inventing the machine he may receive a patent, but no patent may be granted for discovering the comet or the law of nature because he did not invent either of them.

Patents for inventions or discoveries may be granted for four kinds of things, arts, machines, manufactures, and compositions of matter. Obviously none of these things are discoveries in the broad sense, but are the result of original thought and reasoning, whereby the thing is invented, and by which laws of nature are utilized. This is the thing and not the laws of nature, that may be patented. Ohm's law of the electric circuit is a law of nature, and would never have been patentable in this country, but a multitude of valid patents have been granted for electrical machines operating under Ohm's law.

The hope of reward through protection by patents has caused inventors to embody physical discoveries (laws of nature) in concrete material forms adapted to minister to the welfare of humanity. Except for this encouragement many such discoveries would have largely remained academic additions to our knowledge, exemplified at most in apparatus for merely demonstrating physical laws, and not of enough practical importance to be dignified as more than philosophical toys. Such was the apparatus ingeniously devised by Franklin in his electrical experiments and discoveries until he invented the lightning rod, which, however, he did not patent, although that could have been done by favor of the King even in those colonial days. The ground wire for protecting high potential transmission lines of today is a modified form of lightning rod, and utilizes the same electrical laws. Such also was the crude apparatus of Faraday with which he discovered the law of magneto-electric induction, or production of electricity by means of magnetism. But the efforts of inventors have so perfected the utilizing of this law in electrical machinery and appliances that the world is today receiving a marvelous benefit therefrom.

Laws of nature are ordinarily not referred to, as such, in patents, but manipulative steps, or the operation of a combination of devices or mechanisms by which the unexpressed laws of nature are utilized, and the results thereby obtained, are set forth in describing the invention. Occasionally, however, a law of nature is specifically mentioned in a patent, particularly if the inventor believes he discovered it, but this is unnecessary.

Furthermore, it is not necessary to give a theory of operation of the invention, or should a theory be propounded and subsequently be found wrong, no harm is done, so long as the patent does not mislead, and sets forth the invention sufficiently to enable those skilled in the art or calling to which it pertains, or to which it most nearly relates, to put the invention into practice and obtain substantially the result described.

## SUBJECTS OF PATENTS

Let us consider the general characteristics peculiar to the useful arts, machines, manufactures, compositions of matter, and improvements thereof, and to ornamental designs for articles of manufacture, for which patents may be granted.

### Useful Arts

A useful art, as distinguished from the liberal, polite, or fine arts, relates to a mode of treatment of, or a method or way of operating upon, an object by which a change in its form, condition, quality, or properties is produced. Such an art is usually termed a "method" or "process" (Renwick). Generically, a process is an operation performed by rule to produce a result. A patent for an art or process is a patent for the described *combined use* of the two or more laws of nature, as the case may be, that are utilized by the process. If a patent for the use of only one of the laws of nature utilized in a process were granted, it would be a patent for a "principle" and would be invalid (Walker).

Merely heating an iron article would, in the absence of any additional operation, utilize only one law of nature in respect to the iron, namely, conduction of heat thereto and therethrough; it would then involve the application of a principle, and not be patentable invention even if new. But if the article were an iron wheel, which after being expanded by heating, were slipped on a shaft so that when it shrunk on cooling, it became fixed to the shaft, this would be a process involving the combined use of several laws of nature resulting, respectively, in heating, expanding, cooling, shrinking, and cohesion, and, if new, would be invention. But the mere application of one of the laws utilized in the process, say, in the expanding, or in the cooling, or in the cohesion, would not be patentable.

Likewise heating an article of carbon steel would be the application of a principle. But hardening the article first by heating and then suddenly cooling it by plunging in water is a process involving two steps, and the utilizing of the laws of nature comprised in the heating, sudden cooling, and in the resulting molecular condition that produces the hardening. Tempering the article by reheating it to the requisite degree is an additional step bringing another law of nature into play.

Merely inducing magnetism in a soft iron armature by means of a steel magnet is a simple process involving one law of nature, but causing the armature to be attracted to the magnet involves a compound process utilizing two laws of nature, to wit, magnetization and magnetic attraction. Attracting the same armature by means of an electro-magnet calls for the operation of at least four laws, those pertaining to the electric current, electro-magnetism, magnetization and magnetic attraction.

Morse invented an electric telegraph in which the marking of intelligible signs upon paper was made by an electro-magnetically operated device energized by a current sent over a wire. The current represented one law of nature, while the electro-magnetic device was the concrete embodiment of another law discovered many years later, but before his invention was made, and magnetic attraction had been known for centuries. Morse might properly have claimed the method or process of marking intelligible signs at a distance, by causing an electric current to flow from the signalling point through a conductor to the distant point and there operate an electro-magnetic sign-marking device; this would have involved the combined use of at least two laws of nature. But the Court said in substance that he had not discovered that the electric current will always mark intelligible signs at a distance, no matter what the form of device operated thereby; that his broad eighth claim covered merely the use of the motive power of electro-magnetism, or magnetic attraction, for this purpose, and thus was for the application of a principle, and invalid. (O'Reilly v. Morse, 15 Howard, 412, 1853.)*

Processes consisting of operations partly or wholly employing heat, light, electricity, magnetism, chemistry, pneumatics, hydraulics, or some other non-mechanical science, are subjects of patents.

Processes made up of operations that are wholly mechanical, but which may be done either by hand or by any of several machines, are also subjects of patents; for example, the art of weaving, if it were new.

But all operations that are wholly mechanical, and are only the peculiar function of the respective machines constructed to accomplish them are not proper subjects of patents, although the machines themselves may be so (Walker). There cannot be a true patentable process worked out by machinery alone (Renwick). A claim for a method of forming cigarettes by drawing a paper ribbon through a tube-forming die and simultaneously feeding tobacco upon the ribbon, the same being previously gummed and finally pasted, was declared invalid on the ground that the process of making cigarettes by wrapping paper about tobacco was old, and the so-called method of the claim was only the operation of mechanical parts resulting in nothing new; the process was old, and only the mechanical means for performing it were new. In a patent for an envelope machine, a claim for feeding the envelope blanks under the table supporting the gum box, instead of over it, was declared invalid as a process because it covered merely that particular function or mode of operation of that machinery. A process claim for the operations performed upon a blank to form heel-stiffeners for shoes was pronounced invalid because these operations were wholly due to the machine devised for the purpose. The claim was merely a recitation of the peculiar functions performed by the machine, which itself was patentable. Such operations as sawing, grinding, planing, etc., which are merely the performance of, or results obtained by machines are not patentable processes.

A process is not a substance affecting the physical senses, but can only be comprehended by noting its constituent acts during their performance. So also, laws of nature are not substances, but when discovered become mental conceptions only. Thus processes and principles are alike in that they are intangible, which sometimes makes it difficult to distinguish them, or causes one to be mistaken for the other (Walker).

### Machines

A machine is a combination of heterogeneous mechanical parts adapted to *receive energy*, and apply it to the production of some *energetic result* or results. All the parts of a machine may be old, while the machine as a whole, and also the sub-combinations which are contained therein, are properly subjects of patents. An improvement of a machine may consist of additions thereto, or any subtractions therefrom, or in substituting for one or more of its parts something different, or in so rearranging its parts as to make it work better than before (Walker).

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* Morse's eighth claim read: I do not propose to limit myself to the specific machinery or parts of machinery described in the foregoing specification and claims, the essence of my invention being the use of the motive power of the electric or galvanic current, which I call electro-magnetism, however developed, for marking or printing intelligible characters, signs, or letters, at any distance, being a new application of that power of which I claim to be the first inventor or discoverer.

From another standpoint, the term machine comprehends every device by means of which *force can be utilized or a useful operation can be performed.* Machines are simple or compound, the former consisting of a single member or device having but one function, and the latter of two or more members or parts; the class therefore includes tools, implements, etc., whose members are fixed relatively to one another, as well as mechanisms whose members are relatively movable (Renwick). Simple machines are comparatively rare; an example is a peck measure. Many machines seemingly simple are really compound; thus a chisel is generally regarded as a simple tool or machine, whereas it has two cooperating members, the cutting point to do the work for which it is designed, and the shank or handle by which the point is efficiently held to the work and force is applied to do the work.

### Combination and Aggregation of Parts in a Machine

A machine is patentable in respect to combinations of elements included therein, but:

> The combination, to be patentable, must produce a different force, effect, or result in the combined forces or processes from that given by their separate parts. There must be a new result produced by their union; otherwise it is only an aggregation of separate elements. (Reckendorfer v. Faber, 92 U. S. 357, 1875.)

The above opinion of the Court related to a lead pencil having a rubber eraser at one end. The decision practically was that the presence of the eraser made no difference in the mode of operation of the pencil, or the result obtained in writing, and vice versa, that the lead of the pencil had nothing to do with the erasing, and therefore the whole structure was not a *combination* of cooperating elements, producing by their joint action a unitary result, but a mere *aggregation* or collection of separate, non-related parts, as far as the lead and rubber were concerned, each producing its own result, and thus not patentable.

In the case of patents for certain self-feeding coal stoves, which were made of parts that were all individually old in other stoves, but so selected and assembled as to make a stove superior to its predecessors, it was decided that the parts assembled did not cooperate to perform any joint function, but each did only what it had done in former stoves, and that the whole was therefore only an aggregation of parts, and not a combination (Hailes v. Van Wormer, 20 Wallace, 353, 1873).

But it is not necessary for the performance of a joint function or unitary result that elements of a combination act simultaneously. The Court has said:

> To make a valid claim for a combination, it is not necessary that the several elementary parts of the combination should act simultaneously. If those elementary parts are so arranged that the successive action of each contributes to produce some practical result, which result, when attained, is the product of the simultaneous or successive action of all the elementary parts, viewed as one entire whole, a valid claim for thus combining those elementary parts may be made. (Forbush v. Cook, 2 Fisher, 669, 1857.)

This opinion was given years ago, but the same view has been held in more recent times. (San Francisco Bridge Co. v. Keating, 68 F. R. 353, 1895).

### Manufactures

The term manufacture or article of manufacture is generally applied to articles of utility made by hand or by machinery, that is, manufactured products or articles of merchandise, as cloths, pottery, nails, domestic utensils, and in general an almost innumerable number of made things. But the term "manufacture," as used in patent law in this country, has a very indefinite meaning. An article of manufacture, properly so called, should be distinguished by its peculiar properties, qualities, mode of operation, or structure. Thus the peculiarities which distinguish a rubber shoe from one of leather or cloth are readily apparent, chief among them being the waterproof character of the rubber shoe (Renwick). The word manufacture has a narrower significance in America than in England. In the latter country it includes everything made by the hand of man and also includes processes of manufacture. In America processes are patentable because they are "arts." While some of the things made by the hand of man are patentable as machines, others as composition of matter, and others as designs, whatever is made by the hand of man, *and is neither of these,* is a "manufacture" in American patent law (Walker).

In a suit relating to a patent for indexes to be used in connection with books, in which the defendant contended that the invention was not included among the things specified in the law as patentable, it was decided that the patent was for a manufacture. The Court said:

> The term "manufacture," as used in the patent law, has a very comprehensive sense, embracing whatever is made by the art or industry of man, not being a machine, a composition of matter, or a design. * * * * * I have no difficulty in holding that the subject matter of the patent in suit is patentable. (Johnson v. Johnston, 60 F. R. 620, 1894.)

### Compositions of Matter

A composition of matter may be defined as a compound of two or more substances which possesses a property or quality not possessed by the substances individually. The substances used constitute the ingredients of the composition. The composition may be chemical, as in nitro-glycerine, or mechanical, as in dynamite, which is a mixture of nitroglycerine and diatomaceous earth, or in black gun powder, which is a mixture of charcoal, saltpeter and sulphur (Renwick). The term covers all compositions of two or more substances, and includes composite articles, whether the result of chemical union, or of mechanical mixture, or whether they be gases, fluids, powders or solids. The composition must be new and useful to be an invention (Walker).

### Uncertainty Attending Classification

The distinction between a machine and a manufacture, and between a composition of matter and a manufacture, cannot be stated so that its application to every case would be clear to every mind, although in most cases it is obvious to which class a thing made by the hand of man should be assigned. If an inventor is certain the thing belongs to one of the three classes, no harm need result from not knowing, or stating, nor does it ever become vitally important to determine, to which class it really belongs; a seventeen-year patent may lawfully be granted for a thing that may come under either designation (Walker).

For example, if an art, or process, for extracting metals from their ores, and likewise a machine that may be employed in operating the process, be invented, the process must be distinguished from the machine, and each must be separately claimed, as a combination of operations in a process, and as a combination of elements in a machine, respectively, if both inventions are to be protected, although both may now be included in one patent. Incidentally, it may here be mentioned that both the process and the machine should be patented, for if the process alone be patented, some one might find a way to use the machine to advantage in a different process, or, if the machine alone be patented, the process might possibly be followed without using the particular machine.

But should an improved barber's chair be invented, the use of which involves no patentable process, it is not necessary in the patent to class it, either as a machine or as an article of manufacture. It may be referred to in the specifications and claims simply as a barber's chair.

Again, if the well-known process of making vulcanized rubber by heating a certain mixture of raw rubber and sulphur were a new invention, both the process and the resulting vulcanized rubber product night be patented, but whether the product be described and claimed as a manufacture, or as a composition of matter would be immaterial to the validity of the patent; the inventor might simply refer to it as a product, or merely call it vulcanized rubber. As a matter of fact, the product invented was claimed as a manufacture (Rubber Co. v. Goodyear, 9 Wallace, 795, 1869.)

While the law only specifies arts, machines, manufactures, compositions of matter and designs as subjects of patentable invention, these subjects have been subdivided by the Patent Office for convenience of closer designation, so that on January 1st, 1912, they included 243 classes of subjects of invention and about 14,000 sub-classes.

### Designs

The design of an article, whatever it may be, is the appearance of the thing as distinguished from its structure (Renwick). According to amended Section 4929 of the Revised Statutes now in force, the thing must be a "manufacture," and of new, original and *ornamental* design in order that such design—not the thing itself—may be protected by a patent. The single claim ordinarily granted in a design patent reads: "The ornamental design for [the thing, say, a watch case], as shown." Designs have been granted for freight cars, auto bodies, lamp shades, silver and china ware, oil cloth, ink stands, toys, and a great variety of other things, and even for machines. But there have been instances where the Courts have declared design patents invalid on the ground that the thing was not a proper subject for *ornamental* design.

(*To be Continued*)

# POWER-FACTORS OF ALTERNATING CURRENT CIRCUITS

By G. M. Brown and N. Shuttleworth

British Thomson-Houston Company

The authors have presented a very complete and interesting discussion of an important practical problem confronting the central station manager. Formerly, the question of power-factor was no problem because the loads were chiefly lighting or railway. However, the past ten years has seen a rapid industrial development. For all classes of this work, the induction motor has taken the lead until now we find on many systems that the induction motor load is larger than the lighting load. The authors have described English practice in particular. In America, both the synchronous condenser and phase advancer are in successful use. On this side we have been forced by our long high voltage lines to the general use of the synchronous condenser with its excitation under automatic control, this arrangement giving automatic voltage control as well as automatic phase or power-factor control. These machines are in operation in various sizes up to 15,000 kv-a. The phase advancer has only recently been developed in this country and reports on it are most encouraging. In early issues other articles will appear on these important subjects.—Editor.

The advantages to be gained by the use of electric motors driven by electric power from a central supply station are now fully recognized by the vast majority of power users. The results of this movement are evident in all directions, but more particularly so in the rapid extensions of municipal and other electricity generating plants and the great increase in the capacity of the generating units employed. The amounts of power distributed and the areas served by single generating stations have so increased as to make compulsory the adoption of polyphase alternating current systems of distribution even in cases where the continuous current system was originally contemplated and installed.

For the great majority of industrial purposes the alternating current induction motor is eminently suitable and its extended use has been due in no small measure to the rapid growth of alternating current supply systems and the natural desire to avoid the expense, complication and losses involved in the use of suitable transforming plant for the production of continuous current. The induction motor possesses, however, one great disadvantage from the point of view of the power supplier in that the current it draws from the mains includes a large wattless component which not only increases the losses in the generators and cables, but also makes the maintenance of a steady voltage at the consumer's terminals an expensive matter. As its name implies, this wattless component has no effect on the wattmeters by which the consumption of power is usually measured, and is not therefore in any way a disadvantage to the consumer who pays only for the power as measured by the wattmeter.

From the consumer's point of view the best motor is that which has the highest efficiency, an ample margin of power and a suitable speed for the purpose in view. An induction motor with such characteristics may have a comparatively low power-factor under normal conditions, and therefore the most undesirable from the power supplier's point of view; for high power-factors are generally only obtainable by sacrifices in efficiency and overload margin and at comparatively high speeds which may not be permissible or practicable for the applications in question. It is possible to improve the power-factor by reducing the clearance between the stationary and rotating parts, and therefore at the expense of reliability and durability, or by increasing the size and cost of the motor; so that unless some restriction is made by the power supplier it is not to the interest of the consumer to trouble about the amount of lagging or wattless current he may draw from the supply mains.

These points are well illustrated by the following figures for standard 400 volt three-phase slip ring induction motors.

| Size of Motor | Relative Amounts of Energy Recorded by Consumer's Wattmeter at | | |
|---|---|---|---|
| | 25 H.P. | 50 H.P. | 100 H.P. |
| 50 h.p., 725 r.p.m. | 30.7 | 60.4 | 118 |
| 100 h.p., 725 r.p.m. | | 59.8 | |
| 50 h.p., 360 r.p.m. | 31 | 61.2 | |
| 100 h.p., 360 r.p.m. | | 60.4 | 119.5 |

Apart from the prices of the motors, the consumer wishing to install an additional machine to deal with a load of 50 h.p. would find little in these figures to influence him one way or the other, and would probably decide on the motor with the most suitable speed and capacity to meet possible overloads. How his choice would affect the power supplier is shown by the following figures, indicating the relative losses in the supply main due to the lagging currents required by the various machines.

| Size of Motor | RELATIVE LOSSES DUE TO WATTLESS CURRENTS AT LOADS OF | | |
|---|---|---|---|
| | 25 H.P. | 50 H.P. | 100 H.P. |
| 50 h.p., 725 r.p.m. | 729 | 963 | |
| 100 h.p., 725 r.p.m. | | 2170 | 3250 |
| 50 h.p., 360 r.p.m. | 2210 | 2600 | |
| 100 h.p., 360 r.p.m. | | 4625 | 5820 |

The matter does not end here, for the power supplier has to provide plant to generate and transform these unprofitable lagging currents, which, were it possible to neutralize them, might be profitably employed in the further expansion of his business. Consider, for example, the case of a plant installed to deal with a load of 1000 kw., made up of motors, lamps, etc. Under normal conditions the power-factor of such a load would probably not exceed 0.7. From Fig. 1 it is clear that the generators, cables, transformers, etc., would have to be designed to deal with a load of 1430 kv-a., compounded of the useful load of 1000 kw. represented by $BC$ and 1020 kv-a. due to magnetizing and other lagging currents taken by the apparatus on the system and represented by $AB$.

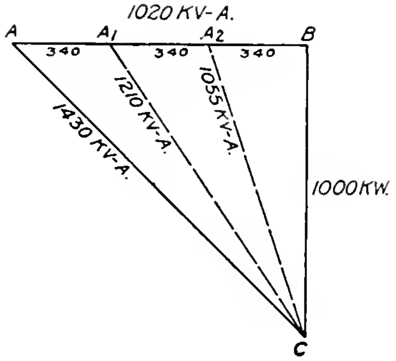

Fig. 1

If by suitable means one-third of the wattless load could be removed, leaving only the portion represented by $A_1B$, Fig. 1, that is 680 kv-a., the total load $A_1C$ would be reduced to 1210 kv-a. and the capacity of the plant might be reduced by not less than 15.3 per cent.

A further and similar reduction of the wattless load to 340 kv-a. ($A_2B$ Fig. 1) would result in a diminution of the resultant load to 1055 kv-a. ($A_2C$ Fig. 1), which would correspond to full load on a plant smaller by 26.2 per cent than that originally installed.

The total removal of the wattless component of the load of 1430 kv-a. at 0.7 power-factor would correspond to a reduction of 30 per cent in the capacity of cables, transformers, generators, etc.

The effect of the various reductions in the amounts of lagging current drawn from the mains may be summarized thus:

| | | | | |
|---|---|---|---|---|
| Useful load, kilowatts | 1000 | 1000 | 1000 | 1000 |
| Wattless load, kilovolt-amperes | 1020 | 680 | 340 | |
| Resultant load, kilovolt-amperes | 1430 | 1210 | 1055 | 1000 |
| Power-factor | 0.7 | 0.83 | 0.95 | 1.0 |
| Transmission losses | 1.00 | 0.71 | 0.55 | 0.49 |

It will be seen that there is no great object to be gained by the entire removal of the wattless component of the load. Assuming therefore that the removal of two-thirds of it is effected, the capacity rendered free for further expansion of business is 1403 − 1055 = 375 kv-a. and its capitalized value may be estimated as follows:

1. Extra generator capacity available 375 kv-a.

The capital cost may be taken from 15/- to £2 (approx. $3.75 to $10.00) per kilovolt-ampere according to capacity and speed.

2. Transformer capacity rendered available, 375 kv-a.

The capital cost per kv-a. may be taken at 10/- ($2.50) for transformers of large size and the value of extra capacity rendered available by improved power-factor will therefore be £187.10.0. ($910.00) if step-down transformers only are used, but will be £375 ($1820.00) if both step-up and step-down transformers are installed.

3. Transmission line capacity rendered available, 375 kv-a.

The saving effected in this direction is difficult to evaluate and at the least will be equal to the capital value of the copper required to transmit 375 kv.a. If by the improvement of the power-factor the necessity for laying an additional cable or an additional overhead line is obviated, the saving will be many times greater.

4. Switchgear capacity rendered available, 375 kv-a.

There will be a small advantage gained on this account which may be taken at, say £20 ($97.00).

The estimate therefore runs as follows:

| | | |
|---|---|---|
| By increased capacity of generators—high speed | £280 | |
| low speed | | £750 |
| By transformer capacity gained | 187 | 187 |
| By extra capacity of 1500 yd. of 3000 volt cable | 200 | 200 |
| By extra capacity of 200 yd. of 440 volt cable | 150 | 150 |
| By switchgear capacity gained | 20 | 20 |
| Total value of plant liberated for further expansion of business | £837 | £1307 |
| | $4050 | $6350 |

There will be further advantages gained through improving the power-factor in the improved regulation of the voltage and the higher efficiency of generators and transformers resulting from the elimination of the large wattless currents. Also, provided that the plant capacity thus made available can be utilized there will be an increased output without any increase in the standing charges for operating it, and consequently a reduction in the cost per unit generated. These gains will, however, be counterbalanced to some extent by the cost of running the apparatus required to produce the improvement in power-factor;—to what extent will depend largely on the nature and location of this apparatus, and therefore on the conditions under which power is supplied to the various consumers; but in any case it will be possible and advisable to offer a *substantial rebate* to those consumers who improve their power-factor to say 0.95 at full load.

Occasionally arrangements are made whereby the consumer pays, not for the true watts he uses, but for the apparent watts, that is, the product of volts and amperes. In cases of this kind it is evidently to the consumer's advantage to make every effort to reduce his current consumption to the lowest possible figure; a state of affairs which is realized when the collective power-factor of his equipment is unity, or at any rate not less than 0.95; but if, for instance, his average consumption of current corresponds to 100 kv-a. and the average power-factor is 0.7, by installing suitable apparatus to raise the power-factor to 0.95, he may reduce his average load to about 74 kv-a., including the small losses in the additional machinery. (Exactly how far it will be advisable to carry the rectification of the power-factor will depend on circumstances).

The various means of minimizing the cause of wattless current or producing wattless leading current to neutralize the wattless lagging currents required by induction motors, arc lamps, etc. are:

1. The installation of rotary converters for supplying those customers whose requirements are best satisfied with continuous current.
2. The installation of synchronous condensers.
3. The use of synchronous motors where possible.
4. The addition of phase advancers to large induction motors connected to the mains.
5. Static condensers.

The first method of improving the power-factor is not one that can be profitably adopted for several reasons, the principal one being that the alternating current induction motor complies quite satisfactorily with the requirements of the great majority of industrial applications, and so renders unnecessary the expense of installing and operating substations equipped with running machinery; and further, the amount of leading current that can be drawn from a rotary converter is strictly limited.

The British Thomson-Houston Company has installed in one of the substations of the Sheffield Corporation the large synchronous condenser illustrated in Fig. 2. This is a two-phase machine and is designed for an output of 600 kv-a. at 2200 volts and 50 cycles, the synchronous speed being 750 r.p.m. On one side there is coupled an induction motor capable of starting it with a comparatively small current and on the other side is a direct current exciter. In the immediate neighborhood of the substation there are consumers whose total day load averages 4000 kv-a. with a power-factor of 0.7. The actual load is thus 2800 kilowatts and the capacity of the synchronous condenser is 600 kilovolt-amperes, so that it is capable of reducing the apparent load to 3580 kilovolt-amperes and so releasing 420 kv-a. capacity in the generating plant and in the cables between the power station and the substation. The following table shows the improvement effected by this machine when the load is less than 1000 kv-a.

In this case the synchronous machine is designed to act purely as a generator of leading wattless current and the whole

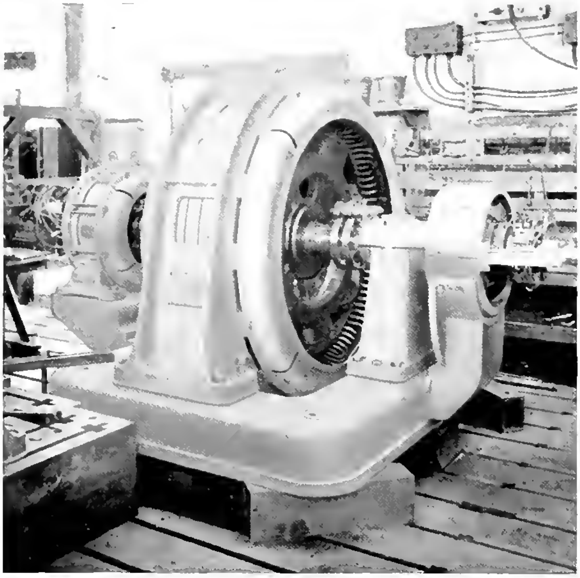

Fig. 2. 600 Kv-a., Two-phase, 2200 Volt Synchronous Converter Built by the British Thomson-Houston Co.

cost of installation and operation has been incurred on account of power-factor improvement; but in many industrial applications where a rebate could be granted to the consumer, advantage might be taken of this property of the synchronous motor at a comparatively small extra cost over and above that of a suitable induction motor. The question whether a consumer should in any given case install a synchronous motor and exciter in place of an induction motor depends entirely on his service requirements and the inducement offered him to incur the slight extra expenditure. The synchronous motor generally requires a large starting current, and is only capable of exerting a comparatively small starting torque; it is therefore only suitable when the starting conditions are *easy, or where it is possible to arrange to start light and apply the load by means of a suitable clutch after the motor has attained full speed; but it has the advantage that it can be constructed to draw leading currents of any desired magnitude no matter how small the mechanical load applied to it. Modern machines of this type are self-synchronizing and their control offers no special difficulties. They are generally started by means of a suitable auto-transformer, or compensator, and a switch for controlling the field excitation.

A group of three-phase motors of this type, built by the British Thomson-Houston Company, is shown in Fig. 3. These have each a capacity of 202 kv-a. at 500 r.p.m., with a working pressure of 400 volts and a periodicity 50 cycles per second. They are arranged for driving by belt, and as continuous current is available are not provided with exciters. When working under the best conditions each of these motors will give an output of 175 brake horse power and supply at the same time a leading current equivalent to 140 kv-a. which is sufficient to neutralize the lagging current required by induction motors having a total capacity of 450 h.p. To facilitate starting and reduce the starting current to a minimum, the rotors of these motors are provided with auxiliary squirrel cage windings similar to the rotor windings of ordinary induction motors. These special windings are shown in Fig. 4.

Where the conditions are such as to render a synchronous motor undesirable, or an induction motor is already installed, the phase advancer offers great advantages. By its use the power-factor may be raised to unity over a considerable range of load, and it may even be so proportioned as to cause the induction motor to draw a leading

| | Load in Kw. | Power-Factor | Load in Kv-a. | Kv-a. Supplied by Condenser | P-F. at Generator | Load on Generators Kv-a. |
|---|---|---|---|---|---|---|
| Without condenser | 1200 | 0.74 | 1620 | 0 | 0.74 | 1620 |
| With condenser . . | 1200 | 0.74 | 1620 | 630 | 0.93 | 1300 |
| Without condenser . | 1620 | 0.69 | 2350 | 0 | 0.69 | 2350 |
| With condenser . . | 1620 | 0.69 | 2350 | 610 | 0.84 | 1980 |

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*EDITOR'S NOTE: In American practice, certain applications of synchronous motors have arisen wherein difficult starting and running conditions have been successfully overcome. Among these cases may be mentioned the use of synchronous motors for driving line shafting, pulp grinders and pumps. In all of these cases the starting and pull in torque must be at least 40 per cent of the full load torque.

current from the supply mains and thus neutralize the effect of the lagging currents taken by other motors not provided with phase advancers.

Fig. 5 shows a British Thomson-Houston phase advancer with a capacity of 35 kv-a. at 750 r.p.m. It is a three-phase commutating machine designed for a full load current of 500 amperes and arranged for driving by belt from the shaft of the induction motor with which it is used or by a separate small motor, as may be more convenient. The power required is only that necessary to overcome windage and friction, and ranges from ½ to 2 h.p. according to the size of the phase advancer. In this particular case it is less than 1½ h.p.

The armature is similar to that of an ordinary continuous current machine and the stator is made with laminations after the manner of an ordinary induction motor, slots being provided for a suitable number of former-wound coils which ensure satisfactory commutation. The whole construction is even simpler than that of an ordinary continuous current motor.

This particular machine, when used in conjunction with an induction motor of 450 h.p., is capable of relieving the supply system of wattless current equivalent to 650 kv-a. and thus liberating plant capacity of a capital value of at least four or five times its own cost, which is approximately £250 ($1210).

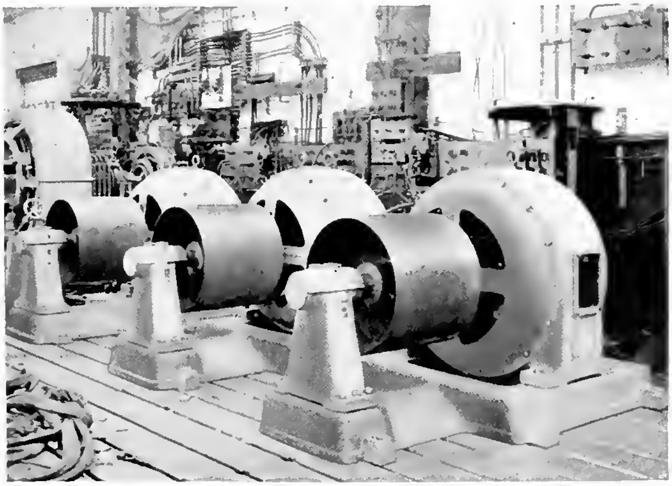

Fig. 3. Group of Three-phase Synchronous Motors Built by British Thomson-Houston Co.

The interaction between an induction motor and phase advancer is easily explained by a brief discussion of the principles involved. The principal cause of the comparatively low power-factor of an induction motor is the magnetizing current required to produce the working magnetic field of the machine. This current lags 90 deg. behind the working current, and were its neutralization possible the power-factor of the induction motor would at once be raised practically to unity, while over-compensation would result in the replacement of the lagging magnetizing current by a leading current which would be effective in neutralizing the lagging currents taken by other machines not provided with means for effecting such compensation. As far as the production of the working flux is concerned it is evidently immaterial whether the necessary magnetizing current passes through the stator or the rotor windings, and evidently it can be caused to pass through the rotor circuit if a suitable electromotive force is introduced in that circuit. On account of the much lower frequency in the rotor circuit a very much smaller electromotive force will be necessary to produce the magnetizing current in the rotor windings than is required to make it flow through the stator circuit at the full frequency, and the kilovolt-amperes it represents will be proportionally reduced. The function of the phase advancer is to provide a suitable electromotive force for this purpose, which it does in the following manner:

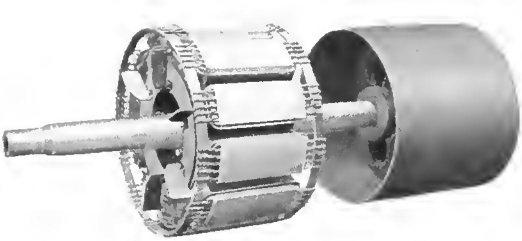

Fig 4. Revolving Field of Motors of Fig. 3, showing Amortisseur Winding

The rotor current flows through the phase advancer and the rotation of the armature in the flux so produced results in the generation of an electromotive force differing in phase from the current. This electromotive force is of the correct phase for producing the desired magnetizing current component in the rotor circuit of the induction motor; but its magnitude is evidently dependent on the design and capacity of the phase advancer and the load on the induction motor. If the electromotive force generated by the phase advancer is insufficient to force sufficient magnetizing current through the rotor windings, the deficiency must evidently be made good by lagging current flowing through the stator windings and drawn from the supply mains, but if on the other hand the electromotive force generated by the phase advancer is sufficient to force more than the necessary magnetizing current through the rotor windings the excess must be compensated by an opposing and therefore a leading component of current in the stator circuit. In other words the phase advancer may be designed to produce either lagging or leading currents in the stator circuit, and since it is excited by the rotor current it is evident that at light load when the rotor current is small its effect will be much less than at full load when the rotor current, and therefore the flux in the phase advancer, is large.

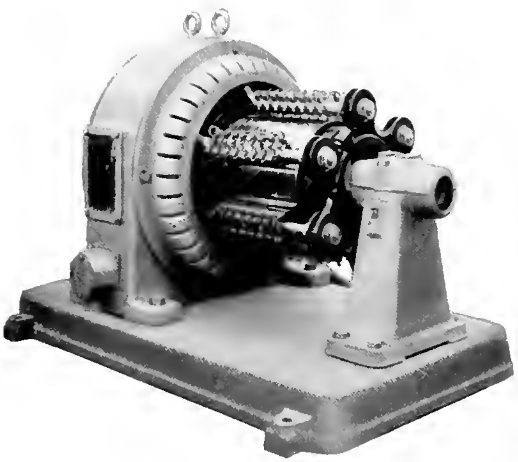

Fig. 5. Phase Advancer Manufactured by British Thomson-Houston Co.

In Fig. 6 are shown the results of tests with a phase advancer and a 10 pole, 450 h.p., 25 cycle induction motor. The normal power-factor without phase advancer is indicated by curve A, and the power-factor with the phase advancer in circuit and driven at a speed of 400 r.p.m. by curve B. Curve C shows the results obtained by introducing a higher electromotive force into the rotor circuit, the increased electromotive force being obtained by increasing the speed of the phase advancer to 600 r.p.m.

In the design of the British Thomson-Houston phase advancer special attention has been paid to commutation and provision made to ensure practically perfect operation. It is thus possible to use graphite brushes, which maintain a highly polished surface and reduce wear and tear of the commutator, and therefore attendance and maintenance, to a minimum. The low voltage at which the machine works and the simplicity of its construction are other factors in its favor. Further, as the electromotive force it generates differs in phase from the current by 90 deg. it exerts no torque either as a motor or a generator and the power required to drive it is simply that necessary to overcome friction and windage. Thus should the drive fail for any reason, there is no danger of the machine racing to destruction.

In addition to improving the power-factor, the phase advancer very greatly increases the maximum torque that can be exerted by an induction motor—a feature which is of great importance in a drive subject to large momentary overloads. The losses in the phase advancer, which are extremely small, are sometimes more than compensated for by the reduction of the losses in the induction motor, which can often be made considerably smaller than would be the case were it to be used without such an auxiliary.

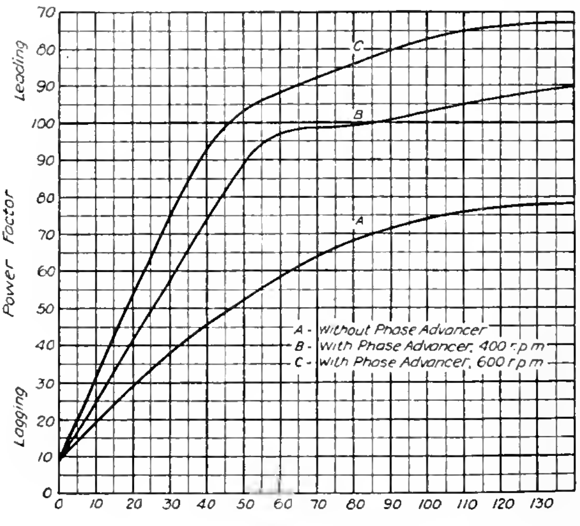

Fig. 6. Results of Tests on 450 H.P. Induction Motor with Phase Advancer

The method of starting an induction motor is not materially altered by the addition of a phase advancer. If the latter is driven from the shaft of the induction motor, the only addition necessary is a triple-pole change-over switch, the blades of which are connected to the slip rings as shown in Fig. 7. The contacts on one side are joined to the starting rheostat and on the other side to the phase advancer, and an interlock should be fitted to prevent any attempt to start unless the slip rings are connected to the rheostat. As soon as the induction motor has been brought up to full speed in the usual way the phase advancer should be thrown into circuit by means of the change-over switch. If the phase advancer is driven by a separate motor, the starting switch for the latter should be interlocked with the main motor switch and the change-over switch in such a manner that the main motor switches cannot be closed until the phase advancer has been started. This requirement offers no difficulty and does not involve any appreciable complication. The cable between the slip rings of the induction motor and its phase advancer should be liberally proportioned and kept as short as possible.

The rotor currents of induction motors of small and medium sizes are proportionally greater than those of motors of large power, and as the price of a phase advancer depends almost entirely on the rotor circuit it has to carry, it is evident that phase advancers for use with small motors will be relatively much more costly than those intended for use with machines of greater capacity. It is therefore not advisable to consider the addition of a phase advancer to each of a number of small motors, but rather to install a synchronous condenser or equivalent device capable in itself of supplying the leading current necessary to compensate the lagging currents drawn by the small machines. At constant excitation such a machine will supply a practically constant leading current, whereas the leading current component due to the use of a phase advancer is almost proportional to the load on the motor to which it is attached, and in this respect it differs from both synchronous machines used as rotary condensers and from static condensers.

The lagging currents required by small induction motors may conveniently be neutralized by leading currents supplied by static condensers connected across their terminals. If such a condenser is capable of supplying just sufficient leading current to produce unity power-factor at full load it will also maintain practically unity power-factor at all smaller loads; so that from this point of view there is nothing to choose between static and rotary condensers except as regards cost.

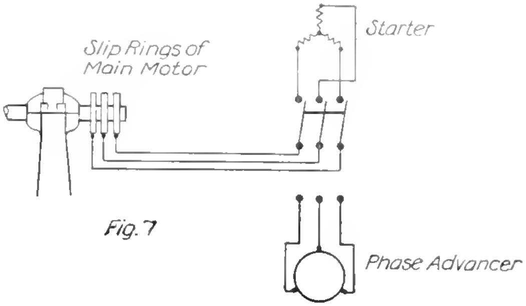

Fig. 7. Connection Diagram of Phase Advancer

The cost of such a machine as that installed in Sheffield may be taken as £2 ($10) per kilovolt-ampere, which is less than the cost of static condensers; but in an installation consisting of a few small induction motors it is possible that the positions would be reversed and the capital cost of suitable static condensers be less than that of a synchronous condenser of the same kilovolt-ampere capacity. As already pointed out, the cost of phase advancers for small induction motors is likely to be excessive, but where large machines are available the cost should not exceed 10 - ($2.50) per wattless leading kilovolt-ampere in the primary circuit. In fact, it has been seen that the phase-advancer described above costs rather less than 8 - ($2.00) per kilovolt-ampere. A synchronous motor working under the most favorable conditions, that is, at 0.7 leading power-factor and a reasonable speed, should not involve an expenditure of more than £1.5.0 ($6.00) per kilovolt-ampere of leading wattless output. In any case it is fairly evident that if a customer of electricity can obtain a rebate of 5 per cent by improving his power-factor to 0.95, the cost of the necessary apparatus will be saved in three or four years. The consumer who generates his own power will benefit to a larger extent by the improved conditions of operation, especially if his establishment contains a number of motors which are only called upon to exert their full powers for very short intervals during the working day.

# RECORDING DEVICES

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

Early in this article the author points out clearly the necessity for keeping a careful record of the details of operation in a power station. Human observations are faulty; and for the best results, therefore, it is necessary to install those types of recording devices which are most suited for the purpose. A description of the advantages and limitations of the disk, tape, photographic film, and multi-recording devices is then given. A very interesting set of analyses regarding the cause of a disturbance upon a transmission line, which has been assumed by way of example, shows the variance of the conclusions which may be arrived at without the assistance of automatic recording devices. This article was delivered as a paper before the Mid-winter Convention of the A.I.E.E., Feb. 27, 1914.—Editor.

While the keeping of records is essential in any business, it is especially important in the operation of electrical systems, and thus records have always been taken of voltage, current, power, of the time of starting or stopping generators, etc., in electrical systems.

Perfect reliability, however, can be secured only by automatic recording devices.

For instance, where it is the duty of the station operator to keep constant voltage, the voltage record made by noting down the voltmeter readings at constant periods of time would probably show uniformity, while an automatic recording device may show bad fluctuation between these times. A protection against neglect or carelessness of taking records, and a check on the operating force, is afforded only by automatic recording devices. But especially when things go wrong, when accidents happen, and the necessity of action interferes with careful observations, the human machine more or less breaks down and only automatic devices are reliable in recording the events.

Automatic recording devices are therefore extensively used: Revolving-disk recording voltmeters, ammeters, thermometers, steam flow meters, etc.; curve drawing instruments; the oscillograph.

In the revolving disk recording meter, a 24-hour, or 12-hour record is made on a circular chart. The shortest time interval which can, under industrial conditions, be accurately noted on these instruments is not much less than a quarter of an hour. Where the quantity changes slowly, as the temperature of a room, a clear chart is given. Where, however, more rapid fluctuations occur, as with current and often with voltage, the chart shows only a broad blur, and neither the individual variation nor the sequence of events can be seen, but merely the maximum and the minimum values estimated.

Curve drawing instruments, in which an endless tape moves with greater or less rapidity, in front of the recording pen, are used for records of more rapidly changing events, as current, voltage, speed, acceleration of a rapid transit train cycle, etc. But to take a continuous record of an interurban railway substation by a curve drawing instrument, moving sufficiently rapid to show all the fluctuations, would be feasible only in special investigations; but the enormous length of the record would exclude it in commercial operation.

One of the most rapid recording devices is the oscillograph and its use has been of material assistance in electrical development, for instance in giving information on momentary short circuit currents of alternators, on the performance of circuit breakers and other problems, upon which information could be derived in no other way. But the taking of a continuous record of station operation by oscillograph obviously is out of the question.

While automatic recording devices are necessary in the normal operation of electric systems, they are still much more essential under abnormal conditions, when things go wrong, and accidents happen. Usually no serious difficulty exists in designing apparatus to operate satisfactorily under normal conditions; also no serious difficulty exists in operating a system under normal conditions, but to meet the abnormal changes of accidental conditions is the serious problem of the electrical designer and of the station operator.

We really know relatively little of the abnormal conditions which are met in electrical operation, and most of our knowledge is rather theoretical, representing what might happen; but exact information of what actually happens is extremely limited. When some accident happens, whether it be the failure of a transformer, or the shut-down of a big system, usually an investigation is made, reports called for, and the witnesses cross examined. But the information gleaned from these examinations is practically always unsatisfactory and incomplete. Frequently no trained observer was present, or so many things happened almost simultaneously, that most of them could not be observed. The circumstances are very unfavorable for exact observation. The necessity of immediate action excludes close observation and almost always excludes immediate noting of the observations, so that the record must be based on the memory of the observer, which is not very reliable in times of excitement. The personal element also comes in, the natural tendency of avoiding personal responsibility for the accident. The sequence of the events, which is all important for the understanding of their cause, is rarely noted in the excitement, and thus such examination hardly ever definitely fixes the cause of the accident, without the necessity of very extensive guessing of more or less questionable reliability. It is, however, of the greatest importance to the operator as well as the manufacturer of the apparatus, to know exactly what happened, so as to guard against its recurrence, and to fix the responsibility.

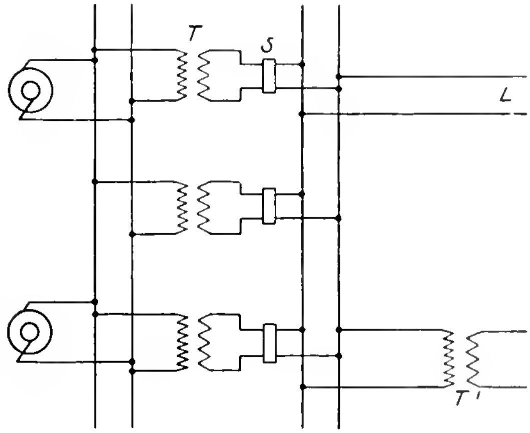

Fig. 1. A Diagram of a Transmission System in which Trouble is Assumed to have Taken Place at T, S, L and T'

For instance, in a large high voltage transmission system, partly illustrated diagrammatically in Fig. 1, a big transformer *T* in the generating station, a high-tension switch *S* in the generating station, and a transformer *T′* at the end of a branch line are destroyed. At the same time a flashover occurs on the transmission line *L*.

Postmortem examination of the transformer showed numerous arc burns on coils and on the tank, and the coils badly deformed and bent out of shape. Questioning of the operators elicited the information that lightning had been frequent during the period preceding the accident. One operator believes to have noticed static in the station for some time before the accident. It is suspected that numerous short circuits have occurred in the lines during the weeks preceding the accident.

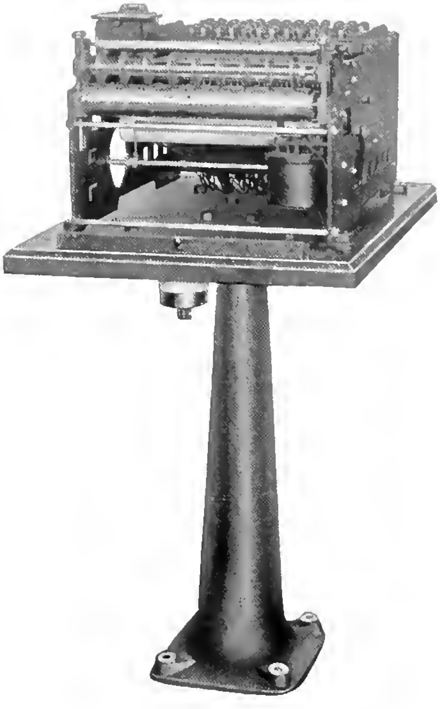

Fig. 2. A Fifty-Point Multi-Recorder

This information is altogether too meager to find out beyond doubt what actually happened. We can only theorize what may have happened, for instance:

1. An arcing ground occurred on the line *L*, producing moderately high frequency—a few thousand cycles. This lasted for some time, possibly hours, until the high frequency broke down somewhere, either by electrostatic heating of the insulation, or by the continual impact of the oscillation. It broke down to ground in the station transformer *T*, and thereby caused a short circuit through transformer *T* and line *L*. The high tension

switch $S$, in attempting to open this short circuit, failed due to the excessive current and the superposed high frequency oscillation, burned up and so created a dead short circuit at the transformer terminals. The mechanical magnetic forces, resulting therefrom in the transformer, moved the coils. The shock of the short circuit broke down the transformer $T'$ at the end of the branch line.

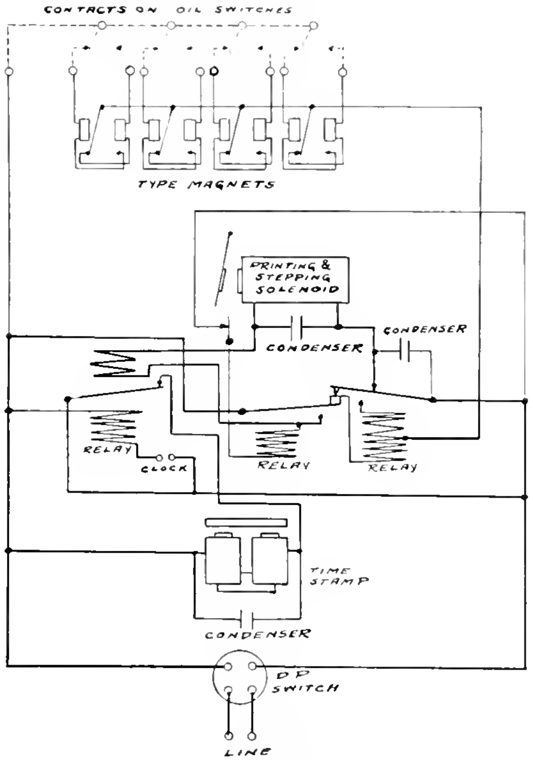

Fig. 3. Simplified Wiring Diagram of a Multi-Recorder

2. Numerous flash overs had occurred during the preceding weeks in the transmission lines, resulting in heavy short circuits. While the transformers were strong enough to stand occasional short circuits, the short circuit stresses were so enormous that continual short circuits gradually impaired and finally broke down a transformer $T$. This resulted in the destruction of the circuit breaker $S$, the failure of the second transformer $T'$ etc.

3. Lightning entering the line $L$ started a high frequency cumulative surge in the transformers, producing spark discharges between the coils. The same or another lightning stroke flashed between the lines, caused a short circuit, resulting in the destruction of the circuit breaker. The spark discharge in the transformers finally led to short circuit, which distorted the transformer coils.

4. An internal oscillation in the transformer, due to entrance of high frequency lightning, or resulting from an arcing ground on the line, caused spark discharges in the circuit breaker, leading to its destruction. The short circuit resulting therefrom moved the transformer coils and brought them sufficiently near to either end of the tank to cause arcing over, with the resulting destruction of the transformer.

Numerous other combinations of the phenomena could still be devised, to account for the accident, for instance, the transformer $T'$ at the end of the branch line may have broken down first, and the accidental arc may have produced the high frequency, which damaged the circuit breaker and main transformer, and flashed over the transmission line, etc. But whether the trouble started with a high frequency oscillation in the transformer, or resulted from a high power short circuit, or from lightning, or from an arcing ground on the line, or from a combination of two cases, as high frequency oscillation and short circuit cannot be obtained from the available sources of information. Neither can it be determined whether the transformer was mechanically too weak to stand a short circuit, or whether it was weakened by frequent short circuits combined with high frequency disturbances. It is, however, of importance to the manu-

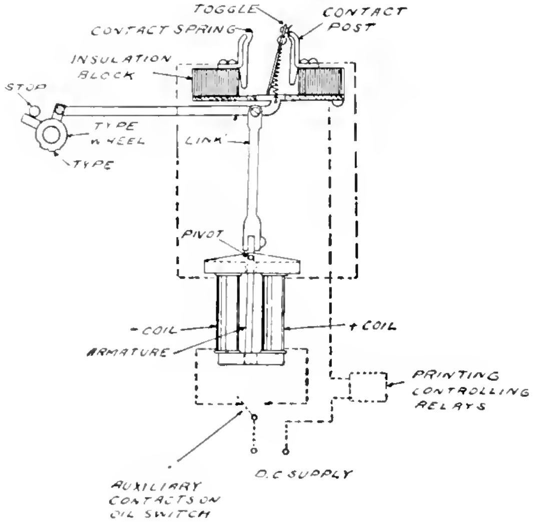

Fig. 4. Mechanism for Operating Type Wheels

facturer to fix the responsibility, and to know whether the transformers are mechanically too weak and should be made stronger, and correspondingly more expensive, or whether and what additional protective devices should be developed. And it is of still greater importance to the operating companies to take such steps as will insure reasonable reliability of operation.

If automatic recording devices would show what happened and the sequence of the happenings, whether the trouble started with lightning, or with an arcing on the line, or a line short circuit and how this originated, or a transformer surge in the generating station or the branch line, etc., then in most cases the phenomena could be exactly determined and with reasonable certainty precaution against their recurrence taken. Also, less difficulty would usually be experienced in fixing the responsibility on the manufacturer of the apparatus, or on the operating engineer, or on *vis major*. As it stands at present, the transformers are rebuilt with greater mechanical strength, and damping devices against transformer surges installed, and it is "hoped" that the phenomena against which these guard were the causes of the trouble, but we cannot possess the confidence that the same will not happen again, and if similar troubles do occur again, it merely means that some of the other various possibilities were the initial cause of the trouble, and that the remedy would lie in the installation of an arcing ground suppressor, or in grounding the neutral, or in disconnecting the grounding of the neutral, or in reducing the sag of long spans to eliminate the swinging together of the lines, or in adding another disk to the suspension insulators, or in better weeding out defective insulators by high frequency testing, etc.

Numerous such instances could be given. Thus, in underground cable systems, breakdowns occur frequently in groups, or practically simultaneously, and it is difficult to determine which cable started the trouble. For some time, often days, troubles with feeders may have preceded the break down, and if properly recorded, would explain its cause and so give a greater probability of guarding against its recurrence, etc.

The difficulty or impossibility of getting complete and exact records of what happens in electrical systems, and of the sequence of the events, is the most serious limitation, at present, to providing protection to such systems.

Automatic recording devices thus are of the greatest importance for the safety of operation of a system, especially where reliability is important. However, in case of trouble, the sequence of events commonly is so rapid, within seconds or less, that such devices must be capable of recording within fractions of seconds. The dial instruments, like the revolving disk recording meters, therefore, are out of the question, as they show everything within a few minutes as simultaneous. Curve drawing instruments would have to run the tape rather rapidly. If we assume that 50 records are needed, and allow between 1/8 and 1/4 in. per second as the minimum, about 15 miles of tape would be unrolled per day, and to look all this over to see the records obviously is impossible, especially when it is desirable to go back for weeks to see what has preceded. With phenomena like lightning, where several strokes may occur in one minute, and then no record for weeks or months, obviously any recording device with continuously moving tape is impracticable. Where records are made at more or less infrequent intervals—sometimes, as with circuit breakers, at fairly regular intervals, and sometimes, as with lightning discharges, at very irregular intervals—an instrument in which the tape does not continuously move, but, as in the typewriter, moves only when making a record, is essential.

To give reasonably complete information on the station performance under normal as well as abnormal conditions, records are required of the closing and opening of every circuit breaker, of the operation of the lightning arresters, of the appearance and duration of high frequency in the lines, of grounds and short circuits, possibly of excess currents, of overnormal and subnormal voltage, frequency, etc., etc. Considering then, that even a small station may connect two or three lines, and each line has three phases, and a separate record of each phase is necessary, it is obvious that a considerable number of records is needed. With a record sheet, moving only whenever a record is made, 50 records can easily be taken on the same sheet, and a 50 point multi-recorder thus appears as a convenient unit. In such a device, a sensitivity of at least 1/4 to 1/2 second is desirable, so that phenomena following each other at intervals of 1/4 second or more, are separately recording, while everything which occurs within 1/4 second appears as of the same time. Such high sensitivity is desirable to get the sequence of events which to the observer may appear simultaneous, as the break down of a number of feeders, etc. At the same time, such great rapidity of action requires a powerful mechanism and when considering that the operating mechanism must be capable of working very many thousand times without failure by wearing out, the problem in the development of such an automatic multi-recorder was rather a difficult one. Also, when a record comes in within less than $^1{}_4$ second from the preceding one, while the record sheet is still moving in receiving the previous record, the second record would blur, but this difficulty thus has to be overcome by retarding the second record until the taps have come to rest.

On such a multi-recorder print, one record point should be reserved for recording standard time at fixed intervals, thus giving the time correction of the clockwork which operates the recorder, so as to make it possible to record the sequence of events occurring almost simultaneously in distant stations and noted on different multi-recorders.

A description of this instrument is given by Prof. E. E. F. Creighton, in the A.I.E.E. Transactions, Vol. XXXI, 1912, p. 825.

# THE DEVELOPMENT OF ELECTRIC TRACTION

## By John R. Hewett

The urgent need for more rapid and better means of physical communication between nations and between sections of the same country has been responsible for the development of our modern transportation systems, to the extent where they have become absolutely indispensable to our present modes of living. Transportation requires energy, and there are only two suitable forms of energy that can be economically transported or transmitted to a distance from the source, electric energy and the chemical energy of coal. The flexibility and simplicity of the former and its ready and efficient conversion into mechanical energy render it greatly superior for almost all cases of energy transmission. The question of the electrification of steam railroads, however, is one of pure economics—whether it is cheaper to build a distribution system for the whole length of the line, or to carry the fuel and converting apparatus along with the train in the shape of a steam locomotive. A brief review is made of existing systems of electrification, and an argument is advanced to show that the so-called "Battle of the Systems," instead of hindering development as is contended by some, must of necessity work to its advantage, as only by attacking the problem from all sides can the best of which the art is capable be produced.—Editor.

The steam railroad is just about a century old and the electric railway about a quarter as old, and when we think of the astounding developments that have taken place in this comparatively short space of time, we can hardly refrain from asking ourselves why this development has come about. The answer to this question would seem to be that the civilization of the world is absolutely dependent upon rapid communication between man and man—the communication of thoughts and of material matter. The invention of the steam engine and locomotive pointed the way and then, with the introduction of the electric telegraph and the submarine cable, the different peoples of the world became so much more closely connected in thought that the general extension of a more rapid means of physical communication seemed imperative. The stage coach on land and the sailing ships on the seas had to be replaced by quicker methods of communication. It was about the beginning of the nineteenth century that people began to recognize that the country which developed the best means of rapid communication with other countries would be the leader in the commerce of the world—those that had most ships would control the seas and the markets of the world; and, similarly, that it was only those countries that developed an efficient system of land transportation that could develop their natural resources and consequently become manufacturing countries.

The recognition of these great economic truths came about just at a time when the whole world had been well nigh torn asunder and rent by a series of wasteful and disastrous wars. In looking back at the history of this period, the development seems miraculous. All sections of the civilized world would seem to have taken on a new form of life, and commerce became to be recognized as a better trade than war. The development of better means of communication aided the rapid spread of civilization and the spread of civilization stimulated industrial developments of all kinds. Thus was started an action and a reaction which has been continued up to the present time, with the result that today a man living in New York knows more about the capitals of China and Japan than his grandfather knew about many towns scarcely a hundred miles from his own door, and that each of us individually today are virtually in connection with the whole rest of the world. It is easier to make a trip around the entire globe today, in comfort and in luxury, than it was to travel from one end of New York State to the other, at the cost of hardships and dangers, a hundred years ago.

These developments have absolutely changed our modes of living and during the transition stage one thing of vital importance has happened, viz., we have let these means of communication become our masters as well as our servants. When we stop to consider the enormous populations congested into our large cities, and the distances from which their daily food supplies have to be transported, it is apparent that our means of communication are the masters of the situation. Should they for any reason fail to fulfill their functions in the community for even a brief time, it would spell death by starvation to hundreds and thousands of human beings.

So in this brief period of one century we have built up a set of conditions that has so complicated our modes of living and increased our dependence on the labors of others, living at a great distance from us, that now our transportation facilities have become just as much one of the necessities of life as are food and clothing. The character of our transportation systems has thus become a matter of national importance.

It was long after this civilizing movement had set in and become well established that the electric railway made its appearance. In fact, it is just about twenty-five years ago that Sprague, Van Depoele, Daft and Bentley-Knight, amongst other energetic pioneers in the industry in this country, began to show the possibilities of this new mode of traction. In this short space of time electric traction has not only become well established, but has grown to be one of the most important industries in the country. In the last twenty-five years electric traction has, practically speaking, superseded all modes of transportation for city, suburban and interurban service, including elevated railways and subways. A whole paper could be written with profit to show the advances that have been brought about in our social status by the electric railway. There are few who realize how much the public and especially those interested in real estate have benefited by the enterprise of those who have been responsible for the building of our electric railway systems, but we have not time to go into this phase of the subject here.

It seems today that the field for electric traction is as broad as the traction field—that is to say, that it has been developed to a stage where there are no longer any technical limitations to its adoption on every railroad in the country. The traffic could be handled electrically and the considerations which govern the choice between steam and electric traction are financial and economic, not technical. Within the last decade, we have seen many notable examples of the electrification of steam railroads, and judging by the general interest that has been awakened in railroad circles and the recognition of the splendid service being performed by those electric installations already made and the economies secured by their adoption, we shall see many more examples of steam railroads adopting electric traction during the next decade.

All modes of traction depend primarily upon energy, and whether steam or electric traction ultimately becomes universal depends upon the relative economic values of the form of energy used. It should be noted here that of all the forms of energy available, only two are generally considered for traction purposes, viz., the chemical energy stored in coal and electric energy. Dr. Steinmetz in a paper before the Franklin Institute has recently pointed out the reason for this, viz., because they are the only two forms of energy that can be economically transported or transmitted over long distances. The two following paragraphs are taken from Dr. Steinmetz's recent paper:

"Electrical energy can be transported or, as we usually call it, transmitted—economically over practically any distance. Mechanical energy can be transmitted over a limited distance only, by belt or rope drive, by compressed air, etc.; heat energy may be carried from a central steam heating plant for some hundred feet with moderate efficiency, but there are only two forms of energy which can be transmitted over practically any distance, that is, which in the distance of transmission are limited only by the economical consideration of a source of energy nearer at hand—electrical energy, and the chemical energy of fuel. These two forms of energy thus are the only competitors whenever energy is required at a place distant from any of Nature's stores of energy. Thus, when in the study of a problem of electric power transmission we consider whether it is more economical to transmit power electrically from the water power or the coal mine, or generate the power by a steam plant at the place of demand, both really are transmission problems, and the question is whether it is more economical to carry energy electrically over the transmission line, or to carry it chemically, as coal by the railroad train or boat, from the source of energy supply to the place of energy demand, where the energy is converted into the form required, as into mechanical energy by the electric motor or by steam boiler and engine or turbine.

"Electrical energy and chemical energy both share the simplicity and economy of transmission or transportation, but electric energy is vastly superior in the ease, simplicity, and efficiency of conversion into any other form of energy, while the conversion of the chemical energy of fuel into other forms of energy is difficult, requiring complicated plants and skilled attendants, and is so limited in efficiency as to make the chemical energy of fuel unavailable for all but very restricted uses: heating and the big, high-power steam plant. To appreciate the complexity of the conversion of the chemical energy of fuel, compared with the simplicity of electrical energy conversion, imagine the domestic fan motor with coal as source of energy: a small steam engine, with boiler and furnace, attached to the fan: to start the fan, we have to make a coal fire and raise steam to drive the engine. This illustrates how utterly unavailable the chemical energy of fuel is for general energy distribution. Generally energy distribution, therefore, may justly be said to date from the introduction of electric power."

From the foregoing it will be seen that electrical energy and the chemical energy stored in coal are the only two available sources of energy for traction purposes, and that in the case of coal we have to carry our fuel and generating apparatus adding enormously to the weight of the moving element and consequently to the cost of transportation, while in the case of electrical energy, there is no fuel or generating apparatus to be transported. This gives electric transportation a tremendous advantage, but at the same time it must be remembered that in the case of electric traction we have to provide the means for supplying the moving elements with a continual supply of energy, which means the construction of a trolley system or third rail for the whole length of the line.

The general extension of hydro-electric developments which is fast covering the country with a network of high tension transmission lines is making a source of cheap energy available in many localities. This development will prove quite an asset to many roads who would rather buy than manufacture their own power.

In the case of electric traction, the range of energy supply is very flexible—we have the whole resources of the power house available—while with steam traction, if we want excessive power for only a short distance we have to transport sufficient generating apparatus and fuel all the time we are working at light loads.

So the question of the electrification of steam railroads resolves itself to a question of whether it is cheaper to build a system for the distribution of energy for the whole length of the line than to carry the fuel and generating apparatus along with our freight and passenger trains.

This is absolutely a question of economies, and will be settled as such in each individual case after a careful analysis has been made of the individual requirements.

If the traffic was sufficiently dense, it would always pay to electrify a railroad, because the economies to be secured by electric operation would more than offset the interest to be paid on the initial expenditure, but where the traffic is scarce and the length of the line is long, that is to say, where the initial cost of electrification and the cost of operating and maintaining permanently an extensive system of energy distribution would be great, in comparison with the cost of hauling the fuel and generating apparatus along with the train, then steam traction is still the most economical.

We have many examples of steam railroads with dense traffic that have made or are contemplating the change from steam to electric traction to secure these economies, and also many special cases where electrification has come into being to secure some special economies or overcome some special conditions, such as the abatement of smoke in terminal stations, etc.

The analysis of operating conditions to determine whether it would be economical to electrify or to continue steam operation is becoming an important branch of the engineering profession. There are today many instances where electrification would pay, but where difficulty would be found in financing the undertaking. When some of the roads that are contemplating electrification have done so and have gained the experience from actual practice, it is likely that other roads will follow their example and that the electrification of our steam railroads will become one of the large electrical industries of the country.

When an analysis of the conditions in any particular instance has shown that electrification would be economical, we still have to determine which of the available systems of electrification is best suited to the requirements. This is purely a question of economics, and here again is the necessity for a careful analysis to determine the most economical way of distributing the expenditures to be made in the initial construction, the operation and the maintenance of the system.

For example, when the traffic is very dense, and where cars or trains of moderate size have to be run at very frequent intervals and the total energy used at any one instant is not very greatly in excess of the average load, then standard 600 volt apparatus has no equal. There is no objection to the heavy outlay in substation apparatus and feeder copper when such apparatus will be in operation at an efficient load factor for a good percentage of the twenty-four hours.

It is when the load is such that the cost of copper and of the machinery installed in the power house and substations is excessive, and the percentage of time that they will be working at anything like an efficient load factor is small, that we look about for ways and means of reducing the amount of machinery necessary and of increasing the time that it will be in actual use. As a matter of fact, these conditions are just what exist on most systems where electrification is contemplated, and it is to meet such conditions and make electrification an economic possibility that the high voltage systems, viz., the three-phase system, the single-phase alternating current system and the 1200 and 2400 volt direct current systems have been evolved; in other words, higher voltage is an economic necessity to avoid excessive expenditure in copper and in machinery which would only be working at part or no load for a great percentage of the working day.

The three-phase system has found but little favor up to the present in this country, while it has been very extensively adopted in Europe; but there is one case, viz., the electrification of the Cascade Division of the Great Northern Railway, where such a system has been in successful operation for some years in this country. It would seem in the light of our present knowledge that such a system, at least for conditions as they exist in this country, is likely to be confined to mountain grade work where the advantages of regeneration can be secured. On the other hand, as the high potential direct current system has been developed with these same features, there seems little to warrant the additional complication of the three-phase trolley.

During the last decade the relative merits of single-phase alternating current and high potential direct current systems have been freely discussed, and many examples of each system have been installed and have been operated for a sufficiently long period to enable a logical opinion to be formed as to their relative merits. It would be impossible to enter into a detailed discussion of this phase of the subject in a paper of this length, but judging from the results of operation, as published, and the number of single-phase interurban roads that have been changed from single-phase alternating current to direct current, and from the number of direct current roads now in successful operation, and the fact that no roads adopting higher direct current potential have changed, and the present ratio of alternating and direct current work now under construction and contemplated, it would seem safe to infer that at present, at least, the higher potential direct current road has a decided advantage over all other systems for heavy traction work.

What the future has in store no one can say. The alternating current system or some modification of it may be developed along lines that will enable advantage to be taken of its good features, and its inherent limitations to be overcome. And again, new modes of power transformation may come into use such as rectifying alternating current to direct current when the advantages of the alternating current secondary distribution could be combined with the excellent characteristics of the direct current railway motor. But if we start speculating on the future, there is no limit to the range of our imagination.

There has recently been said, both in the technical press and elsewhere, a great deal about what people are pleased to style "The Battle of the Systems." Some people have taken the attitude that electric railway developments have been hindered because all manufacturers of electrical apparatus are not agreed upon the best system for heavy traction purposes. Such people are prone to infer that such a condition of things is hindering development and that the manufacturers are responsible for this condition. As a matter of fact, such differences of engineering judgment, when there are several different methods of attacking a problem, must, in the long run, be beneficial to the railroads rather than harmful, as without such differences of judgment, the possibilities of the art can at best be but imperfectly developed. When any art has been developed to a reasonable state of perfection and the fundamentals have been well considered and thoroughly tried, and after the process of eliminating the less suitable factors and perfecting those which have shown themselves capable of meeting the necessary demands, under actual service conditions, has been carried to the point where our knowledge, based on experience, enables us to retain the good and reject the bad, then and not until then, is the time to talk of standardization. An attempt at standardization when an art is in a more or less embryo state is likely to work a permanent harm inasmuch as it limits our knowledge of the broader engineering possibilities that might be brought to bear upon the subject. This question is of such importance today that it is worthy of consideration from both sides.

This so-called "battle of the systems" today is, as we all know, applied to heavy traction between single-phase and high voltage direct current. Briefly, there are two courses open: to attempt to standardize one, or to try both. First, let us imagine that we are living under such conditions that an imperial edict has been issued that single-phase is par excellence and that henceforth every railroad in the country that wishes to be electrified must use this system. This is not very far from what has happened in Germany. The first fruits of such a condition might possibly be that a great amount of talent would be focussed upon one subject and that developments along certain limited lines might be stimulated. Also, the customers or railroads would be relieved of any worry concerning the selection of the correct system. There would be no choice in the matter: they must take what was presented or leave it. Under such conditions, the field of research and development would be limited to such an extent that any inherent limitations in this one system of electrification would literally form a stone wall across the paths of progress. If there are inherent limitations in any system and we insist on its adoption, we are hindering rather than helping the permanent sound progress of the art. On the other hand, when there are two or more systems that are recognized as competitors, and there are, as it were, opposing camps, one side championing one system and the other side championing the second system, we are building on broader foundations. As a matter of fact, the battle of the systems is merely a bogy—the selection of the best electrical apparatus to meet the service conditions in any particular case is the settlement of engineering details—not the adoption or rejection of a system.

There are some engineering firms that have thoroughly tried out all the apparatus which has been developed up to the present time, and their judgment in these matters is tempered by experience and costly tests, and the railroad companies are getting the benefit of this experience.

The development of the higher potential direct current railroad is of peculiar interest, as the apparatus used has gone through such a logical sequence of evolution. It is just about a decade ago that we began to recognize that 500 or 550 volts was no longer the standard potential for railway work. The voltage had gradually been raised from these figures to 600 volts until there were more roads operating on 600 volts than at any other potential. When this condition was recognized, 600 volts was talked of as the standard. The evolution from 500 to 600 volts was largely brought about by a gradual increase of the traffic on existing systems, the raising of the voltage being the simplest and cheapest method of meeting the severe demands. There have been isolated cases of roads operated at 700, 750 and 800 volts, and the step from these potentials to 1200 volts was a comparatively small one. It should be specially noted that the increase from 500 to 600 volts made no difference whatsoever in the design, construction and operation of the equipments. When the jump to 1200 volts was taken, it was made for purely economic reasons, and no radical changes were made in the equipment. To retain the good and well tried features of 600 volt control, a very simple piece of apparatus called the "dynamotor" was devised which enabled the control and auxiliary circuits to be operated at 600 volts and the main motors to use the higher potential. The only change in the motors to suit the higher voltage was that they were insulated for 1200 volts instead of 600 volts, the common arrangement being to operate two motors in series so that 600 volt windings were still used. The adoption of commutating poles on railway motors greatly facilitated the raising of the trolley potential without the introduction of complications. The marked success that attended the operation of 1200 volt apparatus under severe service conditions encouraged further steps along the same line with the result that some roads of 1500 volts were installed. The results were equally satisfactory. Most of the roads at present operating at higher direct current potentials are in the nature of interurban railways but some, however, approximated steam railroad conditions. In all cases the apparatus has proved itself as well suited to the severe conditions as the older 500 and 600 volt apparatus had. Under these circumstances it is not surprising that a still higher direct current potential should have been considered for a heavier class of service. In 1912, just five years after the first 1200 volt road was put into successful operation in this country, 2400 volt direct current was adopted as the most suitable system to meet the peculiarly severe conditions existing on the Butte, Anaconda & Pacific Railway—thus direct current apparatus has evolved from a small beginning until it has reached a stage where it meets the demands of the heaviest traction undertakings contemplated.

This is as far as we have gone at present in this direction, in actual practice, but there seem no logical reasons or limiting conditions, that we know of at present which would prohibit the use of still higher direct current potentials.

Since the initial adoption of 1200 volts, the extension of its use has been exceedingly rapid, and it may now be regarded as the standard for all new interurban railways. In some cases where marked economies can be secured 2400 volts may be used in interurban service. One example of this is already under construction, viz., the Michigan & Chicago Railway.

The first road to adopt 1200 volts in this country was the Pittsburgh, Harmony, Butler & New Castle Railway. This road started operation in 1907. Since this date, the extension of high potential direct current railways has been exceedingly rapid as shown in the following table.

| Date of Installation | No. of Roads | Total Road Mileage |
|---|---|---|
| 1907 | 1 | 41 |
| 1908 | 2 | 134 |
| 1909 | 0 | 0 |
| 1910 | 6 | 424.6 |
| 1911 | 2 | 201 |
| 1912 | 3 | 196.5 |
| 1913-14 | 17 | 1061 |
| Totals | 31 | 2058.1 |

Most of the roads are in the nature of interurban railways, but it should be noted that as far as we can see the vast majority of the heavy traction work now under construction or contemplation will employ direct current apparatus and this will, in most instances, be operated on "higher potentials."

We are apparently fast coming to recognize that there is such a thing as "a science of development" and that such a science among other factors must include the following fundamentals:

(1) An accurate determination of the actual operating conditions which will enable us to settle definitely what is wanted.

(2) The co-ordination of the work of a large number of differently trained men, so that the finished product may embrace the experience of each worker in his particular line, and thus become in every detail the product of experts.

(3) The confidence and cooperation of the users and makers of apparatus both before and after its manufacture, this cooperation to continue in some form or other during the useful life of the machine.

(4) The standardization of apparatus when such will be profitable to all concerned.

(1) There are, perhaps, many who do not realize the costliness of determining what is wanted to suit a particular set of service conditions. An accurate determination of the precise requirements will often necessitate months of exhaustive investigation, often including costly tests. This is particularly true in large undertakings. If we compare the work done in this direction today with the older haphazard methods of designing machinery first and seeing whether it would do the work afterwards, it is apparent that the art has benefited enormously by the work of the large corporation along these lines. Some phases of the research and development work undertaken today are so costly and require such a large staff of expert workers that no small engineering undertaking could shoulder the burden, as assumed by the large corporation.

(2) The proper co-ordination of the work of a host of men who are contributing to the design, manufacture and testing of electric railway apparatus is no small part of the Science of Development. The extent of this work is enormous, including as it does, preliminary proposition, final proposition, designing, drafting, actual manufacture and work incident to following apparatus through

the factory, assembling, testing, installing, and preliminary operation. The final cost of the apparatus depends largely upon whether this co-ordination of work is done in a scientific or unscientific manner.

(3) A whole paper might be read with profit on the subject of the confidence and cooperation between the user and the maker. Upon the encouragement and extension of what we might call "the modern business idea," the rapidity with which we are going to develop in the future must largely depend. The successful development of electric apparatus for traction purposes depends on "how it is made" and "how it is used." The manufacturer is dependent upon the user just as the user is dependent upon the manufacturer. An ounce of mutual confidence and cooperation will do more towards the development of the art than a ton of fault finding and mutual distrust. In the broadest sense, the aims and objects of both parties are identical. The user wants the best obtainable for his service and the maker wishes to produce the best and most efficient apparatus, as upon this his reputation and future business depends. The work of all parties concerned is in reality the part of one great plan.

(4) The correct time at which the standardization of electric apparatus should be attempted is a science in itself, e.g., it would undoubtedly be profitable to all concerned if all trolley systems would cooperate with the manufacturers in using standard apparatus, especially standard railway motors and standard control equipment, where such standards will fulfill the requirements. There will, however, always be special conditions arising that will demand special apparatus, and the things that dictate these special requirements are many and varied, e.g.: Who could have foreseen that the fashion of ladies' skirts could affect the design of railway motors? But such has been the case—the hobble skirt gave birth to the low step car—and the low step car required a new design of motor.

The standardization of all apparatus that is used in large quantities and has reached a high state of perfection would be a great asset to the industry.

On the other hand, until we have more experience with the different systems of electrification, it would seem unwise to lay down too definite standards for heavy traction work, although it might be profitable to standardize such things as trolley voltages that would vitally affect the future development of the art as much as the present.

In conclusion, it is well to emphasize one point, namely, that modern engineering involves, above all things, the study of economics. Yesterday we were finding out how to do things—today we are striving to find out how to do them more cheaply than yesterday. To combat the increased cost of living and of labor, etc., and the generally more complicated social and commercial conditions under which we are living, the work of the scientist and the engineer is to teach the world at large how to do for one dollar that which they could not do for two dollars yesterday.

# AUTO-TRANSFORMERS

By Lee Hagood

Lighting Department, General Electric Company

This article cites an instance of trouble which has been experienced in applying auto-transformers to an ungrounded system, and concludes with a statement of the factors which must be taken into consideration in such an installation.—Editor.

On account of cheapness an auto-transformer for power transmission makes an attractive proposition. Although some are in successful operation considerable care should be observed before adding an auto-transformer to a system.

The following example will serve to illustrate how serious some of the troubles may be which arise from the improper use of an auto-transformer.

A contract was made with Company "A" for the purchase of 60 cycle 22,000 volt power by Company "B." Available for supplying this power was a 16,000 volt 60 cycle system and a 25 cycle system. A frequency changer set was installed arranged for 2300 volts on the 60 cycle side. It was therefore necessary to furnish apparatus to step the voltage from 2300 to 22,000 volts and from 16,000 to 22,000 volts. To meet the two conditions of voltage transformation a transformer was installed having a delta connection from 2300 to 22,000 volts and the high tension winding connected as an auto-transformer for 16,000 to 22,000 volts. The connections are illustrated in the figure. In view of the fact that both systems were isolated the auto-transformer neutral was not grounded, since grounding would involve changing all the two-pole relays on the automatic oil switches to three-pole relays. This would have also involved the addition of another current transformer for each automatic switch. The transformer in question was 3600 kv-a. made up of three single-phase units.

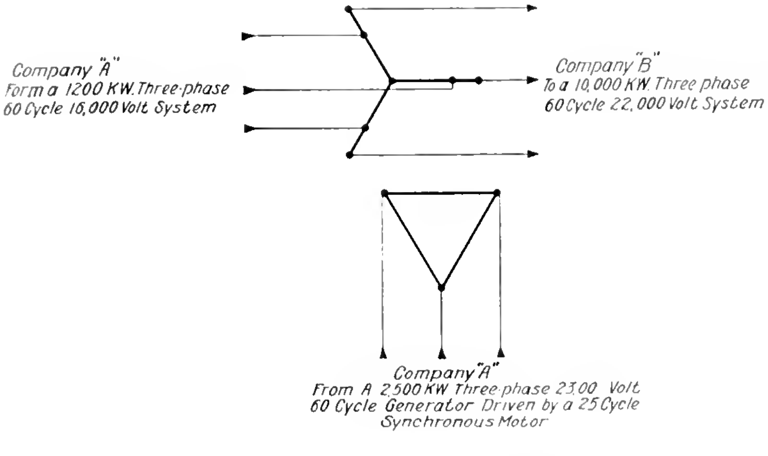

Fig. 1. Bank of Transformers consisting of three single-phase 1200 kv-a. transformers, connected delta on the low and Y on the high tension side. The high tension side is arranged for an auto-transformer connection from 16,000 volts to 22,000 volts

The first serious trouble arose as follows:

An attempt was made to supply power from the 16,000 volt system with the 2300 volt delta connection open. Immediately serious telephone disturbances arose. These troubles, it seemed, were so serious that some of the telephone lines were almost useless. One telephone company actually requested the manager of Company "B" to shut down his system until the trouble could be located. The best telephone men were sent out in search of the difficulty and its seat was finally located in the transformer bank in question. The remedy for the trouble was a simple one, since by closing up the 2300 volt delta winding the disturbance was brought to an end.

The next trouble arose some time later when Company "B" received a ground. This raised the dynamic voltage of the 16,000 system on Company "A" side to 19,000 volts. Simultaneously a high frequency was transmitted through the auto-transformer due to the arc at the ground on Company "B" side. This caused the horn gaps of the 16,000 volt lightning arresters to arc and thereupon the lightning arresters were destroyed. Lightning arresters are not suited for protection at a dynamic voltage exceeding fifteen to twenty per cent above normal. In the present case nothing can be accomplished by changing the lightning arresters. Adding cones will not help matters as the voltage at which protection is afforded depends upon the voltage at which the arresters are charged. Since the grounding of the auto-transformer is inadvisable due to the expense of changing to triple-pole relays on the oil switches the customer is led to face the proposition of purchasing an additional transformer for supplying power from the 16,000 volt system. As a matter of fact, if a transformer with two secondary windings had been selected in the first place it would have been only slightly more expensive than the present auto-transformer combination, and would not have been exposed to any of its troubles.

It might appear from the above that grounding an auto-transformer is a solution of all serious difficulties. Nevertheless the following should be borne in mind:

First. If a system is isolated and a grounded neutral established, all the automatic oil switches should be protected by triple-pole relays. It is customary on isolated systems to only use double-pole relays. The expense of such a change in most cases would be excessive.

Second. Having more than one ground on a system offers a path for harmonic currents and stray currents. These may cause serious telephonic interference. Furthermore, such currents may be of large enough magnitude to destroy apparatus. We are familiar with cases of both.

Third. It does not seem advisable in any event to tie two large systems together by means of auto-transformers, since disturbances due to lightning, arcing grounds, etc., have a free path from one system to the other. This, of course, does not exist to a serious extent where the transformation is by means of primary and secondary windings, since the electromagnetic coupling allows more flexibility.

# REPORT OF TEST OF ILLUMINATION ON PENNSYLVANIA AVENUE, WASHINGTON, D. C.

By Walter C. Allen

Electrical Engineer of the District of Columbia

The following article reports the results of the first illumination test of the luminous-arc lamps recently installed in Washington, D. C.—Editor.

Upon request of the Commissioners of the District of Columbia, the Bureau of Standards has made foot-candle measurements of a typical section of Pennsylvania Avenue, Washington, D. C. These show a remarkably uniform distribution of light obtained from the luminous arc lamp installation recently made on that thoroughfare, and fully described in the March, 1914, issue of the General Electric Review. The section of Pennsylvania Avenue chosen for this test lies between Fourteenth and Fifteenth streets where the lamps as actually installed follow as closely as possible the spacing of 100 feet, measured along the curb, which was chosen as necessary for proper illumination. The report states:

"The measurements were made by laying milk-glass test-plates on the pavement and determining the brightness of their surface by means of Sharp-Millar photometers. The test-plates were tested to determine their deviation from the cosine law of diffuse reflection, and the results as given (Fig. 1) are corrected for this deviation.

"At 35 of the stations, covering a representative rectangular portion of the block, entirely independent measurements were made at different times by two observers with different photometers, and the separate results are given under the headings photometer A and photometer B. The arcs flicker considerably, besides showing a more or less regular and continuous change as the arc stream grows longer between readjustments of the feeding device. Consequently considerable variations occur, especially at the stations near lamps where the light comes almost entirely from one lamp. It may be noted that the results obtained by the two photometers show a greater systematic difference than we usually have in measurements of this kind. For this difference we have no satisfactory explanation, although it may possibly arise in part from a difference in judgment of the proper mean value for flickering lights.

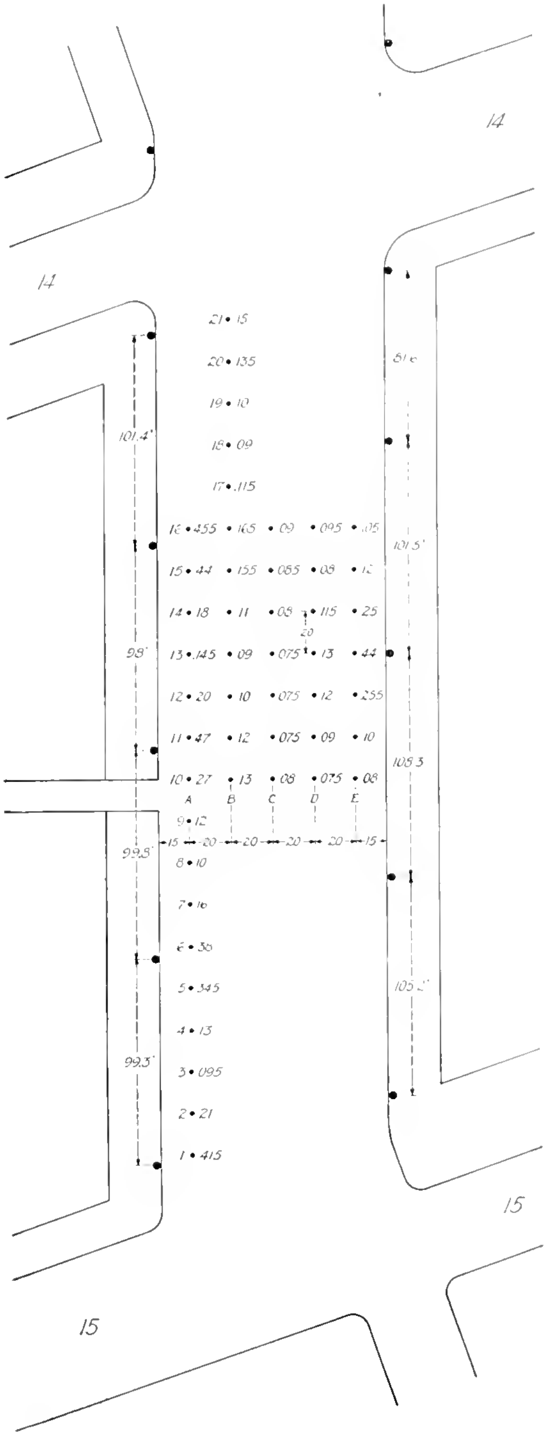

Fig. 1. Location of Test Stations with Reference to Lamps, and Values of Readings in Mean Foot-Candles

## ILLUMINATION IN FOOT-CANDLES ON SURFACE OF STREET

### I. Single Measurements

| PHOTOMETER A | | PHOTOMETER B | |
|---|---|---|---|
| Station | Illum. | Station | Illum. |
| 1 | 0.415 | 17 | 0.115 |
| 2 | 0.21 | 18 | 0.09 |
| 3 | 0.095 | 19 | 0.10 |
| 4 | 0.13 | 20 | 0.135 |
| 5 | 0.345 | 21 | 0.15 |
| 6 | 0.38 | | |
| 7 | 0.16 | | |
| 8 | 0.10 | | |
| 9 | 0.12 | | |

### II. Double Measurements

| Station | Photometer A | Photometer B | Mean |
|---|---|---|---|
| A10 | 0.263 | 0.274 | 0.27 |
| 11 | 0.498 | 0.442 | 0.47 |
| 12 | 0.202 | 0.195 | 0.20 |
| 13 | 0.158 | 0.129 | 0.145 |
| 14 | 0.177 | 0.184 | 0.18 |
| 15 | 0.425 | 0.456 | 0.44 |
| 16 | 0.525 | 0.385 | 0.455 |
| B10 | 0.132 | 0.126 | 0.13 |
| 11 | 0.124 | 0.119 | 0.12 |
| 12 | 0.103 | 0.099 | 0.10 |
| 13 | 0.093 | 0.088 | 0.09 |
| 14 | 0.110 | 0.107 | 0.11 |
| 15 | 0.161 | 0.153 | 0.155 |
| 16 | 0.176 | 0.157 | 0.165 |
| C10 | 0.084 | 0.073 | 0.08 |
| 11 | 0.083 | 0.071 | 0.075 |
| 12 | 0.080 | 0.070 | 0.075 |
| 13 | 0.082 | 0.069 | 0.075 |
| 14 | 0.090 | 0.074 | 0.08 |
| 15 | 0.091 | 0.079 | 0.085 |
| 16 | 0.099 | 0.078 | 0.09 |
| D10 | 0.081 | 0.071 | 0.075 |
| 11 | 0.096 | 0.080 | 0.09 |
| 12 | 0.128 | 0.110 | 0.12 |
| 13 | 0.130 | 0.127 | 0.13 |
| 14 | 0.115 | 0.118 | 0.115 |
| 15 | 0.083 | 0.080 | 0.08 |
| 16 | 0.092 | 0.097 | 0.095 |
| E10 | 0.074 | 0.087 | 0.08 |
| 11 | 0.104 | 0.092 | 0.10 |
| 12 | 0.262 | 0.247 | 0.255 |
| 13 | 0.512 | 0.365 | 0.44 |
| 14 | 0.250 | 0.251 | 0.25 |
| 15 | 0.121 | 0.117 | 0.12 |
| 16 | 0.097 | 0.114 | 0.105 |

"These measurements were made between eleven and 1:30 o'clock on the night of March 23rd. Ammeters previously calibrated at the Bureau were placed in the circuits at the power plant and the currents were supposed to be kept as nearly as possible at 6.6 amperes."

# THE STORM DETECTOR AND ITS INFLUENCE UPON THE OPERATION OF LIGHTING CENTRAL STATIONS

By W. H. Lawrence

Superintendent Waterside Stations, New York Edison Company

Unexpected overloads have always been a source of danger to central station apparatus and are likely to be detrimental to the quality of the service furnished by the station. Sudden storms have embarrassed central station engineers to such an extent that some of the largest lighting stations keep a man posted on the roof to give warning of their approach. The author, after citing the load conditions in the New York Edison stations, describes a most ingenious storm detector which has been devised to supplant the above practice. The simplicity of construction and the effectiveness of operation are two notable features of this device which employs the principles of wireless telegraphy. Actual records of operation are given.—Editor.

## Introduction

Such public utilities as those supplying gas and water are fortunate in that the commodities they distribute are physical materials. During those parts of the day when the demand for their product is small, the excess delivered from the station can be economically stored in a reservoir for use at later periods in the day when the demand is greater than the capacity of the station.

The public utility that distributes electricity, however, cannot be modeled profitably after this plan on account of the properties of the commodity that it handles.

Electricity, like light and sound, is not a physical material and therefore can exist only as long as the influence of its generating source continues. This property renders it impossible to directly store or preserve electricity for future use. Although such an end may be indirectly accomplished by the use of storage cells, which convert the kinetic energy carried by the current into potential chemical energy and later carry out the reconversion, the efficiency of this method is very low. For this reason, the use of storage batteries in supplementing the generation of electricity has been restricted to such purposes as involve the furnishing of a reserve to safeguard the service against interruption when some accident temporarily affects the generating, transmission, or transforming systems.

Electrical stations, being unable to economically avail themselves of the use of a reservoir which may be charged with the excess energy of the station at light load periods and discharged to assist the station at the heavy load periods, have to be designed with a capacity equal to no less than the maximum demand upon them. This factor of an installed station capacity at least equal to the maximum peak load is the greatest financial handicap to which an electrical station is subjected. That this condition is unavoidable has long been recognized and accepted by our business men and engineers.

The variations in the load which are demanded of a lighting station during the day and the characteristic difference between the summer and winter loads are shown by Figs. 1 and 2, of which Fig. 1 is a typical load curve for a summer day and Fig. 2 one for a winter day. (A typical load curve for the month of March is shown in Fig. 3. It will be noted that the time at which the peak occurs lies between the hours of the winter and the summer peak.)

Since it is only during the peak load of the day that the whole equipment of the station is working, it is evident that the return on the entire investment during the remainder of the day must be earned by that portion of the equipment that is then operating.

This is a condition that makes it highly imperative that an electrical station be operated with maximum economy throughout the entire day. Given a certain station equipment, this is mainly accomplished by a strict adherence to a regular daily routine. Thus, at any period of the day only that number of machines is operated which is sufficient to economically carry the load then existing. At times of light load or average load, a steam-driven station will have a large share of its boilers "banked" and a number of its generating units idle. When under such a condition a large unexpected demand for an increased output may be made so suddenly that the number of machines which are operating will be insufficient to carry the abnormal demand, and it is probable that the standard of service will be lowered until such time as reserve boilers and generating units can be brought into service. For this reason it is imperative that the station receives preparatory warning of any abnormal demand.

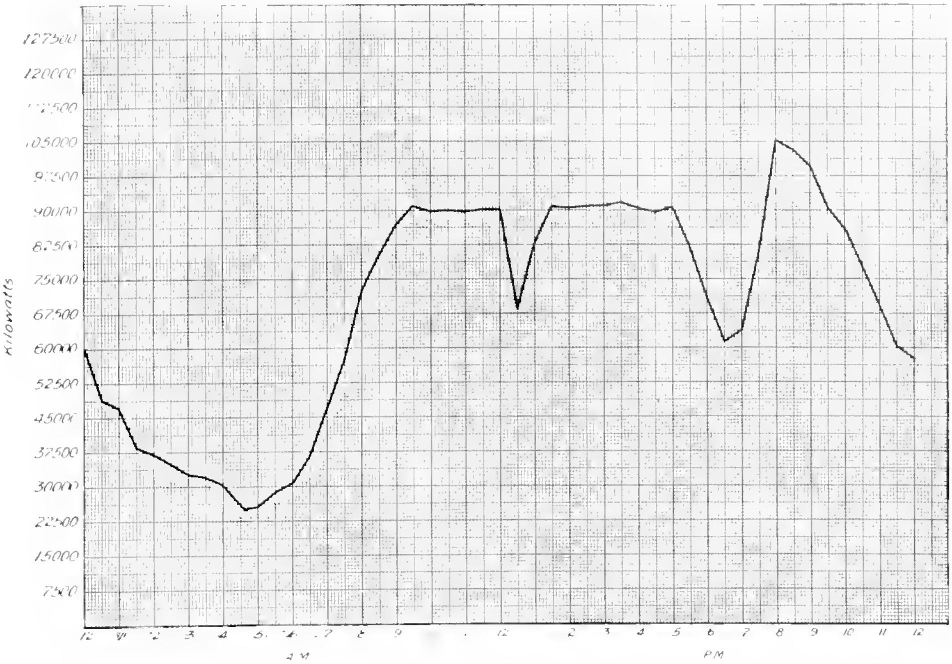

Fig. 1. A Typical Load Curve of a Lighting Central Station for a Normal Summer Day (1913)

Fig. 2. A Typical Load Curve of a Lighting Central Station for a Normal Winter Day (1913)

The rapidly moving clouds which accompany a storm constitute the principal cause for the sudden and unexpected increases in the demand for current from a lighting station. The effect which a sudden and heavy storm may have upon the station's output is shown by the sharp peak at the 3:35 p.m. point of the curve in Fig. 4. This is the record of an actual occurrence which took place during the month of March, 1911. It will be noted from this curve, and by a comparison with that of Fig. 3, that the demand at 3.35 p.m. is 73 per cent greater than it would have been had there been no storm. An increase of 49,500 kw., in this instance, was called for in about 5 minutes, which gives a good idea of the severe demands that may arise and which a lighting station must be prepared to meet.

Any device, therefore, that will provide a warning of the approach of a storm, at a time sufficiently far in advance to enable the station attendants to prepare for the exception to their daily routine in a deliberate and orderly manner, would be most welcome.

The storm detector is such a device.

### Storms and Their Effect on the Detector

All summer storms, or practically all of them, are accompanied by electrical disturbances in the ether. These cover a field far greater than that over which the storm clouds themselves are visible. By use of antennae, some of these radiations may be intercepted and by a suitable apparatus be made to give an indication of not only the presence but also the relative proximity of the storm.

The storms that occur during the winter months are usually snow storms and are of but a weak electrical nature. For this reason, they may perhaps not affect the device. At this season, that is a matter of but small moment. In winter, the load upon the stations during the daylight hours is uniformly greater than during the summer and the demand regardless of the severity of the storm will always be from 20 to 25 per cent less than the demand which occurs daily between 5 and 5:30 p.m., for which the station is always prepared.

This is evident when it is considered that winter storms have no effect on street lighting and other outside lighting, sign lighting, residence and apartment-house lighting, etc., all of which are on at the time of the daily peak at 5:00 p.m. For this reason, winter storms are of such minor importance that the service of the storm detector is dispensed with during that season.

### Description of Storm Detector

The various parts making up the detector are an aerial, a short-circuiting switch, a spark gap, a coherer, a relay and battery, a bell (which also acts as a decoherer) and battery, a condenser, and a ground connection. Fig. 5 shows the diagram of connection of these parts.

*Aerial:* Antennae, similar to the more simple ones used in connection with wireless telegraph outfits, have been found to serve the purpose admirably. It is this part of the equipment that receives the ether radiations resulting from the storm.

The oscillating current thus set up travels to and from the ground through the spark gap, coherer, and condenser.

*Short-Circuiting Switch:* This switch and its connections are shown in Fig. 5. Nominally, it is kept in the "open" position. After the alarm bell has begun to ring continuously, it is closed to protect the apparatus from heavy surges and to silence the bell.

*Spark Gap:* This consists of a simple gap with spherical terminals placed approximately $\frac{1}{64}$ in. apart. The purpose of this gap is to prevent those surges that are induced in the antennae by the radiations emanating from wireless telegraph stations, but which are very weak as compared to the lighting disturbances, from flowing through the remainder of the apparatus and thus causing a false alarm.

*Coherer:* This is also patterned after the type of the simple ones used in the early days of wireless telegraphy. In brief, it consists of a short section of glass tube of small bore loosely filled with nickel-silver filings. These are connected at each end to the outside circuit by german-silver plugs. The action of such a type of coherer is well known and needs no further explanation than to say that it acts as a high resistance to the low-voltage battery current impressed upon it until a high-frequency discharge current, between aerial and ground, has passed through it. This high-frequency current effectively lowers the coherer's resistance to the battery current, which consequently allows a greatly increased battery current to flow through the tube. The resistance of the tube then remains unchanged until it is violently jarred, at which time the high-resistance property returns.

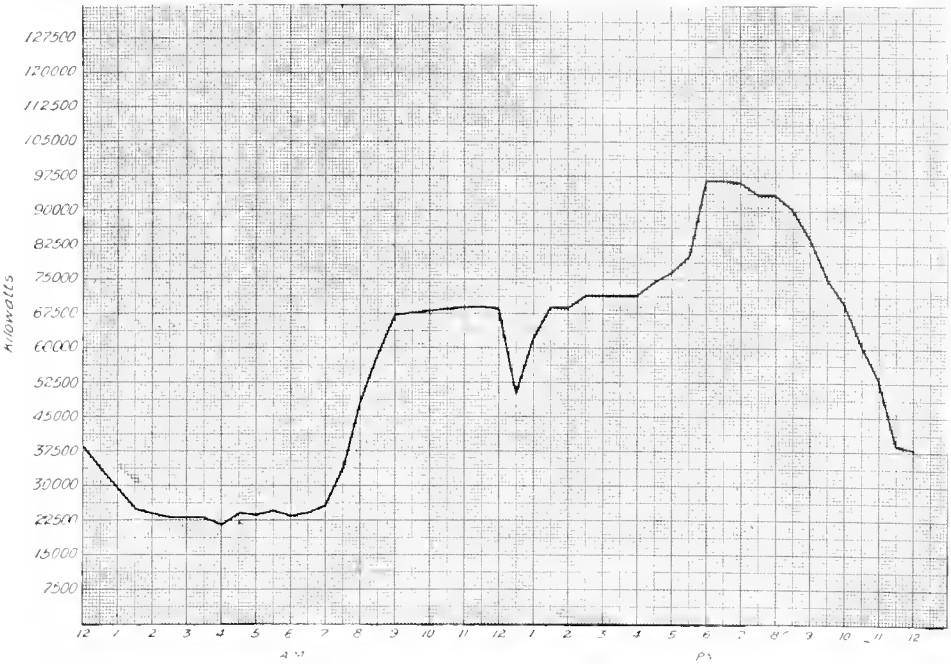

Fig. 3. A Typical Load Curve of a Lighting Central Station for a Normal March Day (1911)

Fig. 4. An Example of a Load Curve of a Lighting Central Station for a March Day (1911) during which a severe unexpected storm took place at 3.30 p.m. But for the abnormal peak occurring because of this storm, the curve would be similar to that of Fig. 3

*Relay and Battery:* The most effective type of alarm is an audible one, of which the simplest form is a bell. However, as a bell requires a greater amount of current for its operation than that increased amount of battery current which is caused to flow in the coherer by a high-frequency discharge, some magnifying or relay device must be used. The relay employed is one of the ordinary telegraph type and the battery $B_1$, Fig. 5, is of dry cells. The connections are given in Fig. 5.

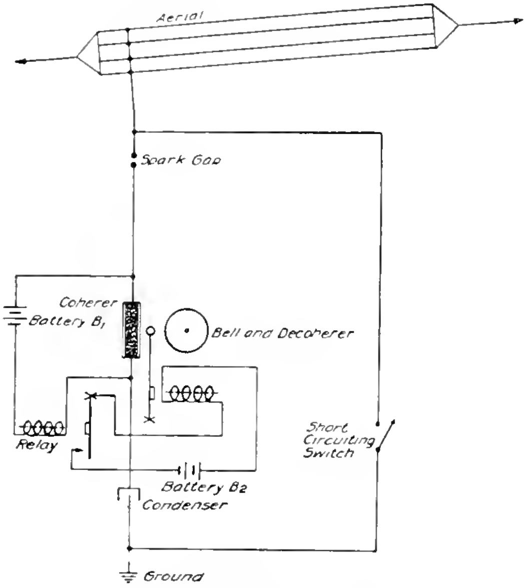

**Fig. 5, Complete Diagram of Connections of the Apparatus Comprising "The Storm Detector"**

*Bell and Battery:* The bell is one employing single-stroke connections and is of a size sufficient to be easily heard throughout the system operator's office. (The coherer, relay, condenser and bell are located in this office.) The bell has its own supply battery of dry cells, $B_2$, and is controlled by the secondary contacts of the relay, as shown in Fig. 5.

As the low-resistance condition into which the coherer is thrown by a high-frequency discharge is permanent until the tube is severely jarred, the bell is mounted so that its clapper will strike the tube and thus perform the two-fold function of bell and decoherer. (It is evident that the tube must be decohered, otherwise it would not show the effect of a later high-frequency discharge.)

*Condenser:* The condenser is an ordinary one and is inserted in the ground wire to prevent stray direct current from flowing in the apparatus.

*Ground Connection:* This connection completes the high-frequency circuit from aerial to ground.

### Operation

The operation of the apparatus comprising the storm detector leaves practically nothing to be desired. The manner in which it enters into the activities of a steam station will be described, as it is perhaps to such a station that it is of the most benefit.

It will be remembered that the bell or decoherer, together with the coherer and relay, are located in the system operator's office.

It is the duty of the system operator that he keep continuously posted on the demands that are or may be made upon the station for power and to so direct the disposal of all the generating machinery that the station will afford the highest quality of service and will operate with the maximum degree of economy. In detail, the latter function he performs by orders to the boiler room specifying how many boilers shall be maintained under load and how many shall be carried "banked," by instructions to the generating room as to which machines shall carry the load and which other units and auxiliaries shall be held idle or in readiness, and by orders to the various switchboard operators as to which feeders shall be used in the disposition of the output.

Under the usual daily conditions of operation the demand which will be made upon the station from hour to hour is accurately known, for the variations of the load curve constitute a daily cycle. These regular changes of load, being anticipated and taken care of by orders from the system operator, become a matter of station routine.

In order to secure smoothness of plant operation, the system operator is informed of the unusual departures from the regular load curve that are to be expected, e.g., exhibition lighting, etc., and also of the weather forecasts. All such is of great assistance in aiding good management. Those unusual irregularities of whose coming he is reliably warned present no difficulties. It has been found by operating experience, however, that the weather forecasts come far from providing a reliable and early warning. Further, the reports are not couched in such terms as furnish the system operator with the information that is of paramount importance to him, viz., the rapidity, in hours, of the approach of the storm.

It is true that the number of severe storms which come over a city with extreme rapidity is much less than that of the slower moving storms, but, on account of their tremendous capacity for suddenly deranging the orderly routine of the lighting station and perhaps even affecting the standard of its service, the fast moving storms make it requisite that all are to be guarded against.

Assume, for instance, such a storm to be approaching a city in which is located a lighting station that possesses a storm detector.

At a time varying from 2 hours to 7 hours before the actual storm clouds reach the city (depending upon whether the path of the storm is a direct or a round-about one), the alarm bell will begin to strike at intervals of from 5 to 15 minutes. The system operator regards this merely as the warning of the possible approach of a storm but gives it no further attention, for the storm may change its direction and pass off without molesting the quiet weather conditions of the city.

The disturbing conditions by their further approach cause the bell to ring oftener. With the storm but about two hours' travel away, the bell will strike about once every half-minute or every minute. When this occurs the system operator orders the reserve boilers into service, the auxiliaries of such generating units as he deems may be required started, and the generating units themselves run at low speed.

These conditions prevail until that later time when the bell gives an insistent warning by uniting its periodic strokes into a continuous ringing. This will ordinarily occur at about one-half hour to one hour before the storm reaches the city. It has been found quite often that even at this time the sky will remain clear and unclouded to the eye, which shows how much superior are the services of a storm detector to those of a watchman stationed upon the roof to observe the conditions prevailing in the sky. (This latter practice was the best one available prior to the development of the storm detector.) The switch short-circuiting the detector is closed when the bell begins to ring continuously to protect the receiving apparatus, for the storm will now be comparatively close, and to silence the bell for its warnings are no longer needed, since it is positively known by this time that the coming of the storm is a certainty. Simultaneous with this action goes the order to synchronize the incoming generating units with the bus. Everything is now in readiness to supply the increased load which will be demanded in but a matter of minutes.

The following are actual records of the frequency of the bell warnings and the loads existing at various times preceding two storms last year.

July 28.
  1:45 p.m. . . . . . . 1 bell.
  2:15–3:30 p.m. . . 1 bell every ½ to 1 minute.
  3:30 p.m. . . . . . . . bell began ringing continuously, load 96,000 kw.
  4:15 p.m. . . . . . . . (very dark, heavy rain storm), load 142,500 kw.

August 1
  8:25 a.m.–2.00 p.m. . . 1 bell every 3 to 5 minutes.
  2:02 p.m.–2:15 p.m. . . 1 bell every ½ minute, load at 2:00 p.m., 100,000 kw. (cloudy).
  2:15 p.m.–3:20 p.m. . . bell ringing continuously.
  3:45 p.m. . . . . . . . . . . . load 150,000 kw.

### Application of the Detector

The storm detector as described is in service and located in the office of the system operator in the Waterside stations of the New York Edison Company. These stations so far as it is known are the only ones possessing a device of the same nature.

The field for such a device among steam-driven lighting stations would seem to be in the larger cities, particularly in those which possess crowded office districts as it is the load derived from such a source that is most sensitive to changes in daylight.

A field in which it would also seem that the device would furnish valuable service is that of keeping the isolated hydro-electric station informed as to the weather conditions existing in the distant cities which it is supplying with lighting current. The places of generation and consumption being so far separated, a visual observance of the weather conditions at the power plant would be of no use. By means of storm detectors located in a few of the widely separated towns, which receive lighting current from the station, the attendants may keep forewarned by a bell in their station as to the irregular demands which may be made on them by storm clouds passing over those distant towns.

# SOME RECENT DESIGNS OF LARGE VERTICAL AND HORIZONTAL ALTERNATING CURRENT WATERWHEEL-DRIVEN GENERATORS

By M. C. Olson

A-C. Engineering Department, General Electric Company

The speed of waterwheel-driven generators varies over a very wide range, the head of water available being the chief factor in determining the speed and consequently the diameter of the machine for a given capacity. The author shows some interesting features in the design of both slow and high speed generators, e.g., one of the machines cited running at only 55.6 r.p.m. and having a larger diameter than any yet built. The mechanical design of some of the large units described are of special interest, and considerable attention is given to ventilation.—Editor.

On account of the wide variation in head of waterfalls throughout the country it is necessary to design large generators for speeds ranging from 50 to 600 r.p.m., and this fact has necessitated a number of different designs, in which the construction of the stator and rotor differs greatly, and in which special provision for ventilation must be made for the different speeds. This article is intended to show by means of sectional views and photographs some recent examples of these machines.

## VERTICAL MACHINES

Fig. 1 shows a 24-pole, 8000 kw. 0.6 power-factor, 13,333 kv-a., 250 r.p.m., 6600 volt generator. The temperature guarantee on this machine is 30 deg. C. rise for continuous operation at 8000 kw. with unity power-factor; 35 deg. C. for 8000 kw. at 0.8 power-factor or 10,000 kv-a.; and 40 deg. C. for 8000 kw., 0.6 power-factor, or 13,333 kv-a. At 25 per cent overload continuously the temperature rise is not to exceed 50 deg. C.; the temperature in each case being taken by thermometer or temperature coils.

This machine is arranged with shaft, two guide bearings, and base. As the thrust bearing is located beneath the generator no provision is made in the design of the generator for supporting the rotating element, thus simplifying the upper bearing bracket.

The armature spider is split in four parts, while the base and upper and lower bearing brackets are made in two parts on account of limiting dimensions and weights for transportation. The field spider, as will be noted, is made up in four sections of solid steel castings split at right angles to the shaft, thus making four wheels with rigid arms so designed as to take up their proper stresses. Making the field spider in sections in this way results in a more convenient structure for handling, and a more favorable shape for obtaining good castings. A steel reinforcing plate is arranged at the top and bottom of the field spider for supporting the ends of the field winding. The weight of the complete rotor is about 200,000 lb., and $WR^2$ is approximately 4,600,000.

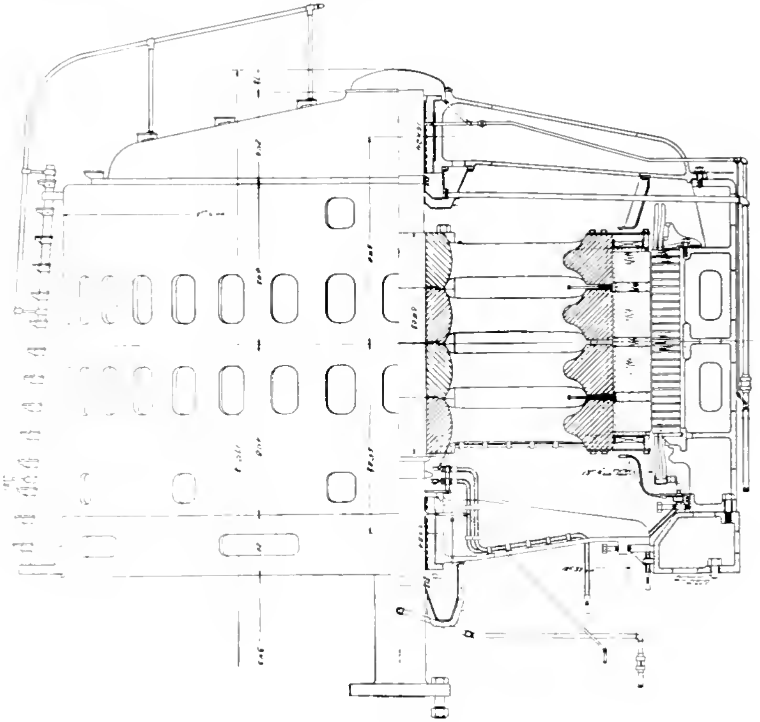

Fig. 1. 24-pole, 8000 kw., 0.6 p-f., 250 r.p.m., 6600 Volt Generator

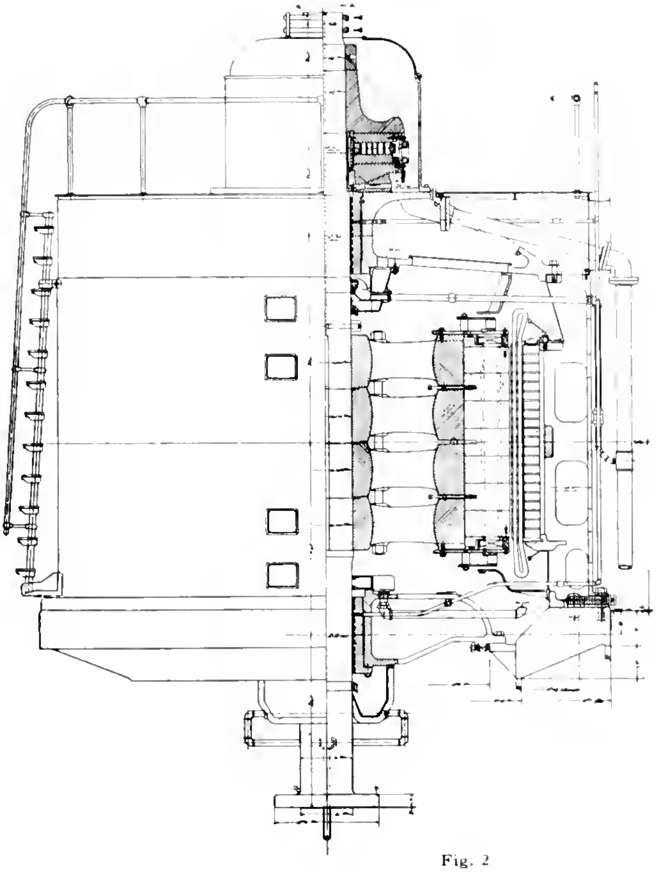

Fig. 2

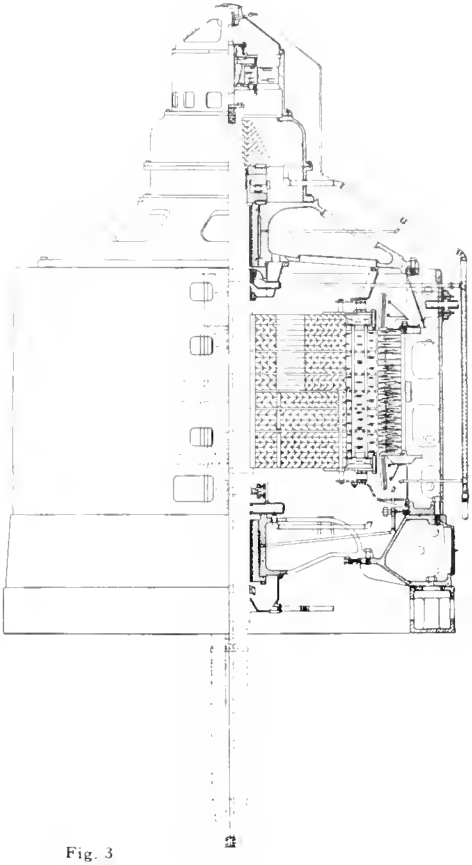

Fig. 3

Fig. 2. 18-pole, 10,000 kw., 0.8 p-f., 400 r.p.m., 11,500 Volt Generator

Fig. 3. 14-pole, 11,000 kw., 0.9 p-f., 514 r.p.m., 6600 Volt Generator

Fig. 4. 136-pole, 7500 kw., 0.75 p-f., 55.6 r.p.m. Generator with Single Runner Turbine.

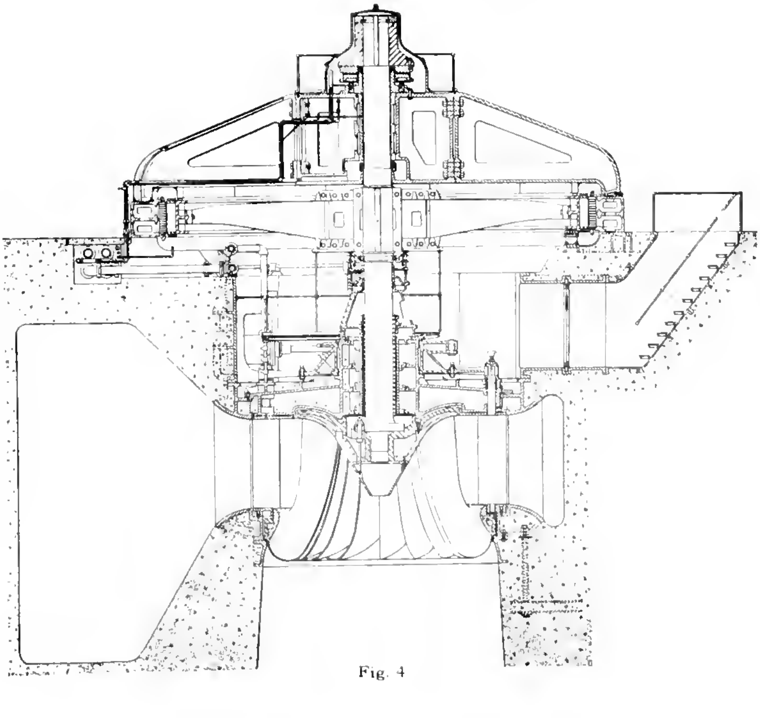

Fig. 4

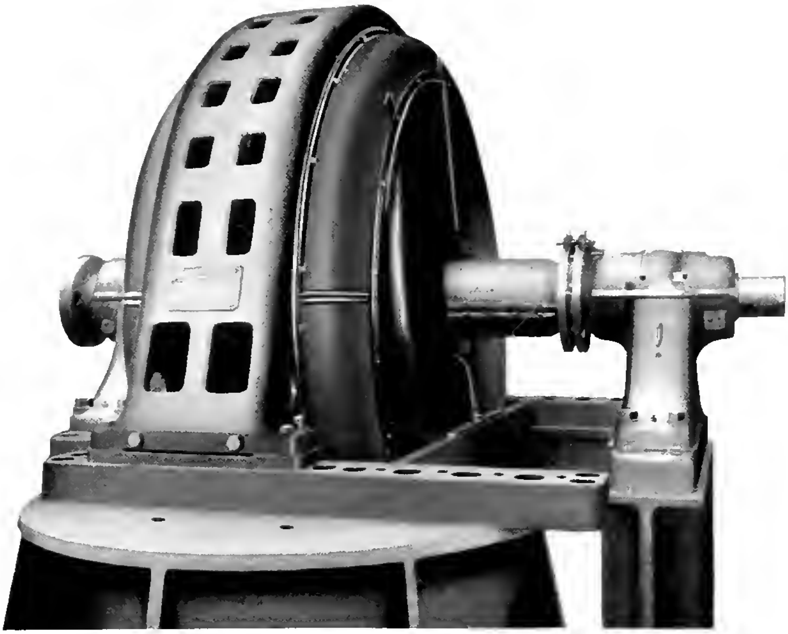

Fig. 5. 20-pole, 6250 kw., 0.8 p-f., 360 r.p.m., 4000 Volt Generator

Rotors for waterwheel-driven generators are designed to keep the stresses due to centrifugal force well within the elastic limit of all the material at the runaway speed of the waterwheels, which is usually from 80 to 100 per cent above normal.

Air for ventilation is supplied at the bottom of the machine and by means of bafflers is directed to all parts where heat is generated, and out through openings in the stator frame.

Fig. 2 shows an 18-pole, 10,000 kw., 0.80 power-factor, 12 500 kv-a., 60 cycle, 400 r.p.m., 11,500 volt generator. The heating guarantees are 50 deg. C. rise by thermometer or temperature coil. This machine has a combination roller and pressure bearing at the top for supporting the combined weight of the waterwheel and generator rotors, which is approximately 160,000 lb. and of which 25,000 lb. is the weight of the waterwheel. The hydraulic thrust in this case is nearly balanced, so that it may be neglected. The $WR^2$ of the generator rotor is 1,450,000.

Ventilation is provided for in a similar manner to that for the previous machine, except that the armature frame is entirely enclosed and the air, after passing through the stator, is expelled at the top.

Fig. 3 is a 14-pole, 11,000 kw., 0.9 power-factor, 12,222 kv-a., 60 cycle, 514 r.p.m. 6600 volt generator. The temperature guarantee is 50 deg. C. by thermometer. The machine is provided with a thrust bearing and direct-connected exciter at the top. The armature frame is entirely enclosed, and air for ventilation is admitted through large openings in the subbase, which is located between the stator frame and base.

On account of the peripheral speed of the rotor, the field spider is built up of a number of turbine plates approximately 2 in. thick, with large holes for ventilation. The total weight of waterwheel and generator rotors is approximately 147,000 lb., of which 12,000

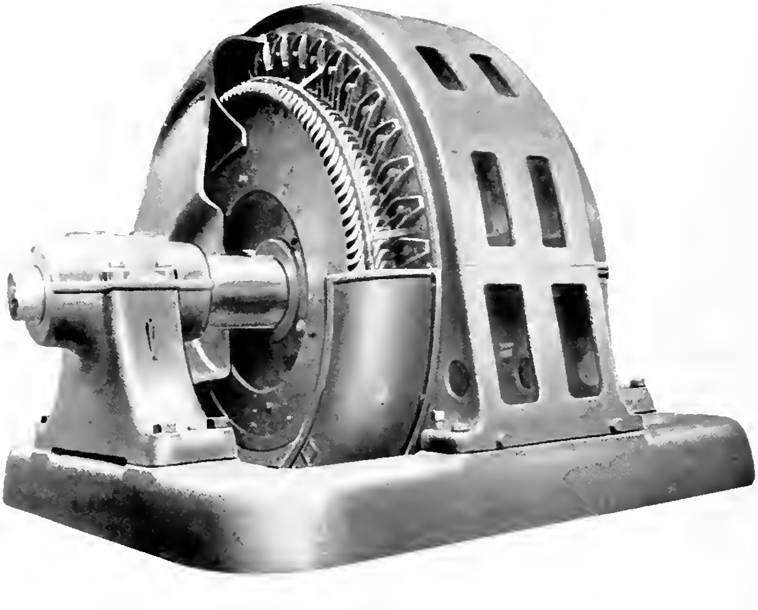

Fig. 6. 12-pole, 5600 kw., 0.8 p-f., 500 r.p.m., 11,000 Volt Generator

lb. is the weight and water thrust of the waterwheel. The $WR^2$ is 1,293,000. The maximum runaway speed of the waterwheel in this case is 975.

The lowest speed generator as well as the one of largest diameter ever built is shown in Fig. 4. This is a sectional view of a 136-pole, 7500 kw., 0.75 power-factor, 10,000 kv-a., 55.6 r.p.m. generator with single runner turbine.. Its temperature guarantee is 45 deg. C. for continuous operation, and 25 per cent overload for two hours without injury, the temperatures being taken by thermometer or temperature coil.

The weight of the waterwheel and generator rotors is carried by a roller bearing in the upper bearing bracket. The stator is made in four parts and is supported by foundation plates embedded in concrete.

The field spider consists of a cast iron field center made in two parts and a steel rim in four sections with bolted poles. The approximate weight of the generator rotor without shaft is 213,000 lb. and the total weight of the revolving elements including waterwheel is approximately 470,000 lb. The $WR^2$ of generator rotor is 31,000,000.

Ventilation is accomplished by fans at the top of the generator rotor and bafflers so arranged that the air, which is supplied to the bottom of machine, will not escape through the upper bearing bracket but will pass through the machine and out at the stator frame. Although these generators have large diameters, the peripheral speed is low and air for ventilation is supplied by blowers.

Most all large vertical generators are equipped with a brake to stop the revolving parts within a reasonable time. This brake is usually supplied by the waterwheel makers and works against the lower surface of the field spider rim.


Fig. 8. Field Spider of Generator shown in Fig. 7

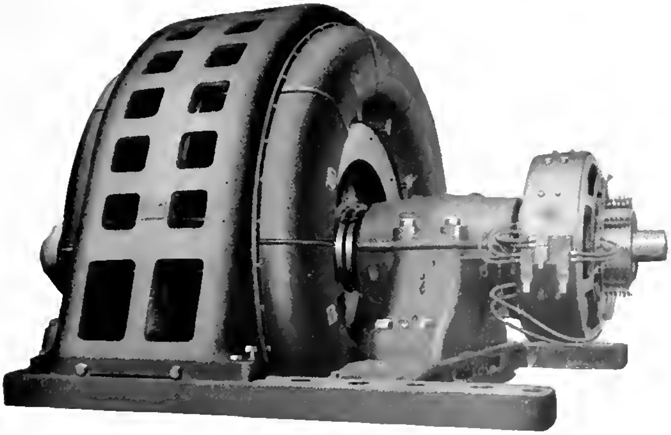
Fig. 7. 20 pole, 7500 kw., 0.8 p-f., 360 r.p.m., 6600 Volt Generator

### HORIZONTAL MACHINES

Illustrations of several horizontal machines are included, which show the general features of design and the means that have been adopted to secure proper ventilation.

On large units operating at certain speeds it is necessary to make special provision to prevent the warm air from passing through the machine again and again.

Fig. 5 shows a 20-pole, 6250 kw., 0.8 power-factor, 7800 kv-a., 60 cycle, 360 r.p.m. 4000 volt generator. Its guarantee for continuous operation is 40 deg. C. rise by thermometer. This machine has ventilating hoods to which air is carried by ducts in the station; the air after passing through the machine, being discharged into the room through large openings in the stator frame.

Instead of a regular base, this generator has foundation plates, and subbase for standards. Provision is made for movement along the shaft for convenience in repairing, It is, of course, necessary to remove the ventilating hoods before moving the stator.

Another type of construction is shown in Fig. 6. This is a 12-pole, 5600 kw., 0.8 power-factor, 7000 kv-a., 50 cycle, 500 r.p.m. 11,000 volt generator, with standard 25 per cent overload guarantee. In this case a base is provided and the bearings are equally spaced. Details of the ventilating hood are shown, as well as the method for clamping the armature laminations and anchoring the armature coils to an insulated steel ring by non-metallic lashing.

A very compact arrangement is shown in Fig. 7 which represents a 20-pole, 7500 kw., 0.8 power-factor, 6600 kv-a., 60 cycle, 360 r.p.m., 6600 volt generator with standard 25 per cent overload guarantee for 2 hours. Movement of armature frame for repairs is obtained in this case without the additional expense of heavier shaft and larger bearings, and without removing the exciter. The shaft at the exciter end is first blocked up, and the shields at the waterwheel end and the lower section of shields at exciter end are removed. The bridge under the bearing pedestal at exciter end is next removed and the stator then raised by means of adjusting bolts and rollers inserted in the track under the armature spider foot. The stator now can be moved along the shaft over the bearing and exciter.

The field spider for this generator is shown in Fig. 8. It is a steel casting made in two sections, with an opening at the center for ventilation.

# PUBLIC UTILITIES AND PUBLIC OPINION

By G. R. Parker

Turbine Department, General Electric Co.

This is an article dealing with the relationship between the public and public utilities. The author defines public utilities and notes specially that they are dependent upon the public. The author points out that some industries by their nature should be monopolies where competition in others is desirable. The regulation of public utilities by means of commissioners is dealt with, and it is pointed out that the regulation of such is for the benefit of all concerned. The public is protected against inefficient service and exorbitant rates, while the public utilities are guarded against the granting of franchises which would lead to the unnecessary duplication of service in one district. The author pays considerable attention to rate making.—Editor.

Public utilities may be broadly defined as those business enterprises which supply a community or a group of communities with a class of service not readily produced by individuals, and depending for its successful operation on the patronage of a large proportion of the population. In recent years the term has come to apply more generally to telephone and telegraph companies, electric railways, gas, electric light and power companies. However, steam railroads and steamship lines may properly be considered in the same category, since most of the general conditions governing them are similar.

In defining a public utility, attention has been called to its dependence upon the public. Yet in spite of the fact that its success, if not its very existence, is dependent upon the good will of the public, probably no other class of business enterprise has been the subject of greater antagonism, abuse and villification. Some manufacturers have grown rich by the exhorbitant profits on their products, some tradesmen have swindled and over-charged the public, many wild cat mining schemes have been successfully launched and their promoters enriched by a confiding populace; yet in no large number of such cases has the popular animosity and distrust been so generally aroused as against these corporations furnishing light, transportation and other modern necessities. Doubtless, in the past the public has had much justification, but it is probable that back of it all is the perfectly human dislike for paying for the intangible. It is human to like to have value in hand for money expended. A railroad ticket costs money. The bit of pasteboard doesn't look as if it were worth it. No matter what the amount, the resulting transportation does not seem like an adequate return. A gas or electric light bill is rendered the first of the month. No one likes to pay it. There is nothing to show for it. If it is larger than last month, probably the meter is wrong. At any rate it is too much. Many a crabbed customer of the lighting company would more cheerfully pay for a barrel of kerosene outright, and have something to show for his money than pay an equivalent amount for gas upon presentation of the bill.

In times past it is true that in many instances the Public Service Corporation was inclined to disregard public opinion; but in recent years, the more progressive companies have realized that even though they possessed a monopoly, no lasting success could be achieved without the good will of the community. Today we see everywhere evidence of the tendency to regard the interests of the public. Telephone and telegraph companies are constantly seeking to better their service. Street railways are endeavoring to provide better equipment. Electric light companies in particular have been active in establishing closer relations with the people whom they serve. It is not unusual to find the local electric light company the leader in arousing civic sentiment and in doing gratuitous advertising for the general betterment of the city. Evidently the company profits, along with other local enterprises, with an increase in the number of industries and the population. In addition they have done much to educate the public in the uses of electrical apparatus, both in its domestic and industrial application. Whether or not an altruistic motive should be attributed to the supply company, the net results are a benefit to the community.

Perhaps one of the principal causes of distrust is the fact that usually the public utility is a monopoly, and the individual is, therefore, obliged to accept its service or do without. The theory has often been advanced and occasionally put into practice that better results will accrue to the public through more than one competitive company supplying the same service. The fallacy of this is now generally recognized. A public utility is a natural monopoly. We cannot have two pairs of railway tracks through our streets. We cannot have our pavements torn up by several gas companies. We do not care to see the number of electric light and telephone poles doubled. Many similar examples could be cited. In addition, the cost to the consumer in such cases must inevitably be more in the end, due to the duplication of capital and consequent interest charges, the duplication of administrative charges, and of selling organizations and all those other items comprising overhead charges, which must be figured in the final cost of the product.

In other commercial enterprises a certain amount of healthy competition is no doubt of general benefit. Two merchants selling a community the same character of goods exercise a desirable influence over each other; and their product and method of doing business are necessarily kept at a high standard and both the public and they themselves are benefited. But the transaction of this competitive business does not involve the entire occupancy of the public thoroughfares, curbs and sidewalks.

Admitting, therefore, the necessarily monopolistic character of the public utility, the problem arises how to avoid the inevitable abuses which are bound to arise and how to encourage as good service and as low prices as would maintain were there open competition. This problem has been partly solved by the Public Service Commissions created in most states, and the supervision and regulation of rates by them.

While the scope and powers of the Public Service Commissions vary in the several states, in general they perform two broad functions. On the one hand they regulate the amount a corporation can charge the public for service and on the other they prevent the establishment or the granting of franchises to competing enterprises where service is being satisfactorily rendered by an existing company. In other words, the broad function of the Public Service Commission is to preserve the monopoly as such and at the same time prevent it from imposing on the public.

In some cases the Public Service Commission goes further than to merely pass on the rate for service based on the cost of the latter. It insists that the service shall be of a character consistent with the best modern practice, comparable with that obtainable in other similar communities, and that the cost shall be based on efficient methods of production.

A few examples of Commission regulations will be of interest. Recently a gas and electric light company applied to the Wisconsin Commission for permission to increase its rates. The Commission not only refused to grant the increase, but on the contrary ordered a reduction in rates. The decision notes that the interests controlling the property had actively extended the gas business, but had done little to develop the electric light and power business along modern lines. Commenting on this, the Commission states: "Companies holding indeterminate permits, whether for single or joint utilities, have assumed the responsibility for the highest reasonable development of their business, as well as for adequate distribution and sale." The decision further states that consumers should not be compelled to bear the high costs resulting from "what might be termed the neglect of the management to stimulate properly the sale of the utility product." In this case the corporation was penalized for failure to push its own business.

In another instance the Public Utilities Commission of the state of Oregon has denied application for the establishment of electric supply companies in districts already served. In rendering its decision, the Commission states: "One Company properly regulated and administered can generally give better and cheaper service than two.... Most utilities are natural monopolies, and the highest efficiency and lowest rates are possible only when each one has the entire business of a given city or territory."

Here we find the Commission protecting the established enterprises from competition. Similar decisions have been rendered by the Commission in Wisconsin, California and other states.

It is true that regulation has its disadvantages. A private undertaking in open competition with others of a similar character is privileged to charge whatever it can get for its product and retain its trade. The necessity for making competitive prices is a great stimulus to the most efficient methods of production and sale. On the other hand if a public utility is compelled to limit its profits to some pre-determined percentage, the incentive to strive for low production costs is largely eliminated. If a decrease in costs is immediately accompanied by an enforced reduction in selling price, it is evident that the tendency is to expend less effort on reducing costs. In other words, if the reward for originating new and better methods ceases, less brains and money are likely to be expended in perfecting such methods. It remains to be seen whether the state Commissions can devise satisfactory means for encouraging efficiency, and at the same time limit exhorbitant profits.

Another question which has taxed the genius of those interested is whether or not a corporation may add to the value of its physical property out of its earnings and then consider the increased valuation as a capital charge on which to base the percentage of subsequent net earnings. Assume for example, a corporation with a property valued at a million dollars. Assume also that the commission allows as a fair profit 6 per cent net, or sixty thousand dollars to be divided among the stock-holders. The corporation in due time decides that a larger or better plant is needed, and from time to time takes from its gross earnings enough to increase the real value of its physical property to a million and a half, at the same time maintaining rates which net the stockholders 6 per cent. It now appears that the total capital charge on which the rates are based is a million and a half instead of a million, and the public are therefore paying an interest charge on money which they themselves have contributed. The courts have generally held that the undertaking can set aside adequate funds to take care of depreciation and maintain the plant at high efficiency. But just where maintenance for depreciation stops and increase in plant value begins, is one of the vexing questions with which the courts and the commissions are constantly wrestling.

A phase of the situation as regards electric supply companies, which the lay public often fail to understand, is the reason for the wide difference in rates charged. A manufacturer pays the local electric concern say four cents per kilowatt-hour for power delivered at his factory. He goes to his residence and uses electricity supplied by the same company and his bill is based on ten cents per kilowatt-hour. If it is a steam plant, the same coal is being burned, the same boilers supply steam, the same turbines or engines generate electric current. A natural assumption is that the small consumer is paying more than his share. The fact is that a scientific study of the actual costs will often show that the reverse condition holds true; that the profit made on the ten cent rate is less than on the four cent rate. The causes of this are numerous, and some of them exceedingly complex. The general conditions governing wholesale and retail trade of any kind apply. It always costs less to sell a product in large lots than in small. The cost of selling to one customer is less than to several. The administrative and accounting charges and other general overload expenses are less. But this consideration is among the least in establishing the difference. It must be remembered that investment charges form a large part of the cost. To supply a single power customer with 100 kilowatts involves one set of transmission wires, one transformer, one meter. To supply twenty residences with a maximum demand of 5 kilowatts each, requires a perfect network of wires and poles, and practically as many transformers and meters as there are houses served. The total power sold is the same in both cases, while in the latter the investment required to supply service to the twenty small users is enormously greater. The cost of maintenance of service, repairs, renewals, etc., are similarly larger.

But another and more important condition exists, governed by the time of day and the time of year electric service is required. It is not generally appreciated that the average residence takes electric current for lighting for brief periods of the twenty-four hours. In winter the lights are turned on about five in the afternoon, and reach a maximum between six and seven, then gradually diminish toward midnight. In other words, the power house supplies current for lighting during about seven hours of the day, and the bulk of it is supplied during a period of two or three hours. This causes what is called the "peak load" on the power house. Its value depends on the amount of load carried by the station during the remainder of the twenty-four hours. In a majority of cases the peak load is more than double the average load for twenty-four hours, and occurs regularly each day. In addition, the lighting load causes an annual peak due to the fact that during winter, people turn on lights earlier, and since they spend more time in the house, a greater number of lamps are in service. This annual peak occurs the latter part of December, and is augmented by the increased lighting of residences and stores during the Christmas holidays.

Now let us see what these peaks have to do with costs. The manufacturer of electricity differs from nearly all other manufacturers in that he is unable to store his product. He must produce it at the very instant it is being consumed. In other lines of business production can be fairly well distributed by manufacturing the product during dull times and storing it in anticipation of a larger demand. Even the gas companies which have similar peaks can store up their product in tanks. In all these cases manufacturing equipment and labor need be only large enough to provide for the average output. The electric light plant, however, must provide generating apparatus and all the complex power house equipment, with necessary labor, to properly take care of the peak load, lasting but two or three hours a day. It must have large and expensive machinery standing idle nearly all day to light the city houses for a few hours each evening. All this means an investment bearing interest which must be figured in the rate.

The power load, however, consisting of electric motor service to various industrial customers can be counted on for all day, and sometimes at night. It is large and steady. The apparatus in the plant which produces this power would have to be there anyway, to take care of the lighting peak. If it can be used in the day time a low rate for power is justified, because the investment is in use for a longer period. The object of all electric company managers is to get as large a day load as possible. Evidently the larger the day load the more it is possible to reduce the rate for lighting. But even in the best managed companies, the day load seldom equals half the lighting peak. There is, therefore, no other just basis for figuring rates than to charge the lighting rate with the interest on the relatively large equipment necessary for supplying current during the two or three peak hours. Furthermore this investment must be based on the equipment necessary to carry the load during the holiday season in December, or at the time of the annual peak, since apparatus must be carried and maintained throughout the year for that one period.

Even this is not sufficient. Ample reserve apparatus must be installed to provide for breakdowns and repairs. Beside this the supply company must consider what is called its total connected load. By this is meant the number of lamps and motors which could be simultaneously thrown on the system. For example, in our houses there may be twice as many lamps as we ever use at one time. Yet the company must be ready to supply current if the unusual happened, and for one cause or another a large part of its customers decided to turn on all their lights at once.

In a word, a very much larger investment has to be carried to supply residence lighting than for an equivalent number of kilowatt-hours for motor power.

It has been suggested that an average rate for all classes of service should be established. A current writer* commenting on this, points out that the only conditions under which a schedule of charges based on average costs can succeed are those resulting from a natural or artificial monopoly, as for example, our postal system. This is an extreme case of average costs, since a letter may be sent across the street or across the continent for two cents. In the past, some local enterprises have undertaken to deliver mail within a given city at less than two cents. But the federal government has maintained its monopoly by making it a penal offense for anyone to compete against it in the carrying of letters.

Let us consider for a moment the somewhat analogous situation in reference to the steam railroads. Freight rates vary with the material handled and the character of the train. Goods going on a fast freight cost the shipper as high as five cents per ton mile. Coal on the other hand has a rate of about five mils per ton mile. Yet coal at that rate actually nets the railroad more than the high class merchandise of the fast freight. The reason is, that the latter usually runs with cars two-thirds empty. The "l.c.l." or less than car load lot is the bane of the traffic manager. It means that the dead loss of transporting the weight of the heavy trucks and the car above is not being compensated for by the maximum possible revenue producing load It costs almost as much to run a string of empty cars as one fully loaded. The train load of coal is run at maximum capacity, it moves right along without stop. Not only is coal cheaply handled at shipping points, but it has only to be handled twice—to be loaded and unloaded. Hence the statement which is truly made, that the railroads will transport a ton of coal three miles for a postage stamp. And that is more profitable than transporting a passenger weighing about a tenth of a ton, a third of the distance at the same price.

Railroad rates are older than electric light rates, and wide variation for different kinds of service rendered have stood the test of time. A farmer does not complain that it costs more to transport sheep than bailed hay, or that it costs more to transport his family than it does his sheep. And the farmer will, in time, come to realize that it may be quite as reasonable for him to pay the nearest electric transmission company one rate for power for his threshing machine, and another rate for lighting his house.

Indeed it is quite likely that before long various systems now in process of development will permit a housewife to iron and cook by electricity at a comparatively low rate, while electricity for illumination, although supplied from the same transformer and distribution lines, will be charged at a higher rate.

No criticism of charges is justifiable without due consideration to the value of the service rendered the consumer. Evidently, electric light service would not be worth much if it were available only in the day time, or if it were supplied only every other night, or if only two or three lamps could be lighted at once. It is the value of all the elements combined in the word "service" that the consumer pays for.

Obviously, there is nothing to compel an individual to avail himself of the service offered by an electric supply company. He is at liberty to burn kerosene if he prefers, and can operate his own engine for power. But a large percentage of present day consumers had decided that central station service was worth a definite value to them, before present comparatively low rates were in effect, and before modern high efficiency lamps had cut lighting costs in two, even based on the old rates.

Close study leads to the conclusion that most public utilities, even without the stimulus of competition, are making a constant effort to let the public share the benefits resulting from improvement in the art, and to give the community greater value for each dollar it expends.

As time goes on, the public will more and more come to realize that because a corporation is big it is not necessarily bad, and that because it has a monopoly does not means that it will resort to extortion. The interests of the public and the public service corporation are mutual, and will be best served by a common undertaking of each other's problems, and a proper tolerance for the occasional faults due to human weakness and human frailty.

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*Mr. W. H. Winslow, Electrical World, Jan. 3, 1913.

# EDDY-CURRENT LOSSES IN SHEET STEEL AS A FUNCTION OF THE RESISTIVITY

By J. D. Ball and W. E. Ruder

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It has been assumed for some time that the eddy-current losses in various magnetized materials vary inversely with the specific resistance. A number of observations have shown, however, that such is not always the case. For instance, certain silicon steels of five times the resistivity of common iron have been found to give only half as much eddy-current loss as the iron; and also certain heat treatments, which do not materially alter the resistivity, increase the eddy-current losses. It is also shown that the eddy currents increase rapidly with grain size up to a point where the grains can easily be seen with the naked eye. This article gives the results of several tests which have been made in an investigation of the factors influencing eddy-current loss. In addition it points out the unsatisfactory state of the knowledge on the subject at the present time.—Editor.

The present article gives the data of tests which have been made on sheet steel, and although the results herein recorded are insufficient to define a law, they may at least afford a step toward that end.

A few of the variables affecting eddy-current loss are generally accepted. For instance, its dependence upon the general kind, shape and geometrical construction of the sample tested, its variation with the square of the thickness of the laminations and with the square of the frequency and of the induction are acknowledged. For a given variety of steel this eddy-current loss has been found to be practically independent of the total loss except in that it is a part thereof, and, as is the resistivity, it is independent of the manner of cutting, so far as the grain or direction of rolling are concerned.

Eddy currents are induced currents and it would be expected that, other things being equal, they would vary as the induced voltage unless the thickness of the plates are sufficient that screening would appreciably affect the flux distribution. Following ohm's law, the resultant loss would therefore vary as the square of the amount and rate of flux change. We might also expect that, as these induced currents are flowing in the metal as a conductor or short-circuited secondaries of a transformer, the amount of current and loss would vary inversely with the electrical resistance of the material. The latter, however, has been found not to be the case. A few values that have been determined in the standardizing laboratory are here plotted to show the relation of eddy-current loss and resistivity, although the tests were not made with this purpose in view. Fig. 1 gives plotted results of a number of separation tests of Epstein samples. This method of testing consists in measuring the loss, at various frequencies, of a 10 kg. (22 lb.) sample of steel strips 50 cm. ($19\frac{11}{16}$ in.) by 3 cm. ($1\frac{3}{16}$ in.) built into a square magnetic circuit, details of which have been published elsewhere and need not be repeated here.* These results show that the eddy-current loss does not vary inversely as the first power of the resistivity. The average value of eddy-current loss for silicon steel is about one-third as much as that for standard iron, although five times the resistivity. Taking the standard iron alone, we find a variation as high as 400 per cent in eddy-current loss for the same resistivity and a variation of 45 per cent in resistivity for the same eddy-current loss. The tests were made assuming the specific gravity of standard steel as 7.7 and of silicon steel 7.5. Although some of the separation tests were made at two frequencies only, the errors of test are not large enough to appreciably alter the results. The plotted points in many cases are representative values of several samples.

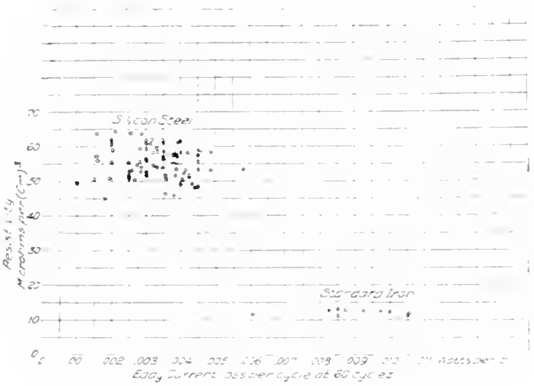

Fig. 1. Eddy-current Loss in Epstein Samples Having Different Values of Resistivity. B = 10,000

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*ETZ—1900, pp. 303-307; 1905, pp. 403-411; 1911, pp. 334-339, pp. 363-368.

ASTM, Specifications for Magnetic Testing of Iron and Steel, 1912.

Trans. A I E E., Vol. XXX, 1911, pp. 747-755.

The eddy-current loss has been defined at "per cycle at 60 cycles." As the separation tests obtained gave practically straight lines, the per cent variations would be the same taking any ordinary frequency.

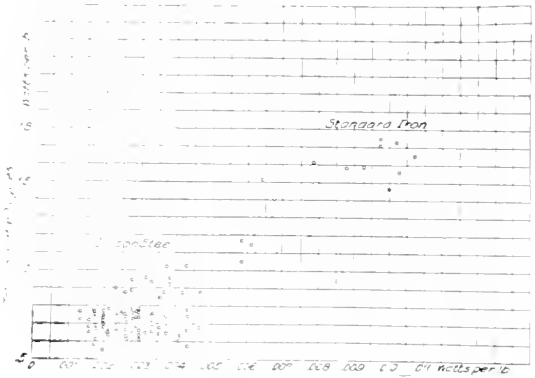

Fig. 2. Eddy-current and Total Loss in Epstein Samples. B = 10,000

Eddy-current loss is partly a function of the total loss as it is a component thereof; the hysteresis loss, however, being of the order of 80 per cent of the total loss at 60 cycles and at $B = 10{,}000$ is sufficient to overshadow this. Fig. 2 shows plotted values of eddy-current loss compared with total loss. Examination of the values for silicon steel shows eddy-current loss variations as high as 200 per cent for the same total loss, and total loss variations of 70 per cent for the same eddy-current loss.

These relationships may also be noted when the samples are tested as straight strips and the magnetic circuit is closed through air. In such a case the measured eddy-current loss, and consequently the total loss, is greater for the same weight of material than would be obtained in a closed ferro-magnetic circuit, and the measured eddy-current is not the same as would ordinarily be represented as the eddy-current in the iron. The unequal flux distribution alters the conditions somewhat; for example, if the test is made to give a hysteresis loss equivalent to a given uniform induction, the eddy-current will not be the representative value for the same induction, due to the difference of the loss exponents by which is determined the point where the induction is the same as that for which the properties are desired.

Figs. 3 and 4 show the results of tests made on 1 lb. (454 gr.) samples of straight strips 10 in. (25.4 cm.) by ½ in. (1.27 cm.) according to a separation method elsewhere described.* Fig. 3 represents the eddy-current loss derived from such tests on some 200 samples in which 19 cycles, 16 cycles, 13 cycles, and 10 cycles were the frequencies employed. The eddy-current loss is taken as the loss per cycle at 10 cycles and plotted as a function of the resistivity. In this case the silicon steel of five times the resistance of standard steel has about 4 7 as much average eddy-current loss. Here we find 200 per cent variation in eddy-current for standard steel of the same resistivity, and the same amount of variation in case of silicon steel. For constant eddy losses, the resistivity variation is 80 per cent for standard iron and 25 per cent for silicon steel, although, in amount, the variation for silicon steel is greater. While this variation in eddy-current loss is large, when it is remembered that this loss is a small per cent of the total loss at the testing frequency of 10 cycles, it will be seen that the average eddy-current loss, for any given kind and thickness of material, subtracted from the total loss will give sufficiently accurate hysteresis results. This is the method of procedure for which the outfit employed was designed. The adding of an average eddy-current loss to the hysteresis loss of a given material is also sufficiently accurate to determine the Epstein 60-cycle core loss

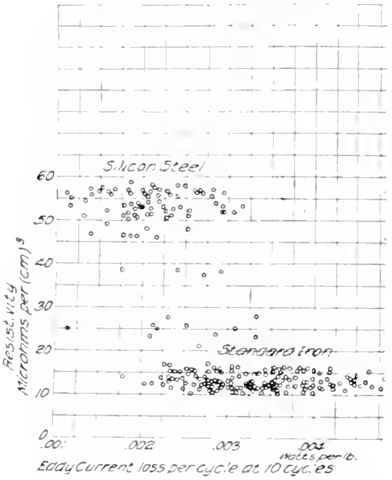

Fig. 3. Eddy-current Loss in 10 In. by ½ In. One Pound Samples. B = 10,000

required for ordinary commercial testing. For such a purpose, the eddy-current loss has been stated to be a function of the resistivity, if the variety of heat treatment

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* Trans. A.I.E.E., Vol. XXX. 1912, pp. 743-747.

of the steel is known.* Plotting the eddy and total loss values obtained on the 1 lb. sample shows the independence of these functions. For constant total loss, the eddy-current variation for standard steel is 80 per cent and for the silicon steel 175 per cent.

An interesting phase of the matter lies in the results of investigations conducted to examine certain special annealing methods. A special heat treatment super-imposed upon a regular factory anneal was found to radically change the magnetic properties, and show a decided increase of eddy-current loss although the resistivity was practically unaltered. Table I gives some of the results obtained. The variation in average eddy-current loss of 20 samples is greater than the variation in average resistivity; whereas, analysis of Fig. 1 showed the contrary. The special heat treatment referred to alters the granular structure of the material by the formation of unusually large grains, which may account for the differences in general behavior,† although qualitative tests indicate that the resistance of a definite length of a strip is the same whether length be taken within a single grain or from grain to grain. Resistance measurements made on long wire, of 0.025 in. silicon steel, however, show that the large-grained material has a resistance 15 per cent lower than the same wire in the fine-grained state. By examining the structure of the sheet it was found that the eddy currents increased rapidly with the grain size up to a point where the grains could be easily seen with the naked eye. Above this size there was little change in the eddy-current loss, e.g., for steels of a certain composition, a value of about 0.0044 was obtained which remained practically constant for a wide range of grain size. It was also found that annealing in a reducing atmosphere would considerably increase the eddy currents independently of the change of grain size.

### TABLE I—RESISTIVITY AND EDDY-CURRENT LOSS OF EPSTEIN SAMPLES

| Sample No. | ANNEAL AT 800 DEG. C. | | SPECIAL ANNEAL AT 1300 DEG. C. | | SUPERIMPOSED ANNEAL | |
|---|---|---|---|---|---|---|
| | Eddy | Res. | Eddy | Res. | Eddy | Res. |
| 1 | 0.0038 | 56.9 | 0.0028 | 59.3 | 0.0044 | 58.2 |
| 2 | 0.0038 | 58.0 | 0.0029 | 55.5 | 0.0042 | 52.2 |
| 3 | 0.0036 | 50.3 | 0.0036 | 55.9 | 0.0028 | 55.4 |
| 4 | 0.0030 | 53.4 | 0.0034 | 54.3 | 0.0058 | 53.7 |
| 5 | 0.0032 | 60.5 | 0.0032 | 61.9 | 0.0042 | 50.5 |
| 6 | 0.0034 | 58.0 | 0.0034 | 59.2 | 0.0034 | 57.4 |
| 7 | 0.0026 | 52.2 | 0.0026 | 52.5 | 0.0038 | 51.6 |
| 8 | 0.0026 | 51.7 | 0.0036 | 57.4 | 0.0044 | 51.6 |
| 9 | 0.0026 | 51.2 | 0.0034 | 56.5 | 0.0042 | 52.8 |
| 10 | 0.0024 | 54.5 | 0.0042 | 51.9 | 0.0046 | 57.7 |
| 11 | 0.0038 | 53.9 | 0.0038 | 45.5 | 0.0044 | 48.2 |
| 12 | 0.0036 | 57.3 | 0.0042 | 53.8 | 0.0042 | 49.0 |
| 13 | 0.0030 | 55.9 | 0.0040 | 49.3 | 0.0034 | 46.4 |
| 14 | 0.0028 | 53.8 | 0.0038 | 56.8 | 0.0044 | 53.4 |
| 15 | 0.0028 | 54.1 | 0.0038 | 58.9 | 0.0044 | 57.7 |
| 16 | 0.0022 | 70.5 | 0.0026 | 66.3 | | |
| 17 | 0.0028 | 64.0 | 0.0028 | 59.3 | | |
| 18 | 0.0024 | 68.5 | 0.0026 | 65.5 | | |
| 19 | 0.0022 | 59.2 | 0.0034 | 56.1 | | |
| 20 | 0.0022 | 74.0 | 0.0026 | 70.0 | | |
| Avg. 20 | 0.00295 | 58.0 | 0.00334 | 56.84 | | |
| Avg. 15 | 0.0031 | 54.8 | 0.0035 | 55.2 | 0.0042 | 53.1 |

Eddy-current loss values are given in watts per cycle at 60 cycles, $\beta = 10{,}000$.

Resistivity is given in microhms per cm³.

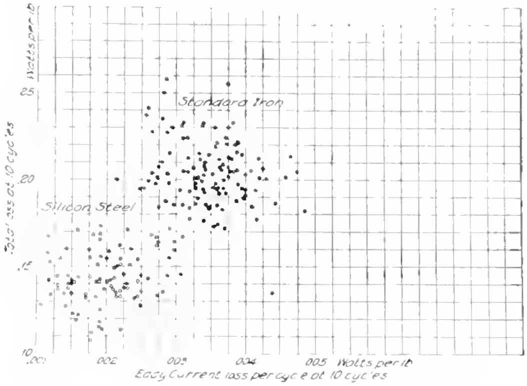

Fig. 4. Eddy-current and Total Loss in 10 In. by ½ In. One Pound Samples. B = 10,000

All samples referred to in this paper were cut from 0.014 in. sheets.

The conclusion from the foregoing data is that the eddy-current loss does not vary inversely as the first power of the resistivity and the effect of heat treatments and other considerations are so large that, except in a very general way, no definite value may be given for the power representing the variation. For a given variety of steel, therefore, no statement of a law seems warranted.

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[*] From Electrotechnik und Maschinenbau, Vol. XXXI, 1913, pp. 737-742:

Eddy-current loss in watts per kilogram $= \frac{c\,(d\,n\,\beta)^2}{s\,\rho}$, where $c$ is a factor, $d$ thickness of plate in mm., $n$ the frequency, $\beta$ the induction, $s$ the specific weight, and $\rho$ the resistance in ohms $\frac{m}{mm^2}$.

[†] Journal Industrial and Engineering Chemistry, Vol. V, 1913, pp. 452-458.

Bull. Min. Eng., December, 1913.

# ECONOMIES IN THE OPERATION OF ELECTRIC CAR EQUIPMENTS

By J. C. Thirlwall

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The author, after having made a thorough investigation of the operating conditions at El Paso, records in this article the means adopted to greatly decrease the power consumption per car mile. The special physical conditions of the system are cited, which show that some of them are usually severe. Wattmeters were installed on the cars and a predetermined normal power consumption, called a bogey, was established for each run. Motormen kept records of the power used on each trip, and these, compared with the bogey, form a measure of the efficiency of operation. The spirit of competition that this system has developed between the men has led to very material savings, both in the power bills and in the cost of maintenance, as the maintenance charges are reduced by motormen immediately reporting defects in the equipment that would lead to inefficient operation. Actual service data are given.—Editor.

The writer was recently given the privilege of looking over some of the operating records of the El Paso Electric Street Railway Company at El Paso, Texas, and noted certain features in the operation of the system which are unusual in America. As the practices referred to have reduced the cost of power and the maintenance of electrical equipment, it is believed that they are of sufficient interest to record in the Review.

Operating conditions at El Paso are in many respects unusually difficult. The city is situated in the valley of the Rio Grande river, and surrounded on three sides by mountains and foothills, so that the majority of their lines have to climb long, steep grades. Some of these run up to 6 per cent or 8 per cent. This has necessitated the general use of four-motor equipments on double truck cars, with a heavy weight per passenger as compared with the two-motor maximum traction equipments so widely used in city service. Moreover, the town being situated in a desert country, where suburban property values are low, it has spread out over an unusually large area in proportion to its population, so that the average length of ride and the track mileage is high in proportion to the population served. These conditions have made overhead expenses and the cost of power more serious items than they are in the average city, and necessitated the closest analysis of every detail of operating expense to keep the road on a paying basis.

A study of power station records some two years ago showed a steadily rising cost per car mile, which was out of all proportion to the normal increase in traffic. In analyzing this it appeared to be largely due to the manner in which motormen were handling their equipment. To verify this, and as an aid to correcting the evil, wattmeters were installed on every car on the system. Tests were then made in the following manner to establish the standard figure for power consumption of each type of car on each line on which they operated. Experienced motormen made a number of runs on every line, under the personal supervision of an official, who watched and instructed each man in the rate of notching up the controller, particularly on grades; in the handling of his brakes, with especial reference to preventing starting up or running with brakes partially applied; and in coasting, with the object of securing as much coasting as possible, particularly at the lighter hours of the day, when the tendency is to overrun the schedule.

The average of a large number of such test runs, which were made in regular passenger service, established what they call a "bogie" on each line, for each of the four classes of cars owned; in other words, an average power figure for each trip. Conductors were then instructed to take readings of the wattmeter on their cars at the end of each trip, and to enter them on a card in the same manner that they record fare register readings. In this manner a daily record of each motorman's performance on power consumption was available, and at a negligible clerical expense for tabulation. Many motormen, usually those least experienced, were found to be far exceeding the standards. These men were at once given personal and individual instruction, and shown how the proper operation of the equipment resulted in lower power readings. On the other hand, those men making the best record in this respect had their names entered on an "Honor List," which was posted monthly. A spirit of competition speedily developed among the men, with most gratifying results.

In November, 1911, the month before this system was put into effect, power charges at the station averaged 2.75 kw-hrs. per car mile. By the end of January, it had dropped to 2.36 kw-hrs. and averaged for the whole of

1912, 2.39 kw-hrs. During the latter part of that year, a number of new four-motor equipments weighing approximately 41,000 lb. were put into service, replacing some single truck cars of about half this weight, which slightly raised the consumption per car mile for the system for 1913, the average for the year being 2.43 kw-hrs. The average reduction for 1912 and 1913 over the previous year was 200 watthours per car mile, and with an annual mileage of approximately 1,600,000 car miles, this totals 320,000 kw-hrs. per year or a monetary saving of approximately $6000.00 annually. This figure, while not large in itself, is a big item on a small road. It was made with an average of 40 cars in operation, so the saving per car was about $150.00 per year.

But even this did not represent the entire gain. Repeatedly, cars were noticed that showed high readings with a number of different men; on looking into the cause, some defect, either in the adjustment of brake rigging, in the rheostats, or in the motors, would be found and corrected, much sooner than would otherwise be the case. Indeed, motormen, impressed with the necessity of keeping within the "bogie," would report defects to the mechanical forces that otherwise would have been ignored, provided the car could be run to schedule. Partly from this, and partly from the reduced amount of abusing equipment by fast feeding, by running too much on resistance points, or by holding brakes partially on while running, a very appreciable reduction in equipment troubles resulted. Brake shoe consumption became much lower, resistance troubles dropped, and motor defects, in particular, reached a most gratifying figure. For instance, during July, August and September, 1913, out of 156 motors making a total of 850,000 motor miles, there were but 12 motor failures, or an average of 70,000 motor miles run per defect, a showing which is remarkable for motors of the classes operated, GE-54s, 57s, 80s and 81s. Cost figures on equipment maintenance were not available, but it is believed that the reduction there secured would amount to at least $2000.00 more, annually.

It is not believed by the writer that the chief credit for these savings should be given to the wattmeters. These were merely a means to an end. The psychological effect on motormen of any apparatus by which his handling of the equipment can be checked, whether it be a wattmeter, ammeter, or coasting clock, counts for more than the records themselves, provided they are even approximately accurate. But unless this feeling of carefulness on his part is reinforced by personal supervision and instruction on the part of some one who has a greater knowledge and appreciation of the effect of improper operation of equipment than the motorman, himself, any results secured will be but temporary. Even now, after two years operation of the system, any relaxing of the personal instruction and attention is followed by a marked rise in power consumption.

In riding upon the lines of this Company, the trained observer is immediately struck with a number of points of difference from what he is accustomed to see in most cities. The handling of brakes is unusually good, motormen releasing completely before applying power, except when ascending steep grades. This is especially marked on single truck cars, with hand-brakes. On such equipment, in most cities, motormen practically always run with brakes partially applied, with two purposes: One to be able to apply the brakes quicker for a stop, and the other with the idea that it holds the car body from swaying and lurching when running at full speed. That neither practice is necessary was demonstrated to the writer's satisfaction.

Another point, of even greater importance, is the usual methods of operation during the light traffic hours of the day. Schedules are usually laid out on the basis of the fastest time that can be made on a rush hour trip, when the load and number of stops are the greatest. Then during the lighter hours of the day, motormen will usually do one of two things; either they will push their cars to the limit, and reach the end of the line several minutes ahead of the next leaving time, and take an uncalled for "layover" to smoke or to sit down and talk with the conductor; or they will loaf along on series notches, running an excessive part of the time on resistance points, in order to keep on schedule. In either case, the power consumption and strain on the equipment is greater than necessary. In El Paso, neither practice was seen on any trip at any time of the day. Where schedules were light the motormen would notch up normally to full multiple, wherever possible, then throw off power and coast to the greatest possible extent. No unnecessary layovers were seen at any time. It is believed that the thorough instruction of the motormen in the importance of coasting accounts for the greater part of the reduction that has been made.

Individual wattmeters on cars are notoriously unreliable, in making an exact or accurate record of power; but when a very considerable number of such instruments are in service, and their readings averaged over a considerable length of time, it is believed that the resulting data can be regarded as substantially accurate. The figures shown below are the averages of 9 months operation, January to September, 1913, for two classes of cars. The first, known as their class B, are for double truck cars, weighing without load, approximately 41,000 lb., with a seating capacity of 44, and equipped with four GE-81 motors geared 67 14. There are 18 of these cars in service. The second, known as class D, comprise 36 single truck cars, weighing 24,000 lb., seating 26, and equipped with two GE-80 motors, geared 71 15.

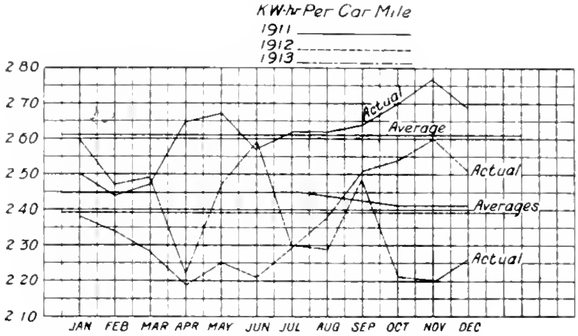

Fig. 1

The first four lines listed below are practically level. Sunset Heights line has about 4000 ft. of 3½ per cent grade; Fort Bliss line has 6500 ft. of 2½ per cent. These figures are averages, as grades for short stretches run up to considerably higher percentages.

The power figures show that on a level track, the factor affecting the power consumption of any type of car is primarily the number of stops made per mile. Where the difference in elevation of the two ends of the line is marked, as on Sunset Heights, the consumption will of course be high. This line, in spite of its schedule being less than that of the Second Ward line, takes more power per ton mile. The high readings on Fort Bliss are harder to explain. This line, however, extends further from the power station than any other, and it is believed that low voltage may have entered into the abnormal power consumption, together with the slight difference in elevation between the two ends of the line.

## POWER CONSUMPTION PER CAR-MILE AND PER TON-MILE.

| Line | KW-HRS. PER CAR MILE | | WATTHOURS PER TON MILE | |
|---|---|---|---|---|
| | Class B | Class D | Class B | Class D |
| Mexico | 2.20 | 1.64 | 100 | 126 |
| Washington Park | 2.02 | 1.51 | 92 | 116 |
| Government Hill | | 1.16 | | 89 |
| Fort Bliss | 2.82 | | 128 | |
| Second Ward | 2.13 | 1.55 | 97 | 119 |
| South Heights | | 1.73 | | 133 |
| Fort Bliss with trailers | 3.79 | | 95 | |

N.B.—In the figures per ton mile, an average load of 22 passengers is assumed for Class B and 15 passengers for Class D, these being actual records in service. The weight of a loaded trailer in Fort Bliss service is approximately 18 tons.

## SERVICE DATA

| Line | Distance Round Trip Miles | Schedule Speed M.p.h. | Average Stops per Mile | Average Duration of Stops Secs. | Average Passenger Load | Average Line Voltage |
|---|---|---|---|---|---|---|
| Mexico | 3.3 | 5.5 | 10.3 | 19 | 25 | 525 |
| Washington Park | 6.5 | 8.7 | 7.5 | 8 | 20 | 525 |
| Government Hill | 9.25 | 9.9 | 6.7 | 8 | 29 | 475 |
| Second Ward | 2.6 | 8.2 | 9.2 | 5 | 14 | 525 |
| Sunset Heights | 1.96 | 6.0 | 9.4 | 10 | 10 | 525 |
| Fort Bliss | 11.51 | 9.2 | 6.7 | 8 | 29 | 475 |

These figures are presented merely to show what are the actual readings at the car. As a basis for comparison with other roads, under different conditions of schedule, loads and voltage, they could hardly be applied.

What the writer has wished to bring out in this article is not the actual amount of power necessary to operate a car under any specified conditions, but simply the general idea that the education of motormen in the correct handling of car equipment can be made to yield very handsome returns upon the time or money invested in the effort. This is real economy and efficient management.

# NOTES ON METAL REFLECTOR DESIGN

By H. J. Tait and T. W. Rolph

It is erroneous to assume that a porcelain surface reflects light in exactly the same manner as a perfect mirror, and if such a false assumption is made in designing reflectors the results will not be satisfactory. It is essential to have accurate data on the reflecting properties of any material used in the manufacture of reflectors to obtain good results, and such data cannot be obtained from general laws without due deductions being made for the characteristics of specific material, i.e., rough surface materially alters the conditions. The author shows these differences in the reflection properties of smooth and rough surfaces by diagrams and discusses the differences between porcelain enamel and aluminum reflectors.—Editor.

Not long ago an advertisement appeared in the electrical trade papers in which a manufacturer of lighting specialties described his method of reflector design. The illustration of the advertisement was a diagram showing how the contour of a porcelain surface was calculated to produce a desired distribution of light. The basis of the design was the assumption, tacitly made, that a porcelain surface reflects light in *exactly* the same manner as a perfect mirror.

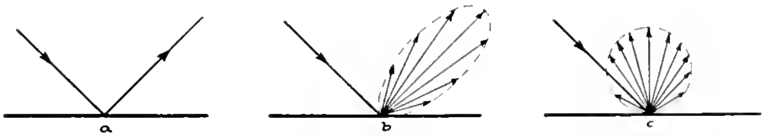

Fig. 1. Laws of Reflection:
(a) Regular Reflection
(b) Spread Reflection
(c) Diffuse Reflection

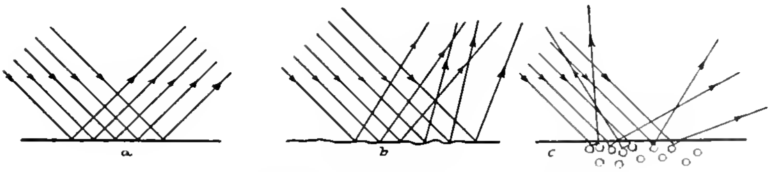

Fig. 2. Reflection of Pencils of Light Rays:
(a) Regular Reflection
(b) Irregular Reflection
(c) Sub-surface Reflection

That this assumption is in error, and that the error is greater than can be allowed in practical work, would have been proved if the design had been checked by a photometric test. The actual distribution of light would have been found to be so different from what was expected that the manufacturer could not have failed to recognize it.

Reflectors designed on such a basis are unfair. The purchaser is trying to buy, first of all, a lighting effect, and the manufacturer thinks that he is selling it. That both are fooled, illuminometer tests of installations in actual service have often proved.

Reflectors can be designed to produce the exact lighting result demanded, and, although practically all designs must finally be perfected by checking against actual photometric tests, the number of checks and changes in design can be made to a reasonable proportion of the design cost by a little investigation of the reflecting properties of the material used in the manufacture. An intelligent use of the knowledge of these reflecting properties will preclude the possibility of such absurdities in reflector design as occasionally appear in the technical press. The principles involved are not new but they are so seldom appreciated by designers that the repetition of them here is worth while.

The well-known law that the angle of light reflection is equal to the angle of incidence is illustrated in Fig. 1a. This is the law of regular reflection, which applies to every reflection of a single light ray from the infinitesimal surface which it strikes. But the law cannot be universally applied to the problem of reflector design in which a pencil of light rays must be considered. Practically the law can be applied to reflection from the surface only of a smooth reflecting medium. The action of such a surface on a pencil of rays is shown in Fig. 2a. Reflection from a rough surface or from particles lying beneath a smooth surface does not follow this law.

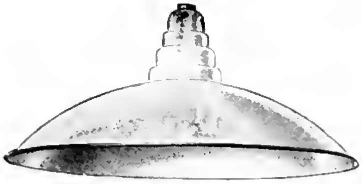
Fig 3. Shallow Dome Reflector

Of the metal reflectors now being sold for industrial lighting, the largest number have reflecting surfaces of porcelain enamel or of applied aluminum, the latter usually protected by a surface coat of lacquer to facilitate cleaning. With neither of these surfaces is a pencil of light rays reflected in accordance with the law of regular reflection.

Applied aluminum acts according to the law of spread reflection. Fig. 1b illustrates this law, showing the direction of rays emanating from a small portion of the surface with a given angle of incident light. Fig. 2b shows how spread reflection is produced by the action of infinitesimal portions of the surface on individual light rays. The major portion of the light deviates only slightly from the direction which it would take when regularly reflected.

Porcelain enamel acts by the law of diffuse reflection, illustrated in Fig. 1c. The maximum candle-power of the reflected light is normal to the surface, regardless of the angle of the incident light. This reflection is not produced by the surface itself but by the particles beneath the surface, as illustrated in Fig. 2c. In addition to the sub-surface reflection there is a small amount of reflection from the smooth surface itself, following, of course, the law of regular reflection. This amount is negligible in quantity as compared with the amount of diffusely reflected light.

The best control of light-rays can be obtained with surfaces giving regular reflection. Such surfaces are used for searchlights and projectors where it is important that every light-ray take a definite predetermined direction. With spread reflection, as shown in Fig. 1b, the major portion of the light deviates only slightly from the direction which would be taken by light regularly reflected. Consequently, reflectors with aluminum finish afford good light control and can be designed accurately to give pre-determined light distributions. With diffuse reflection (Fig. 1c), however, the reflected light is spread in all directions and the approximation of pre-determined results is difficult and often impossible. It follows that aluminum finished reflectors are preferable to porcelain enamelled reflectors from the standpoint of obtaining given distributions accurately. This is an important point for the user of reflectors who must have available a variety of distributions—focusing, intensive, extensive and widely distributing.

The difference between the action of porcelain enamel and aluminum is strikingly illustrated in the shallow dome shape of reflector. This reflector was designed as a porcelain enamel reflector to give the distributing photometric curve. When finished in aluminum, however, the reflector gives surprisingly different results. Fig. 3 shows the shape of the reflector. Fig. 4 shows the photometric curves in porcelain enamel finish and in aluminum finish. Porcelain enamel

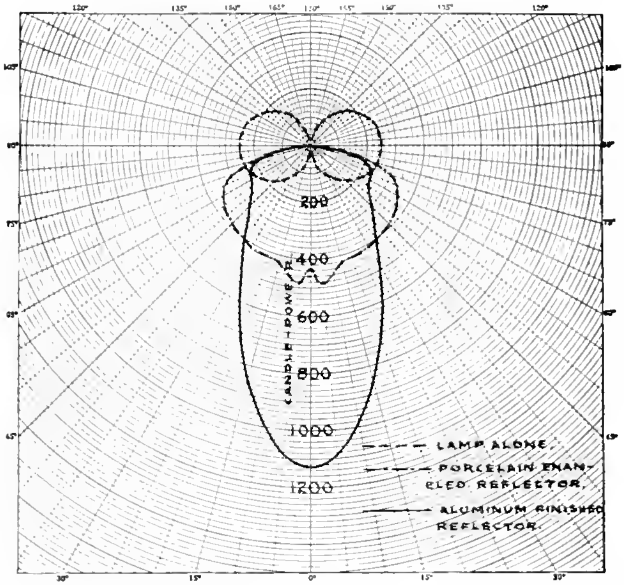

Fig. 4. Photometric Curve of Shallow Dome Reflector Porcelain Enameled and Aluminum Finished

gives the results desired, while aluminum gives a "freak" curve. The reflector approaches a shallow parabola in shape and the surface giving spread reflection naturally concentrates the light downward, though of course not as well as a reflector designed to do so would. The diffusely reflecting surface on the other hand spreads the light in many directions.


Fig. 5

To obtain the widely distributing curve with aluminum finish the shallow bowl shape is used as illustrated in Fig. 5.

To obtain extensive and intensive results in aluminum or porcelain enamel finish the deep bowl reflector is used. Fig. 6 shows a typical deep bowl. The focusing curve is also obtained with aluminum finished reflectors of the deep bowl type. With porcelain enamel, however, good focusing results cannot be obtained with any shape of reflector, owing to the diffuse nature of the reflection.


Fig. 6

Reflectors are being sold now in many instances on the basis of actual test in trial installation and those types are coming more into use which give a definite predetermined result, when installed according to rule.

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# AIR COMPRESSORS FOR FOUNDRY USE

By B. L. Spain

Turbine Department, General Electric Company

In the introduction of this article the author defines the different types of air compressors in common use, viz., the fan blower, the positive pressure blower, the reciprocating or piston-type compressor, and the centrifugal compressor, and states what ranges of pressures are to be expected from each. The body of the article is given to a description of these various types, and their characteristics as influencing their selection for foundry use. In conclusion, data of combustion are furnished which will assist in computing the size of compressor to apply to a particular installation.—Editor.

The problem of compressing air should be of interest to every foundryman, not only from the standpoint of obtaining the best efficiency, but also from the standpoint of absolute reliability and ease of operation of the compressor, and above all the proper choice of a type of compressor that will assist in producing the increased output and best quality of castings.

There are now in existence four distinct types of air compressors and they may be classified as follows. The first is the fan blower, which is generally used where large volumes of air are required at low pressures, e.g., pressures ranging up to $\frac{1}{2}$ lb. per sq. in., and in some cases as high as 1 lb.; but this type has a rather low efficiency and should only be used for very low pressures. The second is the positive pressure blower, which compresses air to medium pressures, e.g., from 1 to 10 lb., but which has characteristics such that the higher the pressure the lower the efficiency, or the larger the volume the lower the efficiency. The third is the reciprocating or piston-type compressor, which is best adapted for compressing air to high pressures, e.g., from 30 lb. upwards. The fourth is the centrifugal compressor which is designed for any volume and pressure for which either the reciprocating or positive types have been used, viz., for volumes from 500 to 50,000 cu. ft. of air per minute, and pressures ranging from $\frac{3}{4}$ lb. per sq. in. upwards.

The fan blower as shown in Fig. 1 consists of an impeller mounted on a shaft, supported by bearings and enclosed in a sheet or cast-iron casing which provides the passage for the compressed air from the impeller to the discharge pipe. The impeller revolves at a comparatively low speed, and the pressure is produced almost entirely by centrifugal force because the fan blower is not provided with passages beyond the impeller for the efficient conversion of the velocity of the air, existing at the impeller exit, into pressure. Practically all of this velocity energy therefore is dissipated in eddy-currents and is lost in the form of heat. Blowers of this type are used for compressing large volumes of air to pressures of ½ lb. per sq. in. or less, and although the efficiency is not as high as that of other types, the first cost is of greater importance; consequently, as the powers involved are usually small, it does not pay to install a more efficient but costlier type. When, however, the power involved is considerable, or its cost is the main consideration, this type should not be used.

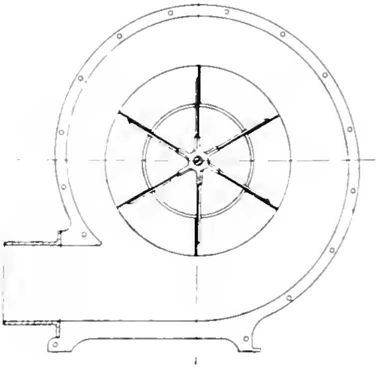

Fig. 1. Diagrammatic Section of an Ordinary Fan Blower

The principle and the characteristics of the positive pressure blower are different from those of the fan blower. This type consists of one or more drums with lobes arranged in such a manner as to provide pockets to receive air at the intake and convey it to the outlet as shown in Fig. 1a. If the outlet is not restricted, the air will be transferred from the intake to the discharge but without any rise in pressure. If a pressure above that of the atmosphere exists at the discharge, the air in the pockets will be raised to that pressure. If a positive pressure blower is run at full speed with the discharge pipe closed, the pressure will increase sufficiently to burst the casing, stall the driver, or produce a leakage between the drums and the casing equal to the amount of air entering. Usually, a by-pass valve is provided to compensate for changes in the load. This will pass air from the discharge side into the atmosphere when the pressure reaches a predetermined value. The power required to drive this blower against any given pressure is constant, even though the volume of air delivered varies greatly. This is shown by the curves in Fig. 2. The upper dotted line indicates the pressure that would be obtained from a positive pressure blower, provided with a by-pass valve and operated at constant speed, when delivering various volumes up

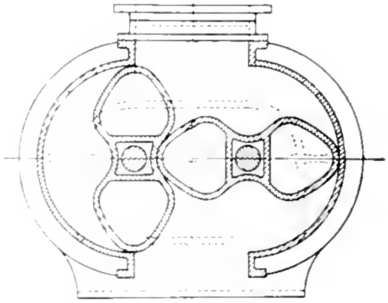

Fig. 1a. Diagrammatic Section of One Type of Positive Pressure Blower

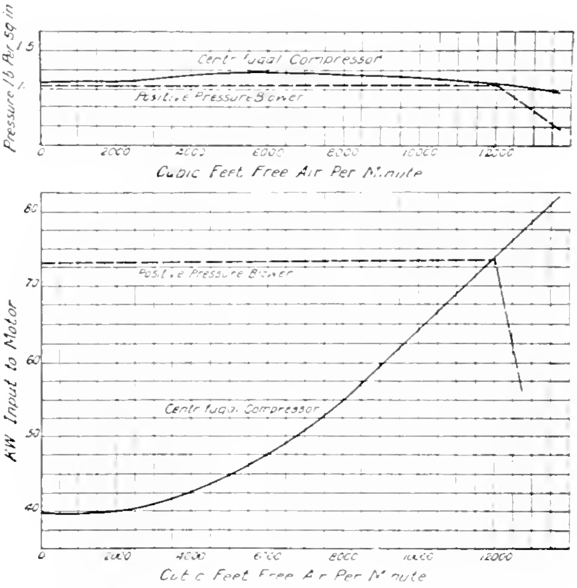

Fig. 2. Power Input and Delivered Pressure Curves for a Centrifugal Compressor and for a Positive Pressure Blower

to its normal free air rating of 12,000 cu. ft. per min. The lower dotted curve represents the power input of the motor corresponding to this pressure curve.

The power curve also shows that whereas the efficiency of a positive pressure blower in first class condition may be good at full load, for fractional loads it decreases rapidly, otherwise the curve of power required at fractional loads should be similar to that shown by the lower solid curve.

The efficiency of this type of blower at full load is good if the clearance between the rotating elements themselves and between them and the casing can be maintained small, but the unbalanced pressure on the two sides of the drums or impellers causes the bearings to wear rapidly, allowing the impellers to come in contact with the casing and to wear larger clearances. When these machines are designed for intermediate volumes and low speeds, the wear is not so great as in the case of larger units with their greater distances between the bearings, because the unequal pressures just referred to cause a greater deflection of the impellers and produce a greater loading on the bearings which results in more rapid wear of the parts named. This, of course, means an increased leakage of the high-pressure air back into the intake, which is accompanied with a corresponding decrease in efficiency.

A positive blower is usually connected to its driver by gears, the wear of which produces wear of the drums and hence lower efficiency. The wear of the various parts of this type of blower is also accelerated by the presence of dust and grit, which is always present in foundries. In order, therefore, to maintain good efficiency of the positive pressure blower, frequent repairs and replacement of parts are necessary.

Since the delivery of air to the discharge pipe intermittently, usually between one hundred and two hundred intervals per min., causes the pressure and flow of air through the tuyeres to fluctuate, and since the output of the cupola depends on the steady descent of the charge and the melting of the iron at a constant rate, it is easily seen that this fluctuation in the flow of air is not productive of the best results from the cupola.

Reciprocating compressors may be used to compress air to any desired pressure, but the application of this type of machine to low-pressure requirements is prohibitive on account of the cost. They are therefore used only where pressures from 30 lb. per sq. in. and upwards are required.

This type of compressor consists of a piston which moves forward and backward in a cylinder provided with ports and valves for the proper admission and discharge of air. The pressure in the clearance spaces between piston and cylinder head and in the ports leading to the discharge valves, is equal to the discharge pressure when the piston reaches the end of its compression stroke. When the piston returns the compressed air in the clearance space must expand to somewhat below atmospheric pressure, or the pressure of the air at the intake, before any air from the intake pipe can enter the cylinder. Consequently, air is admitted during only part of the piston stroke, and therefore the reciprocating compressor does not deliver a quantity of air equal to its piston displacement, but a considerably smaller quantity. The ratio of the actual air delivered to the displacement of the piston is called the volumetric efficiency. The volumetric efficiency is further affected by leakage of air through the valves which always wear with use and seldom remain tight. The usual rating of reciprocating compressors, as well as positive pressure blowers, is based on displacement of air and is therefore in excess of the actual free air delivered. The displacement in either case is between ten and fifteen per cent greater than the actual air delivered, and when wear occurs this percentage becomes very large. The term, *free air,* as usually applied to positive pressure and reciprocating blowers is used erroneously, because displacement of air is referred to and this differs greatly from the actual free air delivered. The necessity of frequent repairs to this type of apparatus, in order to maintain good efficiency, is self-evident.

The development of the steam turbine led to the introduction of the centrifugal pump. Since this type of pump could be direct connected to a high-speed driver and since its efficiency had been greatly increased over that of previous models, its success was well established.

The success of these two high-speed pieces of apparatus led to the development of the centrifugal compressor, and we can say today that the centrifugal compressor stands where the centrifugal pump stood five years ago. The initial development of this apparatus, which took place in Europe, was always of a type in which the air was admitted to only one side of the impeller and, just as in centrifugal pumps, in order to balance the end-thrust in multi-stage designs the impellers were placed back to back or some other equivalent means had to be employed.

The General Electric Company was the first to take up the design of the centrifugal compressor along lines entirely independent from those employed in Europe. The chief difference lay in the design of the impellers and in their arrangement in the compressor. Impellers of the double-inlet type are always used in both single and multi-stage machines for, as this type has inherently no end-thrust, their use prevents the necessity of a special arrangement of the stages or the use of the complicated devices which are necessary to counterbalance the end-thrust of single-sided impellers.

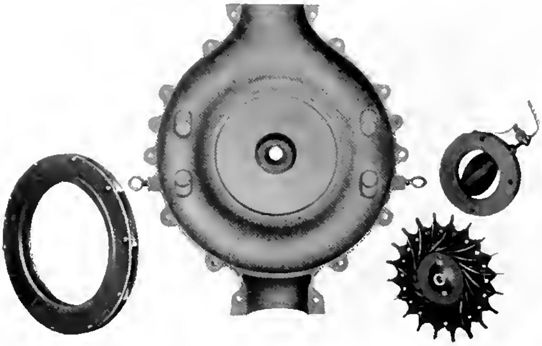

Fig. 3. The Parts of a Single-Stage Centrifugal Compressor

A centrifugal compressor consists of one or more rotating impellers supported on a shaft and surrounded by a stationary set of discharge vanes, the whole being enclosed in a casing. These parts are shown in Fig. 3. The driver may be a direct-current or alternating-current motor or a steam turbine. Figs. 4, 5, 6 and 7 show various types of compressors and drives.

When the impeller shown in Fig. 8 is made to revolve, it will entrain by centrifugal force a fluid, such as air, at its inner periphery and discharge it at its outer periphery. At this latter point the air contains by reason of its centrifugal pressure and its velocity two forms of energy, potential and kinetic. The function of the discharge vanes is to convert the velocity energy into pressure energy. These discharge vanes, Fig. 8, are designed in such a manner as to gradually reduce the speed of the air as it passes through them and thus recover the velocity energy in the form of an increased pressure. Fig. 9 illustrates the gain in pressure due to the discharge vanes; the lower curve represents pressure resulting from the centrifugal action of a perfect impeller with the small amount of velocity conversion obtained by the casing only, and the higher curve shows the increase of pressure due to the action of the discharge vanes. About 95 per cent of the energy supplied by the driver to the compressor appears in the two forms spoken of above. The five per cent loss is due to friction of the

Fig. 4. A Centrifugal Compressor Driven by a Direct-Connected 30 H.P., 230-Volt Direct-Current Motor

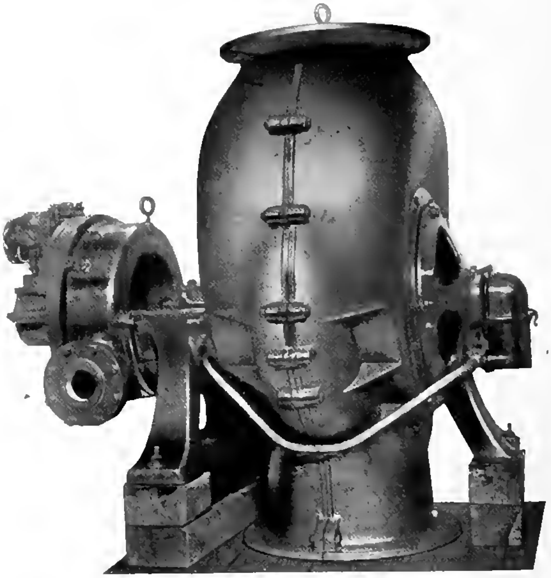

Fig. 5. A Centrifugal Compressor Driven by a Direct-Connected 75 H.P. Curtis Steam Turbine

air through the passages of the impeller. Of the 95 per cent energy existing at the discharge end of the impeller, or at the tips of the blades, approximately one-half exists in the form of centrifugal pressure and the other half exists in the form of velocity energy. The centrifugal pressure is directly available and is used without any additional losses. The velocity energy is transformed by the discharge vanes into pressure with an efficiency varying from 40 to 70 per cent depending upon the quantity and the pressure of fluid handled. It is this proportion of velocity energy recovered by the centrifugal compressor that is entirely lost in the fan blower. The centrifugal compressor is, therefore, much more efficient than the fan blower. Fig. 2 shows a pressure curve of a 12,000 cu. ft. centrifugal compressor, and also the power required at various loads. Note the decrease in power at light loads and the saving resulting therefrom.

The efficiency of this type of apparatus is but slightly affected by large clearances, and the clearance is therefore made ample to permit of satisfactory operation. When the rotating element is properly adjusted by means of shims in the bearing linings, it is impossible for it to come in contact with stationary parts. Consequently, we have in this type not only a blower of high efficiency but also one which will maintain that efficiency after long periods of service.

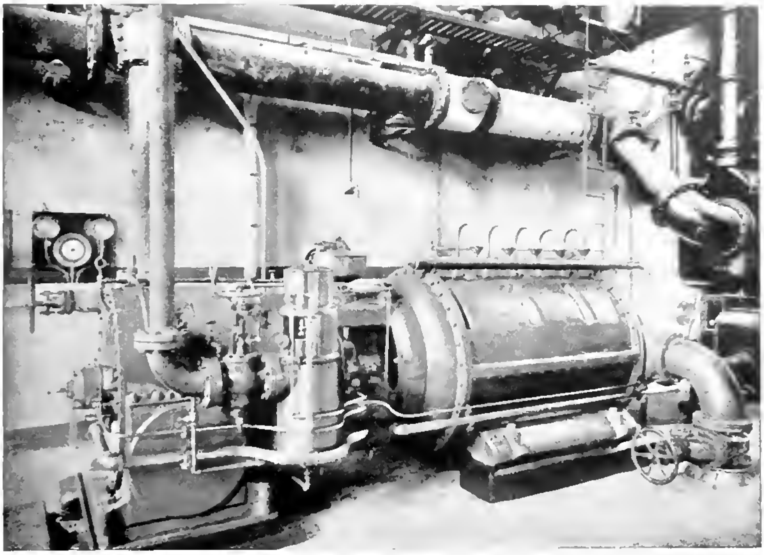
Fig. 6. Turbine-Driven Centrifugal Compressor for Bessemer Converter

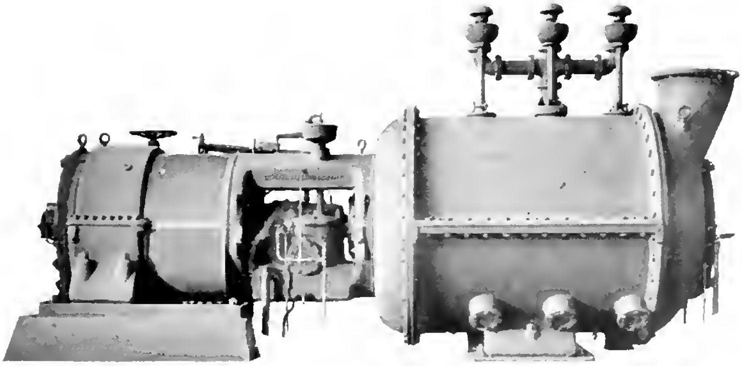
Fig. 7. A Large Centrifugal Compressor, Built Especially for Blast Furnace Work, Driven by a Direct-Connected Curtis Steam Turbine

The characteristics of the centrifugal compressor make it especially adapted to cupola blowing because the air is delivered from this apparatus at perfectly steady pressure, as shown in Fig. 9. The steady flow of air through the tuyeres, resulting from the steady pressure, produces a steady condition in the cupola and this causes not only the steady descent of the charge but also uniform melting. This in addition to being true for theoretical reasons has been borne out in practice.

Some of the other advantages which are possessed by this type of compressor are the small floor space occupied; the ability to use a direct connection to the driver without the use of belts or gears which involve additional losses and wear; the light weight which permits of the use of smaller foundations and lighter floors than are necessary for positive pressure types; the small number of bearings, never more than three;

and the elimination of repairs to the compressor end. For these reasons the centrifugal compressor is especially adapted for foundry use.

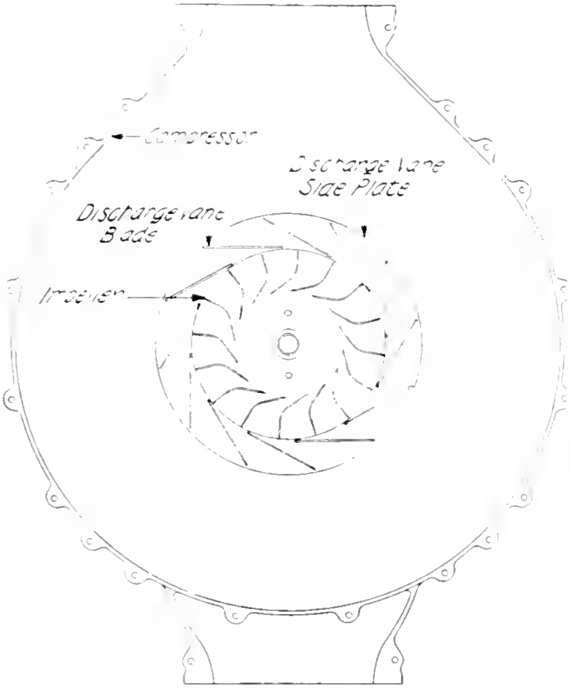

Fig. 8. A Diagrammatic Section of a Single-Stage Centrifugal Compressor

A large number of centrifugal compresssors have been manufactured and are in satisfactory operation. Without any doubt these machines will supplant all other types of air and gas compressors. There are several other manufacturers in this country which have begun to build the centrifugal compressor, but in all cases their designs are in accordance with European practice.

The established rule for the selection of positive pressure blowers for iron foundry cupolas has been the cause of the principal difficulty experienced with centrifugal compressor installations, in that the first machines supplied for this service were much too large. According to this rule, thirty thousand cubic feet of displaced air should be allowed for each ton of iron, and this has been interpreted to mean the actual free air delivered. In supporting this rule, computations have been made showing that 150 cu. ft. of air are required to burn 1 lb. of carbon to $CO_2$, and attention has been called to the results of experiments which show that 1 lb. of coke will melt 10 lbs. of iron. Assuming, for the moment, that coke is pure carbon and that all of it is burned to $CO_2$ it follows that 30,000 cu. ft. of free air should be provided for each ton of iron.

Since analyses of coke show a carbon content of from 85 to 92 per cent, only these percentages of air would be necessary to burn commercial coke to $CO_2$. As a matter of fact, however, all the carbon is not burned to $CO_2$, since some only reaches the CO stage. On account of this incomplete combustion of part of the carbon, it has been found that only about 90 per cent of the air necessary to produce complete combustion of all the carbon will be required. These two factors, impure coke and partial burning, are together responsible for reducing the demand for air by about 20 or 25 per cent. Eighty per cent of 30,000 cu. ft., or 24,000 cu. ft., of air would therefore be considered a liberal figure.

This theory has actually been proved by tests of positive pressure blowers and centrifugal compressors in conjunction with a cupola where it was found that 30,000 cu. ft. of displaced air from the former and 24,000 cu. ft. of free air from the latter are necessary to melt one ton of iron. It is of interest to know that this represents about the ratio of actual free air delivered to the displacement rating of a positive pressure blower.

The following conclusions may be drawn from the preceding description:

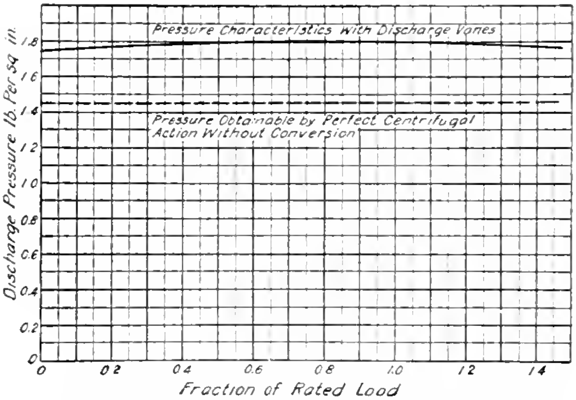

Fig. 9. Curve Showing the Discharge Pressure from a Centrifugal Compressor: Perfect Centrifugal Action, and Employment of Discharge Vanes

First, the principal difficulty with the fan blower when compressing air to sufficient pressure for cupola blowing is that its efficiency is lower than that of other types.

Second, the positive type of blower does not maintain its efficiency without excessive maintenance cost. It creates a fluctuating pressure which produces unsteady conditions in the cupola and results in irregular melting of the iron.

Third, the reciprocating compressor, although better adapted to higher pressures, is not applicable to cupola blowing.

Fourth, the centrifugal compressor has a high efficiency, maintains this efficiency, requires very little attention, the cost of maintenance is extremely low, and above all it produces a steady pressure which results in uniform operation of the cupola. It is therefore better adapted for foundry use than any of the other types in existence.

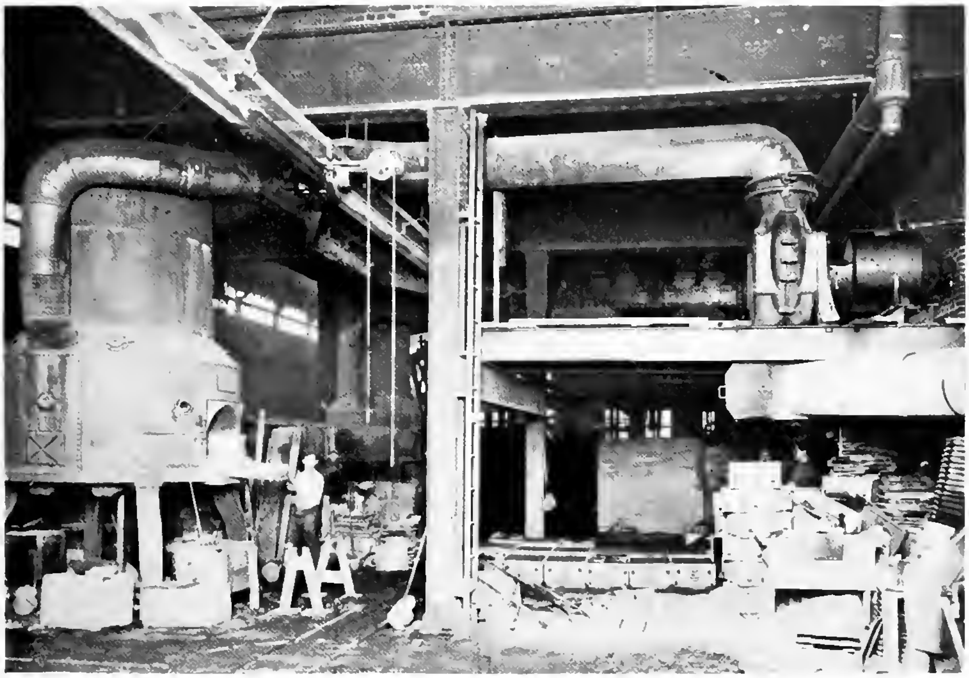

**Fig. 11. An Installation of a Centrifugal Compressor, Driven by a 30 H.P. Direct-Current Motor, Blowing a Ten-Ton Foundry Cupola**

# MILITARY CAMP LIGHTING

By John Liston

General Electric Company, Schenectady, N. Y.

The following article describes an innovation in the use of electricity, viz., electric military camp lighting. In the introduction are named the primary requisites that must be possessed by the generating set to be used for this purpose, and the remainder of the article records the success of the first installation of this kind, which was at Camp Sulzer, August, 1913.—Editor.

In order adequately to supply electric illumination for temporary military camps, the lighting equipment must, of necessity, be portable and capable of meeting the following conditions:

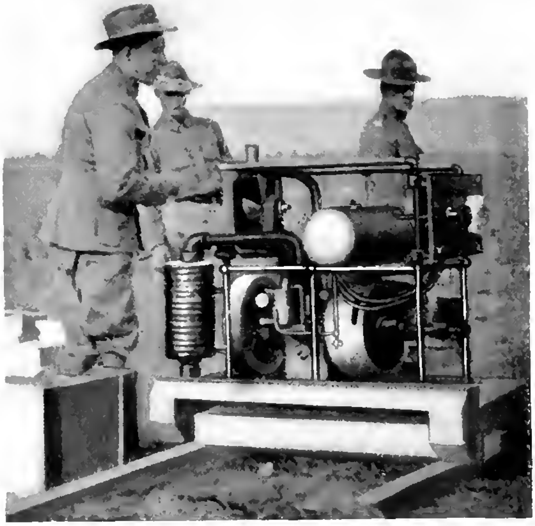

Fig. 1. Portable Gas-Electric Set in Service at Camp Sulzer, Glens Falls, N. Y., August, 1913

It must be compactly constructed, self-contained and of relatively light weight, so that it can be easily handled by a few men in loading and unloading the military transport wagons.

It must be sufficiently strong, mechanically, to successfully withstand the rough usage to which it may be subjected during its removal, transport, and installation at successive camp sites, and to minimize repair work which might be rendered exceedingly difficult or even impossible with the limited facilities ordinarily available under field service conditions.

It must be both simple and reliable in operation so that it may be safely entrusted to men lacking special electrical or mechanical training, and the fuel and other supplies required must be of such a nature as to be readily and generally procurable, or else easily and safely transported with the lighting equipment.

It must be so designed that the installing and assembling of the necessary wiring and lamps may be accomplished rapidly and also in a manner to insure freedom from accident during operation, by a comparatively few men and with a negligible effect on their purely military duties; and, lastly, its electrical characteristics must be such as to insure steady and efficient lighting.

The superiority of electric lighting over all other forms is so generally conceded that the relative values of the various forms of illumination available for temporary military camp lighting will not be here discussed, and the context will be devoted to an analysis of an electric lighting set which has already successfully undergone the "acid test" of actual service. This description will serve to indicate to what extent it meets the stipulated requirements.

The set consists of a single cylinder gasolene engine and a direct-current generator, the combined units having only two bearings and a common base, as is shown in Fig. 2. With the exception of the magneto, which is mounted on a bracket bolted to the end shield of the generator and directly coupled to the generator shaft, all the auxiliary equipment is compactly arranged above the generator on a metal pipe framework so that the radiator, gasolene tank, oiling system, rheostat, switch, etc., are readily accessible and require practically no addition to the ground space necessary for the generating unit alone.

The complete outfit is mounted on a small platform sledge, and has an overall length of 3 ft. 3 in., width 2 ft., and height 3 ft. 5½ in. Its net weight is about 465 pounds, and the necessary boxing for protection during transportation adds about 100 pounds to this figure. It is, therefore, evident that as far as bulk and weight are concerned, it is well adapted to meet the exigencies of temporary military camps and can be suitably housed, while in operation, in a standard "A" tent.

The fuel required is commercial motor gasolene, and approximately four hours running can be secured per gallon consumed. An efficient centrifugal governor, located within the flywheel, responds instantly to changes in load; and as the generator field is compound wound so as to compensate for any drop in engine speed between no-load and full-load, the maintenance of a practically constant voltage and, consequently, steady lighting is assured throughout the entire load range of the set. It is, therefore, obvious that the attention of a skilled attendant is not required for successful operation, as when once started the set is self-regulating and the proper initial adjustment of the hand-operated rheostat, which forms part of the equipment, can be readily made even by an inexperienced operator.

During the week ending August 9, 1913, a set of this type having an output of 1 kw. at 125 volts direct current was utilized at Camp Sulzer, near Glens Falls, N. Y., for lighting the tents of the officers of the 2nd Infantry, N.G., N.Y. Fifty 25-watt mazda lamps were used on three parallel circuits, approximately 700, 550 and 450 ft. in length.

The generating set was placed in an "A" tent about 100 ft. from the center of the three circuits, as shown in Fig. 3, and the feeder wires, which consisted of No. 14 rubber-covered twin-conductors enclosed in a weatherproof case, were embedded about six inches in the sand. In each tent a loop was made, extending a foot above the ground, and to this loop a 10-foot length of lamp cord provided with a porcelain key socket was connected and the lamp suspended from the ridge pole of the tent.

The entire work of installation was performed by six men in less than two hours, but as they had had no previous experience to guide them in the work it is reasonable to assume that the time required would be subject to a considerable reduction if this system of camp lighting were standardized for military use.

During the week the lights were in operation from 7 p.m. to 11:30 p.m. and on one occasion were kept going all night. In spite of the fact that high winds and two severe rain storms were experienced, there were no grounds or short circuits and the lighting service remained unaffected. The novelty of the equipment attracted a considerable number of visitors to the small power plant, and for this reason one man was stationed in

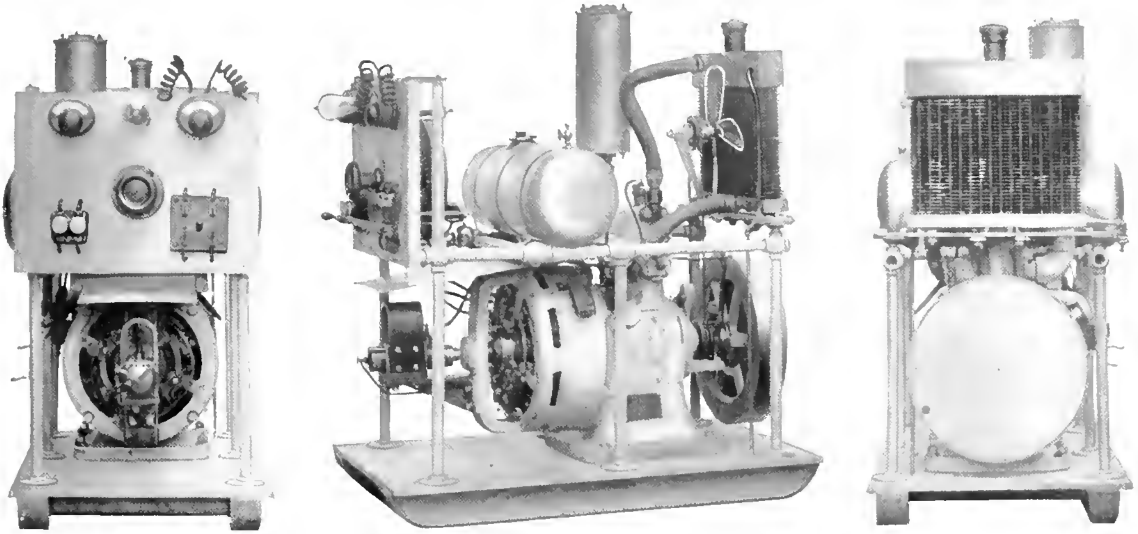
Fig. 2. Three Views of 1 Kw., 125 Volt Portable Gas-Electric Set

attendance throughout the operating period. His services as an operator, however, were almost purely nominal, and under ordinary circumstances only a very small amount of his time would be required.

An interesting auxiliary service rendered feasible by the generating set at the camp consisted in the use of a 10-inch incandescent hand-controlled searchlight projector at the guard house. The source of light in this equipment was a 6-volt, concentrated filament mazda lamp, and current was supplied by a compact 3-cell storage battery, which, in turn, was charged daily by the generating set. As the weight of the batteries was less than 20 pounds, the entire equipment could be readily manipulated or carried by one man, and any desired change in the location of the searchlight could be made easily and promptly.

While this particular service at Camp Sulzer was confined to the single unit, referred to above, the 1-kw. generating set was capable of supplying a considerable number of small independent searchlights in this way, or even of operating a limited number of more powerful arc-light projectors, although in the latter case it would have been necessary to connect the searchlight equipment to the generator feeder wires.

In addition to the general favor which the use of electric light gained thoughout the entire camp, it may perhaps be said that in no department was its use more appreciated than in the field hospital.

While the installation was originally regarded as an experiment and the generating set was not especially designed or constructed for the work actually performed, its successful operation under conditions paralleling those which might be expected to obtain in military field service clearly indicates the feasibility of providing a durable and convenient portable lighting outfit for military camps.

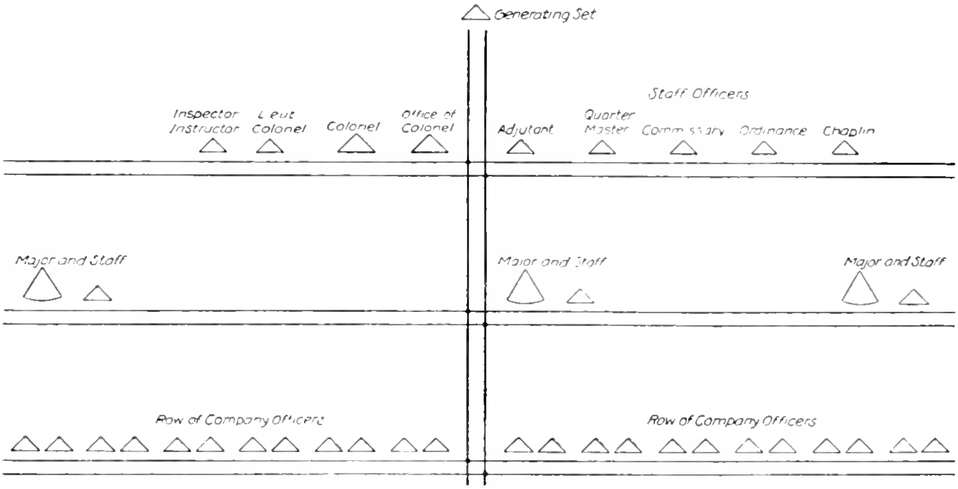

Fig. 3. Arrangement of Officers' Tents and Electric Wiring, Camp Sulzer, Glens Falls, 1913

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## IRON CONDUCTOR AS A PROTECTION AGAINST HIGH FREQUENCY DISTURBANCES

Although skin effect and other high frequency phenomena in iron conductors is pretty thoroughly understood, there seems to be a general misconception as to the value of iron in affording protection to apparatus from line disturbances. A partial acquaintance with the phenomena that takes place in iron conductors at high frequencies, leads to the false conclusion that such a conductor affords considerable protection from line disturbances. After a careful perusal of all the available data, the question arises as to whether it affords appreciable protection or not.

A discussion of the relative merits of an ordinary copper coke coil and one using a soft iron conductor will perhaps throw some light on the subject.

It is assumed that the coil is to be placed in the high tension side of a transmission line, in series with the station apparatus, for the purpose of choking back high frequency disturbances and forcing them through the protective apparatus. There is a certain critical frequency between $10^4$ and $10^5$ cycles, which is destructive to station apparatus, and this article deals only with frequencies between these limits. Chapters VI, VII, VIII and XI of Dr. Steinmetz's "Transient Phenomena" cover the entire field thoroughly in a theoretical way, and if actual research data is desired a reference to Mr. E. F. W. Alexanderson's paper on "Magnetic Properties of Iron at Frequencies up to 200,000" in the Proceedings of the A.I.E.E. 1911, Part III, page 2433, would be of benefit.

It is well known that a copper choke coil does not give a sufficient degree of protection to station apparatus. Although it may choke back the greater part of the high frequency energy, enough seeps through before the protective apparatus is brought into play to start up destructive oscillations. To prevent this seeping an iron coil must have an appreciable increase in effective resistance and internal reactance at high frequencies over that of copper, and the high frequency hysteresis losses should be much more than at a commercial frequency. Even at low frequencies there is considerable skin effect in iron conductors; that is, the current flows only in the outer shell of the conductor and thus only a small volume of a solid conductor would have hysteresis loss. It must be remembered that, in most cases, the high frequency current is superimposed upon the commercial current in the form of a path in the outermost shell of the conductor, its depth of penetration being much less than that of the lower frequency. It would thus have a very small volume of iron to produce hysteresis loss, and for this reason the loss is not so pronounced as would be supposed. This is shown in Mr. Alexanderson's article.

There is, however, a considerable increase in effective resistance and internal reactance at high frequency. They vary as the square root of the frequency. But, the coil reactance varies directly as the frequency and thus at high frequencies is much greater than the internal resistance and reactance.

It seems then, that an ordinary copper coil, with an increased number of turns would be more effective in holding back disturbances than would one made of iron.

J.D.B.

## CLAUDE NEON VACUUM TUBE LAMP

Last year a Claude neon lamp was imported from France. However, owing to breakage in transit of an electrode connection within the tube, the lamp could not be operated with alternating current in the manner intended, but only in an incidental way, and at much lower than normal brilliancy by means of high-frequency current and the use of an external electrode, which was applied to the tube after it was received.

Two other lamps have lately been received which appear from preliminary tests to be in perfect condition. One of these lamps is now installed in the laboratory of Dr. C. P. Steinmetz, at his residence, and the other in the Light Research Laboratory, Building 28, Schenectady Works.

The lamp is nearly 20 feet long and made of a straight glass tube about 1¾ inches internal diameter, with enlarged cylindrical ends, which contain cylindrical sheet copper electrodes 13 inches long and 2⅜ inches in diameter. The tube contains pure neon gas at a pressure of about 1 mm. of mercury.

According to Claude, the lamp has a life of over 1000 hours, taking 800 volts. The current may be varied from 0.06 to 1.3 amperes, the light being redder with the lower current. At 1 ampere the lamp gives about 1000 candle-power, with a power-factor of about 0.8.

The light is of a decidedly rose-red tint; the spectroscope analyzes it into numerous lines lying in the red, orange, yellow and green regions, with an entire absence of blue and violet, which can be compensated for in practice by using mercury vapor lamps, which emit a large excess of blue and violet, in conjunction with neon lamps.

It is proposed to test the Claude lamp thoroughly and now that a supply of neon is at hand the use of this very rare gas in vacuum tubes for other electrical applications is under development.

# QUESTION AND ANSWER SECTION

The purpose of this department of the Review is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the Review.

Second, it publishes for the benefit of all Review readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting subject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

### EXCITER: AUTOMATIC VOLTAGE REGULATOR CONTROL

**(98) Difficulty has been experienced with the control of an exciter by an automatic voltage regulator. The exciter is a 40-kw. machine, over-compounded 10 volts, i.e., 125 volts no load, 135 volts full load. Its delivered voltage at full load, with the shunt field rheostat all cut in, is 75 volts. This we have found is not low enough for satisfactory operation. What steps should be taken to improve the control?**

The most prominent fault which seems to exist in the outfit is that the resistance in the shunt field rheostat is not sufficiently great. Initially, however, it would be better to readjust the exciter for a flat compounding, i.e., 125 volts no load, 125 volts full load; which can be readily accomplished by lowering the resistance of the shunt across the series field terminals. After this has been done, the maximum available resistance of the shunt field rheostat should be increased to at least three times the hot resistance of the shunt field winding, which amount has been found in practically every case sufficient to give the proper time element. This change can best be accomplished by replacing the present exciter field rheostat with one of higher resistance.

O.C.R.

### WATTHOUR METERS: EFFECT OF CHANGE OF FREQUENCY

**(99) Is it a fact that a rise in frequency on a system, owing to the speeding up of the generator, will cause watthour meters to run slow? If so, please explain the cause and state how much they will slow down compared to the change in frequency.**

It is a fact that a rise in frequency on a system will cause some meters to run slow, although others will run fast under such a condition. Sometimes reducing the frequency will make a meter run fast for the first five or ten per cent of frequency reduction, while for a further reduction the frequency-speed curve bends over and the speed of the meter will be somewhat reduced. The change of the meter speed with an increase or decrease of frequency in either direction, however, is very small and, in a well designed meter, amounts to only a part of one per cent for as much as five per cent increase or decrease in frequency. An explanation of this changing action seems hardly feasible in the columns of this Section as the internal relations involved are very complex.

E.C.S.

### EARTH CURRENT: POSSIBILITY OF OBTAINING

**(100) Can an electric current be obtained directly from the earth? If so, by what means can this be done? Of what magnitude would the current be?**

If there is provided a place which is at a different potential from that of the earth and this point is connected to the earth an electric current will flow in the connector.

The current which does flow will then reduce this difference of potential to zero, unless a means is provided for constantly maintaining it at the desired value. This can best be done by an electric generator. The magnitude of the current flowing depends upon the potential difference between the earth and the place above mentioned and also upon the impedance of the connecting conductor.

S.T.

### INDUCTION MOTOR: OPERATION OF 25-CYCLE MOTOR ON 60-CYCLE SUPPLY

**(101) What would be the effect of operating a 25-cycle induction motor on a 60-cycle supply, for a period of not more than an hour?**

This depends largely upon the design and type of the motor. In general, for the same voltage the maximum output at 60 cycles will be roughly one-half that at 25 cycles. The speed will be increased in the ratio of 60 to 25, e.g., the synchronous speed of a 4-pole, 25-cycle motor will be 750 r.p.m. at 25 cycles, while at 60 cycles it will be 1800 r.p.m. It is doubtful, however, whether an ordinary 25-cycle rotor would be strong enough to run at the abnormal speed due to 60-cycle operation. The output being roughly one-half and the speed 2.4 times as great, the torque would be approximately one-fifth as great. The starting torque would be even slightly lower, in the neighborhood of only one-sixth as great. The resistance will, of course, remain unchanged for both frequencies, but the reactance will be proportional to the frequency. The maximum output and the starting torque are inverse functions of the impedance.

It would be impracticable in most cases to run a 25-cycle motor on a 60-cycle circuit of the same voltage. Since the output of any induction motor is roughly proportioned to the square of the voltage, a 25-cycle motor ought to be run at double the rated voltage to give its rated output on a 60-cycle circuit. Such an operation is not to be recommended generally, although it has been used with a considerable degree of success in some instances.

A.E.A.

### CHOKE COILS: REACTANCE FORMULA

**(102) There are four general types of reactance coils: the cylindrical helix, the hour-glass helix, the flat spiral, and the "triangular" spiral. What are the formulae to apply in calculating the reactance of these various types?**

The reactance of all these coils can be calculated with sufficient accuracy by the use of the "Universal Formula" of Prof. Morgan Brooks.

This is,

$$L = \frac{(2\pi\ an)^2 F' F''}{l + 1.5\ c + a} 10^{-6}$$

(Fig. 1 represents a cross-section of a coil wound with insulated wire.)

The symbols used in the formula are explained as follows:

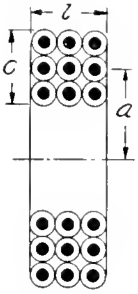

Fig. 1

$a$ = mean radius in centimeters. (See Fig. 1).

$l$ = total length of coil in centimeters. (See Fig. 1.)

$c$ = depth of winding in centimeters. (See Fig. 1.)

(Both $l$ and $c$ include the thickness of the insulation or, if the turns are air-insulated, are equal to the pitch of the winding times the number of turns. If there is only one turn, these equal the diameter of the wire.)

$n$ = total number of turns in the coil.

$L$ = inductance of coil in millihenrys.

$F'$ and $F''$ are correction factors.

$$F' = \frac{10\ l + 13\ c + 2a}{10l + 10.7\ c + 1.4\ a}$$

$$F'' = \tfrac{1}{2} \log_{10}\left( 100 + \frac{14a + 7c}{2l + 3\ c} \right)$$

1 inch = 2.54 centimeters.

Having determined the inductance ($L$), the reactance ($x$) may be calculated from the formula

$x = 2\pi\ f\ L\ 10^{-3}$.

Wherein,

$x$ = reactance in ohms.
$f$ = frequency in cycles per second.
$L$ = inductance in millihenrys.

The constants $a$, $l$, and $c$ are taken as follows in the four types of choke coils.

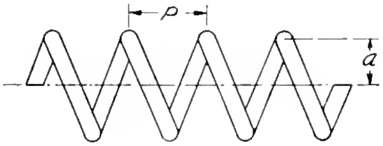

Fig. 2

*Cylindrical Helix:*

$a$ = mean radius of coil.
$c$ = diameter of conductor.
$p$ = pitch of turns.
$l = p\ n$.

Fig 3

*Hour-Glass Helix:*

$a$ = mean radius of coil.
$c$ = diameter of conductor.
$p$ = pitch of turns.
$l = p\ n$.

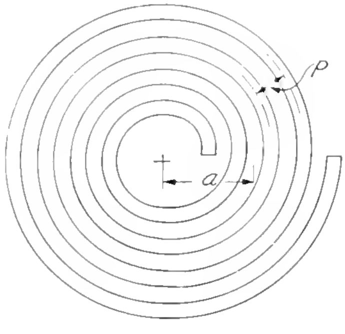

Fig. 4

*Spiral:*

$a$ = mean radius of coil.
$p$ = pitch of turns.
$c = p\ n$.
$l$ = diameter of conductor.

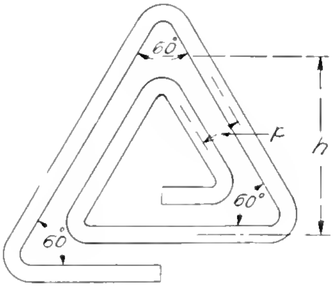

Fig 5

*"Triangular" Spiral:*

$p$ = pitch of turns.
$c = p\ n$.
$l$ = diameter of conductor.
$h$ = mean altitude of coil.

As a fair approximation, we may assume that this coil has the same inductance as has a flat spiral having a mean radius such that the area of the circle drawn with this radius equals the area of the equilateral triangle whose mean altitude is $h$.

Equivalent mean radius, $a = \frac{1}{\sqrt{\pi \sqrt{3}}} h. = 0.4287\ h.$

R. H. M.

### D-C. CIRCUITS: CHARGED DUST PARTICLES

**(103) It has been noticed that more dust particles collect on or around the positive than the negative wire of a d-c. circuit. What is the explanation of this phenomenon?**

It has long been known that when two dissimilar substances are rubbed together one will be found to have a positive charge imparted to it, while the other will assume an equal negative charge. In Faraday's Experimental Researches in Electricity may be found many experiments concerning this phenomenon. Among his experiments Faraday tried the effect of feeding fine powders of various substances into an air jet, which impinged upon some dissimilar substance. The following abstract is of interest:

"*Silica*, being either very finely powdered rock-crystal, or that precipitated from fluo-silicic acid by water, gave very constant and powerful results but both metal and wood were made strongly positive by it, and the silica when caught on a wet insulated board and examined was found to be negative."

Thus, it is probable that dust, which is the result of particles of matter being blown along the ground and then carried into the air, will have a charge imparted to it just as was artificially produced by Faraday in his experiments. If the dust were composed of fine particles of sand or silica which had been blown against trees or wooden houses, etc., it would be negative and the trees or houses would take the positive charge. If these negatively charged particles of dust were blown into a room where there were wires carrying a direct current, it is apparent that the positive wire would attract the negative dust particles, many of which would adhere to it, while the negative wire would repel the dust particles and would thus have less dust collected upon it. Thus, the phenomenon will depend upon whether the dust assumes a positive or negative charge as the result of the friction. For example, in a flour mill, the result might be just the reverse, that is, more dust (flour) might collect on the negative wire, for in this case friction between flour and metal or wood, etc. might result in a positively charged dust—the flour. As judged from the well-known tables of the arrangement of the various substances it is probable that in most instances the dust will have a negative charge, and therefore more will collect upon the positive than upon the negative wire.

C.W.R.

### INDUCTION MOTOR: GENERATOR ACTION

**(104) Is it possible for an induction motor to act as a generator under certain conditions?**

Yes, thoroughly possible.

When an induction motor is running under load it draws a current from the line. This current can be considered the combination of two currents, the first an exciting current which magnetizes the induction motor, and the second a load current whose energy carries the load.

The magnetizing current remains approximately unchanged with any change of load, provided all the qualities of the impressed electricity, such as voltage, frequency, etc., remain unchanged.

The load current varies directly with the power output (or input). An induction motor, as its name indicates, is ordinarily used to deliver mechanical power. It will, however, generate electrical power equally well, provided it is operating under suitable conditions.

Consider the motor under load, which for convenience we will consider a positive output. The motor has a certain input current of which the greater share by far is the load current. A reduction in the load lessens the load current drawn from the line and consequently the total input current. Assume all external load removed. The only load current drawn by the motor will then be that necessary to supply the mechanical losses, e.g., friction, windage, etc., of the motor. Now, maintaining the electrical connections to the motor unchanged, drive it by an engine or another motor at a slightly increased speed than that at which it would run unaided. It is evident that the load current part of the input current will soon fall to zero, for the externally applied power will take care of the mechanical losses. Without the aid of the engine these losses would be supplied by the running light load current.

It will be evident that a further increase in the power applied, which can be accomplished by driving the motor faster, will be more than that demanded by the motor to satisfy its losses. This power being in excess inside the motor must pass outward in some way. It does this in the form of electricity of the same properties as that applied to the motor and passes outward over the same circuits.

In other words, the motor acts as a generator. Under these conditions, it is called an induction generator. Comparable with other types of generators, it requires to be excited. This is done by the alternating current from other generators on the same system coming over the lines to the motor. Its output begins at a speed slightly above synchronous speed and is proportional to the increase of speed above synchronism at which it is driven. The voltage and frequency of its output are exactly the same as that of the alternating-current system to which it is connected.

E.C.S.

### TURBINE-GENERATOR: END-THRUST TROUBLE

**(105) Will you kindly furnish information as to whether such trouble as wear of the main bearing on one side only, and sparking at the commutator in a 25 kw., 4500 r.p.m., oil-lubricated Curtis turbine would be caused by the armature of the direct-connected generator not being in the longitudinal mechanical neutral, that is, midway between the sides of the poles?**

If the armature core of the generator is moved slightly from the longitudinal mechanical neutral with reference to the field cores, a certain sidewise magnetic pull will be exerted by the field on the armature tending to bring the neutral axis of the armature core into line with the neutral axis of the field cores. If the difference between the position of the axes is slight no trouble will be caused, but if the difference is greater the action of the field on the armature will be pronounced, thereby tending to wear the end of the bearing at the shoulder of the shaft, which results in the heating of the bearing and shaft and may possibly cause vibrations affecting the commutation.

F.A.H.

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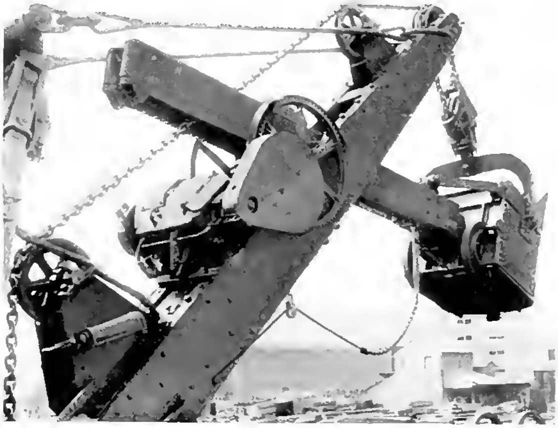
*ERRATUM: Attention is called to the fact that the diagrams designated Fig. 1 and Fig. 3 in Question and Answer No. 94 of the April REVIEW should be interchanged. The text will then apply to this revised arrangement without change.*

# GENERAL ELECTRIC REVIEW

JUNE, 1914



## A Special Number

on

## Electric Power

# GENERAL ELECTRIC REVIEW

*A MONTHLY MAGAZINE FOR ENGINEERS*

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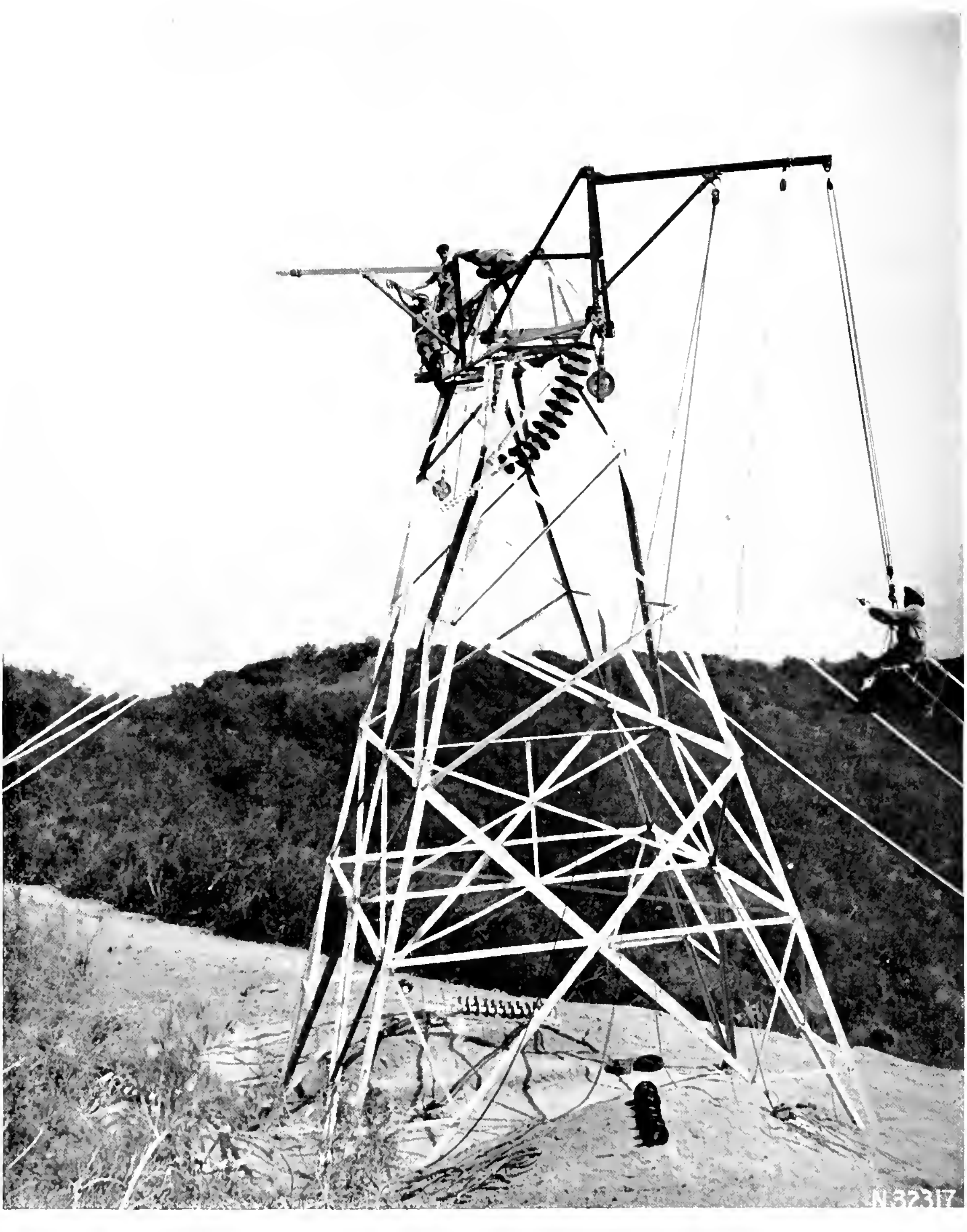

Dead-ending Tower on 150,000 Volt Transmission Line of the Pacific Light and Power Corporation

# GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

The title to this issue, "Electric Power," is very broad, we recognize that "Electric Railways" and "Electric Lighting" could be included, but both of these subjects have been dealt with in special issues recently, so the present number in the main deals with some of the other aspects of "Electric Power" and its industrial applications.

In several previous issues of the REVIEW, we have drawn attention to the fact that we are becoming more and more dependent upon electric energy in our social and industrial life every day, and for this reason the future prosperity of the country must depend in a large measure upon how we provide for our future supply. A hundred years ago it was only those countries that had an abundant and easily accessible supply of coal that could become manufacturing countries. Coal is still the dominating factor in most localities, but the trend of modern engineering is placing our rivers and water-ways, where sites are available for the construction of hydro-electric generating stations, in the first rank of importance among our natural resources. A great many important hydro-electric sites have been developed and the wonderful improvements made during recent years in electrical apparatus has enabled voltages to be used that would have been impracticable only a few years ago with the result that greater quantities of power can now be transmitted economically for great distances, with a wonderful continuity of service, so that certain sections of the country are becoming well covered with a network of transmission lines which is leading to sound industrial developments of all kinds in those favored localities.

It is likely that in the future the fact of whether a place is to become a center of population and industry will depend less and less upon whether coal is really available, and more and more whether it is easily reached by transmission lines emanating from hydro-electric sites. It is then apparent that our hydro-electric generating stations must play an important part in the continuance of our industrial developments.

This being the case, it behoves us to carefully consider what provisions we are making for the future requirements of the country in this direction. There is quite a difference in opinion as to which is the best way to provide for the future, some are convinced that government ownership is the only safe and sane method of procedure and there are others equally insistent that the interests of the future can best be served by private ownership under due restrictions and regulations. From a purely theoretical standpoint, government ownership has much to recommend it, but in human affairs there are a vast number of theoretical possibilities that refuse to become accomplished facts. Politicians whose stock in trade is a multitude of platitudes, flavored according to the susceptibilities of the particular audience whose vote they are trying to catch, tell us that the government is the will of the people—and that the will of the people must prevail. But even the very best platitudes need examination and qualifications at times. As a matter of fact, by reason of our human frailty the government, especially in such matters as that under consideration, by no means represents the popular will, and further it is right to state that the will of the people is often lamentably at fault when judging of technical and economic matters which are entirely foreign to their daily life.

The two things which are of paramount importance are firstly, that a natural resource of such vital importance as hydro-electric power should be developed along rational and sane lines, so that it may be available where and when it is needed, and secondly, that the benefits of such developments should be permanently assured to the community at large at a reasonable cost.

It is by no means certain that a rational scheme of development would follow government ownership, judging by past experience from other things that have been thrown into the vortex of party politics it is likely rather that developments might be undertaken in localities where the chief benefits would be derived by special interests in payment of services rendered, but rendered not to the state, but rather to a political clique.

On the other hand, where a private or corporate interest is to undertake such developments they must be carried out both where and at a time when they are required or they will be financial failures and the loss will be borne by those who invested their money and had hoped to gain by their enterprise, while if a government development is not a paying proposition, the people as a whole must pay the bill one way or another, however ably the loss is covered by the juggling of accounts. The accounts of private interests in these days of commission must be kept in accordance with prescribed rules, while the government may keep its accounts as pleases it best, and the real loss can often be made to appear as a gain by neglecting to provide for such legitimate charges as depreciation which a private enterprise must provide for if they are to stay in business.

That the benefits of our natural resources should be assured future generations is apparent, but does government ownership provide for the future better than private ownership? There is one thing very certain that where private capital is expended in development work, those who are spending their money want to be reasonably sure that there is a market for their product, and if there is an extensive market it is reasonably sure there will be a commission already in power which will look after the interests of the public and also in a measure after the interests of the company or corporation.

The lesson to be learned, by those that take the trouble to study the subject, of what municipal ownership has done to retard electrical progress in some European countries should be carefully considered and the results, that have now been incorporated into the history of industrial development or lack of development, should be carefully weighed by those who advocate a measure the future results of which they are totally at a loss to foretell.

# ENGINEERING PROBLEMS OF ELECTRIC POWER COMPANIES

By David B. Rushmore

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The above subject is very broad and it has been therefore dealt with accordingly in the following article. Just enough supplementary detail has been included to illustrate the working out of the problems considered. In treating of systems in general, the advances which have been made in small generating station equipments, high-tension transmission lines, interchange-power propositions, and consolidations are briefly covered. The predominant factors which concern the location of both steam and hydraulic stations are named; and the most important considerations of plant operation, load-factor and diversity-factor are discussed. There is included in that discussion a very useful table listing the load-factors that are to be expected from different types of consumers. Remarks concerning the proper frequencies and voltages to be generated, and their transformation changes for distribution, conclude the article.—Editor.

D. B. Rushmore

In no other field has there been such a marvelous progress during the past twenty-five years as in the use of electricity for illumination and industrial power applications. In the beginning of this industry electricity was mainly used for lighting purposes and the communities served, as well as the power plants serving them, were comparatively small. The rapid increase in the size and population of these communities, and the progress of the electrical art, have, however, resulted in the gigantic installations which are now to be found in so many places.

## Systems

While it is true that the engineering problems incident to the larger installations have attracted the interest of our greatest and most able electrical engineers, a great deal of attention has also been paid to the smaller plants. Owing to the marked improvements in efficiency and design of electrical apparatus, together with an even more marked decrease in their cost, towns which ten years ago could not have supported electrical plants, can now advantageously consider such installations.

Modern improvements in high tension apparatus and appliances have furthermore made possible the construction of long-distance transmission lines which a few years ago would have been impracticable both from the standpoint of cost and reliability. As a result, small villages which formerly could not support any kind of independent central station, or which were inefficiently served, are now enjoying a high-class service from such transmission lines. It is furthermore safe to predict that in the near future all sections of the country with a substantial population will be served by a network of transmission lines, making it possible to convey energy into remote and rural districts for irrigation, farming, mining or other industrial work.

A marked advancement in the art has been brought about by the tying together of a number of systems under an "interchange" power contract. Such developments naturally are of very great importance, both from an economical and operating standpoint, as advantage may then be taken of the water flow from different water sheds, existing steam plants may be used for emergency conditions, and a most reliable service can be rendered to all sections served.

There is now also a very strong tendency towards central station consolidation with a view of concentrating the power supply for all uses for a large territory from one system. In some instances a company in a large city expands so as to embrace the whole district around it, and the class of service given originally within a small area is unified over hundreds of square miles. In other instances the properties in a given region are absorbed, merged and brought under one management. A striking illustration of this is the Central Illinois Public Service Company, one of the most recent organizations, where nearly one hundred communities were originally supplied by about fifty separate generating stations. These have now mostly been shut down and four modern stations will ultimately generate all the electric energy needed for this service. In still other instances, unrelated properties widely distributed may be brought together under one central control and management.

It is obvious that the advantages of such consolidations are many. The economy in having only one management is considerable. It is possible to obtain the best technical and expert advice. The cost of generating the power is less, and a reduction of the price to the consumer, as the natural result of the all-around improved situation, is generally possible. While these advantages are of very great value, the most important one is undoubtedly that of financing; in providing financial facilities for extensions to meet the growing demands of the public for electric service, the holding company performs its most important function.

**Steam Plants**

The energy supply for cities is, in most cases, furnished by steam generating stations, and the astonishing rate at which the size of some of these has increased is best illustrated by the growth of the Commonwealth Edison Company of Chicago. In the year 1903 this sytem had a total generator capacity of 38,350 kw. and in the year 1913 this had been increased to 302,500 kw.

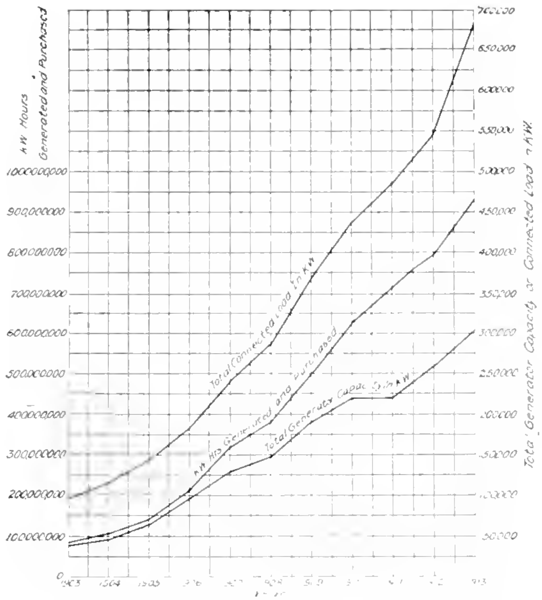

Fig 1. Curves showing Growth of the Commonwealth Edison Co., Chicago

The dominant factors determining the selection of a site for a modern generating station in a large city are usually the ones involving the economical handling of the coal. Unless the cost of fuel is to be increased very materially, the generating plant must be located so as to have the best railroad or wharf facilities. The avoidance of drawbridge tolls is an important factor and inland plants should, as far as possible, not be dependent upon a single railroad for their supply of coal.

The circulating water supply is, however, of greatest importance. The cost of fuel in large stations exceeds all other operating costs combined, and as the consumption of fuel is in the ratio of two to three, depending on whether the station is operating condensing or non-condensing, it follows that the station must be located near an abundant supply of condensing water. The cost of real estate must necessarily also be given consideration. Desirable power house sites are hard to find in large cities. They should be located near the load centers and when a satisfactory location is found it is advisable to provide for a large increase of plant.

The present trend in the design of steam turbines is in the direction of higher speeds and a greater number of stages. Various modifications in the arrangement of nozzles and buckets have also been made from time to time with the object of securing higher efficiencies. As to the size of these machines, the limit seems to be far from reached. The maximum rating has rapidly risen past the 10,000 kw. and 20,000 kw. sizes, and is now at the 35,000 kw. point, while there is every indication that even larger machines will be built in the near future. These enormous units naturally mean thermal economy, as well as economy in space and weight per unit of power developed. In this respect it is very interesting to compare the results obtained in the first 5000 kw. steam-turbo-generators built in 1903 and the 35,000 kw. unit which is being built at the present time. For example, the over-all efficiency has gone up about 25 per cent, while the weight per kilowatt has decreased to about one-third of what it was in the original machines. Obviously, however, these large turbines are only applicable in stations of large size where they can find an effective place on the daily load curve.

In connection with steam plants the problem sometimes arises nowadays, whether it will be more economical to transport the coal from the mines to the plant near the load center, or to generate the energy and transmit it electrically to the point of distribution. By generating the power directly at the mines one of the biggest items that enters into the cost of coal, viz., its handling and transportation, will be eliminated. Another saving is the utilization of the waste product, consisting of coal particles and dust, which otherwise is entirely unmarketable.

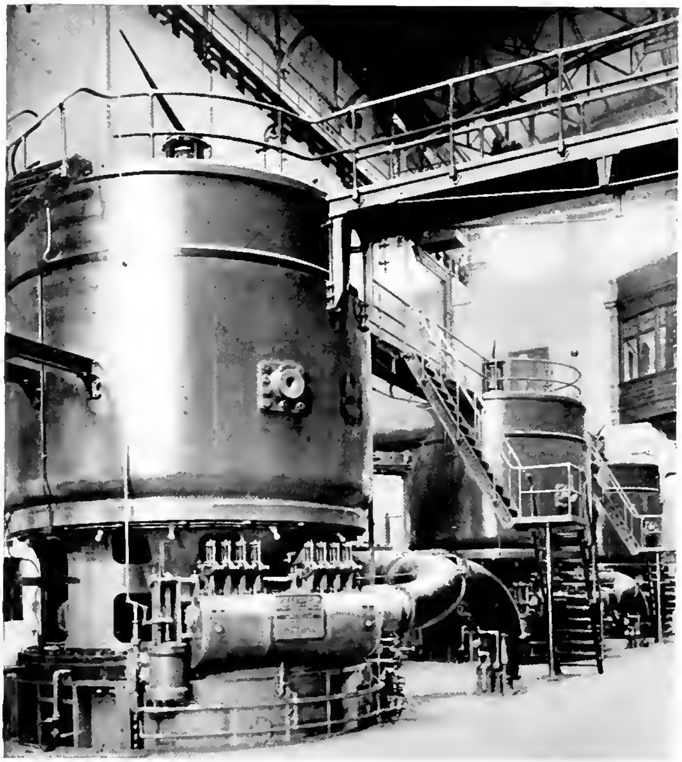
Fig. 2. Three 20,000 Kw. Curtis Turbo-generators, New York Edison Company, Waterside Station No. 1

In this country we have at least two important systems where it has proved to be economical to generate power at the coal mines and transmit it electrically for long distances over high tension transmission lines. In Europe several such systems are in operation and others of very large magnitude are being contemplated; while the South African transmission at the Rand is too well known to need any further comment.

**Water Power Plants**

The utilization of the water powers of the country has become a question of considerable importance to the public, and its success has mainly been due to the rapid development of high-tension apparatus and appliances which has made it possible to transmit the energy from obscure places to localities where a profitable market could be found for the same. It is also true that a general education of the public has had much to do to the conservation of these valuable natural resources, because the only true conservation of our water powers is by developing them. It was formerly generally believed that a hydro-electric plant was always a very profitable investment, that all that was necessary was to let the never failing water supply fall on the wheels, and that the cost of the generating station was the only investment needed. It is, however, now well understood that the cost of the hydraulic installation as well as the transmission lines in many cases reach very high values, so that the total cost of a water power plant is from two to five times that of a steam plant.

There is probably no other undertaking that requires a more careful preliminary engineering study than a hydro-electric power transmission system. The stream flow records for a long number of years must be investigated with a view of determining the minimum stream flow, and the question always comes up, for what stream flow shall the development be made, and to what extent shall an auxiliary steam plant be provided to convert the variable energy supply into a continuous supply.

Water power plants naturally divide themselves into low, medium and high head installations. For the two former, single-runner vertical shaft turbines are now being extensively used, where previously multi-runner turbines would have been used. This has been made possible by the progress in the design and development of high capacity runners, so that for a fixed head and capacity it is now possible to operate modern runners at a much higher rotational speed than was possible with runners of older design. While ten years ago it was considered a notable achievement to obtain a turbine efficiency of 82 per cent, during the past two years, efficiencies between 89 and 92 per cent have been quite common, while a maximum value of 93.7 per cent has been secured. This remarkable efficiency is by no means entirely due to superior runner design. As a matter of fact, the improvements in the design of wheel casings, wicket gates, draft chests and draft tubes have all increased the efficiency of the turbine as much as the more efficient runners.

That water powers may, in some instances, compete with very cheap steam power is best illustrated by the system of the Appalachian Power Company, which furnishes a considerable amount of power from its hydro-electric plants on the New River in Virginia to the Pocohontas coal fields, a distance of about fifty miles.

**Service Conditions**

The ideal condition of operation for an electric generating station is naturally that of supplying a uniform load during the twenty-four hours of the day equal to the full rated capacity of the plant. This ideal is, however, unattainable under practical conditions and even a close approach to it is possible only under very special conditions.

The load factor of a central station is therefore the proportion which the equivalent 24-hour load bears to the station peak, or, in other words, the ratio of the actual station output to the maximum possible output with continuous service. It is also a measure of the extent to which the necessary total investment is being used. A plant with a yearly load factor of 50 per cent is turning out just double the energy of another plant

Fig. 3. 17,500 Kv-a. Generators, Big Creek Development, Pacific Electric Light & Power Company

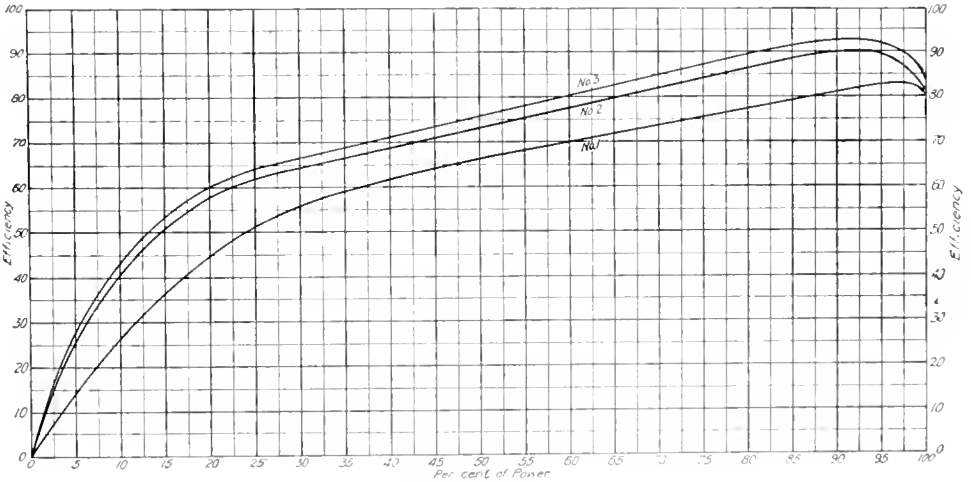

Fig. 5. Recent Development of Hydraulic Turbines

No. 1. Efficiency and Power obtained from two Runner Turbine in 1906 Ns=259.
No. 2. Efficiency and Power obtained from Holyoke Test of Modern High Speed Runner.
No. 3. Efficiency and Power possible from Modern Single Runner Turbine, with Runner as per Curve No. 2 Installed. Same r.p.m. as No. 1—Ns=367.

of the same maximum load and with a load factor of 25 per cent. This means that while the fixed charges of both plants are the same, the gross income of the plant with 50 per cent load factor should be nearly twice as great as that of the other. The importance of a good load factor is thus apparent and everything that will improve this factor should be sought.

There is an enormous variety of uses to which electricity is applied, the yearly load factors of which also vary widely as shown in the following:

### SMALL AND MEDIUM LIGHTING CUSTOMERS

| | |
|---|---|
| Buildings, public | 17.6 per cent |
| Churches | 12.4 per cent |
| Clubs | 9.6 per cent |
| Flats | 6.9 per cent |
| Halls (public) | 6.9 per cent |
| Hotels | 24.4 per cent |
| Offices (business) | 9.2 per cent |
| Offices (professional) | 6.7 per cent |
| Residences | 7.8 per cent |
| Restaurants | 23.4 per cent |
| Shops (bakery) | 13.1 per cent |
| Shops (tailor) | 8.4 per cent |
| Schools | 7.2 per cent |
| Stores (dry goods) | 8.2 per cent |
| Stores (cigar) | 16.8 per cent |
| Stores (drug) | 19.3 per cent |
| Stores (grocery) | 10.3 per cent |

### LARGER POWER AND LIGHT CUSTOMERS

| | |
|---|---|
| Bakeries | 12 per cent |
| Blacksmith shops | 15 per cent |
| Breweries | 45 per cent |
| Boots and shoes | 25 per cent |
| Bottling works | 10 per cent |
| Candy manufacturing | 18 per cent |
| Clothing manufacturing | 15 per cent |
| Department stores | 30 per cent |
| Furniture manufacturing | 28 per cent |
| Foundries | 15 per cent |
| Ice cream manufacturing | 20 per cent |
| Ice making | 30 per cent |
| Laundries | 20 per cent |
| Machine shops | 20 per cent |
| Newspapers | 18 per cent |
| Packing houses | 30 per cent |
| Railroad depots | 50 per cent |
| Tanneries | 20 per cent |
| Textile mills | 20 per cent |

The yearly load factor for any class of service is determined largely by the seasons, the habits of the people, and other conditions which ordinarily do not change very materially. Improvement in the load factor must therefore be obtained largely by combining different classes of service, the maximum demands of which occur at different times of the day or of the year. Also, the larger the number of customers in any class the better will be the load factor.

A recognition of the importance of the diversity factor has undoubtedly the most marked effect in increasing the load factor and thereby the economy of production. This factor is the ratio between the sum of the maximum demands of various classes of service to the actual simultaneous maximum demand, and the more non-coincident these peak services are, the greater will be this factor.

The chief means of improving the load factor has been the addition of industrial load. In the early days of electric lighting companies, the load factors were very low due to the absence of day load. Today many central stations sell far more energy for power than for light and this is naturally distributed over a longer part of the twenty-four hours. The power load, also, not being simultaneous with the lighting load to any great extent, still further improves the load factor. Residence load has generally been characterized by a poor load factor, but by the use of day load devices such as flatirons, cooking devices, fans, heating apparatus, vacuum cleaners, etc., a much improved result is obtained.

The problem of combining electric railway loads and central station loads on one system has received increasing attention in recent years, and in some cities of this country great strides have been made toward effecting such combinations successfully. Chicago is an admirable example of what can be accomplished in this line. The Commonwealth Edison Company is today carrying a larger railway load than any other central station in the country, and the result is that this plant operates at the exceptionally high load factor of about 44 per cent, while from 30 to 34 per cent is the usual load factor of such systems. Furthermore if power should be furnished to the steam railroads in case of electrification, the load factor could still further be increased to about 50 per cent.

There are a number of other industries which offer ideal loads for large power companies, especially for hydro-electric companies; such as mining, electro-chemical work, irrigation and farming, while much is expected from the railroad field when the time has arrived for the economical electrification of our trunk lines.

The consolidation of central station interests creating a monopoly may, unless carefully regulated, result in increased prices to the consumer. In contra distinction to this we find, however, that the public generally has benefited greatly by the increased economies possible where public service corporations or properties have been merged and operated under one common management. The fear that public service commissions would be unduly influenced by political considerations, seems furthermore to have been largely imaginary, for as a rule, the opinions and rulings so far handed down have been free from partiality and prejudice.

One point which always enters into the electric power business and which naturally is very closely connected with the engineering problem is the question of quality of the service rendered. It is generally a very difficult matter to determine what, under given conditions, is good service and whether the quality of the service that has been specified is actually rendered. In general, the more reliable the service is, the more it costs, due to the increased investment in emergency apparatus, etc. Just what additional investment is justified for an increased reliability in operation is difficult to standardize. In other words, what is the value of reliability in the service? It obviously varies to a considerable extent for different classes of service. Take for example, the high pressure fire system in New York city, where an interruption of the service even for a short period would possibly prove disastrous; or a large steel mill where an hour's interruption in service may mean a loss of several thousand dollars. In other instances an interruption may not mean any serious loss, and it is therefore obvious that a fair return should take the comparative efficiency of the service rendered into consideration.

The frequencies most commonly used in this country are 25 and 60 cycles and depend chiefly on the character of the service. Where lighting load is predominating 60 cycles is generally selected, while if the load mainly consists of power, 25 cycles has been mostly adopted. It appears, however, that 60 cycles is being more and more used even for power installations since it gives a much larger number of possible speeds for induction motors.

In many of the large cities steam plants were laid out for 25 cycles and the a-c. power was converted to d-c. by synchronous converters and distributed by the Edison three-wire system. The choice of 25 cycles was in many such instances due to the less satisfactory operation of earlier types of converters for 60 cycles. With the present improvements in the design of such machines, their operation is, however, now just as satisfactory for the lower frequency. As these plants grew and service was required at greater distances from the power station, it became necessary to distribute at higher voltages to the remote districts, owing to the excessive loss in transmission over long feeders and mains at the direct current voltage. This is accomplished by frequency changers which furnish 60 cycle alternating current to customers too scattered to be supplied by the Edison three-wire system.

Many cities having a 60 cycle system and with power formerly supplied from steam plants have found it economical to buy power from hydro-electric developments. It is transmitted over long distance transmission lines at 25 cycles and converted to 60 cycles by frequency changers. The steam plant is shut down but maintained as a reserve in case of low water or transmission line trouble.

In many cases two systems of different frequencies can be tied together and many advantages derived therefrom. For instance, in many places in this country will be found a 60 cycle system which has expanded until it comes into close touch with a neighboring 25 cycle system, which may have its peak load at an entirely different time. In a case like this it would be to the mutual advantage of both systems to interchange power, and a reversible frequency changer set could be installed to tie the two systems together.

The effect of higher frequencies on the regulation of long distance transmission lines and on the capacity current in extensive underground cable systems should be given careful consideration when selecting the frequency of such systems.

The selection of the proper voltage for distribution and transmission is an important matter. The voltage must be high enough for economical transmission, and yet not so high that the amount of substation equipment, consisting of transformers and switching and protective apparatus, is so great as to make it impossible to render a fair return on the capital invested. The distribution of alternating current for general commercial purposes is accomplished almost universally by 2200 volt mains, supplying step-down transformers located near groups of consumers, whose premises are served by secondary mains at 110 to 220 volts. Single-phase circuits are quite generally used for lighting service, while power service is as a rule given from two-phase or three-phase mains. The former system is used chiefly where this method of distribution was established in the early period of the development, and where it is too extensive to warrant a change to the three-phase system, which is standard for all new installations where a polyphase supply is wanted for power service.

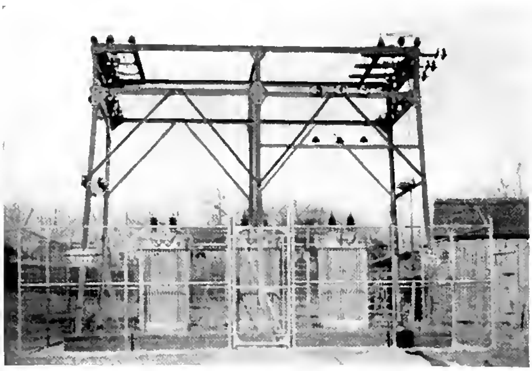

Fig. 5. 22,000 Volt Outdoor Substation

For small and medium sized cities a three-wire, "delta"-connected, 2200 volt system is very generally used for power distribution, while for larger cities there is a steady trend toward the four-wire, "Y"-connected system operating at 2300/4000 volts. There are numerous advantages with this system where feeders are extended more than two miles from the point of supply, and where adjacent towns within a radius of five miles may be served without step-up transformers or substations. It is possible to regulate the phases separately, and there is not so much of a necessity for maintaining a carefully balanced load. Even for secondary distribution the four-wire, three-phase system, operating at approximately 115/200 volts, is being generally used. With this system lighting and motor service may be given for all ordinary retail purposes from the same circuit, the principal disadvantages being that there are three phases to be kept balanced.

The selection of a voltage for a distribution system where there are a number of small demands to be supplied, is a very important matter, and has led to the development of small and inexpensive outdoor substations. The general practice seems to indicate that the most economical voltages for such systems are in the neighborhood of 22,000 to 33,000 volts. These voltages are high enough to carry power a considerable distance with small loss, so as to make the cost of the equipment not excessive.

A large majority of high voltage systems are really distributing rather than transmission systems, and with these the problem comes up as to the most economical way to take off small amounts of power. Even here the outdoor substation has come into extensive use, and numerous examples can be recited where outdoor substations have been built for voltages above 100,000 volts. The voltages of these systems are increasing from year to year, and in some cases it seems as if higher voltages have been used than would have been economically necessary. The highest transmission voltage in commercial use today is 150,000 volts. This is at the Big Creek Development of the Pacific Light & Power Corporation in California. That this is, however, not the limit is clearly indicated by the consideration of much higher voltages for new developments contemplated.

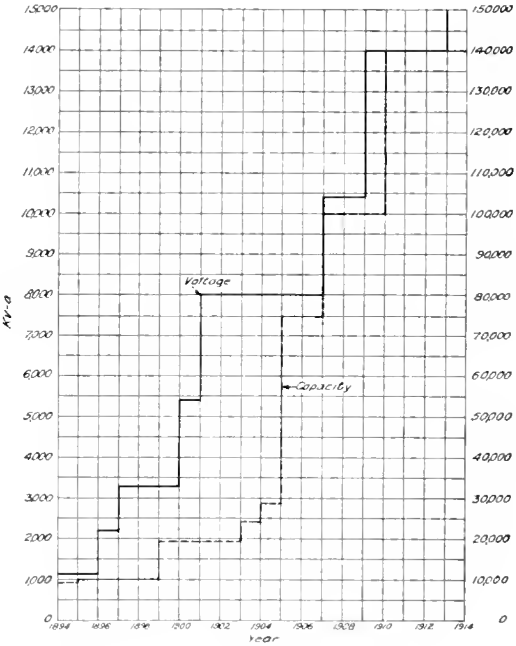

Fig. 6. Curves showing Transformer Development

## Operation

The problems of operation of power systems naturally divide themselves into, first: those of normal operation, and, second: those of emergency conditions. The method of operation and the layout of the system depend upon many factors, some of which are: the relative importance of the different stations, the number of power houses on the system and the relation of each to the whole system, the location and character of the load; the number, capacity and location of the reserve stations; and, with transmission systems, whether the high tension line is purely a transmission line, a high tension distributing circuit, or both. The normal problems of operation, such as starting up the system, paralleling the generators and the power stations and properly dividing the load among them, of putting units into service previous to the demands of the load conditions, of regulating the voltage for the proper distributing points, of connecting high tension lines, and, in general, of so manipulating the generating, transforming and switching apparatus as to deliver the desired load at the distributing centers with the desired characteristics. These problems can only be met after a careful study of the requirements.

Reliability of operation is one of the main problems in every power system, and consideration must be given to the cause of disturbances and the means for minimizing their effects. These are abnormal or so-called emergency conditions, and the possibility of all kinds of failure must be thoroughly analyzed and definite plans worked out for limiting the magnitude of such disturbances and confining them to the smallest possible area. For this reason the apparatus should be so arranged and the system so sub-divided that a disturbance in one part wull not affect the whole, and that such disturbance will be immediately localized within the lowest possible limits in such manner and time as not to cause interruption in the operation of the entire system. It should also be possible to remove the cause of such disturbance and, within the shortest possible time, to replace the disturbed apparatus in operation. This is in many cases, especially in high tension transmission systems, very difficult to accomplish. In such cases all high tension switching should be entirely abolished or confined to the absolute minimum. The reason for this is that high tension switching may set up high voltage surges, which may damage the insulation of the apparatus and cause a break-down of the system. By a careful study it is, however, as a rule possible to so lay out the system that while confining all the switches to the low tension side, a selective switching action may be obtained.

The efficiency and reliability of the operating force is without question one of the greatest assurances for a satisfactory operation, but this is also intimately connected with the means which are provided for communication between the different parts of the system.

The design and selection of the apparatus has necessarily also a most important bearing on the operation of a system, and a brief discussion of some of the important points connected therewith may be of interest.

### Apparatus

The rating and capacity of a generator must necessarily be considered in connection with the prime mover by which it is to be driven. This is fully emphasized by the fact that there are in operation in many stations in this country, units in which the output is unnecessarily limited by a discrepancy in the rating, in that the prime mover is either too small or too large for the generator. The latter may, for example, be designed for unity power-factor, while the actual operating power-factor may be eighty per cent, in which case the full capacity of the prime mover cannot be utilized. In the past every effort was made to adjust the ratings of generators to the station load curves, and the result was that they were designed for overload capacities of twenty-five or fifty per cent, usually for a period of two hours. With the growth of generating stations and improved load conditions, this practice is becoming more and more obsolete and the units are being rated on a maximum constant continuous rating which is not to be exceeded except during momentary peaks.

The generator should be well ventilated and a liberal supply of air should be supplied. While, as a rule, it has not been necessary to make any special provisions for forcing the air through the generators in water power plants, the introduction of very slow speed units seems, however, to indicate that it is highly desirable to provide such means.

Consideration of safety has led to the design of generators with a comparatively high inherent reactance. While this has been obtained by sacrificing a close inherent regulation of the machine, it does not, however, prevent a good regulation of the system, as the same may readily be accomplished by means of automatic voltage regulators.

The problem of excitation cannot be given too careful consideration in any system, and the capacity of the exciters should be very liberal. In certain plants each generator is provided with a direct-connected exciter, and in such cases it is a good practice to make the capacity of each exciter large enough so that it may furnish excitation for two of the main units, so that in case of a break-down of one exciter this will not cripple the entire unit, but excitation can be obtained from the other exciters. All exciters are nowadays, as a rule, provided with automatic voltage regulators for maintaining a constant bus voltage, and means are also being provided whereby, in case of short circuits on the system, etc., the generator voltage can be momentarily lowered by an automatic insertion of resistance in the exciter fields. This has in many cases proved to be quite effective in maintaining an uninterrupted operation, in that arcs, etc., may readily be extinguished through a lack of voltage.

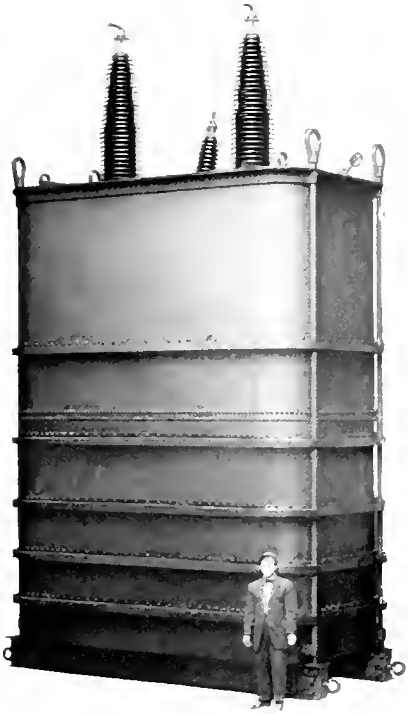

Fig. 7. A Water-cooled, 4500 Kv-a. Transformer, Primary Voltage, 150,000

Transformers also are now designed with a considerably higher reactance than was formerly the case—four to six per cent being now quite common. This will enable them to limit the current output at times of short circuits, and, besides this, to successfully withstand the tremendous mechanical strains to which the windings are subjected due to short circuits. It has been a common practice to provide step-down transformers with taps below the normal operating voltage, so that these taps could be used for compensating for the line drop as the load increased. It is obvious that the provision of these taps involves considerable difficulties, especially in very high-voltage transformers, and as very little use seems to be made of these taps in actual practice, they should be avoided as far as possible.

Considerable activity has of late taken place in the use of outdoor substations. This has been brought about with a view of reducing the investment cost although in many cases it seems as if just the opposite has been the result. In outdoor installations the transformers require the greatest consideration. Special precaution must be taken to protect them from heat in the summer and from cold in the winter. While the former can readily be obtained by providing sun shades, in certain instances very good results

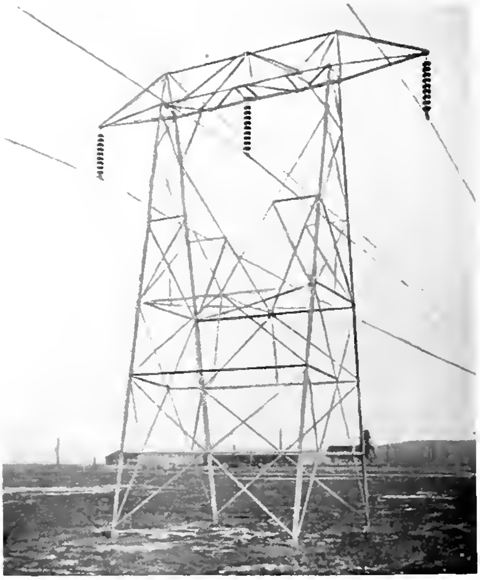

Fig. 8. A Tower of a 150,000 Volt Transmission Line

have been obtained by painting the tanks white. It is, however, more difficult to provide for the cold winter temperatures, especially with water-cooled transformers. With the transformers in service there seems to be no danger of freezing during cold weather, and the transformers should therefore always be connected to the system and thus energized. The main difficulty lies in the formation of moisture, which takes place when the temperature is allowed to fall below that of the surrounding air. This applies equally well to indoor transformers, and precautions must be taken therefore that this does not happen. Non-freezing oil may be used but its cost is comparatively high, and in many cases it is found more advantageous to provide heating grids in the bottom of the tanks.

On account of the increased size of our modern central stations and the concentration of large amounts of power in one place, it has been necessary to make provision for limiting the amount of current that may flow in case of a short circuit. This is, as previously mentioned, accomplished by designing the machinery for a higher inherent reactance and, where this is not sufficient, by inserting artificial reactances in the external circuits, such as the generator leads, the busses, or the outgoing feeders By so limiting the abnormal flow of current into a short circuit the generating system as a whole is relieved from the disastrous effects of such short circuits.

With the increased distances of power transmission lines and the higher voltages used for the same, the question of regulation has become one of utmost importance. The effect of the inductance and capacity of such line causes the voltage to vary within very wide limits from full-load to no-load. At no-load the large capacity current causes a rise of voltage from the generating station to the receiving end, while at full-load the lagging inductive current taken by the load in general more than off-sets the effect of the capacity current and causes a drop of voltage from the generating station to the receiving end. Many recent transmission systems have been made possible only by providing synchronous condensers for improving the regulation; so, for example, the latest 150,000 volt transmission system in California has required two 15,000 kv-a. synchronous condensers to take care of the regulation.

The electrolytic lightning arresters is generally used for protection against high voltage surges and has given very satisfactory results. It should not, however, be assumed that this device is a protection against all kinds of disturbances. Failures of lightning arresters can almost always be traced to some outside causes; as, for example, insufficient charging; poor regulation of the lines, causing higher voltages than for which the arrester is selected; high temperatures such as would be experienced from exposing the tanks to the sun, causing the electrolytic film on the cones to more rapidly dissolve, requiring a more frequent charging of the arrester.

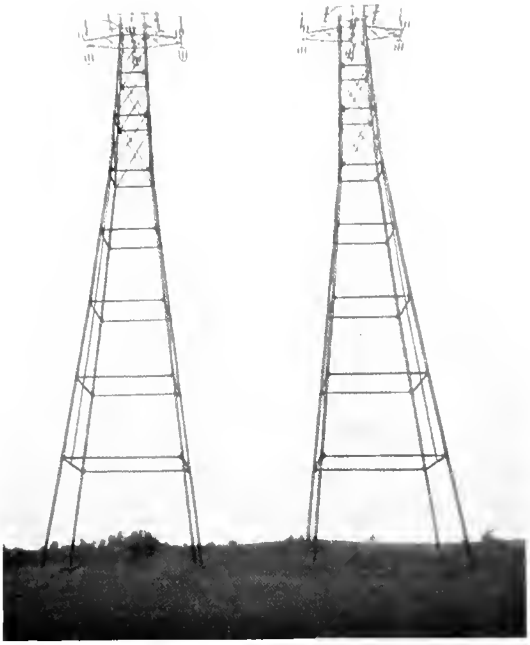

Fig. 9. Two 220-ft. Transmission Towers at River Crossing

The transmission line, on account of its position, is possibly the weakest link in a power system, and its design involves the highest class of engineering. Every precaution should be taken to avoid break-downs. The right of way should be of ample size, as far as commercial conditions will permit. Steel towers should be used as they insure an increased reliability as compared to wooden poles. For important plants it does not seem wise to depend entirely on a single transmission circuit, and double circuits are mostly provided. The same weight of copper divided into two circuits and supported by slightly modified towers will considerably reduce the chance of shut-down, with only a moderate addition of cost. The towers and line conductors should be designed with an ample factor of safety, and too much consideration can never be given to the effects of sleet and wind storms.

# RECENT ELECTRICAL PROGRESS IN THE INDUSTRIES

By A. R. Bush

Manager Power and Mining Department, General Electric Company

In spite of the enormous progress made in the use of electric energy by our industries during the last five years, the field for its useful application has not yet been half covered, and therefore the prospects for future business are very bright. Some of the older industries will have to adopt electric drive as an economic necessity when competition demands increased production at a decreased cost. The author shows that the electric motor has invaded almost every industrial field, and that results have been particularly gratifying in the mining, textile and agricultural industries. He concludes his article by referring to one or two notable accomplishments of the last year.—Editor.

A. R. Bush

During the past five years there has been a rapid increase in the volume of electrical apparatus distributed among the thirty or more industries in the domestic field, and as the number of plants equipped is a comparatively small proportion of the total number available for such installations, the same constant and healthful growth will undoubtedly continue for many years to come. With occasional peaks and valleys, the total amount of such business promises very shortly to far outrun in volume and variety, that of any other single class of manufacture. There is not an industry which can not profit very largely by the use of electricity in some form to enhance its economy, or increase its production with the resultant reduction in costs. There are, of course, many instances where the first cost of the necessary improvements in the way of electrical distribution of power may not be justified because of the previous expenditures made upon some other method of distribution, but there are probably very few, if any, instances where an original installation and distribution by electrical means will not, as a matter of economy, convenience, flexibility and cleanliness, prove its superiority in results over any other method now in use, and it has already been shown that there is a large field in all industries where it has been profitable to discard older methods and dispose of even comparatively new machinery to secure the benefits of electrical distribution, in spite of the added capital charges.

There are many amazing instances of inefficient and obsolete methods in the way of power distribution and power application still in use in some of the widely known industrial plants in this country. It is quite reasonable to suppose that the present profits in such plants are so satisfactory that there has not been that incentive to obtain lower costs in the matter of power and increased production, that is usually obtained. Unquestionably competitive conditions will ultimately make these changes necessary. In many industries, the cost of applied power to machinery is a very small proportion of the cost of the product of the same machinery, but of far greater importance is the increase of production to be obtained by the more flexible electrical methods. Progress in the development of special machinery to obtain the best results has naturally not kept pace with the increase in the volume, but a great deal has been accomplished in the last few years. There is a greater demand, on account of the benefits to be obtained, in the direct application of motors to machines of all types and capacities, and this requires the development of very considerable modifications of what have been called standard types of electrical apparatus, to secure the desired results. Progress in this direction will never cease if we are to judge by the progress in the past, and while the benefits of such development accrue in the largest measure to the user, the manufacturer also benefits in the constant increase of his output.

In the mining field, for instance, the results obtained from a properly designed and applied equipment are most gratifying. There has been a constant improvement in the type and character of mining locomotives with their more substantial steel side frames and electrical equipments, and a consequent lower cost of maintenance, and a promising field is developing in mining work for the storage battery locomotive, and possibly a little later we may see combinations of oil-electric trolley and storage battery locomotives for industrial, as well as mining work. It is not to be supposed that we have reached the ultimate type of locomotive for all such work. Increased economy is to be obtained in the operation of mine fans by the use of alternating current, varying speed motors of the Scherbius and brush shifting types, and the increasing promise of the introduction of electric hoists, as a measure of economy and increased production, will permit of complete operations by electrical means from a central source of power.

It is noteworthy that the two largest mining hoists in the world, thus far contracted for, are to be electrically driven in a territory where air and steam have been completely replaced by electricity. In the mining work, there is a large opportunity for the introduction of electrical or steam driven centrifugal compressors for furnaces and converters, and of electrolytic machines for the deposit of metals. Undoubtedly the process of leaching ores, now being introduced, will call for many machines of the latter type.

The introduction of central power stations, favorably located for the purpose of supplying power to widely scattered mines, has only just begun, and the possible available business in this line alone is enormous.

In the steel and iron industry, there is still a great work to be done in the volume of equipments of all kinds to be installed; but the engineering problems at present are largely those of refinement and improvement in details. The comparatively new varying speed, alternating current equipment of the Scherbius type for the operation of rolling mills introduces a new factor of value and importance in steel mill work. From results obtained, the turbine driven centrifugal compressors for blast furnace and converter work, on account of improvement in the operating conditions of furnace and increased production, will undoubtedly gradually replace other methods of furnishing air for the same purpose.

In the textile industry, new applications of a most interesting character are taking place with the special purpose of materially increasing the production of the mills with the same machinery and labor, and, in a measure, to get these results by automatic operations. This is very real progress and while textile mills were among the first to use the electric drive extensively, and some twenty years of steadily increasing installation work has ensued, there is still very satisfactory promise of new developments that will further enhance the value of the electrical drive. This can be attributed to the fact that our representatives and specialists in this particular line of endeavor have become so interested in their problems that they have spun yarns and woven cloth in order to become thoroughly familiar with the object they are striving to obtain—an idea which can undoubtedly be used to good advantage in various other lines of industrial work.

In practically all other industrial lines, there is the same tendency toward special applications to get better results.

It should be understood that the engineering problems of designing motors, in particular, to obtain the most desirable results, are not confined to any two or three industries. Specialization in this particular is necessary in nearly all the industries, and up to this time attention has been concentrated upon the larger industries, such as steel and iron, textile, cement and mining. This same study, in a measure, must be made in such industries as food products, oil, salt, rubber, sugar, tobacco, chemical works, etc., and while much has been done in such industries as shoe and leather, pulp and paper, lumber, woodworking and clay products, still further engineering investigations are desirable to improve the methods of applying power.

The irrigation field naturally increases with the distribution of transmission lines from central power stations and it is believed that this field for the use of motors will continually increase for many years to come. Naturally the extension of transmission lines through the oil fields brought about the use of motors for drilling and pumping oil wells, at a marked saving to the owner of the wells. In spite of the fact that this seems to be a simple application, standard motors were ineffective and specially designed motors for this particular duty were absolutely necessary to get desired results.

In the equipment of machine tools, specialization is the first principle, and the results obtained, as for instance in the reversing planer equipments, must certainly justify investigation and development. In so short an article, it is not possible to more than glance at the possibilities in the industrial field, but that can hardly be over-estimated.

The year just closed is somewhat remarkable for notable electrical accomplishments in our general work. The installation of the largest turbo-generator, electric locomotive, self-cooled transformers, highest operating voltage, largest d-c. generators and rotary converters is certainly an indication of progress, as well as the development of the Scherbius outfits, brush shifting, varying speed a-c. motors and phase advancers. The past year has been remarkable for the completion of some of the largest plants in existence and the placing of orders for others in the same general class—such as the hydroelectric plants of the Mississippi River Power Company at Keokuk, Iowa, of fifteen 10,000 kv-a. generators; Cedars Rapids Manufacturing and Power Company, near Montreal, of ten 10,000 kv-a. generators; Pacific Light & Power Company on Big Creek in Southern California of four 17,500 kv-a. generators; Southern Aluminum Company at Whitney, N. C., of eleven 5200 kw., 520 volt direct current generators, and the installation for the Aluminum Company of America at Massena, N. Y., of eighteen 2500 kw. rotary converters; together with the volume and variety of apparatus which has been installed on the Panama Canal, the New York State Barge Canal and the Catskill Aqueduct, the largest public improvements of their type in the world.

In general, these are only made practical and possible by the past twenty years of continued growth and progress in the development of electrical machinery.

A 110,000 Volt Outdoor Substation. Georgia Railway & Power Company

# ELECTRIC POWER: ITS SOURCES AND THEIR PERMANENCY

By Fred. M. Kimball

Manager, Small Motor Department, General Electric Company

The author points out that the prosperity of the country depends upon its industries and that its industries are dependent upon an ample supply of energy at a reasonable cost. The industrial progress already made has enabled the worker to live rather than exist, and future progress is likely to still better the conditions of life. While other sources of energy, such as coal and oil, may ultimately fail, the sun, from which they all originally derived their energy, will still remain and will at all times provide ample water power for future generations. —Editor.


**Fred. M. Kimball**

BROADLY speaking, all material progress in the development of a country, all important improvements in the conditions of life and living, are vitally dependent upon a reliable supply of power that can be readily augmented, as occasion requires, that can be easily and economically distributed, and that can be purchased at a moderate price.

In the United States particularly, where manufacturing dominates all other industries, and where success in every competitive business makes it more and more imperative to secure the greatest output in product or service per unit of labor employed, an ample supply of power at moderate price is a pre-eminently important essential.

The use of power and all the mechanical devices used to displace manual labor is by no means confined to manufacturing industries, but has been largely extended into the domains of mining, commerce and agriculture, as well as to those more commonplace, but not less important, domestic and personal services which contribute so much to the comfort of living in the 20th century. Because of the vast natural resources of our country, which modern transportation facilities have made so accessible to development, and which have yielded such generous and well distributed wealth to the inhabitants of the country, and by reason of the universality and excellence of the education which our magnificent public school system has made available to all, the people of the United States have come to exercise a nice discrimination between existence and living, and demand not only the necessities but a measurable share of the comforts and some, at least, of the luxuries of life. The constantly rising wage scale which permits the achievement of this standard of living has even now become so high that all employers must be indefatigable in providing every supplementary means that will insure the most efficient use of human labor. Power and machinery afford the best supplementary means to this end yet devised.

Nature has ever been wonderfully considerate and provident for the needs of her children. She has given lavishly for their necessities, and in no direction more generously than in her provision to supply heat, from which we derive our most important power supply.

While steam and gas engines or waterwheels fully realize the popular conception of primary sources of power, it must not be overlooked that the engine and the waterwheel are only devices for the transformation of other forms of energy into their mechanical equivalents of rotary torque, and in the last analysis and generally speaking, we shall find that that magnificent center of our universe, the sun, is the principal and perhaps the only source of all power which we at present utilize.

As a beam of sunshine of known dimensions has been made to give up its radiant energy to a weighed mass of water, scientists have calculated for us the amount of heat given off by the sun under varying conditions of time, distance and area. A brief reference at this point to generally accepted data concerning the intensity of solar heat may be pertinent and instructive. The sun's radiation in heat units has been calculated as exceeding 1,200,000 great calories per minute for each square meter of surface. Further calculations indicate that to produce this amount of heat by combustion would require the hourly burning of a layer of anthracite coal more than 19 feet thick over the entire surface of the sun—the sun's surface being 11,940 times that of our earth's. This is equivalent to a continuous radiation of about 12,000 h.p. from every square foot of the sun's entire area. Of this extraordinary outflow of heat, equal at the solar surface to 12,000 h.p. per square foot, the earth intercepts only about $\frac{1}{2,200,000,000}$ part. Even this minute fraction is equivalent to 1 h.p. for every 16 sq. ft. of the earth's surface.

The mighty power of this great luminary, 1,300,000 times larger than our own earth, has been appreciatively and eloquently expressed in the following fine passage from Tyndall:

> "I looked over this wondrous scene towards Mount Blanc and the thousand lesser peaks which seemed to join in the celebration of the risen day. I asked myself: How was this colossal work performed? Who chiselled these mighty and picturesque masses out of a mere protuberance of the earth? And the answer was at hand. Ever young, ever mighty—with the vigor of a thousand worlds still within him—the real sculptor was even then climbing up the eastern sky. It was he who raised aloft the waters which cut out these ravines; it was he who planted the glaciers on the mountain-slopes, thus giving gravity a plough to open up the valleys; and it is he who, acting through the ages, will finally lay low these mighty monuments, rolling them gradually seaward, sowing the seeds of continents to be; so that the people of an older earth may see mould spread, and corn wave over the hidden rocks which at this moment bear the weight of the Jungfrau."

The power obtained from falling water and in a large degree the power obtained through the combustion of coal and other fuels was primarily transmitted to the earth from the sun as heat. In case of the water, the transformation of solar heat into the potential energy contained in falling water is still going on. In case of the coal, the absorption of the sun's heat energy, transformed and stored up in the coal, took place thousands of years ago.

In addition to our stores of coal from which heat may be derived, but again essentially dependent on the sun for their contained latent energy, we have extraordinary stores of lignite, petroleum and peat, and an ever-perpetuated growth of wood and minor vegetation, from which latter alcohol may be easily and cheaply prepared, both wood and alcohol possessing high thermal values as fuel.

Finally, we have the direct heat radiated by the sun, and as additional but yet unutilized sources of power, the attractive or gravitational pull of the sun and moon, evidenced by the rising and falling tides and the ceaseless wave motion of our oceans and great lakes. Unfortunately, we have not yet been able to devise practicable means for utilizing the power of the tides and waves directly or with any mentionable degree of commercial efficiency, but both will undoubtedly be brought into the service of man.

The era of the formation of coal and oil deposits in the United States is past. It is hardly probable that any future era will witness conditions on this planet that will bring into operation the combination of forces which are necessary to form new supplies. When the existing coal and oil are consumed, the supply of heat and power derived from these sources will be at an end. Whatever equivalent of heat and power supply can be obtained from falling water is, however, so far as we now know, self-perpetuating as long as the phenomena of aqueous evaporation, condensation and precipitation survive, as long as the attraction of gravitation exists, in short, as long as the sun continues to shine, for the same source of energy which gave us our fuels makes possible our waterfalls.

The observed diminution in the radiation of heat and other forces projected from the sun has been so slight within the time covered by the records of man, that based on a priori reasoning, we feel quite sure that there will be no sensible diminution in the amount of energy which the sun will supply to this earth for thousands and perhaps for millions of years to come.

It is well known that heat and power, or, in its most useful form, rotary torque, are interconvertible, and the energy of falling water may be easily turned into the energy of heat through the intermediary of suitable mechanical and electrical devices.

With an adequate supply of water power available, we need not draw further on our supplies of coal, of oil or of wood for light, warmth or power, since through the agency of electricity we can transform the energy of falling water into the energy of heat, power or light, and in case of power and light particularly, this transformation can be accomplished with comparatively high efficiency. When we consider the average requirements of each individual for heat, light and power, and reduce them to a common unit of measurement, we find that, very roughly speaking, each inhabitant of the United States requires an average expenditure of the equivalent of something like 13 horse-power-hours per day to provide for his or her needs in heating, cooking, lighting, manufacturing, transportation and allied services. Of this amount, about three horse-power-hours is consumed in manufacturing, about 2.5 horse-power-hours is used in transportation; a somewhat smaller amount in lighting and general power purposes; and the balance, or five horse-power-hours, is consumed in heating and cooking. In other words, energy equivalent to about 5 horse-power-hours is consumed for maintaining suitable temperatures within doors and furnishing heat for all classes of domestic and other utilitarian uses.

As no means of distributing, transforming and utilizing power with a high degree of efficiency, wide applicability, thorough dependability and low cost, has yet been discovered that can compete with electricity, this wonderful agency has naturally become man's most popular, reliable and capable servant in doing the world's work. The public is already fairly well acquainted with the extraordinary growth of electric lighting, and the use of the incandescent lamp is quite general, even in small and remote villages. Although the advantages to be derived from the use of electric power are not so widely appreciated, and it is not quite as commonly used as is electric light, electric power is very generally employed in our large cities and towns. The electric motor is becoming ubiquitous; it is dependable, efficient and easily operated, it has been utilized in an extraordinary variety of services, and although now employed to a greater or less extent in almost every industry, the field for its application and use ever grows broader and more attractive as users gain additional familiarity with its advantages.

The present is truly the electrical age. The problems attendant upon the generation, transmission, transformation and utilization of electricity are well solved. We only need a larger supply at lower cost to make its use almost universal. A long step toward realizing this condition will have been taken when our law-makers come to appreciate that true conservation of our water powers really means their immediate development for enhanced supply of electric power, under just but liberal laws, and not the withholding or discouraging of such development for an indefinite time, with consequent irreparable waste of the enormous energies provided by Nature for the comfort and welfare of mankind.

# COOPERATIVE STANDARDIZATION

By J. W. Ham

Power and Mining Department, General Electric Company

This article, after pointing out the advantages that large manufacturers have gained by adopting individual standards for their own apparatus, proceeds to show that great economies could be secured to the industry as a whole if more universal standards were adopted. The author cites some of the advantages gained by international and national standards. He selects fifteen 3 h.p. constant-speed d-c. motors of different manufacturers and shows their physical differences, and after analyzing these suggests how standards might be adopted. The advantages of such standards to both the makers and users of machine tools, large pumps and compressors, and the motors to manufacturers themselves are enormous and the author thinks that these advantages should be secured by proper cooperation.—Editor

J. W. Ham

About 1,250,000* electric motors were purchased in the United States during the year 1913. Such is the demand, and it is ever increasing, for electric motors. To properly care for his share of the growing volume of business each manufacturer has found it necessary to standardize his product as far as possible and to put production on a quantity basis. Not only does this simplify factory methods, cut down overhead charges, and reduce the estimating force, but, what is of equal importance, it means better service at lower cost to purchasers—two vital considerations in business affairs.

The facilities for handling special, or modifications of standard apparatus of necessity extends through an entire organization as each case must be treated separately and on its merits; while in constructing and selling standard apparatus, the most direct course is adopted from producer to user. Herein lies the saving by standardization as it presupposes quantity production and the retailing of the article on the basis of wholesale cost.

If there is an advantage in individual standards how much more general and therefore greater are the benefits to be derived from what might be termed a universal standard,

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*Estimated.

by which we mean one that falls within certain approved limits adopted by all manufacturers of a given product. But in the selection of individual standards has there not been an unintentional misdirection of effort, in that each manufacturer has worked out his own standards without due regard to those of others, so that after all we find as many standards as there are manufacturers of a given product. Due to the activities of the A.I.E.E. much has been accomplished along lines purely electrical. Only a few years ago we met with a great variety of temperature guarantees. Different engineers and different purchasers specified temperatures which were standard with one motor manufacturer but special with another. Out of that confusion the A.I.E.E. has brought uniformity by adopting standards now generally recognized. But there is as yet no mechanical uniformity nor are there any rules suggesting approved methods to serve as a guide to future development. That the minds of men who have to do with these things should be focused on this problem is obvious. One has but to compare the physical dimensions of the various makes of motors to appreciate the need of a concerted action toward a physical standard, within reasonable limits.

Selecting at random fifteen 3 h. p. constant d-c. motors of different manufacturers we find:

| | Min. for 15 Motors in In. | Max. for 15 Motors in In. | No. Alike | No. Different |
|---|---|---|---|---|
| Length over all | $17\frac{9}{16}$ | $28\frac{3}{16}$ | 2<br>2 | 13 |
| Width | 12 | $16\frac{3}{4}$ | 3<br>2 | 12 |
| Center line to bottom of feet | $6\frac{1}{4}$ | 9 | 2<br>2 | 13 |
| Distance between holding down bolts, end view | $9\frac{1}{4}$ | 13 | 3<br>2<br>2 | 11 |
| Distance between holding down bolts, side view | $5\frac{11}{16}$ | $13\frac{1}{4}$ | 2<br>2<br>2 | 12 |
| Shaft extension beyond housing | $2\frac{1}{8}$ | 5 | 3 | 13 |
| Diameter shaft extension | $\frac{7}{8}$ | $1\frac{1}{4}$ | 4<br>4<br>2<br>2 | 7 |

It will be seen that the nearest approach to a uniform standard is in the diameter of the shaft, but even that might be expressed as 46.6 per cent off standard while the greatest deviation is found in the length, which is 93.3 per cent off standard. Considering all the physical dimensions the variation from a universal standard is 100 per cent; i.e., no two are alike or sufficiently so to be easily interchangeable one for the other without more or less changes in the mounting.

Although the foregoing figures are for constant speed motors the comparison holds for those of the adjustable speed type as well, i.e., machine tool motors, because of the almost universal practice of obtaining adjustable speed motors from constant speed frames. It is, therefore, at once apparent that when the driven machine and its driving motor are to be assembled as a unit the problems of securing interchangeability are stupendous and often impossible without involving much additional expense, longer shipments and altogether poorer service to the purchaser. The shafts perhaps could be easily standardized, and there is no reason, except lack of cooperation, why shaft diameters, extensions and keyways for a given horse power and speed should not be alike for all motors of whatever manufacture when used for the same service. Suppose these fifteen motors to have identical shafts for the reception of pulleys, then one size pulley only would be used where now seven different ones are required. The pulley manufacturers cannot standardize all of these because of the limited demand for each size. They must therefore be built to order at necessarily higher cost to the user and delayed deliveries. This is equally true of pinions for geared machines, and for couplings when direct connection is desired so that savings which might be small per unit cost of production would in the aggregate be very great. It is doubtful if the actual savings could be determined in dollars and cents because interchangeability of spare parts is the best insurance against idle machines due to accidental breakage.

That no inflexible rule can be deduced fixing all the physical dimensions of motors is recognized because of differences in shop practices and the widely varying ideas of designing engineers, nor is such a thing to be desired; but there could be approved limits within which new designs should fall and which would not in the slightest degree interfere with each manufacturer's individuality of design or the successful operation of his machines. The art of designing small motors, after years of experience, is pretty well established and it is generally known about what output can be obtained from each pound of steel, iron and copper when properly distributed, so that it should not be difficult to reduce the housing of the different parts to a practical standard.

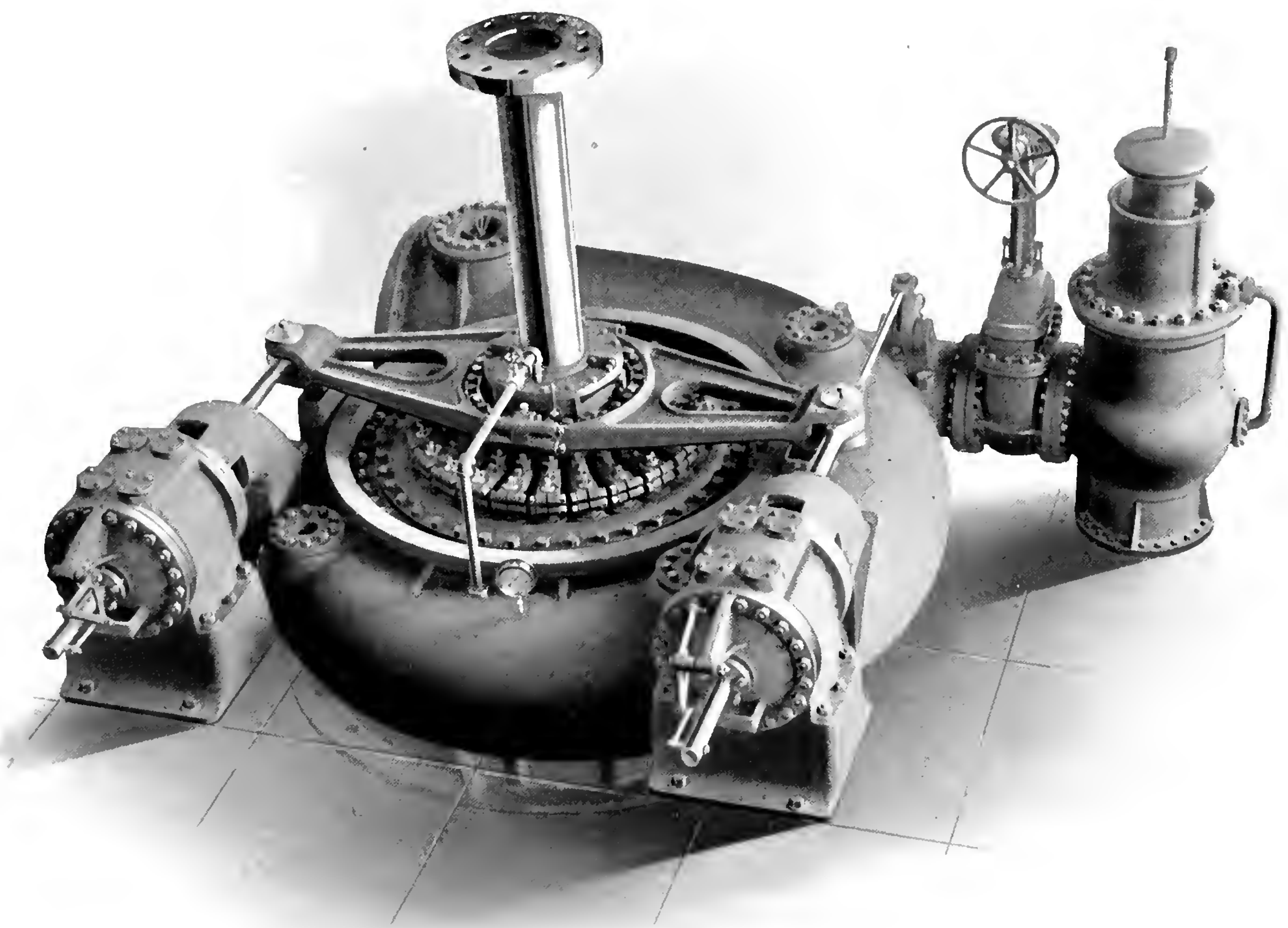
But the scope of a universal standard is much broader than its application to electric motors alone and the benefits to be derived through its realization would be restricted unless similar standards were adopted for the driven machines, such as machine tools, pumps, compressors and all those which in combination with the motor form a complete operating unit.

To construct machine tool motors of predetermined horse power capacities, speeds and physical dimensions would in a measure be like "chasing the rainbow" unless the tools were designed to receive motors capable of driving those tools at maximum duty, and with the proper gear ratios that would permit of standardization of pinions and gears. Reference is made to maximum duty because a given machine tool may be used for light, medium, or heavy duty, thus requiring three different horse power capacities for the same tool under different conditions of work. Here we have a condition where the tool is standard within its range but one for which the motor requirements may change in accordance with service conditions. It is then either necessary to standardize a motor capable of driving the tool under maximum cutting operations, and use it for lighter duties as well, or for the machine tool builders to provide a form of mounting that will take any one of three motors with the least possible inconvenience in the assembly. Obviously this is one of the problems for consideration by machine tool builders, none of which should offer insurmountable difficulties provided there is that cooperation which the results would justify.

That the tendency is steadily toward individual drive of machine tools is incontrovertible. The user first selects the make of tool which he considers best suited to his requirements, one of which is that it must remove so much metal in a specified time. To displace that metal a definite horse power is needed and just as there are reasons which cause the user to purchase a certain make of tool so are there considerations that often lead him to specify the make of motor, which he buys direct from the motor manufacturer or through the machine tool builder. In either event the machine tool builder must make provision for mounting the motor. He frequently has no choice in the matter nothwithstanding the fact he is prepared to furnish a standard outfit while special construction is necessary to meet the wishes of his customer. Were there standards for machine tools and standards for motors of various makes this difficulty would be eliminated.

In the case of large pumps and compressors the conditions are somewhat different from those of machine tool applications in that the physical dimensions are relatively less important, the variables being horse powers and speeds for direct current and induction motors with the added feature of power-factor and torque should the motor be of the synchronous type. Here the first step toward standardization clearly devolves upon the pump and compressor builders, because no scheme of standards for motors at present in use, or possible of adoption, could provide for the almost infinite variety of ratings required. Since electric motors are now generally employed to drive all classes of machinery the view that greater uniformity is needed in horse power and speed requirements of the driven machines seems warranted.

Perhaps this can best be illustrated by actual figures. The writer investigated the motor requirements of six manufacturers producing machines standard with them, and all for similar service. The driving motors required were three-phase, 60 cycle synchronous units and the capacities specified were from 44 h.p. to 1900 h.p., and the speeds were from 90 r.p.m. to 325 r.p.m. There were a total of 135 ratings needed to motor these machines, of which seven only could be used by more than one manufacturer. In other words, the list called for 128 different motors, not one of which could be used by any two manufacturers of the driven machines. As any one of four voltages, i.e., 220, 440, 550 and 2200 volts, is common throughout the country the actual number of motors to design was 512. With reasonably uniform speeds and capacities of the driven machines about 30 motors would fulfill the requirements of the 128, or considering all the voltages, the designs would number about 120 instead of 512. So we urge a greater and more comprehensive standardization, not only individually but collectively. Can it be done? Assuredly, since it is an urgent economic need and we have the faith to believe that that which is good for all will ultimately be achieved through cooperation.



17,000 H.P. Hydraulic Reaction Turbine of the Tallulah Falls Development, Georgia Railway & Power Co.
This turbine operates under a 600 ft. head, and is the highest head reaction turbine in service in this country
(This development is described in an article beginning on page 608)

# A REVIEW OF RECENT DEVELOPMENTS OF THE HYDRAULIC REACTION TURBINE

By H. Birchard Taylor

Hydraulic Engineer, I. P. Morris Company, Philadelphia, Pa.

Mr. H. B. Taylor's contribution to this special issue of the Review is a most comprehensive treatise on a subject which is of the utmost importance to the hydro-electric engineer. It would be impossible to give a brief digest of so full a discussion of this subject. The completeness can be judged by the following headlines, under which Mr. Taylor treats his subject: "The Design of Testing a Turbine in America; Mechanical Features of Turbine Construction; General Arrangement of Unit; Volute Casing; Draft Tubes; Supporting Rings and Face Plates; Pressure Thrust Bearing; Roller Bearing; Guide Bearing; Mechanical Details; and Speed Regulation.—Editor.

H. Birchard Taylor

## Design and Testing of Turbines in America

THIS article is limited to a discussion of the recent practice in the design and construction of reaction turbines in this country, with special reference to certain mechanical features of the modern turbine and the discussion of a number of points where practice has not yet become standardized. It is now well known that the early development of the hydraulic turbine in America was carried along empirical lines, and that the application of logical engineering methods has been of comparatively recent date. It is also known that many turbine manufacturers in this country still adhere to the older methods, and produce turbines of stock designs and standard sizes, relying to a great extent on the use of existing patterns.

It may not be as generally recognized as it should be that a considerable proportion of the current technical literature which has appeared upon this subject has dealt largely with the turbines included under this classification of stock apparatus. As little scientific engineering work has been involved in the development of this class of machinery, the value of such material as can be found in many of our technical papers is not great. When it is realized that many new problems of fundamental importance are being frequently met and solved in this field, and that much engineering effort is being called out in the present widespread development of water powers in this country, the need will be felt of the publication of information regarding recent practice in this field and for fuller discussion of the many important details of this subject.

The "stock turbine," so-called, has not for many years been representative of the best work produced in the United States. A number of American builders have successfully undertaken developments requiring the highest type of engineering skill and initiative, and much pioneer work in the extension of hydraulic turbines, to cover most severe conditions and a wide range of capacity and dimensions, has been undertaken.

A large part of the credit for present attainments in American turbine construction has been attributed to the systematic testing of waterwheels, which has always been a feature of American practice. Several thousand tests have been made at the Holyoke testing flume, and undoubtedly the results of these experiments have been of the greatest service to American engineers. Until these experimental results were supplemented by proper theoretical investigation progress was, however, comparatively slow, and recent progress has been possible only through a more scientific handling of the problems which have arisen.

While reviewing a discussion which took place at a meeting of one of the engineering societies held four years ago, the writer encountered a few statements which may be of interest at this point, such as the following:

"Many of the wheel manufacturers have gone to extreme pains to put their wheels into splendid condition for testing at Holyoke, and the wheels have shown correspondingly excellent results, but these conditions would not last long, so that in actual practice the wheels would doubtless show quite different results from those obtained at Holyoke . . . .

"The wheel manufacturers do not as a rule guarantee their wheels at over 80 per cent efficiency, and this would seem sufficient reason to believe that they themselves do not place too much reliance on the results obtained at Holyoke. There are times, however, when wheel manufacturers will guarantee considerable increases over 80 per cent. But I am strongly inclined to believe, partly from experience, that they will balk when the purchaser asks that this guarantee be placed on paper, that the wheels be tested and that a bonus and forfeiture clause be put into the contract. For these reasons, it seems to me decidedly advisable to test the wheels under conditions of installation . . . . . . . . ."

Quoting from another contribution to the same discussion:

"One of the greatest stumbling blocks in the path of turbine development in this country has been the lack of systematic testing after installation. Errors in design have been made and perpetuated year after year, simply because purchaser and manufacturer have been satisfied to believe that turbines showing splendid results at Holyoke, under a head of 18 feet or less, would give as creditable performances when used with heads five or ten times as great. That this was beyond the limits of reason we know now and should long since have known . . . . . . ."

The writer trusts that no one would at the present time repeat the foregoing strictures on the efficiencies of American turbines, because there have been many well authenticated tests of turbines after installation and, under actual conditions of operation, showing efficiencies ranging from 88 to 93.7 per cent. It is believed that the demand for high efficiency may now be said to have been satisfactorily met.

Before leaving the statements above quoted, attention may be called to a number of points which the writer believes are not clearly understood by some engineers. The following facts are in line with accepted principles, as well as with actual results:

First: If results of the Holyoke tests on a small model runner are properly interpreted and applied scientifically to the design of a large turbine of like characteristics, then the results with respect to efficiency and power obtained from the large turbine when tested in place will be found to check, within a very small percentage, the results forecasted by the Holyoke test.

Second: The variation of efficiency obtained in place from that shown at Holyoke may be calculated with a satisfactory degree of precision. If the setting of the large turbine is equivalent to that of the model when tested at the Holyoke flume, the shape of the efficiency-horse power curve of the large turbine will check the corresponding Holyoke curve very closely.

Third: If the setting of the large unit is superior to that in which the model runner was tested at Holyoke, as is almost always the case in larger modern developments, then the efficiencies of the large machine will exceed those obtained at Holyoke, and the effect of increased dimensions of the runner of the large turbine over the model runner, as well as the variation in head, can be definitely computed without any notable degree of uncertainty.

Fourth: The effect of increases in head and dimensions on turbines of exactly similar design is not to impair the efficiency, as might be inferred from the above quotations, but both changes have the same result, viz., an increase in efficiency if the character of the turbine setting remains the same. This is in accord both with a theoretical formula due to Dr. Camerer, of Munich, and with actual experience.

With reference to one of the statements just quoted, to the effect that it is unreasonable to expect that wheels tested in place under high heads should make as good a showing as the "splendid" results secured under a low head at Holyoke, it is worth noting that results are now secured in large wheels in place, under heads many times greater than the Holyoke head, which exceed the "splendid" results at Holyoke by an average of three or four per cent. In other words, the setting of the experimental model at Holyoke is, at best, by no means splendid when compared with the setting which may be secured in the case of large units.

The writer might also quote in this connection a few sentences from a technical journal regarding the recommendations read before the Boston Society of Civil Engineers, recently submitted in favor of a National Testing Flume:

"Waterwheels have increased so much in size in recent years, and are operated under so much higher heads, that there is no place in the United States where they can be adequately tested before their final installation.

"The Holyoke testing flume . . . . . . is no longer large enough, nor does it have sufficient head to meet all of the present day needs. . . . . . .

"The art of waterwheel design is still in rather a crude state and needs such authentic and reliable information as the proposed flume will furnish. . . . . . . . . ."

While not wishing to injure the movement mentioned in the slightest degree, the writer is of the opinion, in view of the character of arguments advanced, that the technical press in general as well as many engineers are not really familiar with the methods used by the builders of the higher class of apparatus, in respect to the application of the results of the Holyoke tests to the designs of large turbines.

It is not impossible, as may be inferred, to predict from tests at a low head on a small model runner of homologous design, the performance of a large turbine under a high head. The writer also does not consider that the art of waterwheel designing is in rather a crude state.

The efficiency guarantees covering the turbines for the Appalachian, Keokuk and Cedars Rapids developments were made under very severe bonus and penalty clauses. The guarantees made by the builders were based directly upon the Holyoke tests, and the results secured in the Appalachian and Keokuk units have clearly demonstrated to the satisfaction of all parties concerned that the methods used by the builders in interpreting and applying the Holyoke tests to the design of turbines of the largest sizes are correct.

It may be stated that in every instance where a large turbine has failed to produce results as good as those forecasted by the Holyoke tests, such failure may be attributed either to improper application of the tests or to the placing of too much reliance on the runner without proper regard to the effect upon the runner of defective wheel-casings and draft tubes. If engineers permit the runners of large turbines to be used in connection with defective settings, then the failure of the large turbines to come up to expectations should not reflect on the Holyoke flume.

Before leaving the question of the Holyoke tests, it may be pointed out that the builders of the better class of machinery have used and are now using the Holyoke flume only when they desire to secure experimental data beyond the range of the theoretical data previously substantiated, or in cases where it is desirable to insure the successful outcome of an important contract by checking the runner calculations previous to construction.

### Mechanical Features of Turbine Construction

Although the question of efficiency is of vital importance in many installations and is becoming increasingly important every day, there are other questions in connection with the construction and installation of the modern turbine which should be given even greater weight.

Many engineers have come to recognize the value of efficiency, but only those who have had actual experience in the operation of completed plants can realize the importance of questions of design and workmanship used in the structure of the unit and in the mechanical details of the machine. Such questions as continuity of operation; freedom from interruption for repairs; the rapidity with which accidental damage may be rectified; and absence of vibration, noise and rapid wear are vital considerations in any hydro-electric plant. The stability of the design of a turbine as affected by the amount and disposition of the material and the careful calculation of stresses under all possible conditions; the mechanical operation of the unit as affected by careful study of the design of each detail; the convenience of the arrangement of the parts and their accessibility for dismantling for repairs; and many other features of construction, have a much greater effect on the success of the turbine than is generally realized. Unfortunately, many of these points cannot be easily covered in specifications, and although the best solution of many of these problems involves considerable increases in the cost of the turbine, it is difficult to assign to them a monetary value, so that a decision regarding various questions of design is often one of the most difficult problems which the consulting engineer encounters.

Engineers who have been responsible for the operation of large stations over many years of service generally view these questions from a different standpoint from that held by the purchasing agents of new developments.

### General Arrangement of Unit

In the special number of this REVIEW for June, 1913, devoted to hydro-electric developments, the writer contributed an article on vertical shaft, single runner hydraulic turbines as applied to low heads. The advantages secured in this type of unit over the multi-runner horizontal wheels which had been popular until recently were discussed both from hydraulic and mechanical considerations, and it was predicted that in the future the single runner vertical wheel would be generally adopted for low head installations. During the past year, we find that the vertical unit has almost entirely superseded the multi-runner horizontal type and in the case of first class installations waterwheel builders now seldom receive inquiries for horizontal multi-runner units except as additions to existing installations.

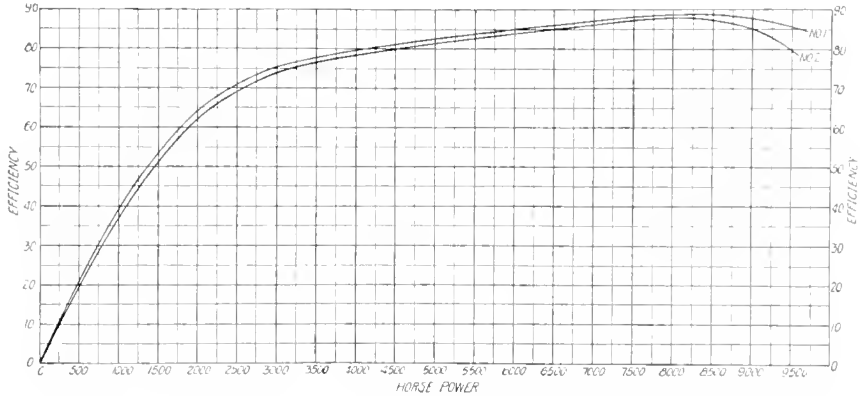


**Fig. 1**

Curve No. 1. Official efficiency test curve of the 9000 h.p. turbines designed and built by the I. P. Morris Company for the Washington Water Power Company. Head 66 ft.; speed 150 r.p.m.; rated runner diameter, 6 ft. 2 in. Test made January, 1911. The Washington wheels are of the horizontal shaft, two-runner, central discharge type, equipped with volute casings. Curve No. 2 is derived from test at Holyoke of the experimental runner, having a rated diameter of 2 ft. $8\frac{11}{16}$ in. Test made October, 1909. Experimental runner was tested in vertical setting.

The curves are almost identical in shape; the efficiency of the large units exceeding by a small margin that of the experimental runner. This illustrates the fact that in the case of large units, with properly designed water passages, even when the type of unit is entirely different from that of the experimental model, an accurate forecast of the performance of the large unit may be secured from the test of the model. Although there were losses in the draft chest of the large turbines which were not present in the experimental testing outfit, these losses were not sufficient to overcome the gain in efficiency in the other water passages.

Plans are now under consideration by a number of power companies contemplating the use in the case of additional units of the vertical single runner type even when the uniformity of the station is thereby destroyed, a fact which speaks strongly for the general appreciation of the advantages of this type of unit. In the plant of the Pennsylvania Water & Power Company at McCall Ferry there are now installed seven vertical shaft two-runner units. The substructure of the power house has been built for ten units of this type. Unit No. 8, however, which is now under construction, will be of the single runner type, and that part of the substructure which had previously been constructed will be remodeled so that the single draft tube required by the newer type of unit may be used, and the existing rectangular intake flume will be modified for the construction of a concrete volute casing. The fact that the company mentioned has found it an economical proposition to alter their existing substructure, at no little expense, to accommodate the single runner type of turbine is a strong argument for the adoption of this type in new installations.

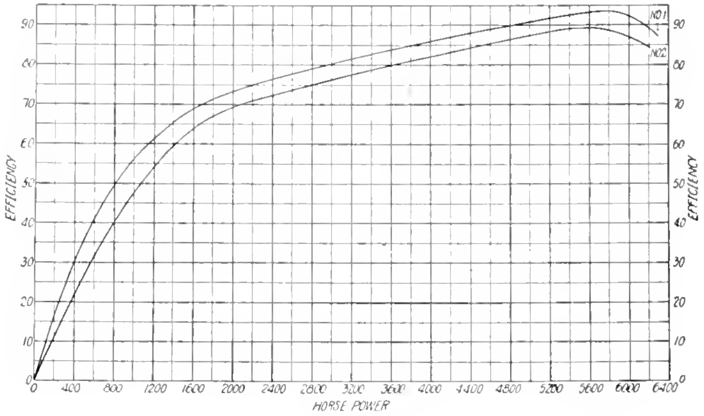


**Fig. 2**

Curve No. 1. Official test curve of the 6000 h.p. turbines designed by the I. P. Morris Company for the Appalachian Power Company. Head 49 ft.; speed 116 r.p.m.; rated runner diameter 7 ft. $6\frac{1}{4}$ in.; test made February, 1913. These turbines are of the single runner, vertical shaft type. Curve No. 2 is derived from the test of the small experimental runner at Holyoke; rated diameter $27\frac{3}{8}$ in.

Both curves are identical in shape, but owing to the superior arrangement of water passages in the Appalachian plant, the efficiencies of the large units exceed those of the experimental runner by a considerable margin.

It has also been noted during the past year or two that the vertical single runner type of unit has found increased application to moderate and high heads as well as in low head plants. While its advantages over the horizontal, multi-runner low head type of turbine are numerous, it also has a number of important advantages over the horizontal single runner or horizontal double runner turbine for high head installations.

The trend of present development in the field of the reaction turbine seems to be in the direction of a still wider application of the vertical single runner unit to all conditions of head and speed. There are, of course, a few cases where the horizontal shaft unit may still afford the best arrangement as, for instance, in plants where the layout of the power house requires an overhead intake to the turbines, and in cases where direct current generators are to be used.

### The Volute Casing

Present practice seems to favor the molding of the volute casing directly in the substructure of the power house, for all low head turbines. For heads exceeding 100 feet, the amount of reinforcement required in the concrete is almost always sufficiently great to call for the use of cast iron casings. As the pressures increase, the cast iron must be increased in thickness, and for heads exceeding about 250 feet the use of cast steel as the material for the casings may be said to be standard practice in the best class of turbine construction. The use of steel for such conditions is advisable upon many grounds, and most particularly from considerations of safety against the severe surges which may occur in most high head plants, since such plants almost invariably include long pipe lines or penstocks.

In this connection the use by some builders of a material designated as "semi steel" may be mentioned. This term may be understood to refer to material run from an ordinary iron cupola, in which a certain amount of steel scrap has been introduced. It may be safely stated, however, that castings made from such material, which is handled at temperatures much below that necessary for steel, are nothing more than cast iron, and when submitted to test will exhibit all the characteristics of cast iron, such as absence of ductility, poor resistance to shock, and rapid fatigue under repeated stresses. The term "semi steel" is, therefore, held to be meaningless, and the most that can be said for it is that it is sometimes used to indicate a good grade of cast iron as distinguished from a poor grade.

In connection with the question of the construction of the volute casing, an important point which is not always given proper consideration is the adherence in the design to principles which are in accord with the best foundry practice. Thus, care should be taken that the casting be of uniform thickness; that the attachments of brackets, lugs, feet or external projections of any kind to the shell be avoided; and, in fact, the recognized rules of good foundry practice be applied to this important part of the turbine. Any junction of an external web or projection with the shell of the casing, or any point where an increase of thickness of metal occurs, will result in unequal cooling in the mold, producing spongy metal in the interior of the casting where it is invisible but dangerous, and with an accompaniment of initial stresses of indeterminate amount. That these well-recognized rules are not followed in all cases is shown by the attachment by some builders of numerous pads and supporting brackets to the cast iron volute casing, and in some instances, the casting integrally with the casing of a heavy base ring or supporting flange; and still worse, of casting the speed ring vanes connecting the upper and lower sides of the casing in one piece with it. The speed ring vanes must be made very heavy in section, and it may be confidently stated that it is impossible to avoid the presence of defective metal at the juncture between these vanes and the casing, or at the juncture between supporting flanges and the casing. In addition to this, initial stress of indeterminate but certainly dangerous amounts must exist in such casings. The best modern practice seems to be in making the speed ring separate from the casing proper and, in the case of medium or high head turbines, to use a cast steel speed ring in connection with cast iron or cast steel casings.

In a number of notable recent developments involving high and moderate heads, the turbine casings have been embedded directly in the concrete substructure of the power house, and have been entirely surrounded by the concrete. This appears to be in line with the best recent practice, since it avoids the use of base rings or supporting flanges on the casings, and provides extremely stable and reliable support for the entire unit. All vibration during operation, or deflection of the casing due to water hammer is prevented, and if the concrete is extended above the turbine to form a foundation for the generator, the latter may be firmly tied to the structure of the power house in such a manner as to provide protection against a wrecking of the unit under the severest short circuits to which the generator may be subjected. The cast steel or iron casings are as well protected on their external surfaces against corrosion as is ordinary concrete reinforcement. Within the casing the water velocities are sufficiently low, and the pressure sufficiently high, to prevent the possibility of corrosion and, in fact, no such action has ever been observed in turbines which have operated over a long period of years.

Fig. 3. One of the Four 17,500 h.p. Turbines Designed and Built by the I. P. Morris Company for the Alabama Power Company

Head 68 ft.; speed 100 r.p.m.; rated runner diameter 9 ft. 11¼ in. This illustration shows the relation between the speed ring and movable guide vanes. At the time these turbines were built they were the highest powered vertical units ever attempted for low heads.

In low head plants where the head does not exceed 100 feet, the best present practice is believed to be the use of reinforced concrete as the material of the casing. Some builders urge the use of riveted plate steel casings embedded in the concrete and, although in some instances the local conditions may require the use of casings of this type, it is believed that progress in this branch of engineering, as in others, is in the direction of the extension of the use of reinforced concrete and its substitution in many cases where other materials were formerly used. In some recent instances a comparison of the cost of riveted steel as compared to the cost of the wooden forms required for concrete volute casings has shown that the cost of the steel exceeds that of forms alone in a ratio of approximately 3:1. The fact that the steel casing is surrounded by concrete does not remove the necessity for designing the steel to carry the entire pressure of the water without assistance from the concrete. In view of the poor resistance of plate steel to corrosion, coupled with the fact that the "breathing" of the casing may impair its bond with the concrete and permit the access of moisture to its outside surface, the advisability must be considered of reinforcing the surrounding concrete sufficiently to carry the pressure after the life of the casing has been exceeded. The writer therefore believes the use of riveted steel casings to be a retrogression rather than a forward step in turbine practice.

In the design of a concrete casing, a cross section of the volute may be given any desired shape, not subject to the limitations imposed by the fabrication of a plate steel casing; and by suitably modifying the form of the section the overall diameter of the casing may be reduced, with a consequent important reduction in the spacing of the units and the length of the power house.

The remarkably smooth surface and the well formed curves obtained in molding the concrete for some recent plants make this a most satisfactory material for the casing.

### Draft Tubes

Many of the points just brought out apply also to the question of the material for the draft tube. Draft tubes molded entirely in concrete with a short cast iron discharge ring below the runner, this ring being made long enough merely to provide a proper bond with the concrete, appears to be the economical and satisfactory solution. No examples are on record of hydraulic corrosion of smooth concrete, even by high velocities.

A prevalent fallacy may here be noted. It is thought by many that draft tube velocities in high head plants are such as to require metal linings to protect the concrete. It is a fact, however, that the proper velocity in the draft tube has no relation to the head on the turbine, and should have no higher values in high head than in low head plants.

### Supporting Rings and Base Plates

A number of years ago it was considered good practice in the construction of horizontal turbine units to provide a continuous cast iron base plate connecting all of the parts of the turbine, and sometimes including the generator, in a single foundation casting.

With the great increases of size of units which have taken place, it has been found that these base plates were serving no useful purpose, and they finally failed to survive in the larger developments, the turbine parts being supported directly by the heavy mass of concrete forming the foundation for the unit. The advantage of the base plate in the case of small units was the possibility of making the unit self-contained so that it could be aligned and completely erected in the shops of the manufacturer before shipment, erection in the field thus being simplified. In the case of large units, however, it was found impossible to make the iron base plate sufficiently heavy to hold the parts rigidly in line, so that it was necessary in all cases to align the unit at site during erection, whether base plates were used or not.

In a recent design of a vertical shaft turbine having a cast iron casing, the engineers required that a heavy cast iron supporting ring be provided below the casing, extending to a considerable depth, the idea being that this ring would facilitate the erection of the unit, in the same manner as a base plate would the erection of a horizontal unit.

Since the casing, when bolted together, is in one piece and embedded in the concrete, it is difficult to imagine what useful purpose this ring would possibly serve, and as it is just as easy a matter to align the casing itself as the base ring, it is very evident that such a supporting ring in the case of this unit cannot have any of the advantages claimed for the base plate of a horizontal unit, since it does not serve to align a number of different parts.

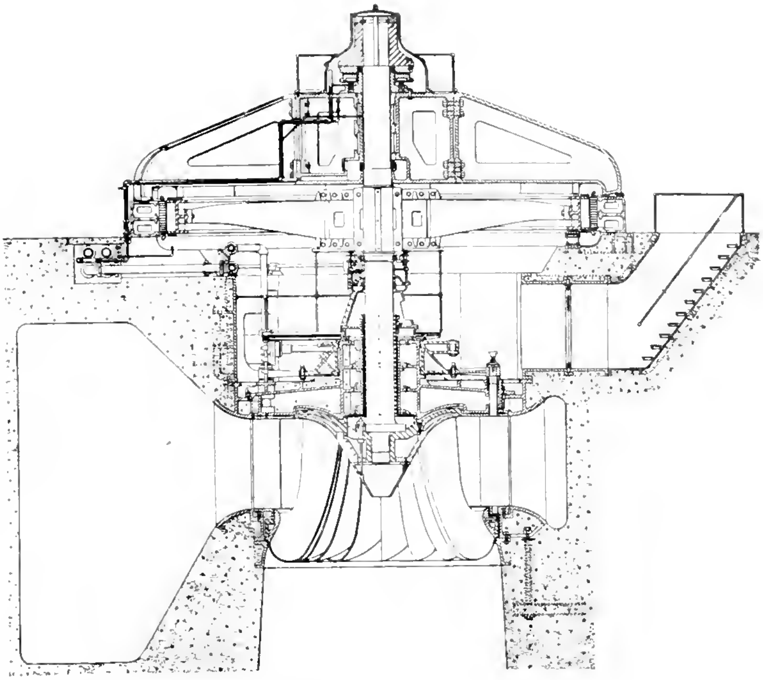


Fig. 4. Vertical Arrangement of the 10,800 h.p. Turbines Designed by the I. P. Morris Company for the Cedars Rapids Manufacturing & Power Company

Head 30 ft.; speed 55.6 r.p.m.; rated diameter 11 ft. 10½ in. These turbines are at present the largest in the world, and it may be noted that in the design there have been incorporated all of the latest features, viz.; volute casings and draft tubes moulded in the concrete; cast iron speed rings supporting the concrete, generator and thrust bearing loads from above; lignum vitae turbine guide bearing; thrust bearing support located above the generator; Kingsbury thrust bearing with roller auxiliary; and pneumatic brakes acting on the rotor of the generator.

The best method of supporting a vertical unit of the type having a volute casing molded in the concrete is now recognized to be the carrying of the load vertically downward through the concrete below the generator to the turbine speed ring, and through the speed ring vanes, acting as columns, to the base of the substructure which forms the foundation of the power house.

The method of support just described has been adopted for the turbines for the Appalachian, Georgia-Carolina, Laurentide, Cedars Rapids, Turners Falls, Northern Ontario, and Alabama developments, and for Unit No. 8 for the Pennsylvania Water & Power Company.

### Thrust Bearing

The thrust bearing of vertical wheels is now almost universally located above the generator on a cast iron supporting truss which forms at the same time the generator head cover. The location of the thrust bearing above the generator has two advantages: first, it places the thrust bearing in the most convenient and accessible location for dismantling and inspection; and second, it eliminates the requirement of a thrust deck in the substructure of the power house, thereby reducing the cost of the power house substructure.

Practice varies somewhat as to the detailed design of the thrust bearing truss, but the principal requirements, viz., that the truss shall be rigid and that the upper face upon which the thrust bearing is mounted shall be level, are adhered to in all cases. The upper guide bearing of the generator is incorporated in the truss directly below the thrust bearing and it is important that in the design of the truss it be made sufficiently rigid against local deflection to avoid binding of the guide bearing. It may be noted that in the design of this truss, time expended in endeavoring to reduce the weight of the truss to the lowest safe limits would not be well spent, since not only are strength and stiffness against deflection important considerations, but also it is desirable to have a considerable mass of metal present in this element in order to avoid the possibility of vibration of the thrust bearing. The thrust bearing support is sometimes included with the generator and in some instances it has been constructed by the turbine builders as a part of the turbine machinery.

The subject of the thrust bearing has been one of the most important considerations affecting the adoption of the vertical type of unit. The hesitation with which engineers formerly adopted the vertical type of unit and the preference which some engineers still express for horizontal shaft machines, have been due almost entirely to doubt concerning the reliability of the thrust bearing. The problem of properly taking care of the vertical load on the shaft due to the weight of the revolving parts of vertical units need no longer cause the apprehension which at one time existed. It may be stated that the difficulties which presented themselves until very recently in securing an economical and reliaable thrust bearing had much to do with the delay in the development and general adoption of the vertical turbine. Today there are, however, at least two types of bearings of demonstrated reliability which are giving satisfactory service in this application.

The old-fashioned pressure thrust bearing, in which oil under high pressure is pumped into an annular chamber between a revolving disk and a stationary disk, was used almost exclusively in large units until about five years ago, when it was generally superseded by the roller bearing or a combination of the roller and pressure bearings.

During the past two years the Kingsbury type of bearing has come into general use and has given eminently satisfactory results through a wide range of conditions. The roller type of bearing has also a number of important advantages and has given entire satisfaction in a number of notable installations.

### Pressure Thrust Bearing

In comparing the various types of bearings, it may be stated that the pressure thrust bearing when taken in connection with the necessary pumps and auxiliaries is the most expensive type both with respect to first cost and maintenance, and also in waste of power. An excessive dropping off of pressure or a momentary failure of the oil supply to the bearing will result in its immediate destruction.

When most successfully used, the oil pressure type of bearing has been operated on the principle of an oil supply of constant quantity. The portion of the thrust bearing load which is due to the hydraulic thrust of the turbine runner increases with the gate opening of the turbine, thus requiring an increase of pressure in the thrust bearing corresponding to the increase of load. As the pressure increases it is essential that the quantity of oil supplied to the bearing shall not be diminished, and this can be best accomplished by means of a positive displacement type of pump such as a triplex plunger pump geared directly to the turbine shaft. In starting up, a motor-driven pump supplies the oil until the unit has been brought up to speed, after which the geared pump is thrown in.

The interconnection of the thrust bearing and governor systems by the use of one set of pumps for both, is dangerous practice, as is also the supplying of the bearings of the various units in the station from a single pressure main. When the governor system is interconnected with the thrust bearings, since there is no connection between the demand on the pump by the governor and the amount of oil required by the thrust bearing, any increase in the load on the thrust bearing may result in a drop in the quantity of oil supplied to the bearing, oil being diverted to the governor system in the line of least resistance. This action need not be carried very far to cause the failure of the bearing.

Centrifugal pumps would be unfitted for use when applied to thrust bearing service, since it is characteristic of most centrifugal pumps that the discharge falls off as the pressure increases.

In some instances where the governor and thrust bearing systems have been interconnected, the attempted solution of the problem was by means of providing a pressure far in excess of that required for normal conditions in either systems, the idea being that even should the governor tend to rob the thrust bearing of its proper share of the oil, the resultant drop in pressure will still be insufficient to reduce the thrust bearing pressure to an unsafe value. This method has many objections, among which are the difficulty of calculating what the demand of the governor will be under abnormal conditions, and trouble with the oil due to its partial breaking down under the high pressure required. High oil pressures in governor systems have been definitely abandoned by engineers having experience in these lines.

The provision of an accumulator in the thrust bearing system in an attempt to create a steady supply to the bearing is not considered good practice, since the cushioning effect in the accumulator is opposed to the above principle of constant quantity supplied to the bearing. The inertia effect of the column of water in the draft tube of the turbine accompanying sudden changes of load on the unit may be such as to cause extremely sudden changes in the hydraulic thrust which must be safely carried by the thrust bearing. Augmenting surges of the water column in the draft tube, due to hunting of the turbine governor, have in some instances become so severe as to lift the thrust bearing disk off its seat, thus relieving the pressure and destroying all means of support. If the supply to the bearing can be cushioned by compressed air in an accumulator tank, there is danger of the thrust disks coming together and burning out under such conditions.

Most of the failures which have taken place in pressure bearings can be attributed to some condition in the pressure system which results in a variation in the rate of oil supply to the bearing. In brief, therefore, the pressure thrust bearing requires a separate pump for each unit and each pump of the positive displacement type, giving constant oil quantity with pressure varying automatically to suit the thrust.

In view of the great importance, in the present development of the vertical shaft hydraulic turbine, of the question of the life and satisfactory operation of the thrust bearing, some data have been collected relating to this subject which the writer believes will be of interest to engineers in charge of new developments.

The following discussion of two types of bearing, viz., the roller thrust bearing and the Kingsbury bearing, are not intended to constitute a comparison of the two bearings except in certain details, and the writer wishes to avoid giving the impression that either bearing can at this time be said to be superior to the other for all conditions of service. While it is felt that both bearings have been in operation sufficiently long and under sufficiently severe conditions to demonstrate that they will do the work satisfactorily, the point has not been reached, if it ever will be, where either bearing can be accepted under all conditions as superior to the other.

### Roller Bearing

The roller bearing was introduced somewhat in advance of the Kingsbury bearing, and the writer is able to give data on some of these bearings which have been in operation for periods as long as ten years. In the application of these bearings to large hydraulic units, the Standard Roller Bearing Company has accomplished excellent work, and the data stated below was furnished by the above company, and also by the engineers of developments in which the bearings have been used.

Table I gives some of the installations, particularly in the hydro-electric field, in which the roller bearing has been successfully employed.

There are a number of points of interest which may be mentioned in connection with this bearing. A distinct point in favor of the roller type of bearing is the fact, which is borne out by many experiences during operation, that even should the bearing be injured by defects in the rollers or tread plates, the bearing will still operate over long periods of time even in the defective condition without allowing the rotating parts to drop from their position of alignment.

One of the first installations in which the roller bearing was used for large hydroelectric units was their application at the McCall Ferry plant of the Pennsylvania Water & Power Company. The forgings required for the tread plates of these bearings were 53 inches in diameter, which exceeded the capacity of any crucible steel mill in the country at that time. The use of open hearth steel led to defective plates in several instances, these defects occurring chiefly in the hardened surfaces of the plates, which developed a spalling of the surface after several months of service. This action was believed to be due to fatigue of the carbonized layer on the surface of the plate under the stresses produced by the rollers. The valuable property of these bearings previously noted is well shown in this case. In one instance a roller bearing in which spalling had commenced was kept in continuous operation day and night without intermission for five weeks after the breakdown commenced without the necessity of removing the unit from service. The Standard Roller Bearing Company advises that they are now able to obtain crucible steel plates which make their bearing available for even the largest units.

It is believed that the minor difficulties which developed in first starting up these bearings in the Keokuk plant were due largely to the use of a combination of the roller and pressure bearings, which combination appeared to introduce complications in the operation of the roller bearing. The small clearances used in the internal seal of the pressure element were entirely closed up when the bearing was operating as a roller bearing, due to the rise in temperature, thus preventing proper circulation of the oil. The bottling up of the oil at the inner rollers evidently caused local heating, which resulted in an unequal distribution of the load carried by the rollers. The Standard Roller Bearing Company advises that these difficulties have been overcome by modifying the clearances in the internal seal of the pressure element.

The purpose of the combination bearing is, of course, to furnish an alternative method of carrying the load, as a provision against failure of either type. At the time the Keokuk bearings were installed, some doubt was felt as to the reliability of the roller bearings under such unusual and severe conditions, so that it was intended to operate the units normally with the pressure bearing in service, the rollers being intended to carry the load in the event of a failure of the supply of pressure oil. This solution, of course, involved all the objections accompanying the large amount of auxiliary machinery required, as well as the complication of the bearing itself.

Regarding the life of very large roller bearings, it may be said that in one of the early units installed in the McCall Ferry plant the bearing had been in continuous satisfactory service for over three years at the time the plates were reversed; and after a similar period the use may be continued by a slight regrinding of the plates. The bearings more recently installed, which are equipped with crucible steel plates, have not as yet been in operation sufficiently long to develop any definite data regarding wear, but are giving excellent satisfaction, and it is felt that with the crucible steel plates these bearings should give as satisfactory service as secured in the smaller bearings made of like materials.

Dismantling, complete examination and replacing of the roller bearing of a size similar to those at McCall Ferry requires from six to nine hours, the primary erection requiring ten hours. The Kingsbury bearing requires from twenty-four to forty-eight hours for initial erection and from nine to eleven hours for dismantling and replacement.

It is characteristic of the roller bearing that a bearing designed for a certain speed and load will run even more satisfactorily at lower speeds and is less suited to prolonged operation at higher speeds. The Kingsbury bearing on the other hand operates even better at high speeds than under normal conditions, but sometimes develops trouble if run too long at an extremely low speed. Thus, any trouble which may develop in these bearings is likely to appear in the roller bearings at runaway speed of the unit and in the Kingsbury bearing when starting or stopping the unit.

It may be of interest to note that the roller bearing plates used in some of the large hydroelectric units require nearly 100 crucibles to pour an ingot from which can be made only one bearing plate. The subsequent treatments are the cleaning of the ingot, forging under 1000 ton hydraulic press, annealing to relieve forging stresses, machining to proper dimensions, hardening, heat treating and grinding. The special steel now used is claimed to be of even finer quality than that used in the manufacture of the higher grade of cutlery.

### Kingsbury Bearing

Referring again to the McCall Ferry plant of the Pennsylvania Water & Power Company, which seems to furnish the best experience in actual service of large thrust bearings, the writer has been advised by Mr. J. A. Walls, Chief Engineer, that the plant now contains roller bearings on Units Nos. 3, 4 and 7 and exciter No. 1, and Kingsbury bearings on Units Nos. 1, 2, 5 and 6 and exciter No. 3. A satisfactory experience from the roller bearings has been noted above. Mr Walls states that the operation of all the Kingsbury bearings has been entirely satisfactory. The first Kingsbury bearing was put into service about two years ago, and frequent examina-

## TABLE I—STANDARD ROLLER BEARINGS

| Installation | Location | Number of Bearings in Service | Length of Service to Date | Total Load Pounds | Normal Speed R.P.M. |
|---|---|---|---|---|---|
| Niagara Falls Pwr. Co. | Niagara Falls, N. Y. | 11 | 1 to 10 yr. | 150,000 | 250 |
| Schenectady Pwr. Co. | Schaghticoke, N. Y. | 4 | 6 yr. | 45,000 | 300 |
| Edison Sault Ste. Marie Elect. Co. | Sault Ste. Marie, Mich | several | 8 yr. | 60,000 | 100 |
| Irrigation Project (Centrifugal Pumps) | Minidoka, Idaho | 15 | 8 yr. | 25,000 | 300 |
| Commonwealth-Edison Co. | Chicago, Ill., Substa. | several | 6 or 7 yr. | 67,000 | 300 |
| Commonwealth-Edison Co. | Quarry St. Substation | 1 | 6 or 7 yr. | 367,000 | 300 |
| North Carolina Elect'l Pwr. Co. | Asheville, N. C. | 2 | 2 yr. | 100,000 | 133 |
| Appalachian Pwr. Co. | New River, Va. | 7 | 1½ yr. | 100,000 | 97 and 116 |
| East Creek Electric Light & Pwr. Co. | New York State | several | | 70,000 | 300 |
| Pennsylvania Wtr. & Pwr. Co. | Holtwood, Pa. | 1 | 4 yr. | 43,000 | 285 |
| Pennsylvania Wtr. & Pwr. Co. | Holtwood, Pa. | 2 | 1 to 3 yr. | 410,000 | 94 |
| Pennsylvania Wtr. & Pwr. Co. | Holtwood, Pa. | 1 | | 350,000 | 116 |
| Mississippi River Pwr. Co. | Keokuk, Iowa | 11 | | 550,000 | 57.7 |
| Canadian Niagara Pwr. Co. | Niagara Falls, Can. | 4 | 1 to 10 yr. | 187,000 | 250 |

## TABLE II—KINGSBURY BEARINGS, MARCH 1914

| Installation | Location | Number of Bearings in Service | Additional Bearings Built or on Order | Diam. Inches | Load Pounds | Pressure Pounds per Sq. In. | Normal Speed R.P.M. |
|---|---|---|---|---|---|---|---|
| Pressed Prism Plate Glass Co. | Morgantown, W. Va. | 1 | | 18 | 160,000 | 920 | 35 |
| Jones & Laughlin Co. | Pittsburgh, Pa. | 1 | | 36 | 66,000 | 100 | 70 |
| Pennsylvania Wtr. & Pwr. Co. | Holtwood, Pa. | 4 | | 48 | 410,000 | 350 | 94 to 116 |
| Pennsylvania Wtr. & Pwr. Co. | Holtwood, Pa. | 1 | | 20 | 70,000 | 350 | 285 |
| Mississippi River Pwr. Co. | Keokuk, Iowa | 4 | 1 | 56 | 560,000 | 350 | 57.7 |
| Great Northern Pwr. Co. | Fond du Lac, Minn. | 1 | 2 | 29½ | 120,000 | 350 | 375 |
| Great Northern Pwr. Co. | Fond du Lac, Minn. | | 1 | 29 | 147,000 | 350 | 375 |
| Utah Pwr. & Lt. Co. | Alexander, Idaho | 2 | | 29 | 155,000 | 370 | 514 |
| Calgary Pwr. Co. | Calgary, Alberta | 2 | | 29 | 130,000 | 310 | 150 |
| St. Lawrence River Pwr. Co. | Massena, New York | | 5 | 36 | 250,000 | 385 | 100 |
| Cedars Rapids Mfg. & Pwr. Co. | Cedars, Prov. of Que. | | 9 | 61 | 550,000 | 350 | 55.6 |
| Georgia-Carolina Pwr. Co. Stevens Creek Plant | Augusta, Ga. | 2 | 3 | 28 | 111,000 | 280 | 75 |
| Alabama Pwr. Co. | Birmingham, Ala. | | 4 | 42 | 324,000 | 370 | 100 |
| Idaho Rwy., Lt. & Pwr. Co. | Snake River, Idaho | 2 | | 21 | 66,000 | 300 | 90 |
| Laurentide Co., Ltd. | Grand Mere, Prov. of Que. | | 6 | 42 | 330,000 | 375 | 120 |
| Salt River Valley Water Users Association | Idaho | 6 | | 18 | 42,000 | 270 | 94 |

tions have indicated that the wear is so small as to be negligible and the life of the bearing, excluding accidents, is estimated by Mr. Walls at over 25 years without re-babbitting the bearing shoes.

In the Kingsbury bearings installed at Keokuk, trouble was experienced in some of the first bearings put into operation, due to a "wiping" of the babbitt at the instant of starting the unit from rest. In the few cases where wiping has developed, it has been due either to lack of proper finish of the rubbing faces of the collar or to the presence of air in the oil. It is important that the oil supply to the Kingsbury bearing is received from a lubricating system free from any disturbances which might otherwise result in the carrying of air to the bearing; also that the bearing itself should be submerged to such an extent that the rotating elements of the bearing will not force the oil away from the bearing shoes sufficiently to allow air to reach the babbitted faces, and it is equally important that the rotating element presents a smooth surface to the oil, as otherwise any churning of the oil would result in an admixture of air and oil. It is appreciated that the presence of air in the film of oil on the babbitted faces prevents proper lubrication and results in the wiping of the babbitt. Such troubles as were experienced during the early operation of the Kingsbury bearings at Keokuk have disappeared so that all of the bearings have now been in operation for eight months or more without giving trouble.

Table II is a list of the important installations of the Kingsbury bearing in connection with hydro-electric plants.

It should be mentioned that both the roller and Kingsbury bearings have had many applications in other fields of service which are not covered here. The roller bearing has been used in many electrical applications, such as in rotary converters and synchronous condensers involving heavy loads, and the Kingsbury bearing has been operated under severe conditions on steam turbines.

Mr. Kingsbury states that the first bearing installed at the McCall Ferry plant was inspected after fourteen months service, during which period it had been stopped and started about two hundred times, and it was found that the wear of the babbitt had not been sufficient to remove the scraper marks made in fitting. The procedure at McCall Ferry in starting a unit equipped with Kingsbury bearings is to allow fifteen minutes for the cooling of the bearing after a shutdown before re-starting the unit, except in case of emergency; and in stopping the unit it must be quickly shut down by the use of the brakes assisted by the generator field. Slight improvements in the details of the Kingsbury bearing which have been made recently would indicate that even these precautions are no longer necessary.

As indicating the high mechanical efficiency of both the above types of bearings, tests show that the total friction loss in one of the Kingsbury bearings at McCall Ferry amounts to from 7½ to 10 kilowatts, with approximately the same low loss in the case of the roller bearings, so that either type of bearing involves a loss well below one-tenth of one per cent of the power of the unit. When it is considered that the guide bearings of the vertical units have a very light lateral load to carry, it will be realized that the mechanical efficiency of large hydraulic units installed in place approaches closely to 100 per cent.

Some tests on the temperature rise in Kingsbury bearings at McCall Ferry result in the following data: Temperature rise for normal or higher speeds with initial temperature of 30 to 35 deg. C., amounted to about 2.3 deg. C. for a twenty-minute run with no supply of fresh oil. At 20 r.p.m. (normal speed 116 r.p.m.) with an oil supply of the normal amount of fifteen gallons per minute, the oil temperature rise was about 1.5 deg. C. for a test of one hour's duration. On tests in which the speed was slowly raised from an initial speed of 3 to 5 revolutions per minute to a final speed of 18 r.p.m., during a run of two minutes duration, no trouble was experienced in a number of repetitions of this test. Either the roller or Kingsbury bearing will operate for a long period of time even when the oil supply is cut off.

An interesting combination of the two types of bearing will be installed in the plant now under construction at Cedars Rapids, Canada, in which the thrust of each unit is carried normally by a Kingsbury bearing. A roller bearing of reduced dimensions is placed within the Kingsbury bearing, but is allowed normally to remain out of action by the provision of a slight clearance. Should any wiping action take place in the Kingsbury bearing, the rotating parts would then settle a slight distance and the load be transferred to the roller bearing. While the roller bearing is not sufficiently large to carry the load indefinitely, it is designed to be of sufficient capacity to operate long enough for the station operators to prepare for a shutdown of the unit, thus providing a safeguard against any injury to the turbine.

**Guide Bearing**

During the past two years, the lignum vitae guide bearing has come into general use with vertical turbines for both low and high head installations. The bearing now used must be distinguished from the old-fashioned lignum vitae guide bearing commonly employed years ago. The older bearing consisted of three large lignum vitae blocks evenly spaced around the circumference of the shaft, each block being equipped with adjusting screws for taking up the wear. This design presented a small amount of bearing area to the shaft, a portion of each block immediately in line with the adjusting screw taking most of the load. The load on the bearing was, therefore, concentrated at the centers of the blocks, resulting in rapid wear and making frequent adjustment and renewal necessary.

The bearing now used is so designed as to present a somewhat greater amount of projected area to the shaft than first class practice would call for in the case of a babbitted bearing. The lignum vitae is dovetailed into the bearing boxes in the form of strips running parallel to the axis of the shaft and with the end grain of the wood placed normally to the surface of the shaft. Twenty or more of these strips, evenly spaced in a liberal length and separated by spaces for the circulation of cooling water, are so proportioned as to present sufficient area to the shaft to insure very satisfactory performance. The resulting bearing pressure per square inch may be made so light as to eliminate the provision of any adjustment for taking up the slight amount of wear which may take place. Bearings of this design have been uniformly applied to the stern tubes of propeller shafts in marine practice, and have been frequently used for turbines of the open flume or submerged type. They have not until recently been generally applied to cases where the bearings are not submerged. Present practice, however, is to use this type of bearing in connection with all vertical turbines, and provision is made to pipe clear water to the bearings in the same manner as oil is brought to the babbitt type. An examination of bearings of the lignum vitae type in connection with large vertical open flume turbines, after continuous operation for a year without shutdown, has shown that practically no wear has taken place and it is quite possible that for a considerable period of time the wood will swell rapidly enough to compensate for the very slight wear which takes place.

In the case of turbines operated in clear water, the supply for the bearing may be taken through a pipe directly from the wheel-casing. A duplex strainer is connected in the line to remove any foreign substances which might otherwise reach the bearing and damage it. In installations in which the water carries large quantities of foreign matter in suspension, the power companies arrange a suitable central filtering system from which the filtered water is piped to the bearings of each turbine.

A bronze sleeve is provided on the turbine shaft where it passes through the bearing and stuffing box. This sleeve prevents the trouble which would be caused by the rusting of an unprotected shaft and also prevents injury to the shaft by the accidental presence of foreign bodies in the water. It has the further advantage of being renewable after a long period of service has produced wear either in the portion within the bearing or where it passes through the stuffing box. In some very old units, a considerable reduction of effective area of shaft has been produced by prolonged wear.

The bronze sleeve is usually, and preferably, cast in one piece and forced over the end of the shaft; but in cases where the turbine shaft is provided with a coupling flange at the lower end for the attachment of the runner, the sleeve is made in halves.

The chief advantages secured by the use of the lignum vitae bearing as compared with the ordinary babbitt type of oil bearing which has often been used for a turbine guide bearing, are as follows:

First: The possibility of locating the bearing much closer to the runner, thus avoiding a considerable space by which the runner must be overhung below the bearing when the babbitt bearing is used in order to accommodate an oil shedder, an oil catcher and seal ring.

Second: No pump is required to remove the lubricant from below the bearing, as in the case of an oil bearing, and to pump the oil back into the lubricating system at a higher elevation.

In connection with the first point, the importance of placing the bearing close to the runner, while perhaps not as great as in a horizontal shaft unit, is still considerable. While a runner may be put in almost perfect static balance, there still remains the possibility of a considerable side thrust developing during operation, due to variations in hydraulic conditions around the circumference resulting from inequalities in the areas and angles of the vanes secured in casting the runner. A runner overhung at too great a distance from the bearing is in danger of developing vibrations under some conditions of loading.

The chamber below the lignum vitae bearing is vented through cored passages in the runner hub into the draft tube, and it is into the draft tube that the circulating water from the lignum vitae bearing escapes. Difficulties have been experienced in the operation of babbitted oil bearings located at this point, on account of the difficulty of providing a seal below the oil catcher which will satisfactorily prevent escape of oil into the draft tube and the leakage of water into the oil catcher, both of which actions involve loss or inconvenience. It should also be considered that the necessity for an oil circulating pump required by the babbitt type of bearing and the dependence which must be placed on this pump is an element of weakness, since any interruption to the lubricating system endangers the burning out of the bearing and the shutdown of the unit.

### Mechanical Details

A number of features of the turbine structure and mechanism deserve to be considered, but lack of space prevents their being thoroughly covered. Present practice in the construction of the large single runner vertical turbine with volute casings molded in the concrete, has endorsed the use of a speed ring for supporting the top of the volute casing and the weight of the parts above. The form of speed ring which has been given preference in the best practice is one consisting of an upper and lower ring, or crown, shaped to conform to the volute, connected by heavy vanes cast integrally with the upper and lower crowns. These vanes are shaped to suit the free path of the water entering the guide vanes. This use of the speed ring vanes seems preferable in every way to round staybolts. The large projected area and the poor form of the circular section causes hydraulic losses, and there appears to be a mechanical advantage in the use of a rigid cast iron connection between the upper and lower speed ring crowns without the possibility of deflection involved in the use of separate parts.

The guide vanes of turbines are now almost invariably made of cast steel, with the stems or fulcrum pins cast in one piece with the vanes. In the case of exceptionally high heads where the water carries sand in suspension, bronze guide vanes are sometimes advisable to resist erosion. The vane stem can be cast integrally with the vane in this case also. In exceptionally large units, such as those at Cedars Rapids and Keokuk, the vanes are of cast steel with separate forged steel stems passing through them and keyed to them, in order to permit the removal of separate guide vanes without requiring the dismantling of the remainder of the unit.

Suggestions have been made at various times, and have in a few instances been put into practice, of using forged guide vanes rather than castings. The question is mainly one of expense, and it is believed that vanes conforming closely to the design and shape and having necessary strength can be much more cheaply obtained by casting than by forging.

It has been claimed by some of the builders who have used forged steel guide vanes that these vanes can be made smaller than steel castings, owing to the greater strength of the forging over the casting. If, however, the vane is reduced in size to compensate for the increased strength, then wherein lies the advantage of the forged vane over the cast vane?

The iron runner cast in a single piece is now standard practice for all turbines for low and moderate heads under ordinary conditions. All of the turbines now under construction for Cedars Rapids, and eight of the fifteen installed at Keokuk, have been built in sections rather than in a single casting. This construction has been adopted at Cedars Rapids on account of the additional ease of handling in shipment and erection, and also to provide greater assurance of sound castings being obtained. The possibility of shrinkage stresses existing in very large runners when cast in a single piece, is an important consideration which is met by the division of the runner into four parts.

This construction of runner has, of course, no connection with what is known as the "built-up" runner. The latter term is used to denote a runner containing steel plate vanes held in a separate cast hub and band. In the large runners referred to above, each section containes hub, vanes and band cast in one piece, so that no local weaknesses at the joints between vane and band or vane and hub may develop, and the runner as a whole possesses great strength and rigidity. The sections are held together by a heavy cast steel crown at the top which encloses the sections, and a cast steel ring in one piece which surrounds the band and is joined to the band by a light forcing fit.

### Speed Regulation

Next in importance to efficiency and mechanical reliability, the regulation of the turbine is a factor which requires much consideration. While it is felt that engineers sometimes desire guarantees of unnecessarily close regulation when considering such extreme conditions as full load thrown suddenly on or off a unit, conditions which seldom occur in a plant, and when they do occur it is usually due to a short circuit or a dropping of load under circumstances in which regulation ceases to be a consideration, still it must be granted that proper speed control is of the utmost importance in modern hydro-electric developments.

The problem of speed regulation may be considered in relation to two considerations which may exist in a plant. First, the control of speed during sudden changes in load which occur during normal operation; and second, the control of speed during a period of constant load on the units.

As is now well known, the control of the speed of a turbine during sudden change of load is dependent to a great extent, in fact chiefly, upon the inertia of the rotating parts and the length of and velocities in the closed water conduit supplying the turbine, and including the draft tube taking the water from the turbine. Given a certain length and velocity of water column, and a certain flywheel effect in the revolving parts, a certain necessary speed variation results, which cannot be reduced beyond a certain minimum even by a perfect or ideal governor. The necessary actions which the governor must provide are few and simple, consisting of a movement of the turbine gates in such a manner as to suit any particular change in load which is encountered, and to restore the unit speed only after sufficient time has been allowed for the acceleration or retardation of the water in the water passages.

There has been a tendency on the part of the builders of stock governing apparatus in this country to throw a veil of mystery over the action of the governor, the idea being suggested that the governor follows some complicated mode of action, and in fact it has been said to show "almost human intelligence." As a fact, the governor mechanism consists of a few distinct parts, and may be built to give perfect action without the use of any partitioned devices or any mysterious mechanisms. The failure to explain clearly to engineers who have encountered these problems the theoretical and actual conditions which the problem of regulation involves, has been a feature of the methods of stock governor builders in this country. Insistent demand on the part of engineers in charge of the older power developments, as well as those projected, has forced some stock governor builders to develop a machine embodying a type of construction more in harmony with the large units to be controlled than the governors which were built a number of years ago. It is felt, however, that in the attempt to meet the demanded reliability, as well as the higher capacities required in modern units, the stock governor designers have failed to appreciate the great importance of a simple, substantial, stable machine which will not be subject to accidental derangement during service and which will operate over long periods of time without being continually shut down for repairs or adjustments due to wear.

The second condition enumerated above, viz., the action of the governor during the normal condition of steady load on a plant, is nearly as important as its action during load changes. The defective action of many governors, and this may be seen in many small plants where stock governors are installed as well as in some larger stations, consists not in their failure to move the gates of a turbine when a change in load occurs, but in their failure to hold the gates steady during constant load conditions. The ever-continuing oscillation of the turbine gates which is seen in some units, even though small in amount, is a sign of an unstable governor, and its result is rapid wear of the turbine gate mechanism with resulting looseness of joints and a consequent augmentation of the unnecessary motion.

Another frequent cause of failure to conform to the second requirement is the susceptibility of the stock governor, which is almost invariably of extremely light and delicate construction, to accidental conditions such as the presence of grit or waste carried by the oil entering the governor valve, or slight changes in the friction of the parts. The writer believes that the best practice demands the installation in connection with large and important units, of governors specially constructed by the maker of the turbine to suit the exact conditions of the installation; that these governors should be of a capacity corresponding to the size of the unit to be controlled, and that all of the governor parts should have strength and rigidity in harmony with the turbine itself.

It may be particularly noticed that some stock governors have been installed with a number of very large units where the centrifugal governor head, which is the element on which all other actions of the governor depend, has been made of the lightest and most delicate construction, sufficient power to move the turbine gates being obtained through a series of pilot and relay valves. The writer believes this construction to be inconsistent with reliability and continuity of service, and contends that the centrifugal governor head should be designed to have an amount of power consistent with the unit which it must control. In the effort to make the governor conform to the character of the turbine design, some governor makers have completely enclosed the governor in a box or casing. This design provides an apparent simplicity to external view, but does not affect the delicacy and complication of the mechanism contained within, and in fact greatly hinders the accessibility of the parts and prevents proper attention being given to the operation of the apparatus.

### Conclusion

Summing up the points brought out in the foregoing discussion, it will be seen that the trend of recent development has been, in almost every particular, in the direction of increased simplicity of the turbine itself and of the accompanying accessories.

Efficiencies have been increased to a high figure even with the high specific speeds used in American practice, and the high efficiencies obtained at Holyoke have been exceeded in large units under operating conditions after installation. The increase of efficiency due to an increased size of unit and increased power under high heads which was expected from theoretical considerations has been verified in actual tests, where the efficiencies obtained at Holyoke in small wheels under low heads have been exceeded in large wheels of homologous design, tested in place.

In the design of the turbines themselves, unnecessary parts have been eliminated and improvements in the arrangement and details of the apparatus have been developed. The large amount of auxiliary machinery installed in some of the older plants has been greatly reduced in recent installations, this change permitting great economies in plant operation and in the cost of maintenance and repairs. In some of the older plants, the equipping of each unit with a separate thrust bearing pump, separate governor pump and individual system of piping, together with the interconnection of the necessary spare pumps, caused a great complication in the apparatus which is now overcome by the use of Kingsbury or roller bearings supplied by the common gravity lubricating system connected to all units, and a central pumping system to supply the governors of all units.

All of the above factors are contributing to the success of a number of notable installations which have been made in the last few years, a success which the writer believes reflects much credit on American engineers.

# MODERN TANGENTIAL WATERWHEEL PRACTICE

By Heinrich Homberger

The Pelton Waterwheel Company

Although there have been may improvements and great changes in the design of tangential waterwheels, the basic principles are the same as those of the old hurdy-gurdy of the California miner. The electric generator has given the waterwheel its present characteristics. The author gives a great deal of interesting detail on the construction and improvement in the tangential waterwheel, such as the number and type of wheels and nozzles, the manner of fastening the buckets to the disks, the construction of the housing, speed regulating devices, and the means of securing good water economy.—Editor.

**Heinrich Homberger**

IN recent years the development of the high head hydraulic prime mover, known as the tangential or impulse waterwheel, has manifested itself primarily in two directions:

(1) Increase in the size or output of the individual unit.

(2) Economy in water consumption.

The Pacific Coast, which has been the cradle of this type of machine, still maintains its position as principal user of high head waterwheels, since the precipitous mountain chains of the Sierra Nevada and Cascades afford more opportunities for economical high head power plants than any other region of the United States.

From the simple wooden hurdy-gurdy of the early California miner, the tangential waterwheel has developed into a powerful and rather complex machine, although still maintaining its original elements and also its simplicity in operation.

The basic principle of a disk shaped wheel, upon the periphery of which are mounted a number of individual buckets or cups upon which a free jet of water issuing from a nozzle impinges, has not been changed. There have been a number of modifications to suit special conditions, such as double or multiple nozzles applied on one wheel and also more than one wheel mounted upon the shaft of one single waterwheel unit.

Electric power transmission has made it possible and profitable to develop water power hundreds of miles from the point of power consumption and the requirements of the electric generator have given the characteristics to the modern tangential waterwheel. The electric generator and waterwheel are direct connected almost always, the methods used for the connection of the two being dependent largely upon the ratio of head, horse power and speed. The three principal types of construction most favored in modern hydraulic practice are the single overhung type, double overhung type and the complete iron-mounted type; and these with their various modifications practically meet all requirements.

Where conditions are such that all the power required can be developed on a single wheel, the single overhung type of construction is generally used. In this type, the generator shaft is carried on two main bearings only, and the waterwheel mounted on the overhung extension of the generator shaft. Two methods of fastening the waterwheel to the generator shaft are used. If the conditions are such that the centrifugal stresses are not too great, the waterwheel is bolted to a coupling which is forged on the generator shaft. For conditions in which this construction is not permissible, the generator shaft is made parallel, key-seated, and the waterwheel pressed on. The objection to this second method is the difficulty of pressing the waterwheel on the generator shaft in the field, although in certain instances this is unavoidable.

In some cases, where all the power required cannot be developed on a single wheel with one stream, the single overhung type wheel is used and equipped with a duplex, or double nozzle, by which means the power output of the one waterwheel runner is practically doubled. This results in a very compact unit with only two bearings and short, reliable governor connections. The general popularity of this type of installation has led the electrical manufacturers to develop a standard line of generators which are specially adapted to the single overhung construction of waterwheel units and which are known as the "waterwheel" type.

Where sufficient power cannot be developed on one wheel, the double overhung type of construction is adaptable. This is exactly like the single overhung type in principle, excepting that both ends of the generator shaft extend beyond the bearings and a waterwheel is mounted on each end. This is the ideal type of construction for large units and there are in operation in California individual units of this type continuously developing as much as 20,000 horse power. In the installation of large double overhung units, where the waterwheel runners are necessarily very massive, weighing frequently 12 tons or more, the duty of the bearings often makes special construction necessary; and owing to the waterwheel engineering problems involved, in many cases it is advisable that the waterwheel manufacturers furnish the generator shaft and bearings as a part of their contract.

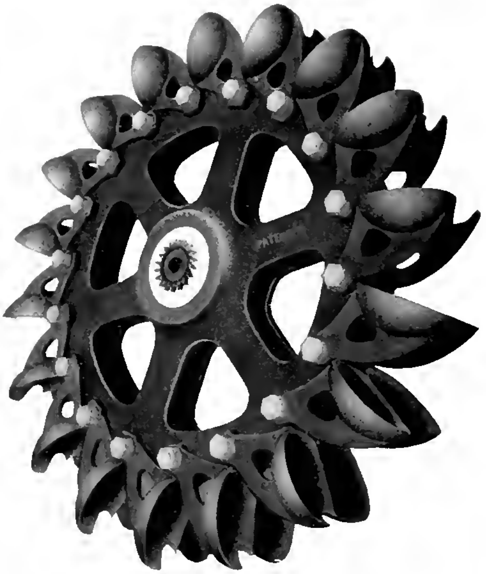


Fig. 1. Pelton-Doble Tangential Waterwheel Runner, equipped with patent interlocking chain type buckets. Diameter 152 in.; weight, 14 tons

The duplex nozzle is also used in conjunction with the double overhung type unit, thus permitting the capacity under a given set of conditions to be practically doubled.

The complete or self-contained type of waterwheel, with its own shaft, bearings, bedplate and housing, independent of the generator, is extensively used and meets many conditions not suitable for either the single or double overhung types. With this type two or more wheels can be mounted upon the same shaft and in the same housing. Water can be supplied to the wheels through nozzles of either the single or duplex type, thus permitting the development of large power outputs at medium heads and speeds suitable for direct connection to the electrical generators. For example, single units of this type are in operation developing as much as 10,500 horse power at 390 feet head.

As many of the most marked improvements in modern waterwheel practice concern the individual parts which go to make up the complete unit, a few of the most important will no doubt be of interest to the reader.

In the past, considerable difficulty was encountered in the fastening of the buckets to the wheel disk, particularly when a large bucket had to be used on a comparatively small diameter wheel. The room available for the fastening lugs in such cases is very scant and it is impossible to place in it two bolts of sufficient size to take care of the stresses with adequate safety. This fact often limited the diameter and in consequence the speed for which an impulse wheel could be designed for satisfactory operation under given conditions.

A great step forward was made by the invention of the "interlocking chain type" buckets, wherein the number of fastening bolts is equal to the number of buckets. As shown in the illustration, Fig. 1, this type of bucket fastening is made by building the runner of two separate disks, the hubs of these abutting each other and in this manner maintaining the correct

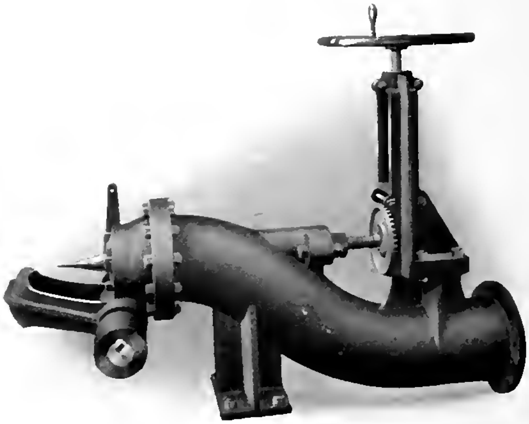


Fig. 2. Pelton-Doble Hand-Operated Needle Nozzle of the Reverse Vertical Curve Type, with balanced stream deflector for speed control

distance between the wheel rims when the wheels are pressed to place upon the shaft. Each bucket is fastened by one central and two outside lugs; the outside lugs being at the rear when the wheel is viewed in the direction of the issuing water jet and the central lug being in front, extending somewhat beyond the face of the bucket. The front lugs of the buckets are placed between the rims of the two wheel disks, while the rear lugs straddle the outside of the two rims; so that when completely assembled, the front lug of each bucket is exactly in line with the rear lugs of the preceding bucket, thus causing each fastening bolt to pass through both rear lugs of one bucket, the two wheel rims and the central or forward lug of the bucket next following it. In other words, the buckets themselves if detached from the wheel and bolted together would form a continuous chain, from which the name "interlocking chain type" has been derived. The particular advantage of this type of construction lies in the fact that larger bolts may be used than with the ordinary type of bucket fastening and the distance between two bolts is much greater than would be permissible if independent buckets, each provided with two fastening bolts, were used, as is the case with the familiar design of bucket fastening. With the arrangement of the interlocking chain type buckets, the stress resulting from centrifugal force is applied approximately midway between the two bolts and is distributed equally on the two bolts when the jet is full off the buckets; and when the jet is full on, the stress will be nearly uniform on the two bolts on account of the greater bolt spacing. With this form of construction, the nuts of the holding bolts are readily accessible for wrenches, and what is more important, this particular type of design admits of a higher speed for a given power output than is possible with other methods of bucket fastening.

Fig. 3. Excellent example showing application and method of governor and hand control connection for double overhung type Pelton-Doble auxiliary relief needle regulating nozzles

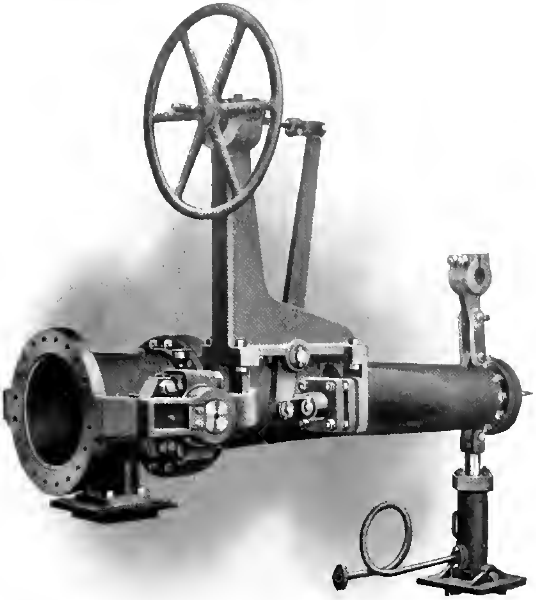


Fig. 4. Pelton-Doble Deflecting Nozzle with Hydraulic Counterbalance and Hand-Operated Needle

It may be of interest to state that on large wheels the fastening bolts securing the buckets to the wheel disks are very simply placed in position or removed with a special portable hydraulic press.

But few material changes have been made in the design of waterwheel housings during the past few years, excepting in some special types of installations. The standard construction of housings for single nozzle wheels still embodies the riveted sheet steel upper part and cast iron lower. The sheet steel upper housing is heavily re-inforced and is riveted to a cast flange which is in turn fastened to the lower housing with cap screws.

The lower housing in many instances also acts as a baseplate, being suitably constructed for this purpose and having a wide base and cast ribs for imbedding in the concrete foundation. The base of the lower housing contains a drip trough which is connected directly to the tail race for the purpose of carrying off condensation water. In many cases the requirements of the waterwheel design are such that the cast lower section of the housing is carried up to the center line of shaft.

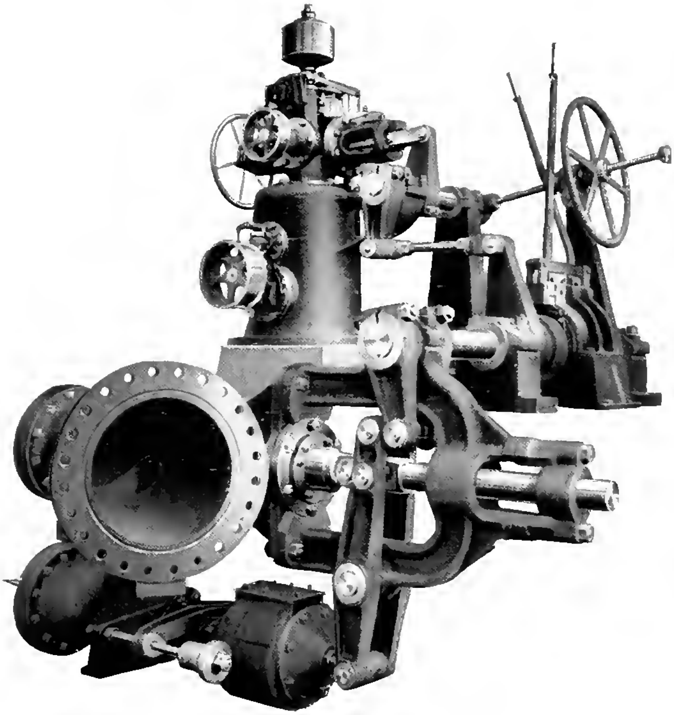


Fig. 5. View showing Pelton-Doble auxiliary relief needle regulating nozzle, with governor and auxiliary hand controls, as applied to a single overhung wheel unit

For wheels equipped with duplex nozzles, the entire housing is usually made of cast iron in order to provide a rigid support for the upper nozzles. Such housings are usually made in three parts to facilitate the removal of one part for inspection and repairs.

Marked improvements have been made in the methods of preventing water leakage where the shaft enters the housing, the present types accomplishing this without any metal to metal contact between rotating and stationary parts and without the use of any packing, thus making the device frictionless.

Excellent speed regulation of waterwheels is an accomplished fact today, as the waterwheel manufacturers have made rapid strides in governor design, which makes it possible to satisfactorily meet the strictest requirements. Good speed regulation requires a means of quickly and efficiently changing the quantity of water impinging upon the waterwheel buckets to conform with sudden load changes. This is accomplished in a number of ways. The oldest form of nozzle is of the deflecting type, consisting of a swinging pipe, pivoted upon a stationary spherical or ball shaped surface known as a ball joint. The swinging part of the device is connected to the power cylinder of the speed governor, by means of which it is lowered in order to have the jet of water miss the buckets and pass out freely into the tailrace in undiminished quantity, until an increase in load causes the governor to raise the nozzle again to a position where the jet partially or completely is received by the buckets.

Other devices for regulation are cut-off hood and jet deflector. Both are placed in front of a fixed nozzle and swing on fulcrums, in order to intercept the jet of water. The cut-off hood is made in such a way that it fits the tip of the nozzle with a spherical surface and is supposed to close it entirely in case of full load going off. The high velocity of

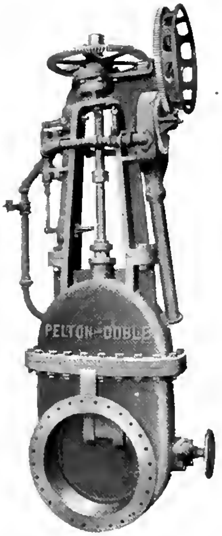


Fig. 6. Modern construction of reversible water motor operated high pressure gate valve with auxiliary hand control

the issuing water, however, causes the cut-off hood surfaces to wear rather rapidly and the desired feature of complete closure does not last long. The jet deflector, of which there are a number of different forms, is placed freely in front of the nozzle tip and regulates the speed by intercepting or deflecting the stream. Economy in water consumption is not expected with the deflector and not obtainable with the cut-off hood for any length of time, on account of the above mentioned rapid wear and water leakage. Of the two devices, the jet deflector is the better and in its improved form is still largely used in modern installations where economy of water consumption is not desired.

The Pelton-Doble deflector is a further development, consisting of a circular ring with renewable liner which is swung in front of the fixed nozzle with the stream continuously passing through it. This has the advantage of only deflecting the stream sufficiently to miss the buckets and discharging it directly into the tailrace in the line of water flow. Moreover, the removable liner may be easily replaced when worn out.

The first device which permitted any economy in water consumption was the needle regulating nozzle, perfected and patented by Wm. A. Doble, now chief engineer of the Pelton Water Wheel Company. This nozzle was equipped with a conical co-axial core-piece, movable in the axis of the jet. It issued an annular jet which, owing to the form of the needle point protruding outside the nozzle tip, closed itself into a solid cylindrical stream immediately in front of the nozzle. A screw spindle, with or without gearing or similar device, was provided to change the position of the needle. This spindle was usually either operated by hand or by an electric motor.

The combination of the needle with the deflecting nozzle or the fixed nozzle with the deflector permits considerable saving of water, but the degree of economy is entirely dependent upon the power plant operator.

The necessity of making the water economy automatic and the water consumption absolutely proportional to the load carried by the wheel became more and more desirable as the number and capacity of the plants increased. Consequently, seasonal storage of water was found necessary. To operate the needle nozzle directly by the governor seemed natural and simple enough; but high head power plants with necessarily long pipe lines and large quantities of water moving at high velocities now possess characteristics making it impossible to quickly stop the flow of water in the pipe, since this would increase the water pressure to such a point as to endanger the pipe material; and, even where such danger does not exist, pressure fluctuations would be set up in the pipe line which would make satisfactory regulation absolutely impossible. It was therefore necessary to provide a means by which, in case of a drop of load, the water could be cut off from the wheel instantly, but the rate of flow in the pipe line reduced at a lesser speed, permitting the moving column of water to adjust itself to the changed condition of velocity of flow without undue pressure rise.

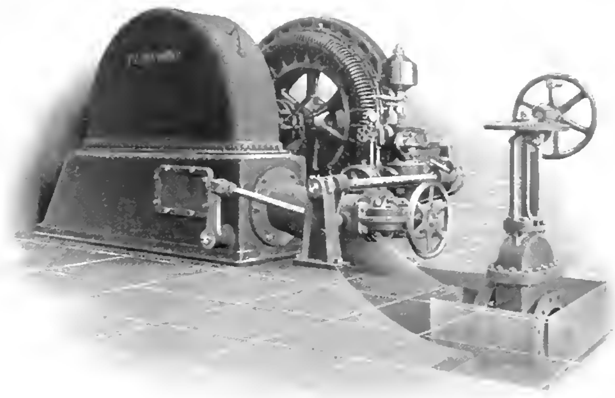


Fig. 7 Example of Single Overhung Type Construction, direct connected to an engine type alternator with belt-driven exciter. The hand-operated needle nozzle and connections for stream deflector speed control by oil pressure governor are clearly shown

This was successfully accomplished by the introduction of the synchronous by-pass or auxiliary relief nozzle in conjunction with the needle nozzle. This was first brought out by the Abner Doble Company and covered by a number of patents which have since become the property of the Pelton Water Wheel Company. The basic feature of this device is the combination of a main or power needle nozzle which furnishes water to the wheel and a branch or auxiliary relief needle nozzle discharging into the tailrace. Both nozzles are operated by the power mechanism of the speed governor simultaneously, but in opposite directions. The auxiliary nozzle opens when the power nozzle closes and vice versa, the volumetric relationship between the two being adjustable, according to the conditions at the plant. This in itself would prevent any pressure rise in the pipe conduit, but would not afford any economy in water consumption. In order to save water, it is necessary to keep the auxiliary relief nozzle closed during a partial and slow motion of the main needle and also to have it close at a safe rate of speed after it has been opened. This result is accomplished by a cataract cylinder which is inserted in the operating gear of the auxiliary relief needle. A description of this device may prove of interest.

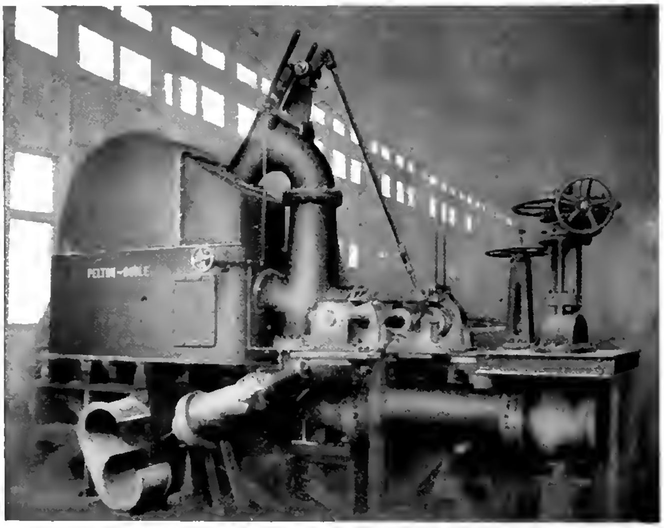


Fig. 8. Pelton-Doble Single Overhung Type Tangential Waterwheel Unit of the auxiliary relief needle regulating type, with duplex power nozzles. The Ensign Patent vortex baffle is also shown in position to receive the stream discharge from the auxiliary relief nozzle

The auxiliary needle is designed in such a way that the hydraulic pressure has the tendency to keep it closed. A cataract cylinder is connected to the auxiliary needle by means of a pin, in which cylinder moves a piston. This piston is connected to the lower arm of a lever, the upper arm of which is connected to the main needle. The cataract cylinder communicates with an oil chamber through a port and adjustable valves. The piston is provided with valve openings which permit the oil to pass from one side to the other in one direction only. When the power needle is opening, the lower end of the lever moves forward in the direction of the issuing jet, pushing the piston forward in the cylinder. The pressure of the oil in front of the piston opens the valve and the oil passes through the piston to the rear. Thus the forward movement of the piston is not impeded.

When the power needle closes, the lower end of the lever pulls the pistons back, forcing oil through the valves and into the oil chamber. The valves are adjustable to permit the oil to pass freely until the piston itself covers the valve openings. In this way, during partial closing of the power needle, the auxiliary relief needle does not come into action. If, however, the main needle continues closing, oil can escape from behind the piston only through a small adjustable pin valve. The rate of oil flow through this pin valve is too slow to permit the piston to continue moving within the cylinder, the oil forming a practically rigid and incompressible connection between the two, causing them to move together to open the auxiliary relief needle. There is now a stream of water running to waste from the auxiliary relief nozzle but, as mentioned above, the hydraulic pressure tends to close the auxiliary relief needle at a rate of speed which is adjustable by means of a small valve. If the rate of speed with which the power needle closes is sufficiently slow to permit all the oil in back of the piston to pass through the small valve, the auxiliary needle will remain closed. On the other hand, should the rate of closing of the power needle be very rapid, the auxiliary relief needle will be caused to open.

This device has proven eminently satisfactory, even when the most difficult combinations of high heads with long pipe lines and heavy load fluctuations were encountered. The adjustable feature of the cataract cylinder makes it possible to try out the apparatus after installation, setting it first for a very slow rate of closing of the auxiliary relief needle and then adjusting it until the point of maximum permissible pressure rise in the supply pipe is reached and the maximum economy of water consumption is obtained. Naturally, where one single wheel receives two streams of water from a duplex nozzle, or where a waterwheel unit is equipped with two wheels, a single auxiliary relief nozzle may be designed of sufficient capacity to serve the requirements of the entire unit.

With the perfection of the auxiliary relief needle regulating nozzle, it became necessary to provide some means for effectively absorbing the energy of the jet momentarily issuing from the relief needle nozzle. The Ensign vortex baffle plate, patented by Mr. O. H. Ensign, Chief Electrical Engineer, U. S. Reclamation Service, has proved to be an eminently satisfactory device for this purpose. It consists of a casting formed like the figure three, with a sharp, renewable, central splitter, much like the central splitter of a waterwheel bucket. The jet impinges upon the splitter and is turned back upon itself and absorbs its own energy in a whirlpool. One of the accompanying illustrations shows an Ensign vortex baffle plate in place opposite the auxiliary nozzle.

In order to insure the safety and continuous operation of the large hydro-electric units used in modern engineering practice, too much importance cannot be attached to the design of the main stop gate valves, which directly control the flow of water from the pipe lines to the waterwheel units. The so-called standard or commercial types of gate valves have so often failed to be satisfactory in operation that their use cannot be considered a justifiable economy. There is such a number of requirements and special conditions connected with the operation of gate valves in high head plants, which do not prevail elsewhere even though the capacity and pressure should be the same, that a special power plant type of gate valve is always desirable. The essential requirements for successful power plan. gate valves are that they must be easily operated by one attendant and also at the maximum safe speed. Therefore, when the load on the operating gear becomes too great and multiple gearing would make the closing time too long, power-operated gate valves have to be used. Of these, electric motor-driven valves have many points in their favor, but the possibility that they might have to be operated when there is no current available gives hydraulically-operated valves the preference. The well known type, operated by a hydraulic cylinder placed on top of the valve, has recently been supplanted by the more modern reversible water motor operated gate, such as shown in the accompanying illustration. This has the great

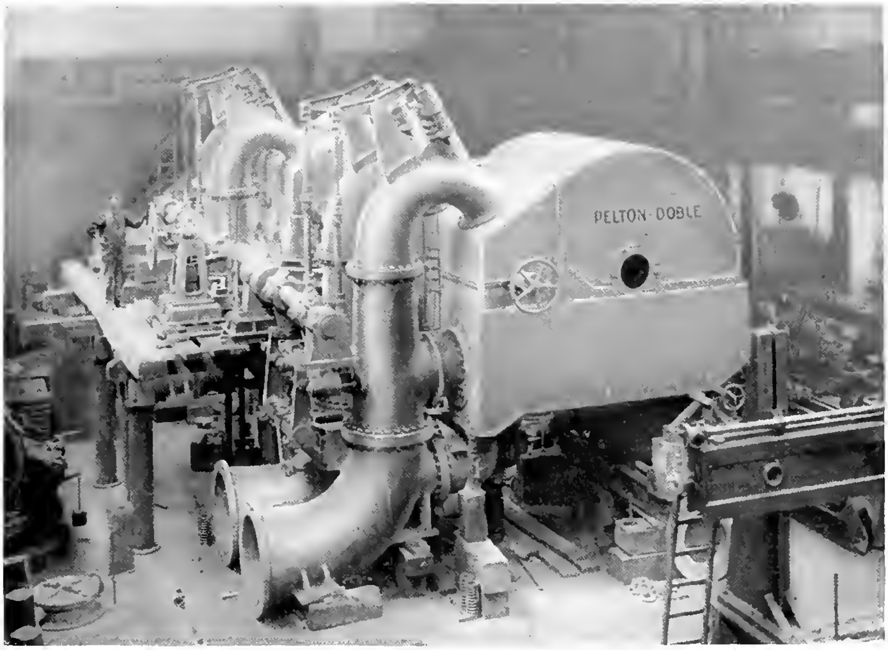


Fig. 9. Shop Erection View of Pelton-Doble Multiple Runner, Duplex Nozzle Type of Construction, four waterwheel runners being provided for each unit

advantage that the operating speed can be definitely fixed, so that the valve will not take too much time for opening or closing and still can never be shut too rapidly. Furthermore, an emergency hand gear can be easily provided, which is rather difficult with the hydraulic cylinder operated gate The waterwheel operated with water taken from the main pipe line, is of the reversible type equipped with two nozzles, one for closing and one for opening the valve. Automatic stops shut off the water, so that it is impossible for the gate disk to travel too far in either direction. The water motors used to operate the gates are constructed so that their torque increases as their operating speed decreases; for it is known that the greatest torque is required when first opening or finally closing, and of course these are the times when the speed of operation is naturally the slowest.

Fig. 10. Interior View Lake Buntzen No. 1 Power House, B. C. Electric Railway Company, Ltd., of Vancouver, B. C., showing a number of high capacity Pelton-Doble Tangential Waterwheel Units of modern design

For handling large water quantities under high heads, the needle type valve, hydraulically or oil pressure controlled, is one of the most marked strides in modern construction. The discharge co-efficient is very high. Since this type of gate is balanced in all positions and losses from eddy currents at partly closed positions are practically nil, the wear is reduced to a minimum.

In modern hydro-electric plants, it has become standard practice to drive exciters with small independent waterwheels, direct connected. In the most modern installations, it is desirable that the exciter set be controlled by a governor where the voltage at the plant is regulated by a Tirrill regulator, as in this case the load on the exciter unit is continually changing and it is essential to maintain constant speed.

Among the most interesting as well as useful modern devices which help much to simplify hydro-electric plant operation, are the tailrace ventilator and the vacuum cleaner attachment. The tailrace ventilators are installed in the walls of the concrete foundation, between the waterwheel and generator pits, and provide a free circulation of cool air for the generator. The vacuum cleaning device is designed to take advantage of the natural vacuum which tends to form at the center of waterwheel runner rotation and by means of suitable attachments it is possible to remove all dust from the power house and direct its discharge into the tailrace, without in any way disturbing the power house atmosphere. Needless to say this means much in the freedom of grit in bearings, collector rings, commutators, etc.

Before closing this article upon modern practice in high head hydro-electric plants, which it is hoped will be of interest to the readers of the REVIEW, one very important point should not be neglected. While it is true that the modern tangential waterwheel still remains the simplest form of hydraulic prime mover, there are many features in the consideration of its proper selection in which only the close cooperation of the consulting engineer and the waterwheel manufacturer, for the determination of such characteristics as size, type and speed, will be productive of best results; for the experience and viewpoint of one must be complemented by that of the other, if the future development of the art is to progress satisfactorily.

# THE SPEED REGULATION OF WATER TURBINES

By Allan V. Garratt

General Manager, The Lombard Governor Company

The author urges a more intimate cooperation between electrical manufacturing companies, water turbine and turbine governor companies in order that matters concerning speed regulation may be more intelligently dealt with in specifications and inquiries. Following this are given very interesting and valuable discussions (illustrated by plotted or instantaneous curves where needed) of the customary speed regulation formula and its factors, relief valves, surge tanks, positive and negative pressure calculations, flywheel effects, and quickness of governor action. A brief description of the method of control employed in the type of governor used in the Keokuk plant of the Mississippi Power Company, and of the types of governor pumps included in the equipments for various size plants, pictures the apparatus which has been developed to fulfill the requirements mentioned earlier in the article. The conclusion names the facts that should be kept in mind by all who are concerned with the speed regulation of water turbines.—Editor.

**Allan V. Garratt**

THE literature pertaining to the speed regulation of water turbines is meager and consists mostly of either purely theoretical treatments of the subject or of popular articles; neither of which aspects is as helpful as it might be to the busy engineer. This article will follow a middle course in presenting briefly some matters which may possibly be useful to the man who is neither interested in designing governors nor in an attempt to treat the question of speed regulation as a purely mathematical subject. It is addressed rather to the engineer who comes in contact with the regulation of water turbines as only one of the many subjects with which he must have an easy familiarity.

Perhaps what bothers the average engineer most in writing the governor part of his specifications for a hydro-electric plant is to know just what he wants the governor maker to guarantee, and what it is reasonable to expect him to guarantee.

It seems to be customary to do one of two things: either to ask the governor builder what regulation he will guarantee, and this frequently without giving sufficient data to enable such a predetermination to be made: or, to specify arbitrarily a certain degree of regulation, which sometimes is impossible under the physical conditions which obtain.

In the first case the governor builder does not know what the engineer wants. In the second case he sometimes knows that the engineer wants something which cannot be obtained. In the first case the governor maker may be destroyed by the Scylla of offering to do something which is not wanted. In the second case he may be tempted into wrecking himself on the Charybdis of offering to do something which he has grave doubts of being possible.

It would seem as though it were a better plan for the engineer to satisfy himself first as to the limits of speed variation, under different conditions of load change, which may be permitted in the plant under consideration, and then to enquire into the feasibility of obtaining the desired regulation. The permissible speed variation in a hydro-electric plant is purely an electrical question and should be treated as such and may not be elaborated here, as it is a somewhat complex matter which warrants careful treatment.

Not only the required speed behavior of an electric generator when the unit is tied into a large electrical system which is more or less self-regulating should be thought of; but also, consideration should be given to its behavior under those large and sudden load changes, which occur with more or less frequency under accidental or intentional conditions, as well as its speed behavior under friction load prior to synchronizing it with the rest of the system.

The limits of speed variation which can be realized depend only partly on the design of the governor. They depend largely on the entire design of the water column from open forebay to tail race and upon the inertia effects in the rotating masses. So far as the present writer knows, that matter was first treated in a paper by him before the American Institute of Electrical Engineers in 1899 (*Trans. A.I.E.E.*, Vol. XVI, p. 361). The experimental data then were very few and the deductions were somewhat crude. Since then the very large amount of data which has become available through the observed regulation of several thousand turbines, operating under a great variety of hydraulic conditions, permits at the present time of approaching such problems with some degree of confidence.

Unfortunately, it is usually unwise to rely wholly upon a purely mathematical treatment of the question on account of the impossibility of getting an accurate knowledge of all the inertia and dynamic forces at work. Some matters pertaining to that subject will be presented later, but for the moment let us return to the customary regulation specifications.

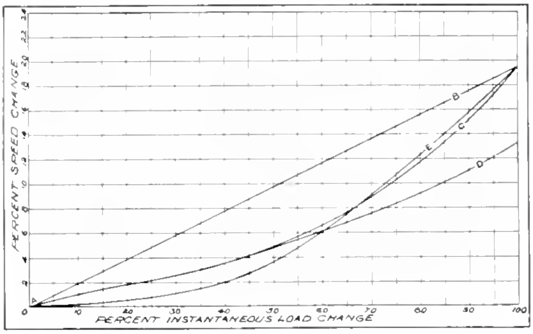


Fig. 1. Curves showing the relationship between the per cent instantaneous load change on a water turbine and resulting per cent speed change for various specified and actual conditions

They are apt to read something like this: "The speed must not vary (let us say) more than 20 per cent upon an instantaneous load change of the maximum horse power of the turbine, 15 per cent upon 75 per cent load change, 10 per cent upon 50 per cent load change, 5 per cent upon 25 per cent load change, and 2 per cent upon 10 per cent load change." Now the above values, if plotted, will result in a straight line curve as *B*, Fig. 1. The waterwheel governor has not yet been built which will give a straight line curve, neither would such a curve be desirable, yet that is what is frequently specified. The curve which obtains is ordinarily concave. The line *C*, Fig. 1, shows a characteristic curve made with one well-known design of governor when the inertia of the rotating masses, hydraulic conditions and time action of servomotor were such that the maximum speed change was 20 per cent upon the whole load of the turbine being thrown off instantly. If the whole load were thrown on instantly the curve would be like *D*, Fig. 1. Just why the load thrown on results in less speed change than a corresponding load thrown off is a rather involved matter which will not be discussed here as it would lead us a long way from the subject in hand.

It is evident that the larger the load variation and the slower the governor action, the greater will be the speed variation; and the greater the inertia of the rotating masses and the higher their rotation, the smaller the speed variation will be. These four quantities, combined with a proper constant, should give a somewhat accurate measure of maximum speed changes in those cases where the inertia of the moving water column is a negligible quantity. Note that there cannot be any predetermination of speed regulation without knowing the four quantities above named. Those who are in the thick of this matter receive many letters every day, which omit one or more of the above four quantities, but which ask for predeterminations of speed regulation which are, of course, impossible. The writing of several thousand letters each year would be obviated if the above matter were kept in mind.

It has become customary to write

$$\frac{K \times h.p. \times T}{I \times S^2} = \delta$$

for the determination of speed regulation of water turbines, where

$\delta$ = percentage temporary change in speed for load thrown off.
$K$ = 81,000,000.
$h.p.$ = the maximum horse power of the turbine.
$T$ = the time in seconds occupied by the governor in moving the turbine gates through their range.
$I$ = the moment of inertia of the rotating parts expressed in $WR^2$.
$S$ = the normal r.p.m. of the rotating parts.

So far as the writer knows, the constant 81,000,000 was first used by Mr. H. E. Warren in a paper written in 1907 and published in the *Technology Quarterly*, Vol. XX, No. 2, which see for the mathematical derivation.

The above formula, which is the best available, applies in practice through only a comparatively small range of values of *T*, *I* and *S*, for it should be remembered that a water turbine is a prime mover, the runaway speed of which is not greatly in excess of its normal speed; and with small values of *I* or *S*, or a large value of *T*, the formula may easily solve for a greater maximum speed than the turbine would acquire if uncontrolled by any governor action. The permissible limits of *I* and *S* will be briefly alluded to later.

The time in seconds occupied by the governor, *T*, is the time for moving the turbine gates through their range, as for example, upon the maximum load of the turbine being instantly thrown off. If the governor moved the gates through the proper range for a half load change in the same interval of time as occupied for a full load change, the speed variation would be one-half and the regulation curve would be a straight line curve, as *B*, Fig. 1. The governor never does this. If the governor occupied only half as much time in moving the gates to the correct position for a half load change as for a whole load change, the speed variation would be only one-quarter of that which obtains under whole load change, and would be curve *E*, Fig. 1. No governor yet built behaves in this exemplary manner, though good governors approach somewhat closely to it, as curve *C*, Fig. 1.

It is interesting to note that in curve *C* the governor actually moved the gates to the correct position for a 75 per cent load change in less than 75 per cent of the time for full load change but at about 67 per cent load change the governor fell behind the theoretical speed of action; the falling behind the theoretical time of action on small load changes is true of all governors, but they vary greatly in this respect. The less they fall behind the better the governor.

Different designs of governor show in practice different approximations of time action to load change; hence each has its characteristic curve or curves. For each design of governor, the curves are more or less homologous for workable values of *I*, *T* and *S*, so that one skilled in the art, looking at such a curve, would know something of the design of the governor that produced it.

The value of *I* is difficult to arrive at accurately in practice, for it is composed of a number of elements, some of which are hard to determine. Generator manufacturers usually know the $WR^2$ of their rotors with considerable accuracy and show perfect willingness to state it, and even to increase it within limits, to conform to the wishes of the engineer. The waterwheel builders seem to have difficulty in stating the $WR^2$ of their runners, and that, therefore, remains an unknown part of the flywheel effect. The water within the turbine runner has also some flywheel effect, but this information is seldom available for purposes of calculating regulation, and hence it has become a general custom to call the value of *I* simply the $WR^2$ of the electrical rotor, which is, of course, only part of it. Also it should be remembered that motors and motor-generators on the line act as flywheel effect and often greatly improve the regulation: so that the regulation under commercial conditions is frequently much better than on a rheostatic test. It is for this reason that the calculated speed regulation of an hydro-electric unit is usually not so good as the results which are actually obtained in practice, where the steadying effect of unknown, and hence unassumed, inertia forces are in operation to assist the governor in its work.

The assumption last made applies chiefly to turbines which are set in open water or under practically open water conditions, for if the water coming to the turbine is enclosed in a lengthy feed pipe, its inertia must be reckoned with, for the water is an exceedingly heavy mass, the velocity of which must be changed with every load change on the turbine; and it cannot change its velocity without either absorbing or liberating kinetic energy which is entirely independent of its potential energy which is the prime moving force of the turbine. This liberation, or absorption, of kinetic energy by the moving water column is frequently the most difficult matter to contend with in holding the speed of a turbine within close limits under large instantaneous load changes. Suppose, for example, that a one thousand horse power turbine is set at the end of a feed pipe of such length and diameter that the enclosed water, when the turbine is developing full power, contains 500 h.p.-seconds of kinetic energy; and that when the turbine is developing only 100 h.p. the velocity of the water is reduced so that it contains only 10 h.p.-seconds of kinetic energy. It is evident that upon throwing off 900 h.p. from the turbine, there are in addition 490 h.p.-seconds of kinetic energy lost, which will re-appear as force, and which will be applied to speeding up the turbine. A very small part of this kinetic energy will be converted into potential energy by compressing the water and in enlarging the steel pipe, but it is so small as to be in most cases of only academic interest.

Relief valves, at the turbine case, are sometimes employed to obviate the difficulties of long feed pipes, but it is evident that they can be of use only upon the load going off. They can be of no use upon the load going on, for they cannot supply to the moving water column kinetic energy which it has lost and which it must regain before it can flow at the higher velocity required by an increase of load.

Surge tanks are better; in fact, they are often imperative. If of improper design, they frequently add to the difficulty of obtaining regulation. If of proper design, they simply result in shortening the closed water column; that is, they bring the turbine nearer to being set under open water conditions which are the most favorable conditions. Where they may be advantageously employed, they offer a complete solution to the difficulties of obtaining regulation. Their design is an intricate subject, which, if presented in only an elementary way, would extend this article far beyond its proper limits.

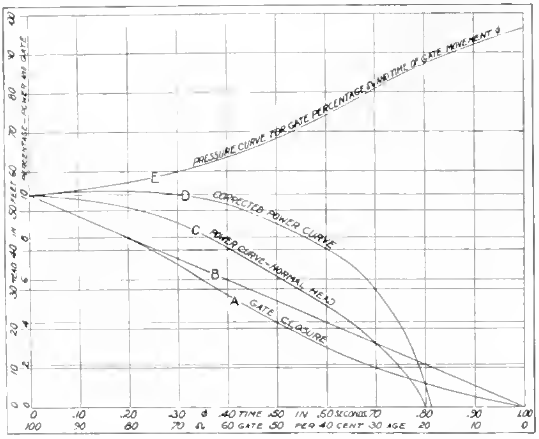


Fig. 2. Curves showing the relationship between the various factors expressed as functions of time action of governor, amount of gate travel, effective head, percentage gate opening and power

Unfortunately the conformation of the country is often such that a surge tank is unfeasible, and reliance must be placed on relief valves to prevent dangerous water pressures being developed and upon flywheels to liberate or absorb kinetic energy as the closed water column absorbs or liberates it. But for the moment, let us defer the flywheel question and inquire further into the kinetic energy in the closed water column and its effect upon the speed of the turbine while the governor is performing its function of altering the turbine gate upon a load change taking place.

Fig. 2 shows some of the phenomena which take place upon a governor closing the gates of a turbine. The time action of the governor and the amount of gate travel are plotted on the abscissa and the effective head upon the turbine and the percentage of gate opening and power are plotted on the ordinates. The curve *B* (a straight line) shows the closure of gates in one second if the governor acted with a uniform rate of motion. The curve *A* shows the actual motion of the governor. The curve *C* shows the power developed by the turbine while the governor is closing the gates on the assumption that the head on the turbine remained constant all the time. The curve *E* shows the pressure rise in the closed penstock due to the gate closure slowing up the moving water; thus causing the turbine to develop more power than that due to normal head. The curve *D* shows the actual power developed by the turbine due to the abnormal head *E*. The area between the curves *C* and *D* shows the amount of power the governor has to correct for in excess of the actual load thrown off the turbine. This area of power must be taken account of in arriving at anything like an accurate predetermination of speed regulation.

The pressure developed in penstocks by governors should be regarded from other considerations also than their effect on speed regulation.

Fig. 3 is a photograph of a model (by courtesy of Mr. George F. Hardy, C.E.) of the entire water column of one of the 20,000 h.p. turbine units in the power house now being built by The Laurentide Company of Grand Mere, P.Q. Of course, the same unit number of cubic feet of water per second is passing through each longitudinal foot of the water way, but as the cross section is constantly varying all the way from open forebay to tail water, the water velocity, and hence its kinetic energy is constantly varying.

Fig. 3. Photograph of the Model of Water Column of a 20,000 h.p. Water Turbine

To get at a close approximation of the abnormal pressure or head, as well as its component parts, it is customary to cut up the entire length of the water way above the turbine, around the scroll and down the draft tube into sections as indicated on the model and calculate the abnormal pressure developed in each of them. From these calculations, the pressure anywhere in the water way may readily be determined.

It is not usually necessary to calculate this force with great accuracy, and the complicated formulae which give very accurate results need not be employed. Merriman's approximate formula

$$P = \frac{.027 \times L \times V}{T}$$

is sufficiently close, or a simpler way is to consult the writer's Table of Time Averaging-Pressures. To convert Time-Average-Pressure into actual maximum pressure, multiply by two, which will give results within a few per cent of being accurate.

## TIME AVERAGE PRESSURE

The following table shows the constant pressure in pounds per square inch which, exerted for one second, will bring to a rest a moving water column. Note that as the pressure is directly as the length and velocity of the water column, and inversely as the time in which it is stopped, the pressure for any length, velocity and time may be readily calculated from this table:

| VELOCITY OF WATER IN FT. PER SEC. | LENGTH OF PIPE IN FEET | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 1 | .662 | .993 | 1.324 | 1.655 | 1.986 | 2.317 | 2.648 | 3.310 | 3.972 | 4.634 | 5.296 | 5.958 | 6.620 | 7.944 | 9.268 | 10.59 | 11.92 | 13.24 |
| 2 | 1.324 | 1.986 | 2.648 | 3.310 | 3.972 | 4.634 | 5.296 | 6.620 | 7.944 | 9.268 | 10.59 | 11.92 | 13.24 | 15.89 | 18.54 | 21.18 | 23.84 | 26.48 |
| 3 | 1.986 | 2.979 | 3.972 | 4.965 | 5.958 | 6.951 | 7.944 | 9.930 | 11.92 | 13.90 | 15.89 | 17.87 | 19.86 | 23.84 | 27.80 | 31.78 | 35.74 | 39.72 |
| 4 | 2.648 | 3.972 | 5.296 | 6.620 | 7.944 | 9.268 | 10.59 | 13.24 | 15.89 | 18.54 | 21.18 | 23.93 | 26.48 | 31.78 | 37.08 | 42.36 | 47.86 | 52.86 |
| 5 | 3.310 | 4.965 | 6.620 | 8.275 | 9.930 | 11.58 | 13.24 | 16.55 | 19.86 | 23.16 | 26.48 | 29.79 | 33.10 | 39.72 | 46.32 | 52.96 | 59.58 | 66.20 |
| 6 | 3.972 | 5.960 | 7.944 | 9.930 | 11.92 | 13.90 | 15.89 | 19.86 | 23.84 | 27.80 | 31.78 | 35.76 | 39.72 | 47.68 | 55.60 | 63.56 | 71.52 | 79.44 |
| 7 | 4.634 | 6.950 | 9.268 | 11.58 | 13.90 | 16.22 | 18.54 | 23.16 | 27.80 | 32.44 | 37.08 | 41.70 | 46.34 | 55.60 | 64.88 | 74.16 | 83.40 | 92.68 |
| 8 | 5.290 | 7.940 | 10.59 | 13.24 | 15.88 | 18.53 | 21.18 | 26.48 | 31.76 | 37.66 | 42.36 | 47.64 | 52.96 | 63.52 | 74.12 | 84.72 | 95.28 | 105.9 |
| 9 | 5.960 | 8.940 | 11.92 | 14.90 | 17.88 | 20.86 | 23.84 | 29.80 | 35.76 | 41.72 | 47.68 | 53.64 | 59.60 | 71.52 | 83.44 | 95.36 | 107.3 | 119.2 |
| 10 | 6.620 | 9.930 | 13.24 | 16.55 | 19.86 | 23.17 | 26.48 | 33.10 | 39.72 | 46.34 | 52.96 | 59.58 | 66.20 | 79.44 | 92.68 | 105.9 | 119.2 | 132.4 |

A careful study of the abnormal pressures which may be developed by governor action in penstocks is advisable for the following reason. Frequently from considerations of advantageous design of power house and proper economy of material, the concrete is not very thick over the penstock where it passes under the generator room floor, and in designing its thickness and reinforcement thought should be given to what the governors are likely to do to the penstock pressures.

It sometimes comes about that the strength of the concrete is limited to a value which leads the thoughtful engineer to [illegible] slower governor action than he would like and compensate for the slower generator action by additional flywheel effect. Governors can be obtained which will give a complete range of gate movement in one second or even less, but it is sometimes unwise to develop the water pressures which such quick action entails.

The negative pressure which may be developed in the draft tube should also be calculated in the same way as the pressure above the turbine. In some cases where the draft tube curves into a more or less horizontal and long extension the negative pressure developed in the draft tube by a very quick governor action may be greater than atmospheric pressure and may cause the water in the draft tube to part company with the turbine and to return with a rush which may be disastrous. This consideration may lead to modifying the design of power house and tail race contemplated.

The proper flywheel effect to give an hydro-electric unit should be given consideration, and in the present state of the art, it is perhaps wiser to lean somewhat upon empirical data rather than to be guided solely by mathematical deductions.

A great amount of empirical data has accumulated. Turbines set under heads varying from a very few feet to several hundred feet and set at the ends of closed penstocks varying from a few feet to six thousand feet, or more, have been observed under governor control and flywheel values through a ratio of from 1 : 50 have been employed. A study of such data is a valuable guide in determining what can be done in the way of regulation under a great variety of conditions.

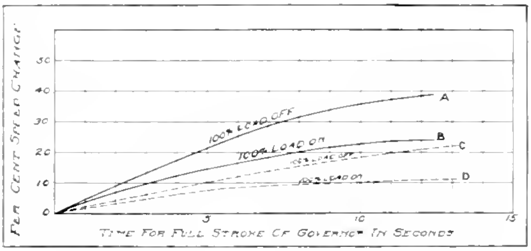


Fig. 4. Curves showing the relationship between the per cent speed change of a turbine and the time required to complete the gate motion

The flywheel effect in the electrical rotor is a very large part of the whole and as stated previously it is customary to consider it only, ignoring the small flywheel effect of the other rotating masses. It is usual to state it as the $WR^2$ or as the weight that will give a corresponding effect at one foot from the center of rotation, symbolized as $I$. Its value in steadying the speed of the unit depends, of course, upon the power of the unit and upon the square of its r.p.m. For purposes of comparison it has become customary to reduce all values of $WR^2$ to corresponding values for units developing one h.p. at one r.p.m. This new value is symbolized by $I_1$, and is obtained by multiplying the known $WR^2$ by the square of the r.p.m. and dividing by the h.p. of the unit. We may write

$$I_1 = \frac{I.\ S^2}{h.p.}$$

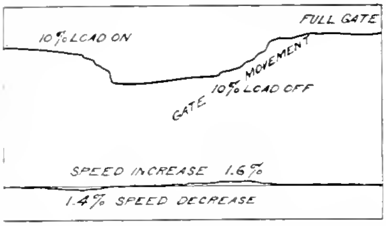


Fig. 6. Curves of the Same Nature as those of Figs. 5 but employing different load changes

Somewhat careful speed regulation experiments have been made with turbine units having values of $I_1$ ranging from 1,000,000 to 47,000,000.

The useful range seems to be from 3,000,000 to about 30,000,000, according to the difficulty of the hydraulic conditions and the severity of the instantaneous load changes.

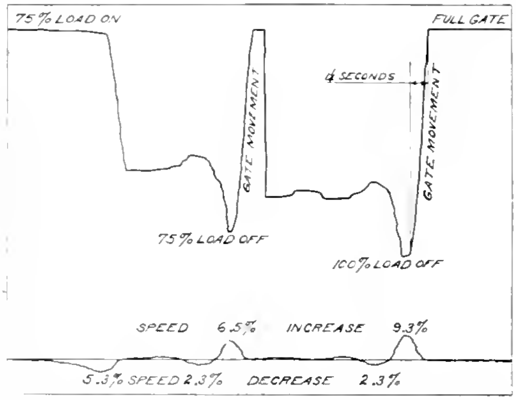


Fig. 5. Curves from Actual Test made to determine the gate movement and the speed change for various sudden changes of load

Above 30,000,000 the gain does not seem to be worth the cost. Commercial electric rotors have a range of $I_1$ from about 2,240,000 to about 14,000,000, and with such values of $I_1$ satisfactory regulation can be obtained under comparatively simple hydraulic conditions unless the regulation requirements are exceedingly exacting, when some additional flywheel effect may be required. Manufacturers of electric generators are usually willing to increase the $WR^2$ of their rotors somewhat upon request. If the hydraulic conditions are very unfavorable, it is often necessary to install an independent flywheel upon the generator shaft.

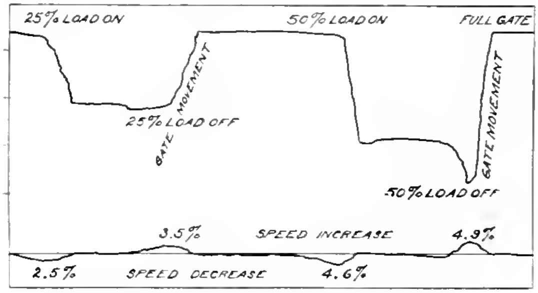


Fig. 7. Curves of the Same Nature as those of Fig. 5, and 6, but employing different load changes

In one plant in New York State, for example, where the turbines are set at the ends of closed feed pipes 2300 ft. long, additional flywheels were installed, bringing the total value of $I_1$ per unit up to 20,000,000. The satisfactory regulation which obtained was due to a careful study of the inertia forces at work, and checking up calculated values of the proposed flywheels with much experimental data already at hand.

The mere statement that a certain governor is a one-second governor, or a two-second governor, or so on, does not mean much unless it is known how long it takes the governor to get into action, and if it starts off at full speed. Governors vary greatly in this respect.

Some modern governors are of such design that they make most of their motion in a very short time and slow up near the point of complete gate closure. It is evident that such governors may safely move much quicker than though they lacked the above adjustment.

The effect of the quickness of a governor upon the regulation it will give, aside from theoretical considerations, and as a matter of experiment is a natural subject of inquiry. Fig. 4 shows an actual experiment made to illustrate this matter. A governor of good design was connected to a hydro-electric unit set under open water conditions and was successively adjusted to give a complete range of gate motion in from one to 13.5 seconds. That is, the governor was first made to perform its function in one second, then in two seconds, and so on. It did not seem desirable to continue the experiment more than 13.5 seconds as the curves had become practically flat. Curves *A* and *C* were made with a value of $I_1 = 13{,}000{,}000$. With curves *B* and *D*, $I_1 = 29{,}000{,}000$. It will be observed with curve *A* that the regulation between one second and six seconds is almost directly proportional to the quickness of the governor; above six seconds, the quickness of the governor did not count for so much, though that is not of much importance, for above six seconds the regulation is so bad that it would be intolerable in most plants. With the larger flywheel effect, curve *B*, quickness of governor action does not count for so much for the curve is more convex its entire length. It will be noted that with the larger flywheel effect the same regulation is obtained with eight seconds governor action that was obtained with the smaller flywheel effect in 4.5 seconds, which illustrates the value of large flywheel effects with long penstocks, previously alluded to. The curves on Fig. 4 indicate plainly that governors should be as quick as the physical properties of the plant will permit if the best regulation is expected.

The reader will naturally inquire as to what may be regarded as first-class practice. Figs. 5, 6 and 7 show the regulation obtained with a governor of very recent design. These curves were made on a chronographic instrument of precision. The upper curves were made by connecting the pen with the gate stem of the turbine by means of a fine wire and a suitable lever. The speed lines were drawn by a sensitive recording tachometer of the mercury, vacuum type. The load consisted of a rheostat. The load changes were as nearly instantaneous as possible for they consisted of opening and closing the rheostat switch. The governor was adjusted for 1.25 seconds time of operation for complete load change. Note that this interval of time is from the moment of the load change to the moment when the governor has moved the gates to the proper position. A governor

**Fig. 8.** **The Type of Turbine Governor used in the Mississippi River Power Company's station at Keokuk**

may move very quickly when it once gets started but is so slow in getting started as to give poor results, for the speed begins to change the instant the load begins to change and does not wait for the governor to work.

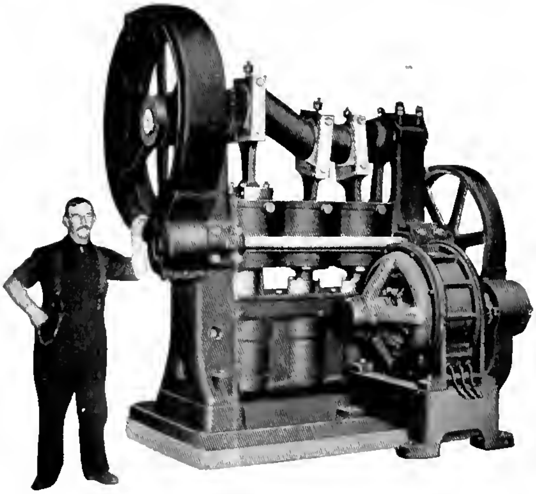


Fig. 9. An Electrically-Driven Pump which furnishes oil under pressure to the governor

Neither the limits nor the purpose of this article will allow much reference to governor design but a brief allusion to a few recent governors may be permitted. Fig. 8 shows one of the governors in the Keokuk installation of the Mississippi River Power Company and several other large plants. The principal idea in this machine, aside, of course, from the technique of the valve motions, centrifugal elements, anti-racing mechanisms, etc., which it would take much space to describe, was to give perfect accessibility to all working parts and at the same time absolute protection from unauthorized meddling. The cast iron case, which is about seven feet high, is provided on the back with plate glass doors, under lock and key, which when opened permit of every part of the governor mechanism to be reached and all adjustments to be readily made. An electric lamp in the interior illuminates all parts which are, of course, visible through the glass doors. The face of the governor carries ten-inch dials indicating tank pressure, back pressure, if any, on the receiving tank, speed of the unit expressed in cycles, and actual gate opening (not gate position). There are also rotary handles controlling the primary and relay valves and near the top and at the center a synchronizing switch which duplicated the function of the synchronizing switch in the switchboard gallery. The central hand wheel on the face of the actuator is of interest, as it consists of an hydraulic hand control for use when it is desired to cut the governor out. By rotating this wheel, the turbine gates will move to any desired position and stay there until the hand wheel is again moved, or until the governor is again cut in. The servomotors or power cylinders, which are under control of the governor, are located on the floor below and are connected to the turbine gate ring by means of tangent rods. Fig. 9 shows one of the pumps which maintains pressure on the oil circulating system of the governor which is the force actuating the servomotors. There is a pump and tank set for each governor. The pumps are intermittently motor-driven. That is, they are automatically started and stopped

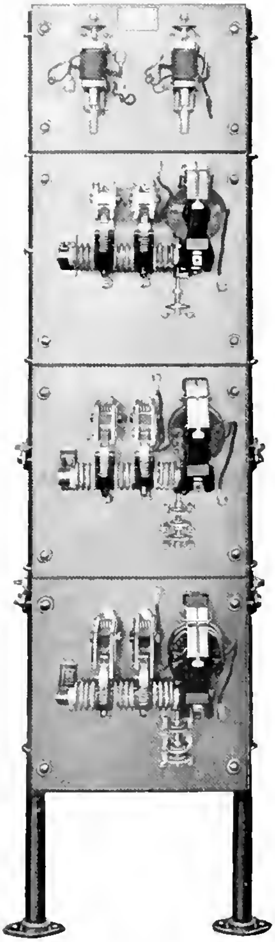


Fig. 10. Contactor Panel for automatically starting and stopping the motor driving the oil pump in accordance with the demands on the governor

according to the governor requirements by means of the pressure controlled motor starting sets shown in Fig. 10.

In some other large plants the motors are allowed to run continuously; magnetic clutches under pressure control being interposed between them and the pumps. Either of these methods is preferable to running the pumps continuously as it relieves the pumps of at least three-quarters of the wear and tear, for the governors ordinarily require that the pumps run only one quarter, or less, of the time.

In the Keokuk plant the various pumping units are not interconnected; in some other large plants they are. Each method has its advantages and disadvantages which make it advisable in one installation and not advisable in another. It is too broad a question to be satisfactorily treated briefly.

Fig. 11 shows a horizontal, direct connected governor built in various sizes up to 60,000 ft-lb. which may be found in many modern plants. In this design the entire governor mechanism except the pump and tanks is self-contained on one bed. Attention is called to the powerful mechanical hand control which may be instantly thrown in or out of action by the lever shown. The connection to the gate shaft is through the link shown to the extreme right. The arrangement permits of direct connection to either vertical or horizontal gate shafts.

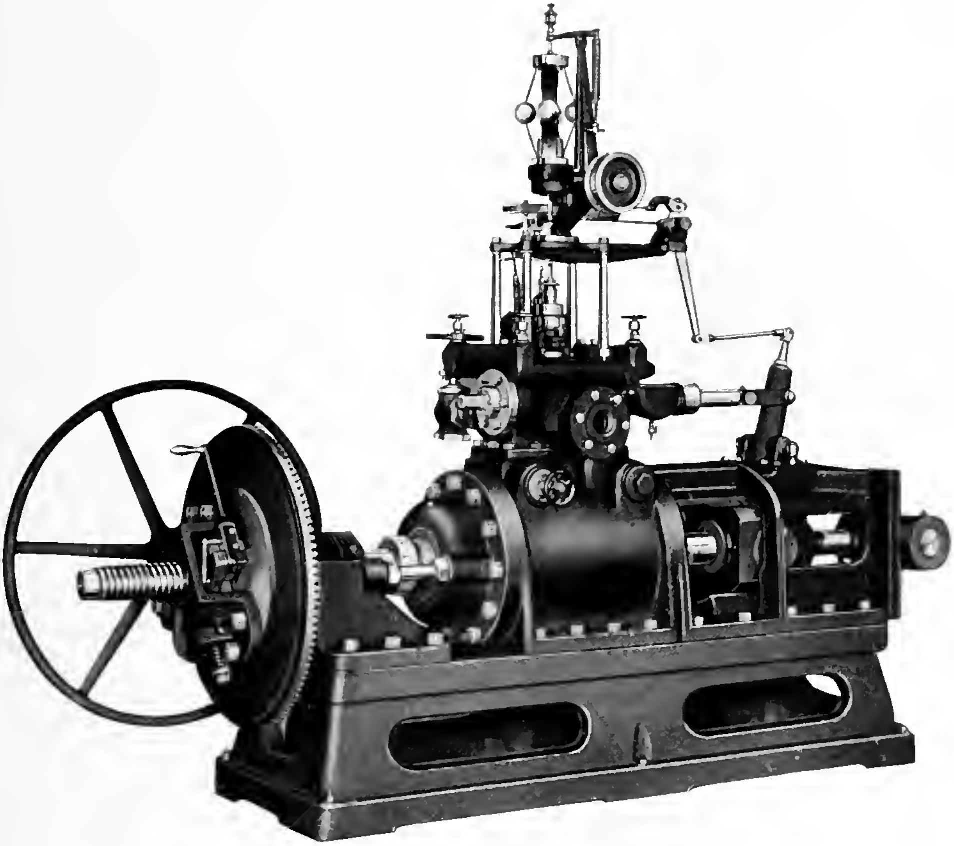


Fig. 11. A Horizontal Direct-Connected Governor

Fig. 12 shows a motor-driven governor pump for governors of moderate and small size. The convenience of this particular design is indicated by the fact that more than fifty of them may be found in various hydro-electric installations on the locks of the barge canals of New York.

In conclusion, a few words may be permitted on writing governor specifications. No general form will be suggested for every engineer should impress his own individuality upon his specifications: but there are some matters of such general importance that they may appropriately be insisted upon.

Every waterwheel governor should be substantial in construction for no other machine of delicate function is subjected to greater shocks or more continuous service. This does not mean simply weight of cast iron but where the strains and wear come ample provisions should be made.

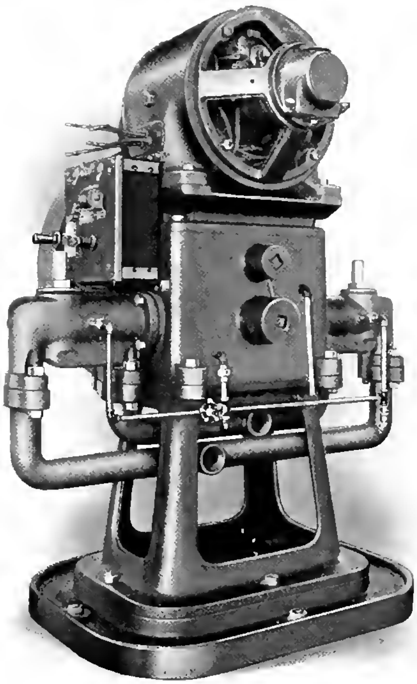


Fig. 12. **An Electrically-driven Pump for small and medium size governors**

They should be built with accurately interchangeable parts so that repair parts that will fit may be readily obtained.

The design should be such that they may be adjusted for any degree of sensitiveness and any degree of quickness (two distinct functions), while they and the waterwheels they are governing are in commercial operation, and the engineer has a right to be convinced that these adjustments can be made and how they are made.

The ratio of pumping capacity and tank capacity to servomotor capacity should be plainly stated by the manufacturer, and if the pumps are motor-driven, the method of driving whether continuous or intermittent, and if the latter, in what manner, should be insisted upon and clearly described.

If the pumping system is to be interconnected, the manufacturer should give very complete details of the piping system.

The requirements as to the degree of regulation under various load conditions should be very fully stated by the engineer and the necessary data for predetermining regulation should be given. This data is: 1st, maximum horse power of unit; 2nd, r.p.m.; 3rd, $WR^2$; 4th, time operation of governor, suggested, or required, or optional; 5th, a very complete statement of the hydraulic conditions.

# EXCITATION OF HYDRO-ELECTRIC POWER PLANTS

By R. E. Argersinger

Power and Mining Engineering Department, General Electric Company

The author gives the result of an analysis of the exciter arrangement of some seventy-five hydro-electric plants, which indicates a general preference for waterwheel-driven exciters. A comparison is made of the waterwheel-driven exciter plant with exciters direct-connected to the main generating units, bringing out the difference in exciter plant capacity and the advantages of the latter arrangement in first cost and operating cost. Some disadvantages are also pointed out, with possible remedies.—Editor.

R. E. Argersinger

THERE seems to be a tendency in laying out hydro-electric plants to give too little attention to the arrangement of the exciter plant, and to assume that since there is running water available it follows necessarily that waterwheels should be used to drive the exciters directly. A study of some seventy-five plants, made by the writer, showed a total of thirty-one using waterwheel-driven exciters only, and thirteen more using waterwheel exciters with motor-generator sets in conjunction therewith. Eight additional plants use exciters having waterwheels and motors attached to the same exciter. Two additional plants use waterwheel exciters with some additional exciters direct connected to the shafts of the alternating current generators. In other words, out of seventy-five plants, a total of fifty-four use separate waterwheel units for exciter drive. Fourteen plants use only direct connected exciters on the alternator shafts. Three additional plants use a combination of direct connected exciters and motor-generator sets. Two plants use motor-generator exciters only, and two have special arrangements which would not fall in any of these groups.

The analysis shows that waterwheel exciters have been much more extensively used than direct connected exciters. The plants using waterwheel exciters embrace a wide variety of types. They cover heads ranging from 20 ft. to 2350 ft., total kilowatt capacities from 1600 kw. to 40,000 kw. and range from plants having a minimum of three generating units to a maximum of twelve. The smallest exciter is of 45 kw. and the largest of 600 kw. capacity. The plants having direct connected exciters cover heads from 20 ft. to 1800 ft., the kilowatt capacities range from 3600 to 54,000 kw. and the number of units vary from two to six, and the exciter capacities from 30 to 150 kw. The main difference in plant characteristics lies in the number of generating units, that is, although the minimum limit is practically the same in either class, the maximum limit is twelve units for waterwheel exciter plants and six units for direct connected exciter plants. This bears out the more or less prevalent feeling that direct connected exciters find their greatest usefulness in plants having a small number of units. There are factors, however, affecting the two types of exciter plants, including both first cost and operating cost, which are usually considered of no great importance and often overlooked. A brief study of these may be of interest.

In laying out a waterwheel-driven exciter plant, it is usually customary to put in two units, either one of which will take care of the excitation of the entire plant. Occasionally three units are used, two of which will take care of the entire plant, but the arrangement is unusual. Out of the thirty-one plants mentioned above, twenty-seven have two exciters and four have three. The two-unit arrangement, laid out as above, gives us 100 per cent reserve exciter capacity and one complete spare unit. This arrangement necessitates the provision for operating both machines in parallel on the exciter bus, with a more or less extensive installation of copper and switching connections for supplying power to any or all of the generator fields from either exciter. Provision is often made, in addition, for auxiliary busses from which station power circuits can be taken, and in many cases this provision for station power and the possible operation of auxiliaries from direct current supplied by this spare exciter is considered as an important item in deciding the type of excitation plant to be used. The exciters are usually made compound wound and often arranged for control by voltage regulators. The installation of 100 per cent reserve exciter capacity usually carries with it the installation of 100 per cent reserve regulator capacity.

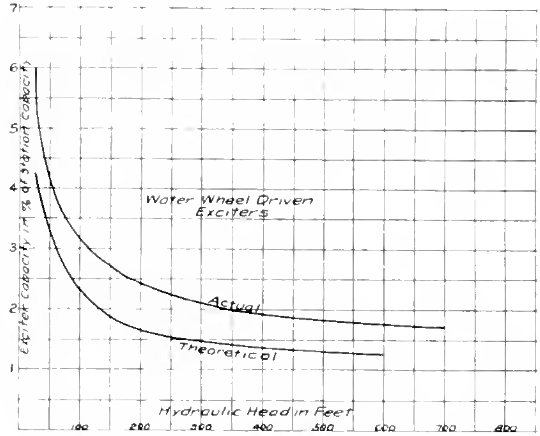


Fig. 1 Curves showing Capacity of Waterwheel-driven Exciter Plant in per cent of station capacity

The practice as regards the layout of a direct connected exciter plant has not been so well established. Where only two generating units are installed each exciter should be, and usually is, large enough to excite both generators. If there are three generating units, it may still be advisable to make each exciter large enough to excite two generators, but with four or more units there seems to be no reason for making each exciter larger than is sufficient to take care of the excitation of its own generator. In order to obtain reserve capacity, motor-generator sets can be installed. It is difficult to imagine a condition which would result in damaging two direct connected exciters without, at the same time, injuring either the waterwheels or the generator units to which the exciters in question are connected. As far as trouble with the main generating unit is concerned, it is usually considered sufficient to have one spare generating unit in the station. At the same time minor troubles with commutating apparatus are more likely to arise than with alternating current generators, and a larger factor of safety in this respect would, therefore, appear reasonable, although exciter service at the worst is not to be compared in severity with the treatment to which other classes of commutating apparatus, such as railway equipment, etc., is subjected, and even in stations containing the latter class of apparatus one spare unit is considered sufficient. It will, however, not be a very severe charge against the station if we provide a total reserve exciter capacity equivalent to the capacity of two direct connected exciters, and it appears that this amount of reserve capacity is sufficient to maintain a high factor of safety in the operation of the exciter plant. We may even go so far as to divide this reserve capacity in two units, say in two motor-generator sets, each equal to the capacity of one exciter, placing them in different parts of the station to avoid any communication of trouble between them.

Some comparisons of waterwheel-driven and direct connected exciter arrangements on this basis may be of interest. Curves have been plotted from a considerable quantity of data, showing variation in the total exciter capacity in per cent of the total kilowatt capacity of the station, with the hydraulic head, for both exciter arrangements.

Fig. 1 shows two curves. The one marked "actual" is plotted from actual data of a large number of stations having waterwheel-driven exciters. The curve marked "theoretical" is plotted taking the actual excitation of a large number of generators actually installed and calculating the total excitation required by the station, assuming that there will be two waterwheel exciters each of a capacity to excite all of the generators. It should be noticed that there is a considerable gap between the curve plotted from actual installations and the curve made up from what might be called the calculated possi-

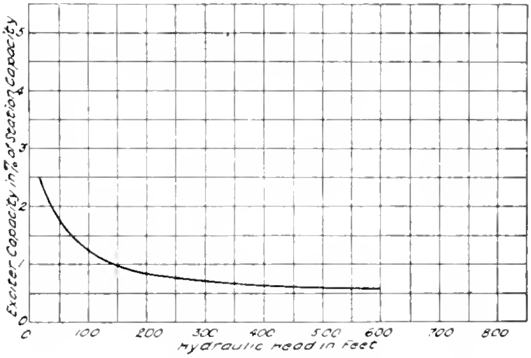


Fig. 2. Theoretical Curve showing Total Capacity of Direct-connected Exciters required for stations of 12 generators in per cent of station capacity

bilities of actual machines. It should be noted in connection with this curve that the percentage of the total station capacity represented by the exciters does not vary no matter how many generating units are installed. For instance, suppose the station contains four 5000 kw. units each requiring 50 kw. excitation, the excitation plant will have a total capacity of 400 kw., or 2 per cent of the total station capacity. If the station contains eight of the same units the exciter plant will be of 800 kw. capacity and the percentage remains unchanged.

Fig. 2, on the other hand, shows a similar curve for direct connected exciters, which is marked "theoretical," that is, it has been made by taking the excitation of actually installed generators, assuming that there are twelve generators installed in each plant, that each exciter is sufficient for exciting one machine and that there is a total reserve capacity equivalent to two exciters. It has been impossible to draw an "actual" curve such as shown in Fig. 1 for the direct connected exciter arrangement, since the percentage varies with the number of units installed in the plant.

Fig. 3 shows a theoretical waterwheel exciter curve and a theoretical direct connected exciter curve based on the use of twelve generators. The difference in the ordinates between the two curves will increase with the number of generators, so that for plants having less than twelve units, the difference in exciter capacities demanded by the two arrangements will be less than that shown on the curve. The theoretical ratio of the capacity between the two arrangements can easily be expressed by assuming that the exciter capacity required by a given generator is equal to $A$. Then, for a waterwheel exciter arrangement the total exciter capacity will be $2NA$, where $N$ is the number of generators. The total exciter capacity of the direct connected exciter arrangement, however, will be $A(N+2)$. By assigning numerical values to these, the percentage difference in the excitation required for any given number of machines can easily be calculated, and the curve in Fig. 4 shows the percentage excess of waterwheel-driven exciter capacity over the direct connected exciter capacity for any number of generators up to twelve. For instance, if there are six generators, the total waterwheel exciter capacity is 50 per cent more than the direct connected exciter capacity, assuming that each waterwheel exciter is large enough for the entire station, and that the direct connected arrangement provides for a total spare capacity equivalent to the excitation required by two generators. In the same way, with twelve generators, the waterwheel exciter capacity will be 71½ per cent in excess of the capacity required by the direct connected exciter arrangement.

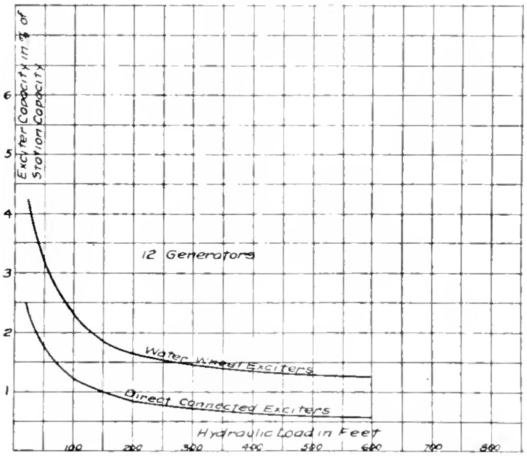


Fig. 3. Comparison of Theoretical Curves shown in Figs. 1 and 2

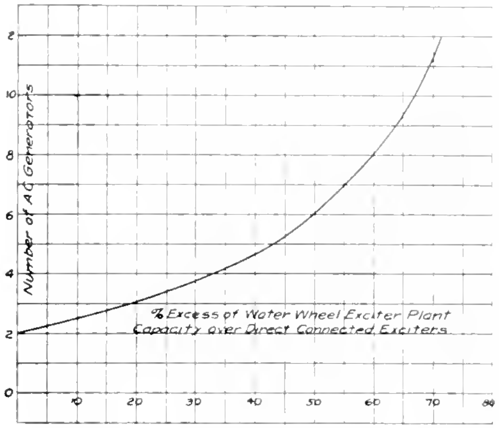


Fig. 4. Curve showing Percentage Difference in total exciter capacities for waterwheel-driven and direct connected exciter arrangements

Referring to Fig. 3, curves of which are based on twelve generators, we should expect the ordinates of the waterwheel curve to be 71½ per cent more than those of the direct connected exciter curve. While they are fairly close to this figure, they do not check exactly. This is due to the fact that they are plotted from actual excitation of various machines at different heads, and are more or less an average of all of these various machines, which of course, vary in operating characteristics. In other words two machines, although designed for the same head and capacity, even though they have the same speed, may vary in excitation through a considerable range. It is rather remarkable that the agreement is so close to the calculated figure. The direct connected exciters will presumably operate at a slower speed, and consequently will be more expensive per kilowatt than the waterwheel-driven units. With a low head and small number of units the direct connected arrangement will doubtless show a higher exciter cost; but as the head and number of units increases the difference in the cost of the electrical machines will decrease, so that the important factor, as far as the saving in first cost is concerned, which should be considered in deciding upon either of the two arrangements, is the saving made possible by the omission of the hydraulic equipment, including the waterwheels, governors, gates, penstocks, possibly forebay gates, etc., necessary to drive exciter units, and the further saving in building cost by the reduction in space required for their installation, and the decreased amount of foundation work.

There is a further factor which is usually neglected; that is, the difference in operating efficiency of the two methods. Assume, for instance, that the full load efficiency of the alternating current generator wheel is 90 per cent, the efficiency of the alternating current generator 95 per cent, the exciter wheel 87 per cent, and the waterwheel-driven exciter 90 per cent, and of the direct con-connected exciter 89 per cent. These figures are probably representative of good modern practice at ordinary heads. The full load efficiency, then, of the excitation at the generator fields with the waterwheel arrangement will be 78.3 per cent, or with the direct connected exciter 80 per cent. It should be borne in mind that exciters are usually given a normal full load rating equal to the total generator excitation at the most severe guaranteed condition of load and power-factor. Under ordinary full load operation, then, of the a-c. generator with average power-factor, and allowing for the fact that for a considerable portion of time at least one of the a-c. generators will not operate, it is probably safe to assume that the exciter will not be operating much above two-thirds of its normal rating. The normal full load operating point of the exciter wheel will probably be at about seven-eighths or nine-tenths gate opening, at which point it will have maximum efficiency. At smaller gate openings the efficiency will drop off quite rapidly, and at the operating load the wheel efficiency will probably be at least 4 per cent less than normal, and the generator will probably drop off 1 per cent, so that the combined efficiency at the generator field will be about 74 per cent. With the direct connected exciter the difference in exciter output, whether it operates at its normal rating or even at one-half load, will not materially affect the efficiency of the main a-c. generator wheel by which it is driven, so that the only reduction in efficiency will come from the exciter itself and will amount to say 1 per cent, giving an efficiency at the generator field of say 79 per cent as against 74 per cent with the waterwheel-driven exciters. Further, when the station is operating at a low load, a number of generators will be shut down, and consequently the waterwheel-driven exciter will be operated at a proportionally reduced output. The number of generators kept in operation will, however, be adjusted so that each will run at as nearly full load as possible, and consequently the direct connected exciters which remain in operation will be run at their maximum efficiency point. This means a still greater difference in operating efficiency over long periods between the two systems. It is probably safe to say that this difference in operating efficiency throughout the year will amount to at least 10 or 15 per cent in favor of the direct connected arrangement.

Suppose that a 30,000 kw. plant is installed with 2 per cent of its rating in waterwheel-driven exciter capacity; that is, assume that the rated excitation required for the machines will be 300 kw., but that the average excitation required is say 150 kw. On the basis of a 10 per cent difference in efficiency, we shall have, then, a constant loss of 15 kw. to be charged against the waterwheel exciter plant. This represents 130,250 kw-hr. per year. The latest figures from the United States census report indicate that the average gross income per kw-hr. from the central stations in this country is approximately 2.6 cents, and, at that figure, the difference in efficiency of the two systems means an annual income loss to the assumed station of $3412.50, a sum not to be despised. From the data cited at the beginning of this article it appears that in many plants having waterwheel-driven exciters, motor-generator sets are also used for the excitation of the station through a considerable period of time. A little consideration shows that with motor-generator sets in use the efficiency of excitation at the alternator field will be from 8 to 10 per cent less than the efficiency of the waterwheel-driven exciter, so that under such circumstances the direct connected arrangement shows up still more favorably.

These figures make the direct connected exciter arrangement attractive. There are however, some objectionable features. For instance, with such an arrangement the exciter system is directly involved with the generating system, and troubles with the generating units, or troubles with generators or generator wheels, directly affect the exciter. Repairs to one cannot be made without shutting down the other. This objection, however, is not so serious as it at first appears, since if the generator is shut down either by internal trouble or by trouble in the wheel there is no occasion for running its exciter.

An objection is also sometimes raised to the effect that in case of low water with some generating units shut down, if it becomes necessary to make repairs on an operating exciter, it is then necessary to start up a large generator wheel in order to run another exciter. This objection is, of course, answered by having available spare motor-generator capacity to provide emergency excitation. Complaints have been made that, with direct connected exciters, the exciter is over speeded as well as the generator, if for any reason the generator wheel runs away, and the generator voltage is consequently increased much more rapidly than would be the case with entirely separate exciters. The writer recently saw data from an actual waterwheel-driven generator runaway where the exciter speed increased synchronously. The normal high tension voltage at the transmission line was 66,000, while under the overspeed conditions it reached approximately 200,000 volts, subjecting all of the apparatus in the circuit to more than three times its normal voltage. This is a very real danger and if direct connected exciters are considered it should be provided against. Two things can be done. First, emergency devices can be provided on the turbine shaft which will admit high pressure oil from emergency storage tanks to the gate operating cylinders, the device being entirely separate from the mechanism operated from the governor. In addition to this, an over-voltage relay can be provided which will cut into the exciter field a large amount of resistance when the a-c. voltage rises above a predetermined amount. In order to accomplish this result, however, the exciter should be shunt wound, since a compound wound exciter might, at high speed, build up its voltage to normal or even higher with only the series field active. Some plants, where hydraulic conditions are severe, have even gone so far as to install water rheostats which can be cut into circuit on overspeed, thus throwing an artificial load on the generators and reducing the speed of the unit. Such devices have been used irrespective of the exciter arrangement.

One of the strong arguments for an isolated waterwheel-driven exciter plant has been that it offers a separate source of direct current for operating station auxiliaries, lights, cranes, pumps, fans, etc. The development of a-c. equipment, however, has made this feature unimportant. Some of the largest stations in the country, such, for instance, as that of the Mississippi River Power Company at Keokuk, are equipped throughout with a-c. auxiliaries, including the cranes. Further, we believe there are objections to operating any such service from the exciter system since troubles are always likely to occur in these circuits that may damage the exciters at times when such damage would cause considerable inconvenience in the operation of the station. The supply of direct current for control circuits can be easily taken care of by the use of a small motor-generator set combined with a storage battery, which gives a reliable source of power at constant voltage, and no complications are introduced by voltage variations, such as those caused by regulators when control circuits are operated from exciter busses.

With the waterwheel-driven exciter arrangement, one, or at most two, regulators are usually installed, while with the direct connected exciters if there are any considerable number of units it becomes advisable to install a regulator with each exciter, otherwise the number of contacts per regulator becomes excessive, and further by installing the separate regulator with each exciter the system is made more flexible and there is no necessity for paralleling. Under such conditions it becomes convenient to wire each direct connected exciter straight to its own generator, providing a tap connection, however, to a transfer bus so that any exciter may be connected to any generator. This connection should be made so that it will not be necessary to connect the exciter to the bus in order to excite its own generator, and normally, the exciters will not be parallelled. Each will be shunt wound and provided with its own regulator and overvoltage relay.

In some localities difficulties have arisen from waterwheel-driven exciters due to bad ice conditions. The exciter wheel passages are, of course, much smaller than those of the main a-c. units, and in a number of instances anchor ice has stopped the passages in the exciter wheels and shut down the station thereby, when the large passages in the main a-c. generator wheels have passed the ice freely without causing any particular trouble. Remedy for this is, of course, the installation of motor-generator sets which can be used for operation at such periods.

The great advantage in the waterwheel-driven exciter arrangement lies in the fact that it is entirely separate in every way from the main generator system, and it will undoubtedly always be used for this reason. The possibility, however, of protecting the direct connected exciter system from its apparent disadvantages and the gain in efficiency to be made in the operation of stations by its use warrants its careful consideration in every important plant.

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# VENTILATION OF HYDRO-ELECTRIC POWER STATIONS

By R. C. Muir

Power and Mining Engineering Department, General Electric Company

The tendency of present practice in hydro-electric power station design is to use individual generating units of large capacity, the economical design of which depends upon a definite circulation of air to dissipate the losses incident to operation. This article does not enter into the design of the generator itself, but treats of the provisions that must be made by the designer of the power station in order to meet the ventilation requirements of the various types of generators. The author points out the fact that this feature in power station design has been badly neglected in the past and shows the necessity of cooperation between manufacturer and architect. —Editor.


R. C. Muir

The ventilation of hydro-electric power stations should be carefully worked out by the designer of the station in conjunction with the manufacturer of the electrical apparatus. In the past this feature has seldom received the attention it deserves, in fact in most cases where any special provisions for ventilation exist it is quite plain to see that such arrangements are the result of an afterthought. It is hoped that the few brief comments following will assist in the correction of this common fault.

The ventilation scheme of the power house is dependent upon the ventilation scheme of the generators; therefore, before completing his design the architect should first ascertain from the manufacturer the size and location of air inlets and outlets and the quantity of air required by each generator. In order to dissipate the losses most effectively provisions must be made for the passage of a definite quantity of cool, clean air through the generators, and the design of the generator room should be such that all of the heated air can pass on readily to the outside. Generally speaking, hydro-electric stations require no special provisions for cleaning the air other than a coarse screen over the air intake to keep out large objects. Air intakes can usually be located over the tail race where the air is most likely to be free from dust and dirt. An arrangement whereby part or all of the heated air can be made to re-enter the generator and heat the station in cold weather should also be made.

No one arrangement is suitable for all types of machines; therefore the following examples are given.

### Slow Speed Vertical Machines

The principal difficulties encountered in the ventilation of large slow speed, vertical type, alternating current, revolving field generators are:

1st. To design a rotor with sufficient fan effect to draw the required amount of air from the pit and force it through the stator.

2nd. To make arrangements whereby air ducts of sufficient cross section can be introduced into the wheel pit.

These difficulties are overcome either by providing forced ventilation, or by using generators having more material (iron and copper) than is customary. The dividing line where forced or natural ventilation should be used is not at all definite; therefore, with all slow speed generator installations comparative costs and efficiencies of installations suitable for each scheme should be carefully investigated before a decision is made.

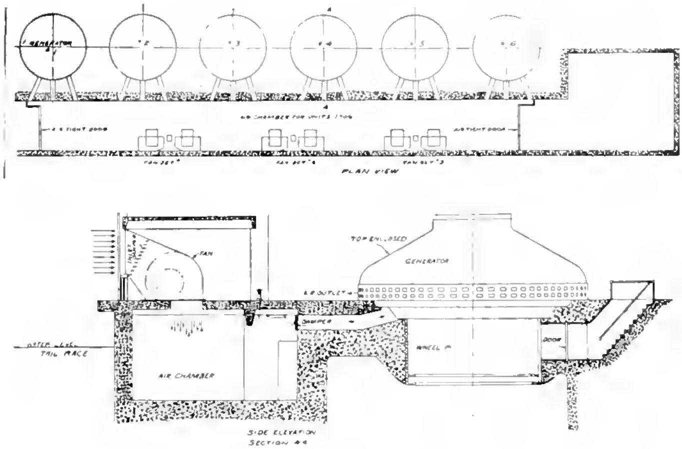

Fig. 1. Plan and Sectional Elevation of Ventilating System for large horizontal slow-speed generators

The following rather complete description of the arrangement being provided by the Cedars Rapids Manufacturing & Power Company for the ventilation of eighteen 10,000 kv-a., 53 r.p.m. generators will serve as a suitable example for machines of this type. Fig. 1 shows a sectional and plan view of the installation. It will be noted that the limited distance between the concrete scroll case of the water turbine and the floor level affords very little space for air ducts into the wheel pit.

The layout is so arranged that every six units have a separate ventilating system. Each system is provided with three blowers which take air through the tail race wall of the power house and discharge it downwards into a large air chamber. The air passes through ducts which lead through the concrete substructure of the power house from the air chamber to the wheel pits and then on through the generator out into the room. A screen of about ⅛ in. square mesh is placed in the blower inlets, and as the air will be free from dust and dirt no further provision for cleaning is made.

Each generator requires a maximum of 35,000 cu. ft. of air per minute. Two of the blower sets have sufficient capacity to supply the required amount of air for six generators, the extra blower acting as a spare. Each fan inlet is equipped with a damper which controls the admission of air, and an automatic shut-off damper is provided on the discharge so that when one fan is shut down no leakage can occur through the fan from the air chamber. The amount of air supplied to each generator is regulated by dampers in the ducts leading from the air chamber to the wheel pits, and these dampers are operated from the generator floor. The air velocity through the ducts is 1875 ft. per minute maximum; 2000 ft. per minute is not considered excessive for forced ventilation. The entrances to the wheel pits are provided with air-tight doors and the pressure in the wheel pits will be approximately 1 in. water, just enough to insure a positive air passage through the generator.

The fans are driven by slow speed induction motors, the power required being approximately 50 h.p. per fan, or 100 h.p. for a generator capacity of 60,000 kv-a. In cold weather the temperature of the station can be controlled by opening the doors to the wheel pits and shutting down one or both fans.

The generators are equipped with temperature exploring coils located in the hottest places and connected to temperature indicators on the switchboard so that any danger of overheating the machines can be avoided.

### High Speed and Moderate Speed Vertical Machines

Vertical alternating current revolving field generators, having sufficient fan effect to draw the required amount of air from the wheel pit and force it out through the stator, afford a very convenient arrangement for ventilation. Fresh air is drawn from the outside through ducts into the wheel pit. The velocity of the air in the ducts depends upon the speed of the generator and upon the length and number of bends in the ducts. The ducts should be made as straight and large as the station will permit in all cases, and where bends or changes in cross section are necessary, they should be made as gradual as possible. With ducts of average length and straightness, air velocities of 1000 ft. per minute for the moderate speed machines and 1500 ft. per minute for the higher speed machines are not excessive.

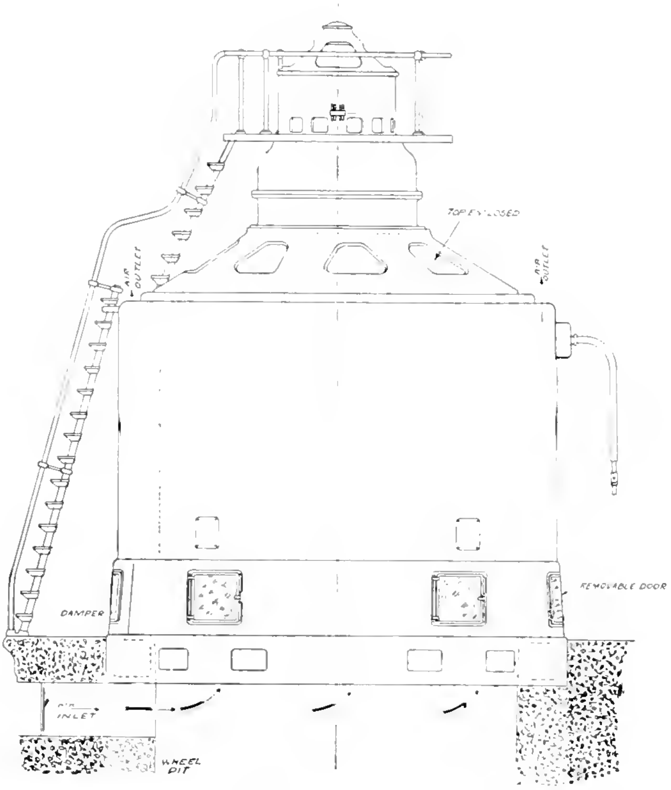

Fig. 2. Elevation of a Moderate or High Speed Vertical Generator showing the path of the ventilating air

Fig. 2 shows the arrangement adopted by the Utah Power & Light Company for ventilating two 12,222 kv-a., 514 r.p.m. generators; the arrangement will serve as a suitable example for machines of this type. It will be noted that in this case removable doors are provided on the base of the generator so that in cold weather the temperature of the generator room can be controlled by adjusting the damper on the inlet ducts and removing part, or all, of the doors in the base as desired. The generators are provided with temperature indicators to prevent overheating.

### High Speed and Moderate Speed Horizontal Machines

Fig. 3 shows the most convenient and effective scheme for ventilating high and moderate speed horizontal alternating current revolving field generators. The ends of the stator are enclosed by a housing so designed that air can be taken only from the pit below the machine. In this case air enters both ends of the generator and is forced out through the stator by the revolving field. Fans are usually provided on the ends of the field to insure a more positive and definite circulation. The bottom of the stator is enclosed so that heated air from the generator cannot re-enter the pit and be used over again.

The ducts should be arranged so that air can be taken from the outside or from the generator room, or from both, as desired. In general, the same principles involved in the ventilation of vertical machines apply to horizontal machines of this type.

### Other Machines

Many of the smaller and slow speed horizontal alternating current generators do not lend themselves to the convenient arrangement of ventilation described above. This remark also applies to direct current machines. With these machines the ventilation is not positive and the generator room should be so designed that there will not be a tendency for the machines to use the same air over and over again.

The most effective method of preventing this is by introducing cool air through ducts in the floor or basement of the power station, preferably into the pits of the machines, and allowing the heated air to escape through openings in the roof. The size of the inlets and outlets depends upon the losses to be dissipated, the allowable difference in temperature between the inside and outside air and the height of the building, but a good plan to follow is that they cannot be too large.

The maximum difference between inside or room temperature and outdoor temperature should not exceed 20 deg. F. (11.1 deg. C.) during hot weather, since the air entering the machine is taken from the room and the air leaving the machine is considerably warmer than the room temperature. The ventilation scheme should be laid out for most severe or hot weather conditions. It is very important to make the difference in height between inlet and outlet openings as great as the station will permit, as is shown from the following table.

**Quantity of Air in Cu. Ft. Discharged Per Minute through a Ventilating Duct of 1 Sq. Ft. in Cross-Sectional Area. Difference in Temperature of Air in Duct and Outside—20 Deg. F.**

| Height of Vent. Duct in Ft. | Cu. Ft. Per Minute |
|---|---|
| 10 | 153 |
| 20 | 217 |
| 30 | 265 |
| 40 | 306 |
| 50 | 342 |
| 60 | 375 |

The amount of air required for the generating room can be easily calculated, as follows:

One kw.-hour will raise the temperature of 10,000 cu. ft. of air from 80 deg. F. to 100 deg. F., a rise of 20 deg. F. (11.1 deg. C.).

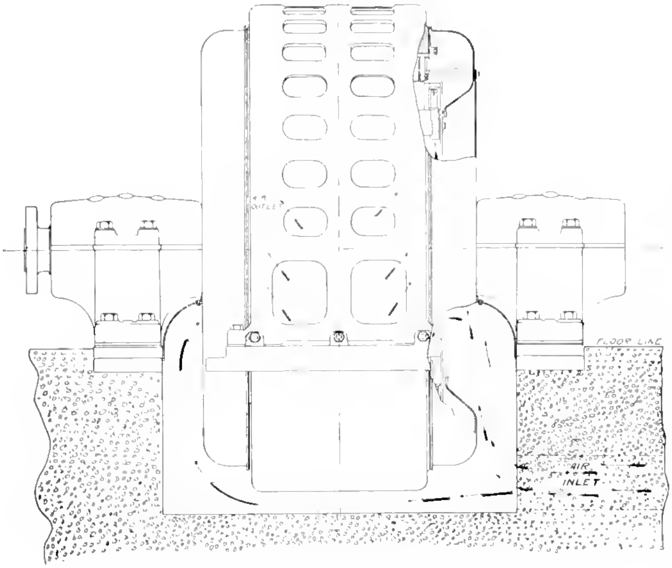

Fig. 3. Elevation of a Moderate or High Speed Horizontal Generator showing a convenient means of ventilation

The total losses in generating room equals (total kv-a. generator capacity) – (total kv-a. generator capacity × generator efficiency).

The total amount of air required for the generator room in cu. ft. per minute equals

$$\frac{10{,}000 \times \text{total loss per hr. in kw-hr.}}{60}$$

The above method will give approximately twice as much air as that required with the forced or positive ventilation schemes shown in Figs. 1, 2 and 3, for the reason that when the ventilating scheme is such that a definite amount of outside air will pass through the machine, a temperature difference of 30 deg. F. to 40 deg. F. (16.7 deg. C. to 22.7 deg. C.) between ingoing and outgoing air is not excessive.

### Existing Stations

Improvement in the ventilation of existing hydro-electric stations can be made economically in many cases. The nature of the improvement depends upon the type of machines and the layout of the station, and each case requires a special study. The following are some of the improvements that have been adopted:

Larger openings in the roof and openings or ducts in the basement or floor.

Fans for supplying outside air and exhausting air from inside where the station does not permit of large openings for natural ventilation.

Humidifiers for cooling incoming air where the amount is limited.

New end housings for generators with external fans for each generator or with suitable duct leading from generator pit to outside, provided the generator has a sufficient fan effect.

Housing the generator in such a manner that the discharged air is carried out of the station through a duct, the generator inlet air being taken from the room.

The object of these improvements is to obtain an increased output from the generating units in cases where the waterwheel capacity is great enough, or to allow the generators to be operated at their rated capacity without overheating and consequent deterioration of the insulation.

In conclusion, good ventilation affords advantages so numerous and important that it is a good policy to give it the most serious consideration in the design of all power stations.

# NOTES ON SELECTION OF SYNCHRONOUS CONDENSERS

By H. L. Unland

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Synchronous condensers are used ordinarily for regulating power-factor directly, or for regulating the voltage by adjustment of power-factor. The discussion of the selection of synchronous condensers for each of these two purposes are dealt with separately in this article. A number of curves are included which, with their accompanying explanations, render the selection of the size of condenser, to be used in a certain installation, a simple matter. The influence upon regulation by the resistance and the reactance of the generator, the transformers, and the transmission line is discussed; and a concrete example assumed for which a set of characteristic curves is derived to show the synchronous condenser capacity required to maintain constant voltage drop. The article concludes with a statement as to the best location for the condenser.—Editor.

H. L. Unland

A synchronous condenser may be defined as any synchronous apparatus, which, when connected to a circuit excited by an alternating current generator, can be made to deliver to the circuit either leading or lagging current, the magnitude of which can be regulated by varying the excitation at the will of an operator.

This definition includes generators, which can be made to carry the exciting current of the circuit by varying the excitation. Such operation is not taken account of in the following which deals only with the use of machines operating as synchronous motors, either with or without load, which, when the excitation is varied, will require either leading or lagging exciting current.

The following discussion will be limited to circuits of not over 50,000 volts and to short transmission lines where the charging current will be small and where the effects of the charging current will be so slight, compared to the inductive action of the circuits, as to be neglected.

The operation of synchronous condensers can be divided into two classes:

First. The regulation of power-factor.

Second. The regulation of voltage by means of varying power-factors.

In the first class of operation the condenser would probably be installed as a portion of the customer's equipment and would, therefore, probably be removed from the control of the power company. Where a condenser is used, however, for regulating the voltage of a transmission line, the condenser will probably be the property of the owner of the line and will be operated as a part thereof, and moreover will probably be controlled by an automatic voltage regulator.

Some operating companies take account of the power-factor of the customer's load in making their rates, and in such a case it is to the customer's benefit to install condenser capacity and thus obtain the benefit of decreased power rates, if, by so doing, the saving in power cost will pay the fixed charges on the capital required, as well as the increased operating charges, due to the installation of such an equipment. Another instance of the value of the correction of power-factor alone would be in case a customer owns the step-down transformers and, due to the natural growth of his plant, the induction motor load had reached the limit of the transformer capacity. The power-factor of the average commercial induction motor load is in the neighborhood of 70 per cent, so that by installing a synchronous motor, which in addition to delivering mechanical power would also furnish sufficient leading current to raise the power-factor of the whole load, the capacity of the plant could be increased by a considerable amount without increasing the transformer or switching equipment. Under these conditions a synchronous motor of 35 per cent of the total transformer capacity will deliver an energy load of 20 per cent of the total capacity and at the same time raise the power-factor of the system to 90 per cent.

The efficiency of a generator is affected by the power-factor, although this variation is greatly modified by the ratio of the constant to the variable losses in the machine. This is determined by the design of the generator. There will be a difference of 2 to 2½ per cent, however, in the efficiency of a generator operating at normal load and unity power-factor, and the same generator operating at the same kv-a. and 0.8 power-factor. The excitation required by a generator when operating at 0.8 power-factor will be in the neighborhood of 50 per cent greater than that required for the same kv-a. at unity power-factor. This rate of increase in excitation does not continue for power-factors below 80 per cent.

On account of the fact that automatic voltage regulators are so extensively used, the regulation of the generator is of relatively little importance, except insofar as it affects the excitation required. In case a regulator is not used, however, where the generator would have a unity power-factor regulation of 8 per cent the regulation at 0.8 power-factor would be from 25 to 30 per cent. This is due to the fact that modern generators are so designed as to have high inherent reactance in order to limit the instantaneous short circuit current.

The capacity of an a-c. generator is measured in kv-a. and with low power-factors the kw. capacity will be decreased with the power-factor. In many cases the prime mover will have sufficient capacity to drive the generator at full kv-a. output at 1.0 power-factor. Since the power sold is measured in kw. any decrease in power-factor really lowers the capacity of the generator, and this reduction in capacity extends also to the prime movers, so that although the machines might be operating at full kv-a. rating at 0.8 power-factor, in reality 20 per cent of the generator equipment is not available. In a steam generating station this extends also to the auxiliaries, such as boilers, condensers, exciters, pumps, etc., which means a very considerable portion of the investment tied up by operating at a low power-factor.

The effects of varying the power-factor on transformers, although smaller in magnitude than the effects on the generator, must be considered since they occur twice, at the step-up and at the step-down transformers. The losses in a transformer with constant kv-a. output are practically the same for any power-factor. The efficiency of a transformer can be written as

$$\frac{\text{kv-a.}}{\text{kv-a.} + \dfrac{\text{losses}}{\text{power-factor}}}.$$

However, since the losses are usually small in a well designed transformer, the decrease in the efficiency, due to decreased power-factor, will decrease about 0.4 per cent with a decrease in power-factor from 0.8.

Due to the fact that transformers contain a certain amount of inductance it is readily seen that lagging current will cause an increase in the internal voltage drop of the transformer and thus will affect the regulation, particularly in the case of large transformers which usually have a high reactance.

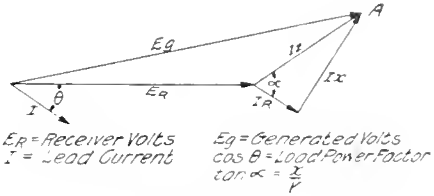

**Fig. 1. Vector Diagram for Circuit having Reactance and Resistance**

The capacity of a transformer decreases with the power-factor in the same manner as in the generating equipment.

In Fig. 1 is shown the general vector diagram for a circuit having reactance $x$ and a resistance $r$ with a current flowing represented by $I$ which lags behind the receiver e.m.f. by the angle $\theta$. It is customary to assume the receiver voltage $E_r$ as constant. The magnitude and location of the vector $E_g$ will then be determined by the vertex $A$ of the small impedance triangle. The reactance drop $(IX)$ is at right angles to the resistance drop $(IR)$ and to the current $I$. For any circuit the angle $\alpha$ has a constant value such that $\tan \alpha$ equals $\frac{x}{r}$. For constant kv-a. and, therefore, constant current the vector $IZ$ will have a constant value, and as the power-factor varies this vector will revolve through a semi-circle, as shown in Fig. 2. The length of this vector will vary directly with the current flowing and, therefore, concentric semicircles can be drawn to show the locus of this point for varying kv-a. loads. The vector $IZ$ at unity power-factor will lead the electromotive force $(E_r)$ by the angle $\alpha$. For lagging current this vector will move in a clockwise direction and for leading current will move in a counter-clockwise direction.

If the kw. output is maintained constant and the power-factor varied, the point $A$ will move along a straight line through the position at unity power-factor, and at right angles to $IZ$ at this power-factor. These lines will then be tangent to the constant kv-a. loci at the unity power-factor point, as shown in Fig. 2.

The only loss in a transmission line, with the exception of the leakage over insulators, which in such circuits as those under consideration can be neglected, is the $I^2R$ loss, which for constant kw. will vary as $\left(\frac{1}{PF}\right)^2$ and for constant kv-a. will remain constant.

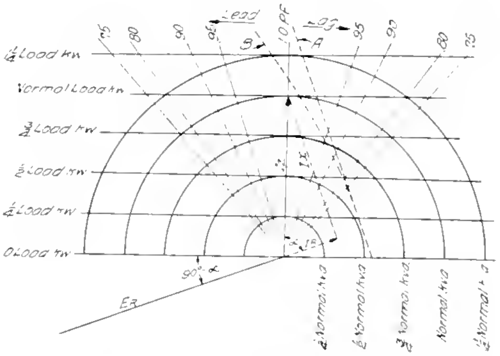

Fig. 2. Loci of Voltage Vectors in Circuit Containing Reactance and Resistance

The efficiency in this latter case, however, will be reduced, due to the fact that the kw. output decreases with the power-factor

The decrease in efficiency, between unity and 0.8 power-factor for constant kv-a. in a circuit, which includes generator, transformers and the transmission line, assuming average values, will be approximately as follows:

| | |
|---|---|
| Generator ............ | 2 per cent |
| Transformers ......... | 0.8 per cent |
| Transmission line...... | 2.2 per cent |

This gives a total of 5.0 per cent decrease in efficiency. The regulation of the system becomes steadily worse with lower power-factors, although the increase varies in different portions of the circuit. This condition results in either greatly increased excitation on the generators or else widely varying voltages at the receiving end of the circuit for varying loads. The capacity of the system for equal heating will be decreased directly with the power-factor. This point is modified, however, in the case of the generator fields, which will suffer an increase in temperature with lagging power-factors, due to the increased excitation required.

The phase characteristics of the synchronous motor are so familiar to all that it will be sufficient to merely call attention to a few points that are of importance in connection with this subject. A representative set of such curves is shown in Fig. 3. For a machine which is to operate as a condenser only, and not to deliver any mechanical output, the no-load curve only need be considered.

It will be noted, by referring to Fig. 3, that the excitation required at full kv-a. output leading with no load on the machine, is approximately twice the excitation required at no-load minimum input or unity power-factor. Such service is usually met with where the machine is to correct power-factor only, since in such service leading current only is usually required. This range of excitation is satisfactory for operation in connection with an automatic voltage regulator, which gives a range of 3 to 1.

In case the machine is required to operate from full kv-a. leading to full kv-a. lagging, the range of excitation is considerably greater, as will be seen from the curves, being for this machine approximately in the ratio of 9 : 1. Such a range is obviously too great for the usual arrangement of the automatic voltage regulator, when applied directly to the exciter field. To meet this special problem a very ingenious and successful arrangement has been developed using auxiliary exciters to automatically control the field of the main exciter on the synchronous machine. Service requiring a range of excitation greater than 3 to 1 is encountered only when a condenser is to regulate the voltage in connection with a high-voltage transmission line having a large charging current.

If a synchronous motor is operated with a varying load and the excitation is held constant, the wattless kv-a. will increase as the load decreases. The variation in the wattless kv-a. under these conditions will be small as indicated in Fig. 4. This curve shows the per cent of wattless kv-a. when a synchronous motor is excited for 0.8 power-factor leading at full load. As the mechanical output is decreased, the field being held

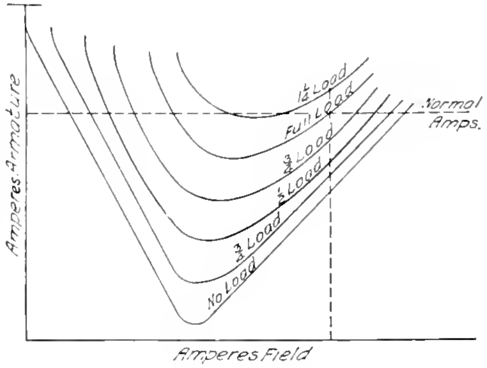

Fig. 3. Phase Characteristic Curves of Synchronous Motor

constant, it will be seen from Fig. 3 that the armature kv-a. decreases, but at the same time the power-factor continually decreases and these two changes tend to neutralize.

The losses in a synchronous condenser will be approximately 4 per cent of the rating for a 1000 kv-a. unit and slightly less for sizes above this. A 200 kv-a. machine will have about 8 per cent losses.

The calculation of synchronous condenser capacity required for correction of power-factor alone is very simple, provided the magnitude and power-factor of the load are known. The well known circle diagram, illustrated in Fig. 5, is very useful for this work and with it sufficient accuracy can be obtained for any practical purpose. As an example, assume a load of 7500 kw. at 80 per cent power-factor lagging. As shown by the curves this corresponds to a total kv-a. of 9375 and a wattless component of 5650 kv-a. Obviously, if it is desired to bring the power-factor to unity it will be necessary to add 5650 kv-a. leading. If it is desired to bring this load to 90 per cent power-factor we find that the wattless component corresponding to this power-factor at 7500 kw. is 3750 kv-a. and this subtracted from 5650 leaves 1900 kv-a. required. If, on the other hand, it is desired to increase the load, keeping the total kv-a. constant, and to obtain a power-factor of 90 per cent, we find that for 9375 kv-a. at 0.9 power-factor, the kw. will be 8400 and the wattless kv-a. 4400. This latter value of wattless kv-a. subtracted from the original 5650 leaves but 1250 kv-a. which must be supplied by a condenser. It will be plainly seen from the above that the condenser calculations depend entirely on what it is desired to accomplish; i.e., whether the power-factor is to be bettered, the actual load increased, or both.

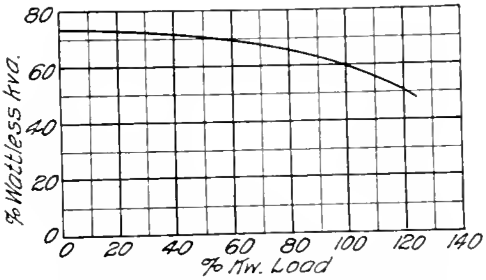

Fig. 4. Relation Between Wattless Kv-a. and Load on Synchronous Motor with Constant Excitation

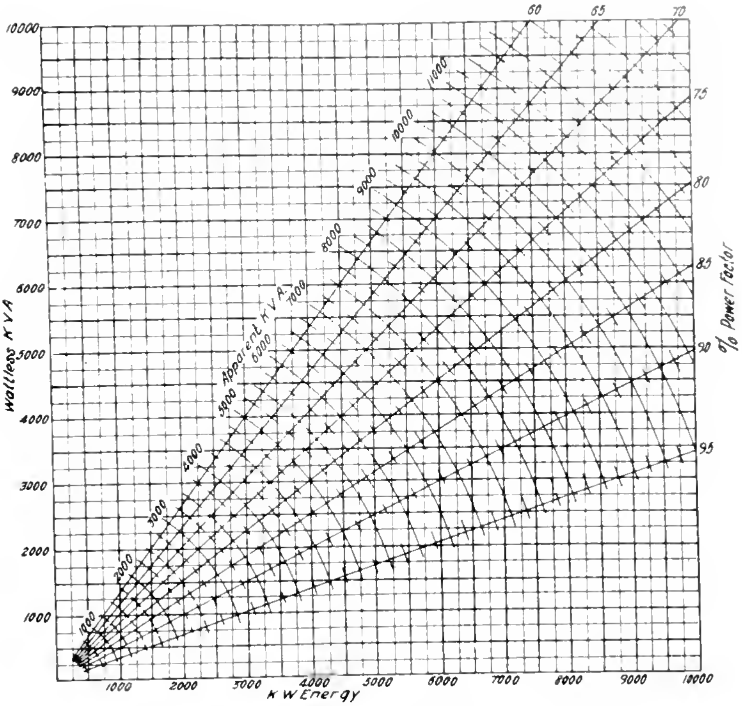

Fig. 5. Relation Between Energy Load, Apparent Load and Wattless Component at Different Power-factors

If accurate figures are not available, in regard to the power-factor and magnitude of the load, the wattless kv-a. of an induction motor load can be estimated for preliminary work. It is well known that the exciting current of an induction motor is practically constant and that the full load power-factor is approximately 80 per cent for 60 cycle motors. Thus the wattless component would be in the neighborhood of 0.6 of the total rated h.p. of the motors which are running. If 25 cycle motors are used the full load power-factors will be approximately 90 per cent and the wattless component will then be approximately 45 per cent of the total rated h.p. of the running motors. These figures vary with the speed, size and type of the motors but can be used for preliminary estimating purposes.

For the above type of service the ideal equipment consists of a synchronous motor which will carry a mechanical load in addition to furnishing power-factor correction. It is not material whether the load on the motor be constant or not, for if the field is excited for the required correction at full load, and the excitation held constant, the corrective kv-a. available will be practically constant as will be seen by referring to Fig. 3.

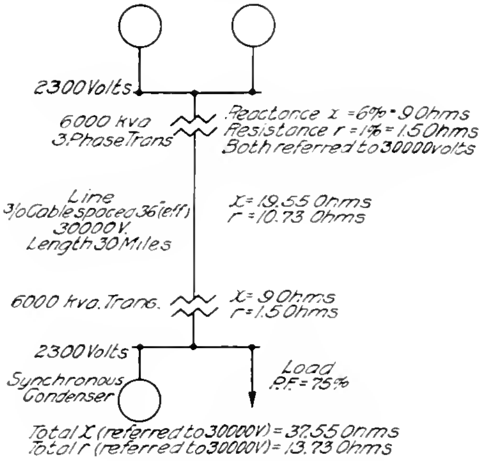

Fig. 6. Simple Transmission Circuit

Where a condenser is required to control or regulate the voltage at the receiving end of a transmission line the capacity of the condenser depends upon the reactance and resistance of the transmission line including transformers, upon the magnitude and power-factor of the load, upon the voltage difference to be held between the generating and the receiving ends of the line, and upon the receiver voltage.

The transformer constants are included in the transmission line for the reason that the voltage at the generator end will be held constant on the low tension buses and, further, the voltage delivered to the load should be maintained constant at the low tension buses at that end of the line. The reactance and resistance of the transformers under ordinary circumstances will in nearly all cases be of about the same magnitude as the resistance and reactance of the line to which they are connected, so that if they are neglected, the voltages actually found on the receiver low tension buses will be considerably different from the expected values. In the following all values of resistance and reactance are the single-phase values or the values from one line to the neutral. These constants for the transformers should be based on the high tension voltage in order to combine properly with the constants of the transmission line. Where a transformer has a certain reactance, for example, *a* per cent, the single-phase reactance in ohms will be given by the expression $\frac{10\,a\,E^2}{K}$. Here $E$ represents the kilovolts between lines and $K$ represents the three-phase kv-a. capacity of the bank of transformers. This formula also gives the resistance in ohms in which case *a* is taken as the per cent resistance.

Referring to Fig. 6, which shows a simple circuit which can be used as a basis for illustrating the calculations, the step-up transformers have been assumed as a 6000 kv-a. three-phase bank. An average value for reactance in power transformers is 6 per cent and for resistance 1 per cent. Using the above formula a value of reactance of $\frac{10 \times 6 \times 30^2}{6000} = 9$ ohms is obtained. These values will apply to both the step-up and step-down transformers. The resistance will then be $\frac{10 \times 1 \times 30^2}{6000} = 1.5$ ohms.

The line as shown is assumed as 30 miles long and consists of 000 cables spaced 36 in. apart. The reactance of the line for these conditions will be 19.55 ohms and the resistance 10.73 ohms.

The approximate formula for obtaining synchronous condenser capacity required to maintain constant voltage drop is given by $I_s = I_w - \frac{V - I_e R}{X}$. In this formula the symbols have the following meanings:

$I_s$ = synchronous condenser current.
$I_{wl}$ = wattless component of the load current.
$I_e$ = power component of the load current.
$V$ = actual voltage difference between generator and receiver.
$R$ and $X$ = resistance and reactance of the line, including transformers.

The above formula can be re-written as follows for a three-phase circuit:

$$K_s = K\left(\sin\theta + \frac{R}{X}\cos\theta\right) - \frac{30\,ae^2}{X}$$

The symbols have the following meanings:

$K_s$ = synchronous condenser kv-a.
$K$ = load kv-a.
$Cos\ \theta$ = power-factor of load.
$Sin\ \theta$ = wattless factor of load = $\sqrt{1-cos^2}$
$e$ = kilovolts between line and neutral.
$a$ = per cent difference in voltage between generator and receiver, expressed in terms of receiver voltage.
$R$ = total resistance of line and transformer in ohms.
$X$ = total reactance of line and transformers in ohms.

The resistance and reactance above are the single-phase or line to neutral values. Using the values as shown in Fig. 6 in the above formula, a set of curves can be drawn showing the relation between kv-a. load and wattless kv-a. required for different values of $a$ or per cent voltage difference. Such a set of curves is shown in Fig. 7, except that instead of kv-a. load this has been multiplied by the power-factor and the kw. values have been plotted instead.

These curves show that without a condenser, at 2500 kw. there will be a line drop of 4000 volts, or 13.3 per cent, and this drop will vary with the load. By adding a synchronous condenser, which will operate between 4300 kv-a. leading and 3200 kv-a. lagging, it will be noted that with 4000 volts drop, the load can be increased to 6000 kw. This drop will be constant for all loads. The dotted curve *B* shows that the power-factor of transmission is very close to unity at 6000 kw. under these conditions.

If a lower value of voltage difference is desired the condenser capacity can be obtained from the curves corresponding to the voltage desired.

The formulæ used above are based on the assumption that there is a straight line relation between the wattless kv-a. and the load. This is not strictly true, as will be understood by referring back to Fig. 2. The dotted curve *B* represents the locus of the generator voltage when held constant. The formulæ used above are based on the assumption that this curve coincides with the straight dotted line *A*.

The distance between these two lines is only a small portion of the generator voltage but is a relatively large fraction of the voltage which must be taken care of by the condenser. The effect of this variation from a straight line relation is shown by the dotted curve *A* in Fig. 7. At 6000 kw. load there will really be required 5000 kv-a leading, whereas the straight line curve would indicate only 4300, making a difference of 16 per cent. The difference in the generator voltage corresponding to this would be only 2 per cent, or if the condenser kv-a. indicated by the straight line were used, instead of obtaining 4000 volts drop at 6000 kw., this would increase to approximately 4600.

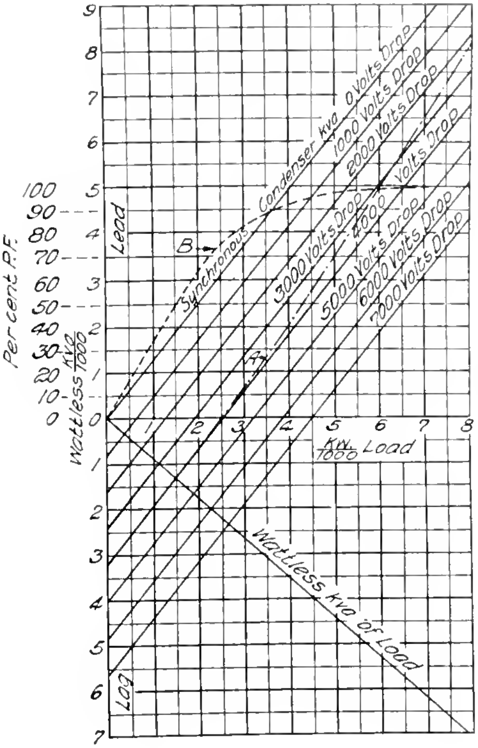

Fig. 7. Synchronous Condenser Capacity Required to Maintain Constant Voltage Drop in the Circuit Illustrated in Fig. 6

If the transmission line only were considered in the above and the transformers not included, the voltage drop for 4500 kw., at 0.75 power-factor would be approximately 15 per cent or 4500 volts—without any condenser being used. The difference between this value and the drop of 7000 volts shown in Fig. 7 represents the drop due to the transformers and in this instance is about 8 per cent which is obviously too great to be neglected.

If the synchronous motor for this service is required to carry an additional mechanical load, care should be taken to see that it does not receive a sudden heavy load while running with a weak field. In such a case it is obvious that there is great danger of the machine falling out of step. Even though the load might not be suddenly applied, the machine might drop out of step if the field is weakened to an undue extent.

For such operation as the above the condenser must be able to deliver both leading and lagging current. If it is satisfactory to have the voltage high at no load and drop with the load, until the desired voltage is reached, then remain constant, the condenser only need deliver leading current. The regulator can have a stop arranged to only allow it to operate when the voltage tends to fall below the desired value.

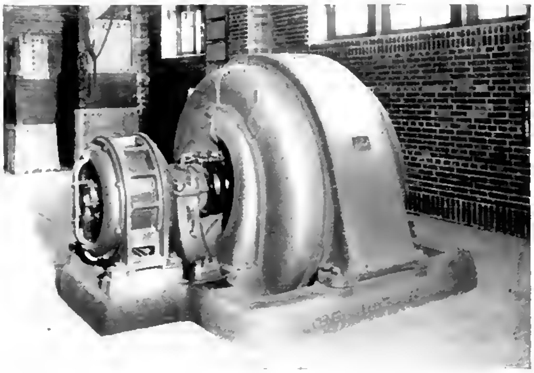

Fig. 8. 1000 Kv-a., 2100 Volt Synchronous Condenser with 35 H.P., 2100 Volt Starting Motor

In addition to improving the voltage regulation of the line the addition of condensers will, in most cases, bring the power-factor very nearly to unity at full load, which will make the losses a minimum and at the same time make available the full capacity of the equipment.

A synchronous condenser which will only be required to deliver leading current will cost approximately 15 per cent less than a synchronous motor having the same continuous rated capacity. If the condenser must deliver both leading and lagging current, the cost will be practically the same as a synchronous motor of the same rated capacity. However, such a condenser will deliver full kv-a. lagging and full kv-a. leading which really amounts to condenser capacity of twice the rating. Thus, if it is satisfactory to have the voltage vary with light load as described above, the first type of condenser can be used at a reduced cost. This also refers to the use of a condenser for power-factor correction only.

In the example just noted relative to voltage control, the addition of 5000 kv-a. in condenser capacity made possible an increase of 3500 kw. in power capacity of the system.

It is thus seen that by the investment of a relatively small amount in the condenser, a much larger amount, represented by the prime movers, generators, transmission line and transformers, is made available. In addition the operating efficiency of the entire system is very largely increased.

This assumed case may apparently be favorable to the use of a synchronous condenser but no attempt has been made to select such values. At any rate it merely emphasizes the possibilities of the use of such apparatus.

For any such installation which may be under consideration the matter should be brought down to a dollar and cents basis, if possible. The cost of the new apparatus should be balanced against increase in capacity. Increased operating costs should be balanced against increase in efficiency, and a comparison should be made of the service with and without the condenser.

In general a synchronous condenser will have the most effect and therefore, will be of the greatest value when it is installed at the same point as the load since in this case it benefits all apparatus between itself and the generator. A further gain is obtained by driving a mechanical load in addition to the corrective action of the condenser.

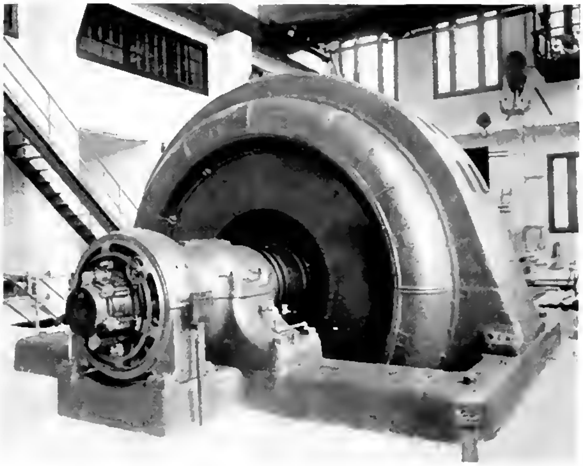

Fig. 9. 15,000 Kv-a., 6600 Volt Synchronous Condenser with Direct-connected Exciter

# PHASE ADVANCERS

By L. F. Adams

Power and Mining Engineering Department, General Electric Company

The following article introduces the subject of phase advancers by a statement of the need of the device and a very brief history of its development. Next is described the construction of the phase advancer, the connections employed in its application and its operation under different conditions. Some numerical examples are then given to show the benefit that is to be derived from the installation of one of these machines, and curves are included which show the effect that these devices have upon the characteristics of the induction motors to which they are connected. The remainder of the article is devoted to a discussion of the commercial views that have been taken of these power-factor improving machines.—Editor.


**L. F. Adams**

As early as 1891 the idea of using paper condensers for providing idle leading current to compensate the idle lagging current due to self-induction in alternating current systems was proposed. However, no real progress was made toward practical applications; conditions then changed and the subject was dropped. For a long time, in many cases, the capacity of the cables in distribution systems provided sufficient compensation.

The great growth in the use of induction motors in recent years has made a marked difference so that now in many cases there is a real need for an improvement of the power-factor in supply systems. The importance of a good power-factor, for various reasons, is very generally recognized, such as keeping down the loss in the lines and increasing the useful output of generators and reducing their cost.

The most commonly used method for improving the power-factor of a system is to install over-excited synchronous motors, converters or synchronous condensers. Paper condensers have had some but not an extensive application. It is the object of this article to give a short explanation of the principles involved and a description, together with the application, of a new type of machine called the phase advancer for improving the power-factor, which is applied to the individual induction motor.

In the synchronous motor the magnetizing field is produced by a rotating magnet excited by continuous current, the frequency being zero. This field is in the secondary winding of the motor. By supplying more continuous current turns than are necessary to produce the magnetic field in any particular machine, it is possible to create in the system a leading current, which will compensate for a lagging current in another part of the system and produce unity or even a leading power-factor.

The phase advancer stands in the same relation to an induction motor as an exciter does to a synchronous motor. However, for the induction motor, continuous current can not be used for the magnetizing current in the secondary because the motor slips under load. The magnetizing current must be a polyphase current of low frequency which corresponds in each instance to the slip of the induction motor.

The phase advancer consists of a continuous current drum armature with a commutator having three brush studs per pair of poles displaced relative to one another by 120 electrical degrees. The stator merely consists of a frame with the laminations assembled but having no slots or windings, see Fig. 1.

The phase advancer is direct connected to a small squirrel cage constant speed induction motor. The power necessary to drive the phase advancer is only that required to supply the friction, windage and hysteresis losses and is therefore comparatively small, i.e., about 1 h.p. for a 600 h.p. 2200 volt induction motor. The copper losses are provided by the main induction motor rotor.

A simple scheme of connections is shown in Fig. 2 where *A* is the induction motor; *B* the phase advancer, direct connected to its driving motor *C*; *D* a standard controller and resistance for starting; *E* a two-pole single-throw short circuiting switch; and *F* a transformer and fuses if the supply source should be of high voltage. The switch *E* is used to short circuit the phase advancer when starting the induction motor *A*, which is accomplished in the usual way by the drum controller. The motor *C* is started, and after the motor *A* is up to speed the switch *E* is opened.

Consider for a moment that the phase advancer is standing still and is receiving current at slip frequency from the slip rings of the induction motor. The phase advancer under this condition acts as a three-phase choke coil, the currents producing a field which revolves in space at a speed corresponding to the frequency of the currents supplied to the brushes. The vector diagram, Fig. 3, shows the phase e.m.f. *E*, at the brushes and the current *I* fed to each brush in which *RI* is the component to overcome resistance and *XI* is the component to overcome the e.m.f. produced by the revolving field (i.e., the e.m.f. of self induction).

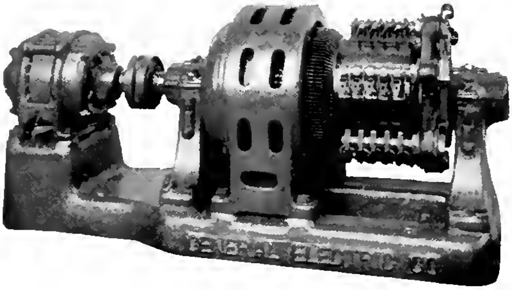

**Fig. 1. Rotary Phase Advancer, 11 kv-a , 520 amp., 12 volts. Driven by 1 h.p. 440 volt induction motor**

Now if the phase advancer is driven in the same direction as that in which the field revolves, the speed of rotation of the field in space will remain unchanged, being independent of the speed of rotation of the armature, because the points at which the currents are led into the winding are fixed in space. Hence when the armature is driven in the direction in which the field revolves and at a speed corresponding to the speed of the field, the relative motion of the field and the armature becomes zero; this is equivalent to the disappearance of the self inductive effect, as is indicated in Fig. 4 which shows the current in phase with the e.m.f.

If the armature be driven at a higher speed than the speed of the field, the *XI* component of Fig. 3 becomes reversed in sign and the vector diagram will be as shown in Fig. 5; that is, the current will lead the e.m.f. This negative reactance e.m.f., in series with the rotor circuit of an induction motor, is able to neutralize the reactances of the induction motor which formerly pushed the primary current into a lagging phase. In this way the condenser effect is produced and the power-factor improved.

It will be recognized that the stationary stator frame in Fig. 1 is not really necessary. The machine then would merely consist of an armature and commutator, but the winding instead of lying on the circumference of the drum would be imbedded in a circle of holes well within the external diameter of the armature so that the iron outside the holes would complete the external path for the flux which passes through the winding. The slow alternating currents supplied from the slip rings of the main motor set up a field which slowly revolves in space while the rapidly revolving armature conductors cut across this field and generate the necessary leading electromotive force. However, the use of the external frame possesses several advantages in that it permits open slots to be used on the armature and enables the commutation to be performed in a thoroughly satisfactory manner.

It will also be noted that the phase advancer can be mounted on or belted to the shaft of the main motor. However, when applied to large motors it is usual and preferable to drive the phase advancer by a small direct connected motor.

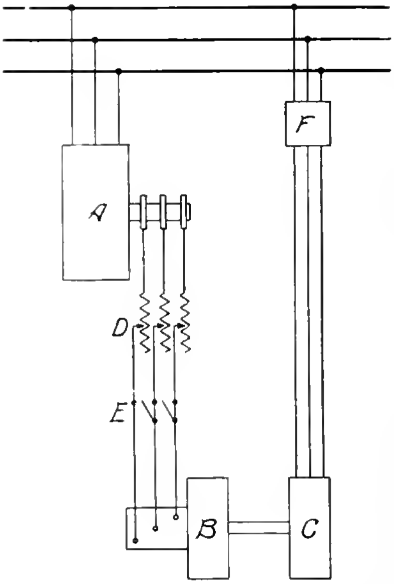

**Fig. 2. Diagram of Connections for applying a rotary phase advancer to an induction motor**

***A*, main induction motor; *D*, starting resistance; *E*, short-circuiting switch; *B*, phase advancer; *C*, phase advancer driving motor; and *S*, transformers and fuses if needed**

The phase advancer can be applied to any induction motor now in service provided it has a wound rotor and slip rings. It can be designed to correct the power-factor to unity or any other desired value from about one-quarter to one and one-half normal load. A new motor designed to work with a phase advancer may be made smaller, that is, an iron machine may be built instead of a copper machine. This results in a cheaper machine but a worse power-factor. This defect is readily corrected by the phase advancer. The saving in cost of the motor itself will go a long way towards paying for the phase advancer. If a very high power-factor is desired it is cheaper to build an iron machine with a phase advancer than a copper machine without a phase advancer. If unity power-factor is wanted the phase advancer is absolutely necessary. A smaller motor has smaller losses so that the power to drive the smaller motor and phase advancer would be in most cases less than that required to drive a large motor without the phase advancer. There is no limit to the size of the motor to which the phase advancer may be applied.

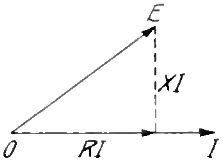

Fig. 3. Vector Diagram showing the current drawn by an induction motor without phase advancer lagging behind the line voltage, i.e., motor operating on a lagging power-factor

Owing to the compensation of the reactance the maximum output of the motor is considerably increased and this is one of the most valuable features of this new design. By the application of a suitable phase advancer the output of an old motor can be increased by 20 to 30 per cent and at the same time improve its power-factor. To secure a high power-factor in machines the clearance between the rotor and stator must be very small, but with the use of a phase advancer to compensate for the power-factor the clearance could be considerably increased.

The phase advancer is intended to be used with induction motors which run continuously in one direction throughout the greater part of the day. If a motor is intended to be started and stopped frequently, reversed, or for variable speed work, the phase advancer can not be used. The most important application of the phase advancer will be to large slow speed motors which have inherently a poor power-factor and to motors which run most of the time at part loads and therefore at a poor power-factor.

An improved power-factor means less copper in the mains, or that the power company can furnish more power from the same size main. Many of the mains in cities are overcrowded and either future customers must be refused or new mains laid. A phase advancer applied to one or two reasonably large induction motors, preferably slow speed, will immediately relieve this condition. As an example, a 30 kv-a. phase advancer is capable of changing the power-factor of a 1300 kv-a. motor from 88 per cent lagging to 95 per cent leading. That is to say, the motor instead of requiring to be fed with lagging wattless current to the amount of 600 kv-a. will relieve the generator supplying the system of a wattless load of 400 kv-a. making a total change in the wattless load of 1000 kv-a. to the good.

Fig 4. Vector Diagram showing the current drawn by an induction motor adjusted by a phase advancer to be in phase with the line voltage, i.e., motor operating on unity power-factor

If the induction motor to which the phase advancer is applied forms a large percentage of the total load on the line then not only is the induction motor improved, but the entire system. To illustrate this we may assume that 50 per cent of the total load consists of small motors with an average power-factor of 75 per cent, the other 50 per cent of a few large motors with an average power-factor of 80 per cent: the total average power-factor would be 78 per cent. If the few large induction motors were equipped with phase advancers and their

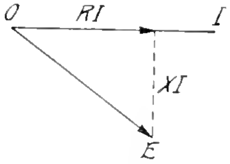

Fig. 5. Vector Diagram showing the current drawn by an induction motor adjusted by a phase advancer to be in advance of the line voltage, i.e., motor operating on leading power-factor

power-factor raised to unity, the total power-factor would be raised to 95 per cent.

Fig. 1 shows a phase advancer as recently built and installed at the Carthage Tissue Paper Company, Carthage, N. Y. The main motor is a 600 h.p. 240 synchronous r.p.m., three-phase, 60 cycle, 2200 volt unit driving a pulp grinder. The phase advancer is rated 11 kv-a., 600 r.p.m., 520 amp. at 12 volts, and is direct connected to a 1 h.p. 600 synchronous r.p.m. three-phase, 60 cycle, 440 volt induction motor. The overall dimensions of the phase advancer set are 60 in. by 22 in. by 27 in. high, and its weight is 1700 lb. The power-factor curves of this 600 h.p. motor operating both with and without the phase advancer are shown in Fig. 8. It will be noted that due to the compensation of the power-factor the line voltage has been increased from about 1980 without the phase advancer to about 2100 with the phase advancer.

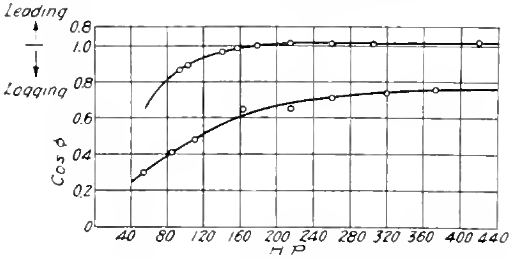

Fig. 6. The lower curve shows the power-factor of a 400 h.p. induction motor when run without a phase advancer. The upper curve shows the power-factor of the same motor with the phase advancer shown in Fig. 7 in circuit

As far as the writer knows this is the only application in this country of phase advancers applied directly to the motor. However, a number of these sets have been installed in Europe and have given very satisfactory results. Fig. 7 shows a phase advancer as built by Brown-Boveri & Company capable of bringing to unity power-factor a 400 h.p. motor. The overall dimensions of the set are 50 in. by 22 in. by 25 in. high and its weight is 750 lb. The power-factor curve of this 400 h.p. motor operating at 160 r.p.m. on 3300 volts, 32 cycles, both with and without the phase advancer, is given in Fig. 6.

Professor Miles Walker in a paper read before the Institute of Electrical Engineers (*Journal of the Institute of Electrical Engineers*, vol. 50, p. 329) gives the following: In a certain mill in the north of England there is a 250 kw. generator which on account of the low power-factor of the motors connected to it is somewhat overloaded. As it would be a rather costly undertaking to install a new generator, the alternative proposition was put forward of connecting a phase advancer in circuit with the rotor of a certain 140 h.p. motor in the mill. It was seen that this at least would help matters, although the capacity of the motor and its phase advancer were not great enough to bring the power-factor up to unity. A 5 kv-a. advancer was installed, with the results shown by the following figures:

TOTAL LOAD ON MILL

| | Amperes per Phase | Volts | Power-Factor |
|---|---|---|---|
| Advancer cut out | 325 | 440 | 0.70 lagging |
| Advancer connected in . . . . . . . | 240 | 440 | 0.92 lagging |

MOTOR LOAD ONLY

| | | | |
|---|---|---|---|
| Advancer out | 105 | 440 | 0.74 lagging |
| Advancer in | 97 | 440 | 0.96 leading |

Whenever the advancer was switched in the voltage of the generator rose from 440 to 470. The figures in the above table were taken after the rheostat had been adjusted to make the voltage normal.

Another case that might be quoted is the case of three 400 h.p. motors installed for pumping water for the Port of London. As the speed of the motors is low the normal power-factor at full load is only 0.55. These machines have been fitted with phase advancers, with the result that they run on a slightly leading power-factor.

The commercial difficulty in applying phase advancers is in deciding who has to pay for them. As practical machines they are completely successful; their commutation gives no trouble and their ability to make an induction motor run at unity power-factor or yield a leading current when desired has been abundantly demonstrated by machines running in commercial service. But, who is to pay the first cost? Motor users can be divided into two classes: First, those who generate their own power, and second those who purchase their power from central stations.

For the first class this commercial problem is readily solved. As this person generates his own power he is evidently deeply interested in his power-factor. This interest not only extends to the power-factor of the system but, as a purchaser of motors, to the individual motors, because every motor with a low power-factor placed on the system means a relatively lower power-factor on the whole system. This class will readily appreciate the value of the phase advancer and in many of these cases in the future we shall see them installed.

For the second class, those who purchase power, the commercial situation on the present basis of tariffs is rather complicated. A large majority of customers purchase power simply on a maximum demand and kilowatt-hour rate. This customer, therefore, is not greatly interested in the power-factor of the motors he purchases and of course is not inclined to spend several hundred dollars in purchasing phase advancers when he can not derive any direct benefit from them. It is true that some slight benefits are derived from the customer's point of view, such as increased output and probable slight gain in efficiency, but these, in themselves, are not sufficient to warrant the initial cost of installing the extra apparatus. In some cases power companies insist that a motor must have a certain power-factor or better and frequently offer their customers a better rate for keeping their load at a high power-factor. As it is to the interest of the power companies to maintain a high power-factor on their system, they must recognize that a customer with a power-factor of unity deserves a much better rate than one with a power-factor of 0.70.

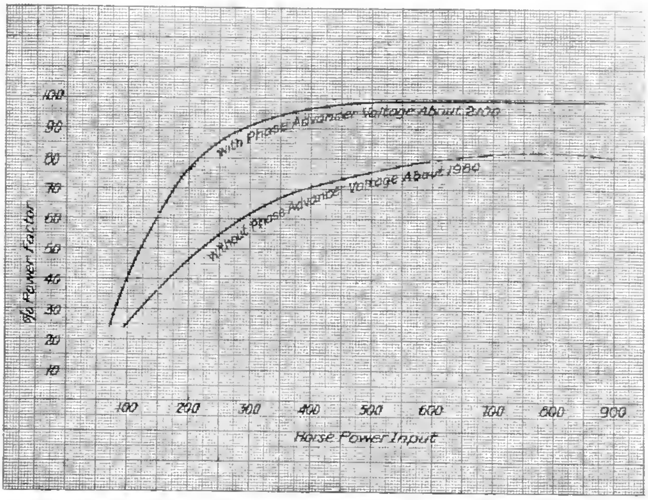

Fig. 8. The lower curve shows the power-factor of a 600 h.p. induction motor when run without a phase advancer. The upper curve shows the power-factor of the same motor with the phase advancer shown in Fig. 1 in circuit

Fig. 7. A Rotary Phase Advancer designed for raising the power-factor of a 400 h.p. induction motor

The commercial success of the phase advancer depends upon the inducement given by the power company to its customer for maintaining a high power-factor. The contract might take the form of a bonus which would be on a sliding scale increasing until 100 per cent power-factor is reached. This bonus might be based on the minimum readings of a graphic power-factor meter. Another way would be to charge for the total kv-a. instead of the kw-hr. An investigation, by Professor Arno of Milan and Mr. Conti, engineer of some Italian power companies, made throughout Italy, with respect to working cost as affected by the power-factor showed that the cost to the power company may be expressed by the formula:

$$\text{Cost} = K\int_0^t (aEI\, cos\, \phi + bEI)dt$$

From a very large number of investigations it was found that $a$ will vary a little but not much and that for an average practical value $A$ can be $^2/_3$ and $b$ $^1/_3$. It can be clearly seen that when a customer is taking no wattless current, i.e., incandescent lighting, $\phi = o$ and cost $= {}^2/_3\, EI + {}^1/_3\, EI = EI$. On the other hand if it were possible to take current at no power-factor at all, $\phi = 90°$, the cost would be $^1/_3\, EI$. That is, the customer pays one third of what he would have to pay if the current he took was energy current and not wattless which seems a fair arrangement. By using a meter of this kind the consumer with a good power-factor would get his power at a cheaper rate than one with a poor power-factor.

The actual saving to the power company and what bonus can be allowed the consumer largely depends on the specific circumstances of each individual case. Some idea of the advantages to be gained by installing phase advancers can be formed from the figures that follow which can be taken as a fairly typical case.

Assume a power company supplying alternating current to a factory, the daily average load of which is 2000 kw., and the power-factor of the system 0.75. Take the load factor at 33 per cent which corresponds to 2890 hours for a year. The annual current consumption is 5,780,000 kw-hr., which at eight-tenths of a cent per kw-hr. means a yearly expenditure of $46,240. The power company has to supply, in addition to the energy current for which the customer pays, all the wattless current for which no payment is made. However, this assumption is not entirely true because power companies would make their rate high enough on the kw-hr. basis so as to include the cost of the wattless power. In this particular case the total output of the station is 2666 kv-a. and the power company is supplying 666 kv-a. of wattless current. Now if phase advancers were applied to say three or four large motors aggregating about 1300 kw. and their power-factor raised to unity, it would be possible to improve the power-factor of the whole system to about 0.95 lagging, assuming the average power-factor of these large motors to be the same as that of the whole system. The power company would, therefore, only have to supply 105 kv-a. of wattless current instead of 666 kv-a. and there would be set free for sale 561 kv-a. or 420 kw. at a power-factor of 0.75. If this is sold to another customer at the same rate and under the same conditions as above it would represent a yearly saving of approximately $9710.

It is evident that the power company could afford to allow the customer 10 per cent on his accounts which would mean an annual saving to the customer of $4624 and to the power company of $5086. The initial cost of the phase advancer to the customer would probably be about $4000 which he would get paid off after the first year and his investment in future years nets him an interest of at least 100 per cent. If the power companies will offer such an inducement then not only will they gain but also the customer.

# SPEED CONTROL OF POLYPHASE MOTORS

By F. B. Crosby

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The increasingly complex requirements of industrial demands continually result in the exploitation of many ingenious devices, the true worth of which can only be determined by the test of actual service. Until recently only direct-current motors were available for strictly adjustable-speed drives, although the many advantages of the polyphase induction motor often lead to its adoption in spite of its speed characteristics. Several methods of speed control with their inherent limitations are outlined in this article, and two systems recently introduced in this country for dynamic control of polyphase motors are fully described. Relatively simple auxiliary equipment will give to the induction motor the speed characteristics of the direct current shunt motor; at the same time maintaining high power-factor and overall efficiency and retaining the many well known advantages of the induction motor. The new brush-shifting type motor also is described and its exceptional operating characteristics for certain classes of service explained.—Editor.

F. B. Crosby

However great the scientific or popular interest in a new or novel electrical application only the test of actual experience can demonstrate its real economic value. With this truism in mind it is still safe to say that no more certain indication of such possible value can be found than in the widespread and intelligent interest with which the announcement of such application is received. Judged by this standard, the development of an efficient means of obtaining for the polyphase induction motor the speed characteristics of a direct current shunt motor stands first among recent achievements peculiar to the further application of alternating current motors.

Although of far more recent inception the polyphase induction motor in some one of its several forms has to a great extent replaced the direct current motor in the majority of industrial applications requiring constant speed drives. The well known form with a squirrel cage rotor is essentially a "constant" speed machine, that is, the speed varies from synchronism but a few per cent with extreme changes in load, and remains constant so long as the load is unchanged. The squirrel cage motor, however, will develop full load torque at starting only when permitted to draw excessive current from the line and save in exceptional cases with special high resistance rotors, it should not be employed where high starting torque is required. For such service the phase wound rotor with external starting resistance is recommended. This form of motor will develop any required starting torque up to its maximum depending only upon the amount of external resistance in series with its secondary or rotor circuits, the line current being approximately proportional to the required torque. With the external resistance short-circuited, the phase wound rotor gives practically the speed characteristic of a squirrel cage motor, but with resistance in circuit its speed characteristic may properly be designated as "variable," that is, the speed becomes a function of the secondary resistance and the counter torque of the load.

Generally speaking, the ideal machine for industrial applications would be one in which high efficiency and high available starting torque were combined with high running torque and strictly adjustable speed characteristics. The term "adjustable" speed as opposed to "constant" and "variable" is used to cover speeds practically *constant* at *adjustable* values for all loads. This ideal has not yet been fully realized in any single unit.

In the meantime, because of the many advantages of a-c. generation, distribution and application as compared with systems involving either d-c. generation or transformation, the industrial public has largely accepted the occasional compromise in speed or efficiency required by the adoption of the simple and rugged polyphase induction motor. Except for certain applications where a large number of strictly adjustable speeds must be had and consequently where, until recently at least, direct current motors must be used, the induction motor has outdistanced all other types in the contest for reliability and popularity.

With characteristic endeavor to overcome the limitations and improve existing designs electrical manufacturers the world over have gone to great expense in a systematic effort to produce a polyphase motor which would successfully compete with the direct current motor in adjustable speed service. For larger capacities and with limitations discussed below the solution of this important problem has been found in a system of dynamic regulation first exploited abroad by Brown, Boveri & Co., but recently modified and developed by the General Electric Company.

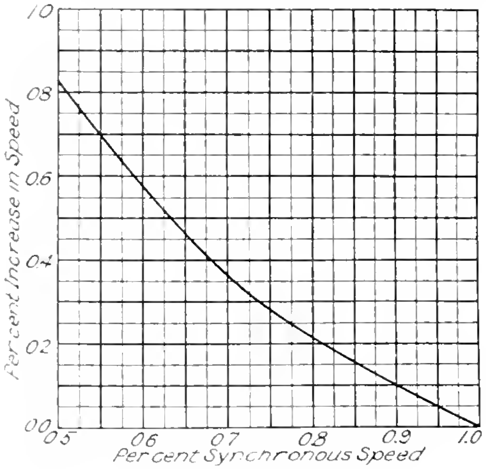


Fig. 1. Curve showing Increase in Speed Due to Diminished Torque

Before discussing this system of speed control it may be well even at the risk of some tiresome repetition to review briefly several methods of speed control for polyphase motors which in the past have proven a more or less satisfactory compromise for the strictly adjustable speed obtainable with dynamic control. Among the more important schemes used are the following:

I. Rheostatic control.
II. Multi-speed windings.
III. Concatenation or cascade.
IV. Internal concatenation.
V. Dynamic control.
VI. Brush shifting motors.

## I. Rheostatic Control

As noted above, the polyphase induction motor when operated with negligible secondary resistance is inherently a constant speed machine. Continuous speed control under constant load can be had by means of an adjustable resistance in the external secondary circuit.

If this external resistance and load each remain constant the speed also remains constant, but any change in either load or resistance produces a corresponding change in speed, the motor tending to accelerate to synchronism as either the load or resistance is reduced. Within a limited range the speed can be maintained approximately constant by increasing either one of these factors as the other is reduced or vice versa, but from a practical standpoint the size and cost of a resistance capable of maintaining any appreciable speed reduction under light loads is prohibitive. This series speed characteristic is of great importance in connection with the effective application of flywheels where a material drop in speed must be obtained in order to render available a portion of the stored energy of the rotating parts as the peak loads come on. On the other hand, it makes rheostatic control wholly impracticable for variable loads at reduced speed such as occur, for example, in the main roll drives in steel mills.

Fig. 1 shows the increase in motor speed corresponding to several initial speeds when the load is suddenly changed from 1¼ to ¼ full load torque without changing the external resistance.

The most serious objection to reduced speed operation for any considerable period of time lies in the fact that with rheostatic control the efficiency is reduced almost in direct proportion to the reduction in speed. For example, if a motor, Fig. 2, is to deliver constant torque from full to half speed the motor input will be constant, but at half speed the efficiency will be something less than 50 per cent, since the h.p. output at the shaft is but half that at full speed with the same electrical input. The relation of rheostatic losses to shaft output for several characteristic types of service is shown in the following table to be constant.

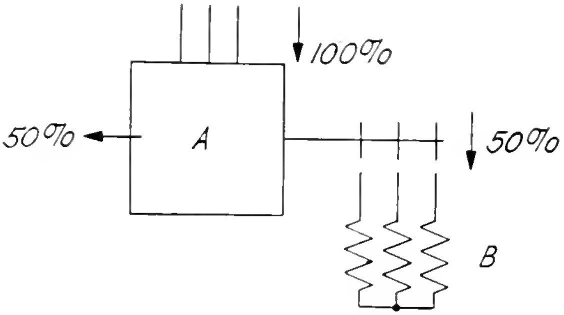


Fig. 2. Diagram of Induction Motor with Rheostatic Control

RELATION OF SHAFT OUTPUT AND RHEOSTAT LOSSES

I. Constant torque.
II. Constant horse power.
III. H.p. inversely as the $n^{th}$ power of speed.

| For any value of $s$ | I | II | III |
|---|---|---|---|
| Torque | $T$ | $\frac{T}{1-s}$ | $(1-s)^{n-1}T$ |
| Shaft h.p. | $(1-s)$H.P. | $HP$ | $(1-s)^{n}HP$ |
| Rheostat h.p. | $s\,HP$ | $\frac{s}{1-s}HP$ | $s(1-s)^{n-1}HP$ |
| or Rheostat h.p. | $\frac{s}{1-s}\times$shaft $HP$ | $\frac{s}{1-s}\times$shaft $HP$ | $\frac{s}{1-s}\times$shaft $HP$ |

Where:

$HP$ = rated horse power at $N$ rev. per min.
$T$ = full load torque at $N$ rev. per min.
$s$ = slip or regulation in per cent synchronous speed $N$.
$1-s$ = speed of motor in per cent synchronous speed $N$.

If the part load efficiencies and respective slips with short circuited secondary are known, the efficiency at reduced speed with rheostatic control and constant torque can be found by plotting per cent efficiency against per cent synchronous speed. A straight line drawn from 0 to the point corresponding to known values of part load efficiency and slip will give the efficiency at any desired speed.

It is evident then that there are two very serious objections to the operations of the standard induction motor with a phase wound rotor and rheostatic control, first due to the effect of the series speed characteristic under varying loads, and second, due to the excessively low efficiency when operated over considerable time intervals at reduced speed and constant load.

### II. Multi Speed Windings

Where two definite constant speeds are sufficient the induction motor can often be supplied with external connections by means of which the polar grouping can readily be changed, Fig. 3, to give the desired synchronous speeds. The cost of such a motor is but slightly more than that of a single speed design provided a 2:1 ratio is used. When a ratio other than 2:1 or where three or four constant speeds are required the conditions can sometimes be met by the use of two independent windings side by side in the same slots, one or both of these windings being arranged for external polar grouping. Three separate windings are not permissible in practical design.

The efficiency of the multi-speed motor is practically constant at full load for each synchronous speed but at the lower speeds the power-factor may become very poor.

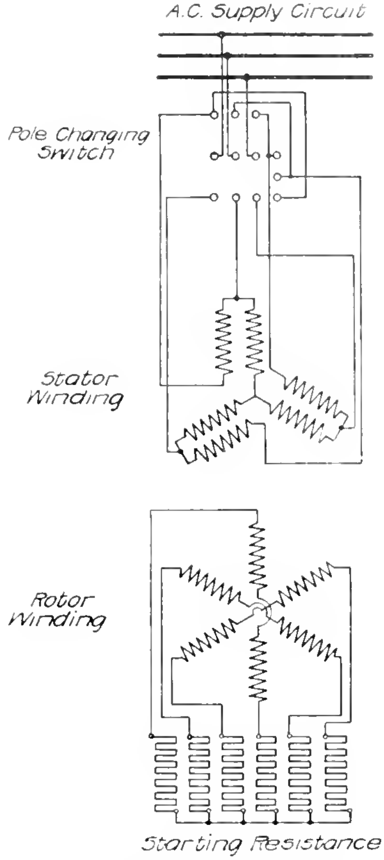


Fig. 3. Diagram of Windings for Multi-Speed Induction Motor

Intermediate speeds can be had with phase wound rotor construction but always subject to the disadvantages noted.

### III. Concatenation or Cascade

Where three or more synchronous speeds are necessary a method involving segregated electrical and magnetic circuits is sometimes employed. This arrangement is commonly known as the concatenated or cascade connection. In general, two single speed motors, one of which at least has a phase wound rotor, are mounted on the same shaft. The primary of motor "A" is connected to the secondary of motor "B." Each of these motors may have either single or multi-speed windings and may be operated independently of the other. The second motor "B" may have either a squirrel cage or phase wound rotor. In the latter case rheostatic control can be employed for intermediate speeds.

Two motors are in direct concatenation if they show a tendency to start in the same direction and in differential concatenation if they tend to start in opposite directions. The several synchronous speeds in concatenation may be determined as follows:

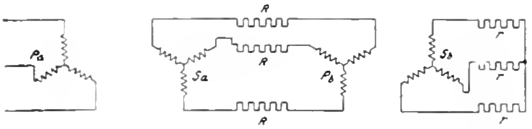


Fig. 4. Diagram of Windings for Concatenated Induction Motor

$$\text{Speed r.p.m.} = \frac{\text{cycles} \times 120}{P_1 \pm P_2}$$

Where $P_1$ and $P_2$ are the number of poles on the first and second motors respectively the plus sign being used for direct and the minus for differential concatenation.

With the multi-speed design mentioned above it is necessary to open the primary circuit when changing from one speed to another: This may be avoided in the concatenated set by introducing resistance, Fig. 4, between the two motors and cutting out step by step when changing speeds. Efficiency and power-factor characteristics do not differ materially from those of the multi-speed motor.

Fig. 5 shows a 600 h.p. six-speed concatenated motor built by the General Electric Company and installed for steel mill service.

### IV. Internal Concatenation

Another method of obtaining two or three definite speeds has been adapted by the General Electric Company to special industrial applications. This consists of a single motor with an internally concatenated winding so arranged that the magnetizing effect of the single winding is practically the same as would be produced by two separate windings. It is, however, a decided improvement over the two windings ordinarily used, since all coils which in such case would neutralize each other are omitted in the concatenated connection. These coils are grouped together and connected to the collector rings for use only at other speeds.

The scheme of connections is shown diagrammatically in Fig. 6. The stator winding is of the full and half speed type which has been in use for a long while. When the primary of the first element is properly connected with two circuits per phase in multiple corresponding to the number of poles, these circuits are in exact opposition for the number of poles in the second element, and form a perfect path for short-circuiting the secondary of the second element. The stator winding, therefore, carries two currents simultaneously; first, a current from the line at full frequency and, second, an induced current at slip frequency.

A serious limitation to the general application of this motor lies in the fact that the three speeds for a given motor must be in the ratio 1-2-3; on account of mechanical vibration the ratio 2-4-6 can not be successfully used.

By inserting an adjustable external resistance between certain points in the stator winding, variable speed control is obtained for the concatenated connection with the slip rings open-circuited. For the other two speeds an adjustable resistance across the slip rings gives the speed characteristics of the ordinary phase wound rotor.

### V. Dynamic Control

As pointed out in the beginning of this article it has been necessary until recently to resort to direct current motors wherever it was essential that close regulation be maintained for a large number of speeds, each constant under varying loads. Two practical methods of obtaining this much desired result have been in use for several years in Europe. Both are subject to modification, yet are fundamentally the same in that each involves certain auxiliary equipment arranged to transfer the secondary or slip energy taken from the collector rings of the main motor

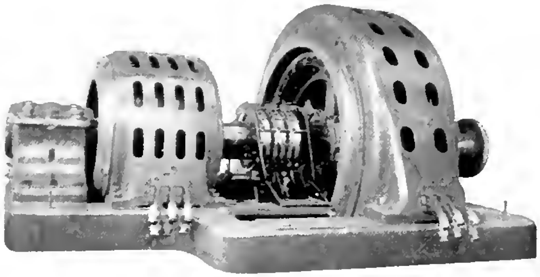


Fig. 5. A 600-h.p , 60-cycle, 514-r.p.m., 2200-volt Concatenated Induction Motor Arranged for Six Synchronous Speeds

at varying frequency and voltage, back to the source of supply at constant line frequency and potential.

These two schemes may be briefly designated as the "rotary converter" and "commutator motor" methods respectively. Both systems were carefully investigated and after very complete factory tests begun at Schenectady nearly three years ago, the General Electric Company adopted the "commutator motor" method, this being by far the more simple of the two systems. The European design has been materially modified and improved to meet the requirements of American practice and will be discussed at greater length below.

The rotary converter method is indicated in Fig. 7. The slip energy of the main motor is transformed in a suitable separately excited rotary converter to direct current which in turn drives a separately excited d-c. motor forming one unit of a two unit motor-generator. The generator is a standard squirrel cage induction motor which is driven above synchronism as an asynchronous induction generator and returns to the system at normal frequency and voltage the transformed slip energy of the main motor. Speed control of the main motor is obtained by varying the field strength of the d-c. motor.

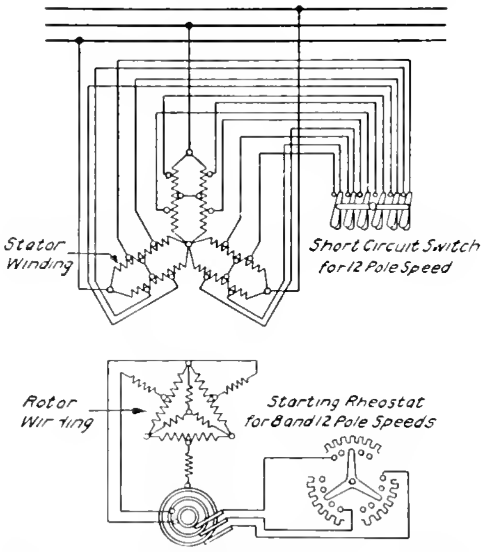


Fig. 6. Diagram of Windings for Internally Concatenated Induction Motor

This method is practically applicable to 60 cycle motors where the range of speed required exceeds 25 or 30 per cent and also for either 25 or 60 cycle motors where the slip energy amounts to 1000 h.p. and upwards. For regulation up to 30 per cent for 60 cycle or 50 per cent for 25 cycle motors the commutator motor method is decidedly preferable.

A point is sometimes made in favor of the rotary converter method, e.g., that standard machines from stock can be used throughout. This is occasionally true for 60 cycle main motors with speed regulation of approximately 30 per cent to 40 per cent, since the maximum slip frequency would be in this case from 18 to 24 cycles, thus permitting the use of a standard 25 cycle rotary. This arrangement compares very favorably with the separate speed regulating set in spite of the fact that a rotary converter and motor-generator are required instead of simply a two unit regulating set.

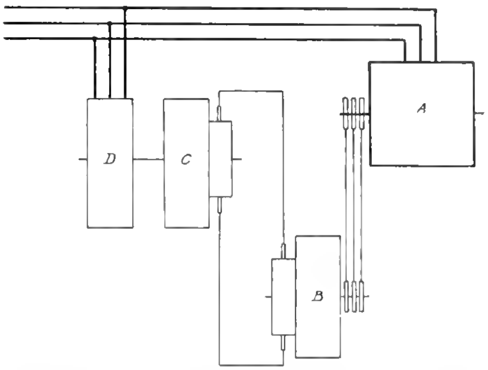


Fig. 7. Diagram of a Rotary Converter and a d-c. a-c. Motor-Generator Arranged for Adjustable Speed Control of Main Induction Motor

For an appreciably greater or less speed range it is probable that the rotary converter would have to be of special design while in case of 25 cycle main motors, which unquestionably include by far the greater number of possible applications, it is certain that to obtain an economical design with high efficiency, a very special rotary converter for operation at slip frequency must be used.

A further limitation of this method lies in the fact that as the main motor approaches synchronism the frequency and voltage impressed on the rotary converter approach zero and operation becomes more unstable at lower slip values than with the regulating set; that is, speeds can not be adjusted as close to synchronism with the rotary as with the regulating set. This point is of special importance in case of low speed motors for 25 cycle circuits.

Theoretically either of these systems will operate equally well for speed control above or below synchronism. By exercising the greatest care the main motor with rotary converter control can sometimes be carried through synchronism by reversing the field of the d-c. motor, provided the rotary converter happens to stop in the proper phase relation when it comes to rest due to reduced frequency and voltage. Its behavior is, however, very uncertain and the only practical method of rising above synchronism involves the use of still another special exciter at this point. Such an arrangement has been tried out abroad and is operative but so far as can be ascertained the results from the standpoint of increased economy of production do not yet warrant the added complexity of equipment.

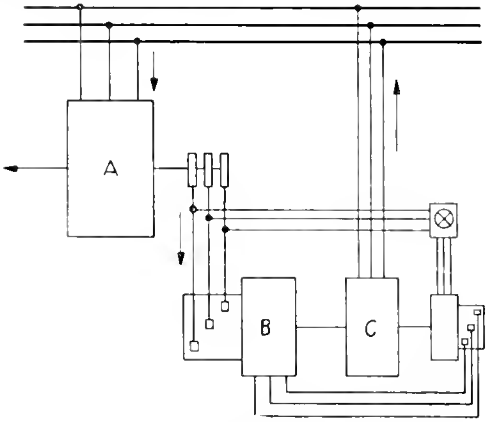


Fig. 8. Diagram of General Electric Speed Regulating Set arranged for adjustable speed control of main induction motor

In passing it is of interest to note that in the fall of 1912 the General Electric Company submitted a formal quotation covering a 2000 kw. rotary and 3000 h.p. d-c. a-c. motor-generator to give approximately 45 per cent speed control of a 6500 h.p.—107 r.p.m., 25 cycle, 6600 volt induction motor already in successful operation. Subsequent developments in the operating conditions rendered speed regulation unnecessary but so far as we can ascertain this was the first and thus far the largest bona fide quotation in this country covering auxiliary equipment for adjustable speed control of induction motors.

Fig. 8 shows diagrammatically the connections of the commutator motor speed regulating set. Referring to Fig. 2, the resistance B, in which the slip energy is dissipated as heat when rheostatic control is employed, is replaced by the three-phase compensated commutator motor B of Fig. 8. This motor forms one unit of a two unit motor-generator the second unit of which is a standard three-phase induction motor with squirrel cage rotor. The series speed characteristic of the commutator motor drives the induction motor C slightly above its normal synchronous speed, causing it to operate as an asynchronous induction generator and return to the system energy proportional to the reduction in speed of the main motor less, of course, the losses in the set itself.

By means of these sets the speed characteristics of the d-c. shunt motor are obtained together with the high power-factor and efficiency at all speeds while the sturdiness, simplicity and general adaptability of the induction motor is retained for the main drive. From what has been said it is evident that the commutator motor receives its energy at relatively low frequencies and in general will have a proportionally small percentage of the main motor capacity. It is also evident that these sets are equally applicable to motors designed for constant torque or constant horse power service. If desired, the characteristics of a compound wound d-c. motor can be obtained and an automatic increase in slip under peak loads when flywheels are used.

A modification of this scheme is shown in Fig. 9 in which case the induction generator is omitted and commutator motor mounted on an extension of the main motor shaft. The general characteristics are unchanged but now the commutator motor must be designed to operate throughout the same range of speeds as the main motor and hence is much more expensive than the former arrangement. This arrangement is particularly desirable where constant h.p. is required at reduced speed since in this case as the speed is reduced the torque of the commutator motor increases in direct proportion. The main motor can therefore be designed for *constant torque* with a very material reduction in cost as compared with the constant h.p. design, and yet, since the slip energy is in this case returned mechanically, the actual total torque increases as the speed decreases and thus maintains constant h.p. at the shaft.

In general, however, the self contained regulating set is quite as satisfactory since both commutator motor and induction generator may be of relatively high speed and inexpensive design compared with the lower speed main motor. Furthermore, the possibility of applying the standard set to practically any normal induction motor with phase wound rotor in the event of a subsequent rearrangement of motor drives is an important advantage.

In Fig. 10 are shown comparative power-factor and efficiency curves for standard induction motors with rheostatic control and with dynamic control. At speeds near synchronism the single motor shows slightly higher efficiency but the margin in favor of dynamic control increases rapidly as the speed is reduced.

In addition to the advantages of adjustable constant speeds under varying loads and high operating efficiency, the possibilities of power-factor correction are often of great importance; if desired unity power-factor can be obtained with all the usual advantages in improved voltage regulation and increased energy capacity in the power system. Unity power-factor correction naturally involves a somewhat more expensive regulating set since the magnetizing current is supplied by the commutator motor instead of directly from the line. The standard set usually has sufficient capacity to raise the power-factor of the main motor about 10 per cent, maintaining at full load an average power-factor of 90 to 95 per cent or in some cases even 100 per cent without increased cost.

In special cases it is entirely feasible to supply sufficient leading current from the commutator motor to give the main motor a leading power-factor and thus obtain a certain corrective effect for power-factor conditions on the external system. The kv-a. capacity, first cost, and copper losses will obviously be increased and the overall efficiency of the system lower in this case.

Contrary to possible impressions the use of these standard regulating sets involves very little additional control equipment. In fact, *so far as the operator is concerned but one single additional act is required in starting or stopping the equipment;* namely, starting the motor-generator set by means of a standard starting compensator.

Automatic magnetic control is used throughout. *To put the equipment in service it is merely necessary to throw first the compensator of the motor-generator and then the master controller to running position. That is all.* The main motor starts; accelerates with current limit, connects the regulating set and automatically drops into a definite speed depending upon the setting of the exciter field rheostat. The desired speeds are obtained by manipulation of this small field rheostat as with a d-c. shunt wound motor.

As the excitation of the commutator motor is increased the tension at the slip rings of the induction motor increases. The current in the secondary of the induction motor is therefore the result first of direct induction between the stator and rotor windings and second of the counter e.m.f. of the commutator motor. The speed-torque and speed-current curves for a given induction motor are fixed by the impressed frequency, voltage and secondary resistance. With these three factors constant there is a definite speed for each value of secondary current and torque. Consequently increasing or diminishing the excitation of the commutator motor produces a corresponding increase or decrease in the speed of the main induction motor. Furthermore, since the excitation is derived from the secondary of the main motor it follows that any tendency to vary in speed, due to varying load, is checked by a corresponding variation in the counter e.m.f. of the commutator motor necessary to supply the required secondary current, or torque, of the main motor.

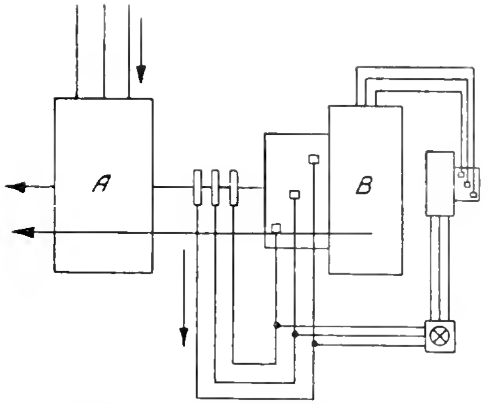


Fig. 9. Diagram of General Electric Speed Regulating Commutator Motor direct connected for adjustable speed control of main induction motor

For the low frequencies involved, the compensating winding of the commutator motor provides practically direct current conditions so far as commutation is concerned. Factory tests have shown absolutely perfect commutation under instantaneous changes from 0 to 100 per cent overloads at 30 per cent regulation with a 600 h.p., 25 cycle equipment.

Eighteen of these speed regulating sets have been sold this past year for use with motors ranging from 250 h.p. to 1300 h.p. for operation on three-phase, 25 cycle and 60 cycle low and high voltage circuits for mine fans and main roll drives in steel plants.

### VI. Brush Shifting Motors

The General Electric Company has also recently placed on the American market a polyphase series brush shifting motor, which for certain classes of service possesses decidedly novel and desirable characteristics. This motor was originally a German invention and for several years has been in successful operation abroad. Its introduction in this country is especially worthy of note in connection with the subject under discussion owing to the simple and efficient means of obtaining speed control. It must not be confused, however, with the commutator speed regulating motor described above as it is entirely different in design.

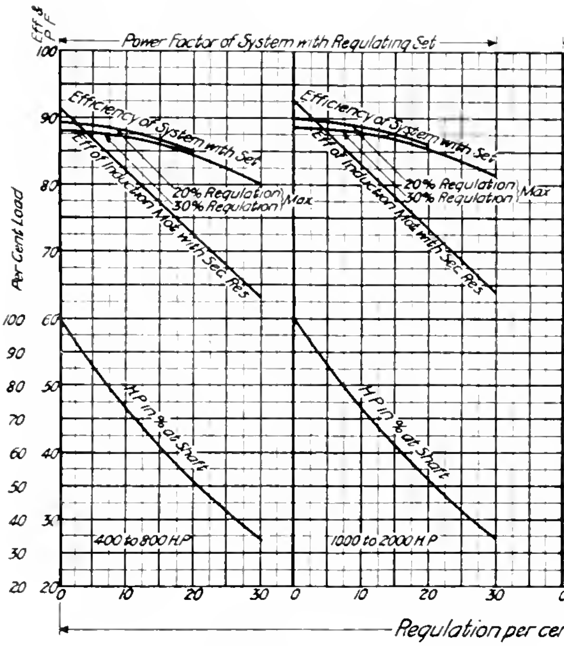
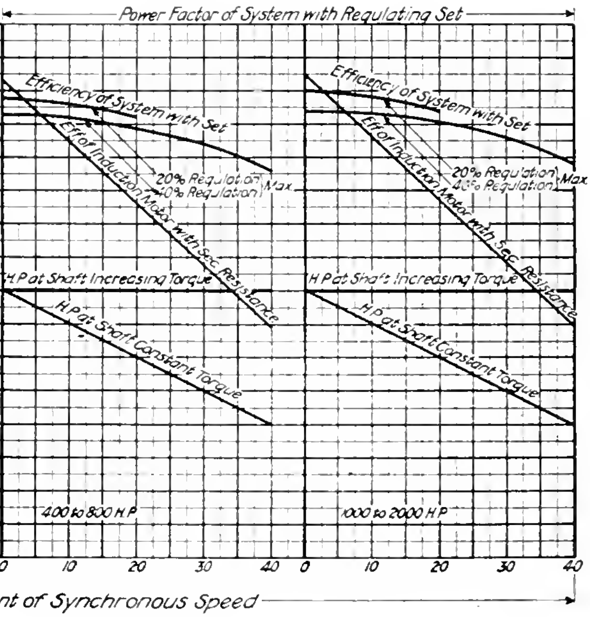


Fig. 10. Over-all Efficiency of Induction Motors operating at different speeds, torque decreasing with speed, (fan service) speed control obtained by speed regulating set and by rotor resistance



Over-all Efficiencies of Induction Motors operating at constant horse power or constant torque at different speeds, speed control obtained by speed regulating set and by rotor resistance

The brush shifting motor although possessing the characteristics of a series direct current motor, has certain marked advantages in the absence of separate control devices, the high power-factor and efficiency, high starting torque, and chiefly perhaps, in the possibility of obtaining such characteristics in an a-c. motor.

The motor consists essentially of a three-phase distributed winding in the stator identical with that commonly used for the standard polyphase induction motor. The rotor is in appearance and design essentially a standard direct current armature with commutator. The arrangement of windings is shown diagrammatically in Figs. 11 and 12. For ordinary commercial voltages the current passes through a triple-pole single-throw disconnecting lever switch and fuses or suitable oil switch with overload and low voltage features, thence through a series transformer *T* to the stator windings *S*. The current from the secondary of the series transformer passes to the brushes *B* and thence into the rotor *R*.

The chief function of the series transformer is to reduce the voltage impressed on the commutator to a satisfactory working value. This usually is approximately 80 to 90 volts and minimizes the danger of sparking at the commutator. If a transformer is employed to step down the primary or stator voltage to suitable values the series transformer can be eliminated (Fig. 11), but in general it is more desirable to retain the customary standard voltages for the stator and employ the series transformer to obtain the desired rotor voltages.

The most striking feature of this type of machine is the complete absence of external starting or speed controlling devices. The motor is started, accelerated, stopped and reversed by shifting the brushes. This shifting is accomplished by means of worm gear and handwheel mounted on the frame of the machine. If desired, a small pilot motor can be used and perfect control obtained from a remote point.

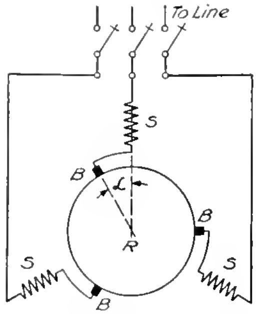


Fig. 11. Diagram of Connections of General Electric Brush-Shifting Motor

Since in effect the total ampere turns in the stator are equal to, and in series with, those of the rotor it is evident that with the brushes set in the same axis as the stator winding, the angle $\alpha=0$ and no field is

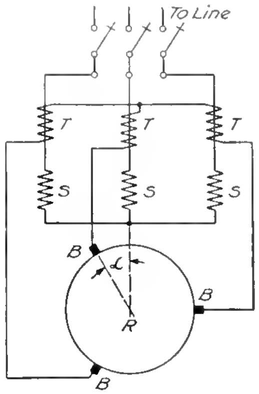


Fig. 12. Same as Fig. 11 Including Series Current Transformer

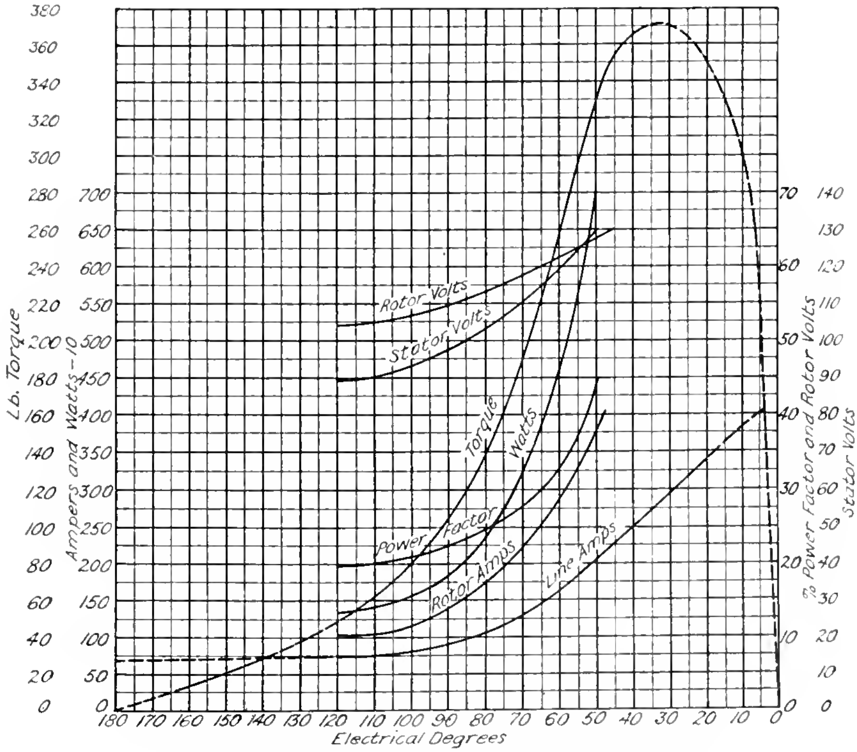


Fig. 13. Characteristic Torque Curves for Standard Brush-Shifting Motor

produced by the line current. If the brushes are now shifted through the angle $\alpha$ the balance between rotor and stator winding no longer exists, and the resultant ampere turns produce an excitation proportional to the current in both windings and to the angle of brush shift. The motor therefore, will develop a torque proportional to the square of the line current and the angle of brush shift. If the angle of brush shift is 180 deg. no torque is developed since the stator field and rotor current are 90 deg. out of time phase. With the brushes in this position, the magnetizing current only, which is about 10 per cent of the normal full load current, is drawn from the line and the main line switch can be closed without starting or in any way injuring the motor. If now the brushes are gradually shifted backward the line current and motor torque increase slowly at first until the motor starts gently. This characteristic is especially desirable in taking up back lash in gear trains or devices where uniform acceleration is important.

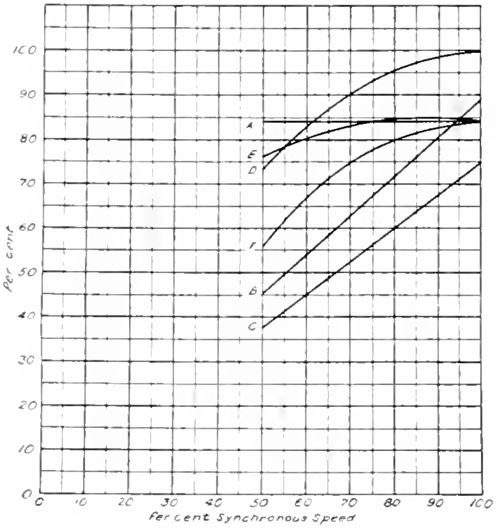


Fig. 14. Comparative Power-factor and Efficiency Curves of brush-shifting motor and induction motor with rheostatic control

| Induction Motor | Brush-Shifting Motor |
|---|---|
| A–Power-factor | D–Power-factor |
| B–Efficiency | E–Efficiency |
| C–Apparent Eff. | F–Apparent Eff. |

As the brush shift is increased the torque curve begins to rise rapidly, as shown in Fig. 13, so that any desired value of starting torque within the limit of the design of the motor in question is available. By actual test some of these motors have started successfully and without appreciable sparking under 400 per cent of normal rated torque. This value, however, is higher than could reasonably be expected in economical design.

By merely shifting the brushes perfect speed control is obtained throughout approximately 75 per cent of the range from rated speed to standstill. In general 40 to 50 per cent speed control is ample and obviously a request for greater range should be avoided unless really necessary as the greater range means a more expensive machine except in certain cases like fan service, where the load falls off rapidly as the speed is reduced.

If the brushes are shifted beyond $\alpha = 180$ deg. the motor will start in the reverse direction. In order to obtain the best commutation, however, it is necessary to interchange two of the primary phases which reverses the rotating field of the stator giving it the same direction of rotation as the armature. Commutation is sparkless from about 10 per cent above to about 70 per cent below synchronism.

The lower speed limit is determined by the torque characteristics rather than by commutation which is very good even to 90 per cent below synchronism. In the higher range of speeds the torque increases rapidly for a given brush shift with any slight reduction in speed, consequently a slight change in the counter torque of the driven device affects the speed but little. The converse is true, however, in the lower speed ranges so that the minimum permissible speed depends largely upon the torque characteristics of the load.

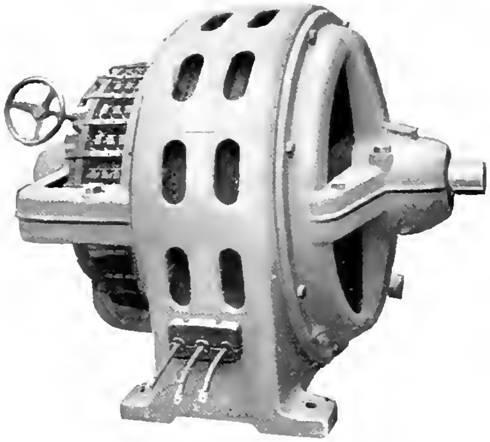


Fig. 15. A 100 H.P., 440-volt Brush-Shifting Motor for Connection to a 100,000 cu. ft. Robinson Mine Fan

For centrifugal fans, pumps, etc., in which the torque falls rapidly, approximately as the square of the speed, stable conditions will obtain even at speeds 70 per cent below synchronism. For load machines offering more or less constant counter torque the lower limit of stable operation is somewhat higher, say about 50 per cent below synchronism.

One of these motors was installed on a cloth printing press and has been in continuous service for more than nine months with most satisfactory results under exceedingly severe starting conditions. Other motors in capacities up to and including 100 h.p. have been in continuous service on mine fans for four to six months night and day with equally satisfactory results.

Fig. 14 shows typical power-factor and efficiency curves for the brush shifting motor as compared with a standard induction motor with rheostatic control.

Fig 15 shows a view of a standard 8 pole, 100 h.p., 375 r.p.m., 440 volt brush shifting motor for direct connection to a 100,000 cu. ft. Robinson mine fan.

Fig. 16 shows typical speed torque curves corresponding to various brush shifts on an 8 pole, 50 h.p., 900 600 r.p.m., brush shifting motor.

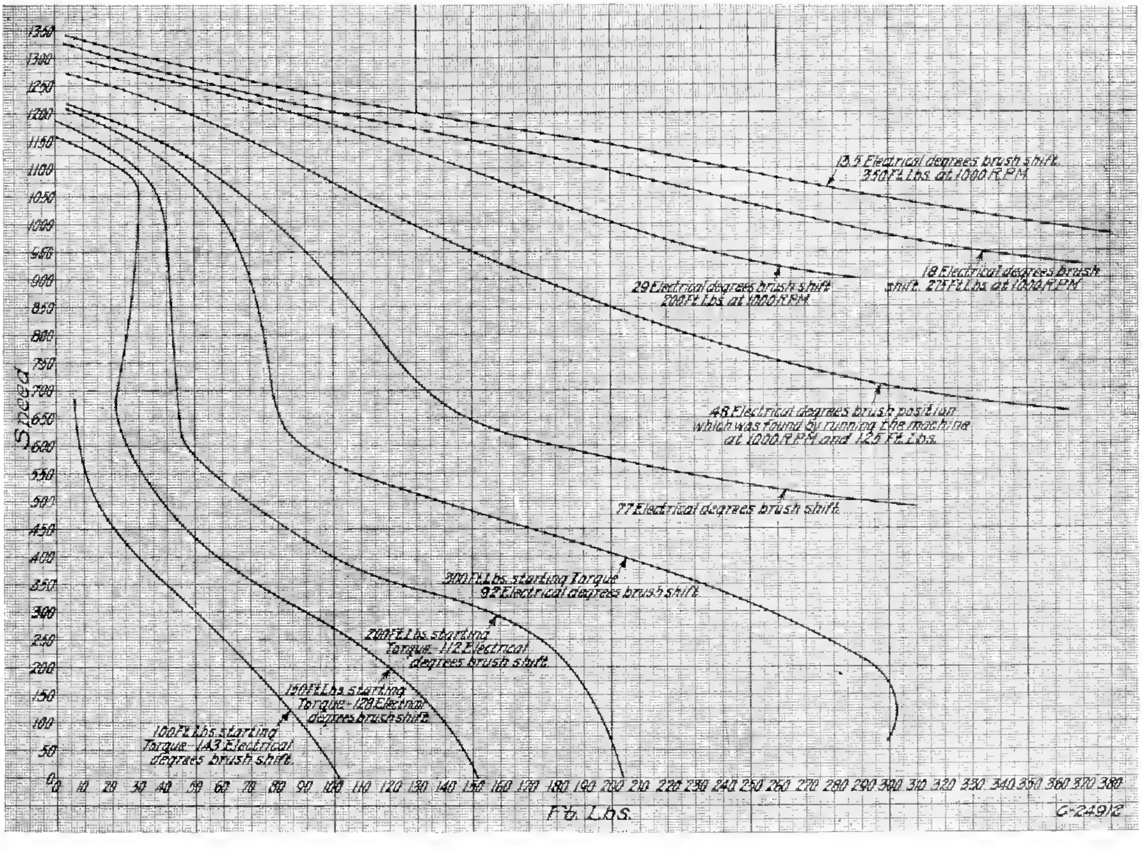


Fig. 16. Typical Torque Curves of Motor for Different Positions of Brush-shift

# METHOD OF DETECTING FAULTS IN TRANSMISSION INSULATORS

By T. A. Worcester

Power and Mining Engineering Department, General Electric Company

The author brings attention to the seriousness of suspension insulator failures which have occurred during the past few years and to the efforts of operating engineers to locate the causes of these troubles and to relieve their transmission lines from the disastrous effects of frequent failures. Studies were made of various possible methods of detecting weak insulators installed on the line before they actually failed by puncture, but most of these methods were found to be unsuitable because of the bulk, weight and cost of the testing equipment. One company adopted a portable megger for this work, and the results of its investigation are given by the author. Other tests made on punctured insulators with a megger are described and the advantages and disadvantages of this class of instrument are discussed. It is pointed out that such an instrument is not suitable for picking out all damaged, punctured or cracked insulators, but that its usefulness is limited to detecting only those in which the surface of the fracture is conducting.—Editor.


T. A. Worcester

During the last few years an unusual number of suspension and strain insulators have failed while in use on high voltage transmission lines. In the majority of cases these insulators had been given standard factory tests and had been in service for a year or two, so that they seemed to be entirely satisfactory. Their failure has occasioned considerable study, which resulted in the belief that there had been a change in the body of the porcelain due to aging or some sort of mechanical deterioration. The failures were so frequent and on some systems resulted in such serious shut-downs that it became imperative to weed out all bad insulators on the lines before additional failures might occur. Usually after an insulator had failed it could be detected by observation either from the ground or tower. Oftentimes, however, the porcelain skirt was not shattered and the defect was concealed under the cap or was in such a position that it could not be easily noticed. In such instances it became necessary to re-apply voltage to the line so as to damage the defective insulator more severely and make the break noticeable. This method frequently resulted in heavy line surging and the breaking down of other insulators on the system which only prolonged the search for the damaged units. The seriousness of this sort of trouble caused operating engineers to investigate the possibility of locating weak insulators installed on the line, before they had actually failed. Various high voltage testing equipments were considered but these as a rule were heavy, costly and ineffective and in general were not adapted to testing insulators on the line. The engineers of one company after careful consideration of other testing equipments turned their attention to the megger which is a megohm meter or a direct reading instrument for measuring high resistances. This type of instrument attracted attention because it is comparatively light and substantial, can be easily carried along a transmission line, and can be readily adapted to testing insulators installed on the towers.

With a portable megohm meter it is practicable to test every disk of the insulators of an entire transmission line in a comparatively short time. The results of such a set of tests are given in A.I.E.E. Proceedings of Feb., 1914, in the report of the Institute sub-committee on transmission. We quote from this report as follows:

"A megger was secured, giving 500 volts, and reading 1000 megohms. The method of procedure was as follows:

"On a single-circuit tower line a party was organized consisting of engineer in charge of the megger and six linemen, working in pairs. One pair would proceed to ground the line on a certain tower and hold the leads of the megger, which consist of about 100 ft. (30.4 m.) of standard lamp cord, to the individual disks in the strings of insulators, by means of two wooden handles. The readings would be taken, whereupon the megger would be taken to the next tower on which another pair of men were ready to go through the same procedure. With this arrangement about four towers per hour could be tested, each tower being provided with eighteen disks.

"On a double circuit line about 26 towers were covered in ten hours.

"The following results were obtained:

"On a total of 2100 disks under observation, fourteen of this number were found defective.

"Twelve disks had defects invisible from the ground, and in two disks the defects were visible from the ground.

"Of the twelve invisible from the ground, two of these could be noted as defective from the tower, four could be detected by very close inspection, after taking down, and six showed absolutely no defect.

"One of these disks, the defect of which was entirely invisible, measured 300 megohms, two measured 250 megohms, and the balance were less than 5 megohms, which was the lowest point on the scale. Good disks were considerably over 1000 megohms."

Two features of this data are especially interesting, first that with a small portable instrument it is practicable to pick out defective insulators which have no visible defects, and second that there is such a small percentage of defective insulators on the line. These are points of considerable importance. As regards the first, operating engineers are given a means of materially improving the insulation of their lines and of greatly reducing the danger of shut-downs which might be caused by punctured insulators. There is, however, a question which naturally arises, namely: Can all weak or defective insulators be detected with a megohm meter? One is apt to think that when an insulator is fractured or punctured its insulation resistance is negligible. This is not, however, always the case. In some instances the path along the fracture is made conducting by the deposition of metal along the surface or of moisture and dirt, but often electrical punctures or mechanical breaks occur which do not cause conducting surfaces. Insulators of this class are immune against discovery with a megohm meter. This leads to the second point mentioned above which had reference to the small percentage of defective insulators found on the line, and makes one wonder if there were not other units in which there were minute cracks or which had been highly strained mechanically so that they were electrically weakened and would puncture easily with excess electrical strain. It is highly probable that there were such units and that these may cause trouble in the future. This marks the limitation of the megohm meter for testing insulators on the line and indicates that this type instrument can not be unconditionally depended upon. The number of defective insulators which may escape in the megohm meter test is possibly small since exposure to moisture will make a crevice conducting and give a low meter reading. On the other hand many breaks occur beneath the metal cap practically out of reach of moisture. Such crevices may become conducting through ionization or the formation of nitrous oxide in the presence of water, but in case there are several suspension insulators in the strings this action will be slow and may not be noticeable throughout a long period.

It is interesting to examine the results on pin insulators with a megohm meter. The writer recently had occasion to observe some such tests on a number of 18,000 volt two-piece insulators which had been in use for some months on an operating system. Six insulators were under observation. They were first punctured by a high frequency test set and then heated up and the puncture enlarged by several minutes run on a 60-cycle circuit. The insulators were provided with iron thimbles cemented in securely. One insulator which showed quite a sizable puncture at the tie wire groove was wrapped with several windings of fine bare wire so that the wire touched the mouth of the puncture. The megger was then applied and showed infinite resistance between the wire wrapping and the pin thimble. The contact between the wire wrapping and the pin was then moistened with a tiny drop of water and the resistance made negligible. Very likely some of this water went into the hole but the quantity was so small that it could not have wet the surface for any great depth. In another instance the puncture took place through the inner shell just above the exposed surface of the cement which held the inner and outer shells together. The mouth of the puncture was in the cement. Contacts were placed on the pin thimble and on the cement 1/8 in. from the mouth of the puncture. Infinite resistance was recorded. With one contact in the thimble and the other on the cement diametrically opposite the puncture the resistance was 2000 ohms. This indicates that the cement contained a considerable amount of moisture and that this moisture had been driven out for a short distance from the puncture by the heat of the current and arc. When contact was made at the mouth of the puncture the resistance was 500 ohms and when a drop of water was placed on the mouth of the puncture the resistance was negligible. These points are important in that they indicate the uselessness of megohm meter tests where the contacts are at any point except the opening of the puncture and where, as is often the case, the surface of the puncture or mechanical break are not conducting.

It has been suggested that a megohm meter would be a valuable instrument for making tests in the porcelain factories on new insulators. From the above discussion, however, it would appear that but little can be gained by such practice. No defective insulators can be detected in this way which cannot be detected by a high voltage test set and in a factory where the latter can be conveniently and permanently installed it offers the best advantages.

It is not meant by the above to in any way discourage the use of megohm meters as a means of detecting poor insulators installed on a line but it is the purpose to point out their limitations and to allay the impression that this class of instrument is suitable for detecting all defective insulators.

# SWITCHBOARD SIGNAL EQUIPMENT FOR POWER STATIONS

By Emil Bern

Switchboard Engineering Department, General Electric Company

It has been remarked that the switchboard and the switchboard operator constitute the brains of the power plant, for they determine whether the wheels shall run or stand still or what amount of work shall be performed. But human intelligence is required at the machines as well as at the switchboard, and therefore communication between the two places becomes necessary. In this article the author briefly explains the principal systems of switchboard signals for large power plants. Mr. Bern's article on switchboard design in the October, 1913, issue of the General Electric Review also refers to this subject.—Editor.


Emil Bern

In the large modern electrical power plant most of the switching apparatus is usually electrically operated from an instrument and control board located at some convenient point which may be a considerable distance from the machines. This puts the switchboard operator and the machine attendant in relation to each other approximately as the navigating officer on the bridge of a ship is to his engineer. It is of course necessary to have some easy means of communication between the two since it is often of the greatest importance to have orders transmitted instantly and without the risk of the confusion that may be caused by excessive noise or mental strain due to emergency conditions. Many different systems of communication between switchboard and machine attendants are in use to meet the various operating conditions. In all cases it is necessary to have a means of signaling between the control board and each machine, with provision for attracting the attention of the machine attendant wherever he may be. This is necessary because he has usually charge of a number of machines.

## Visual Signals

In many stations it is possible and convenient to locate the control board on a gallery overlooking all the machines, and to design the board so that the switchboard and machine attendants can see, and visually signal, each other between the columns supporting the instrument panels, see Fig. 1. With this arrangement the only signal apparatus required is a gong or a whistle for calling attention, and sometimes a semaphore

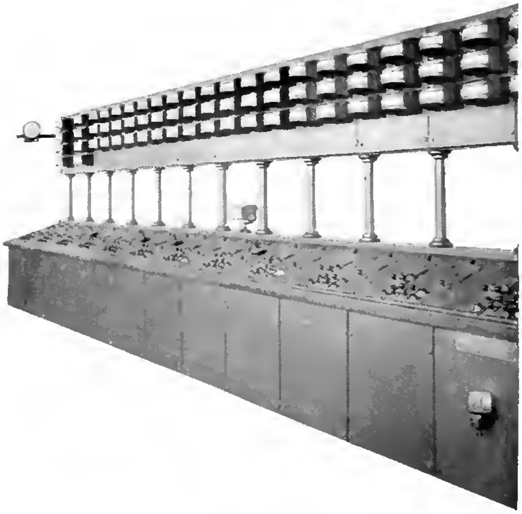


Fig. 1. Gallery Type Control Board which permits the operator viewing the machines through the board

or a few lamps are added to indicate with which machine the switchboard operator desires to communicate.

### Illuminated Sign Signals

In many instances it is not feasible to design and locate the control board so that the operator has a view of the machines. It then becomes necessary to provide a more complete signal equipment. An illuminated sign, installed so as to be in plain sight from every machine, gives often a satisfactory but simple signal device. This illuminated sign carries the designation number of every machine or unit in the station. Each number is energized from the control board by a switch which at the same time sets a gong or whistle in operation. In addition to the unit numbers the sign also contains in illuminated letters the most important signals, such as "START," "STOP," "STAND BY," etc., all controlled by suitable switches on the board. Provision is also made for answering or returning signals to the switchboard. The selection of the signal words should be determined entirely by the method of operation of the particular machines and the division of duties between the switchboard operator and the machine attendant. One prime mover may, for instance, have its governor controlled electrically from the switchboard while another is controlled at the machine by hand only. The signal words should obviously be different for the two conditions.

### Individual Push Button Signals

It is often a great convenience to have individual signal equipments for each unit, both at the switchboard and at the machines; and each equipment complete for transmitting and receiving signals. The push button signal equipment illustrated in Fig. 2 is very compact and reliable. The *stands* at left of the control board are located near the machines. The switchboard signal apparatus is set in the board just above the control bench so as to be in the most convenient position for the operator. The illustration shows six signals for each equipment. These consist of colored glass windows with white letters behind which are small candelabra lamps. Opposite each signal are the two buttons of a flush type three-way switch. Pushing a button at the left of a signal word lights the lamps for that signal word at both ends, and this signal remains until acknowledged by pushing the corresponding button at the receiving end. A gong is installed at

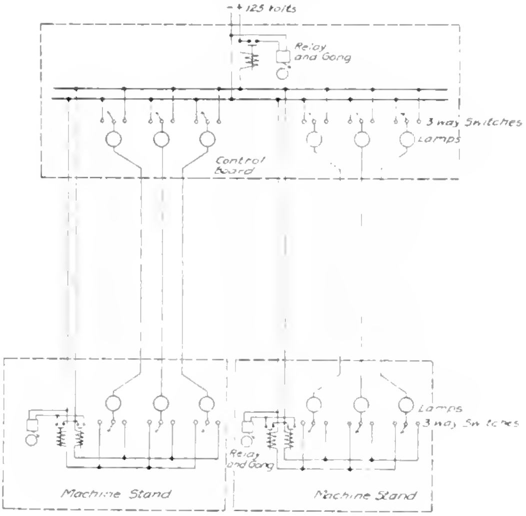


Fig. 3. Connection Diagram of two signal equipments with three signals

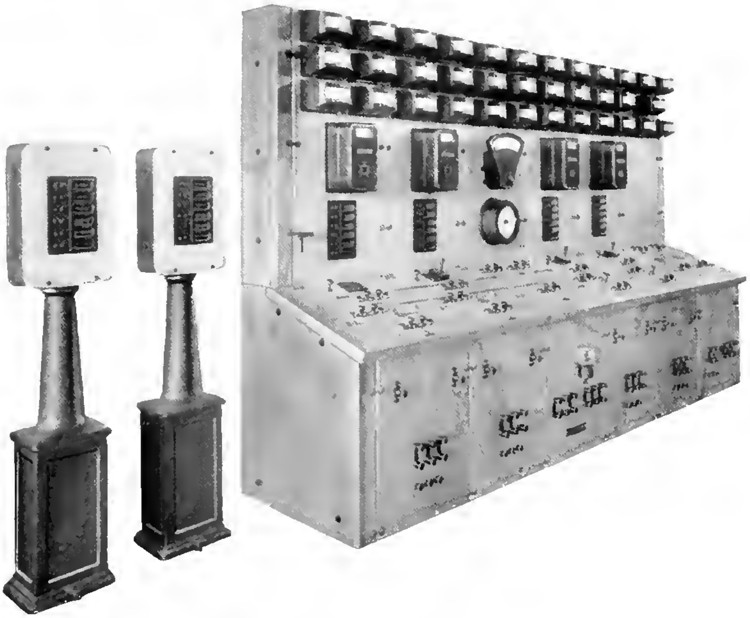


Fig. 2. Individual Push Button Signal Equipment with stands for two machines

the control board, as well as one near each machine and connected so as to ring as long as the signal remains unacknowledged.

Fig. 3 shows the connection diagram for two signal sets of this description. For simplicity, only three signals are indicated for each set. The three-way signal switches are always closed in one or the other positions, from which it follows that reversing either switch closes the circuit; and again reversing either switch opens the circuit. The gongs are energized by relays connected so as to close the gong circuit at each end of the signal set when the current of any signal lamp passes through the relay.

### Dial Signals

Dial signals have long been used on ships. In general they consist of transmitting and receiving dials with the signal words plainly marked on them. A pointer on the receiver dial is mechanically or electrically connected to follow a handle on the transmitting dial. A novel method of gearing the two together employs the now more or less familiar "position indicator" principle, recently designed for the indicating devices on the lock machinery at the Panama Canal.

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# SELECTION OF POWER LIMITING REACTANCES

By H. R. Wilson

Power and Mining Engineering Department, General Electric Company

This article calls special attention to the importance of the selection of the correct amount and proper location of power limiting reactances. The large variety of systems of connections in use prohibits a standard arrangement, and therefore the author selects four typical cases and after specifying certain data governing all, proceeds to show the correct amount of reactance and its location in each case.—Editor.

H. R. Wilson

The protection of generators, transformers, and switches, etc., in large generating stations has become of special importance, particularly so in cases where the equipment consists of several large units, the loss of any one of which would be a serious matter. Transmission at high voltages combined with inter-connections with other large systems increases the liability of trouble, and these conditions, added to the necessity of continuous operation, demand that careful attention be given to the location and the amount of protective reactance. The various systems of connections do not allow a selection which will apply to all cases; so it is necessary to treat each case individually. In the following examples, single buses only are considered and it is assumed that all generators and transformers are of the same capacity and that each generator has 15 per cent reactance and each transformer has 6 per cent reactance. As the transmission voltage is too great to allow the use of reactance coils located in either the high tension transformer leads, the high tension bus or the outgoing line, they must be placed in the generator leads, the low tension bus or the low tension transformer leads. In order to obtain a better comparative basis, all calculations are based on a 1:1 transformer ratio.

### Case No. 1

Consider a system consisting of several generators operating in parallel on a single low tension bus, see Fig. 1. If a fault occurs on the bus at $X$ the value of the instantaneous current at the fault is seen by referring to Fig. 2. By introducing protective reactance in the leads of each generator, equivalent to three per cent of the capacity of one generator, the value of the instantaneous current is reduced about seventeen per cent.

If the same percentage of reactance were located in the bus, between adjacent generators, the current at the fault is further reduced and one less coil is required.

### Case No. 2

A fault on the high tension bus is of course more probable than a fault on the low tension bus. Consider a system similar to Case No. 1 with the addition of transformers and a single high tension bus, Fig. 3. If the high tension bus is not sectionalized we find that by connecting a 3 per cent reactance in either the leads of each generator or in the leads of each transformer, the current at the fault is decreased approximately 12 per cent from what would be obtained if the reactance coils had been omitted, see Fig. 4. If the high tension bus can not be sectionalized, as is often the case in systems designed before the matter of protection had been given due consideration, the location of reactance in the low tension bus is useless as far as a fault on the high tension bus is concerned.

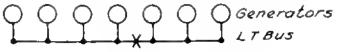


Fig. 1

**Case No. 3**

Assume that the system is one where each transformer and each line is a unit, see Fig. 5, and a fault $X$ occurs on the high tension side of the transformers. The relative values of the instantaneous current at the fault without any protective reactance and with 3 per cent reactance connected in the leads of each generator, or in the low tension leads of each transformer, or in the bus between adjacent generators, is shown by Fig. 6.

It will readily be seen that in such a system the introduction of reactance in the transformer leads is very effective as regards limiting the current when the fault occurs on the high tension side of the transformers, but it is of no value if the fault occurs in any transformer or on the low tension bus or in any generator. There is also the disadvantage in that we have the losses in the reactance coils under normal operating conditions and one more coil will also be required than if the reactance is located in the low tension bus.

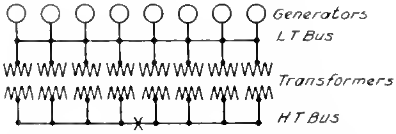


Fig. 3. Representation of a System of Paralleled Generators feeding paralleled transformers in which a fault has developed at $X$ on the high-tension bus

**Case No. 4**

The effect of sectionalizing the high tension bus of a system consisting of twelve generators and transformers, so as to limit the current at a fault on this bus and the further effect of introducing 3 per cent reactance in the leads of each generator or the low tension leads of each transformer or in the low tension bus between the corresponding sections of the high tension bus, will be seen by referring to Fig. 7.

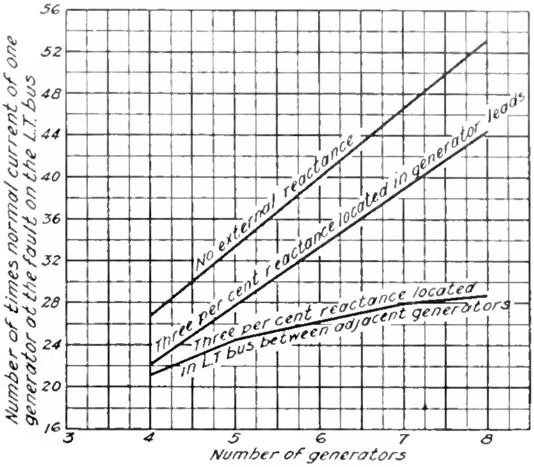


Fig. 2. Curves showing the Amount of Current that will flow at a fault on the low-tension bus of a system such as that shown in Fig. 1. No reactance, and three per cent reactance is employed at various points

Single L. T. bus; Generators, each 15 per cent reactance; Transformers, each 6 per cent reactance; Fault on the L. T. bus.

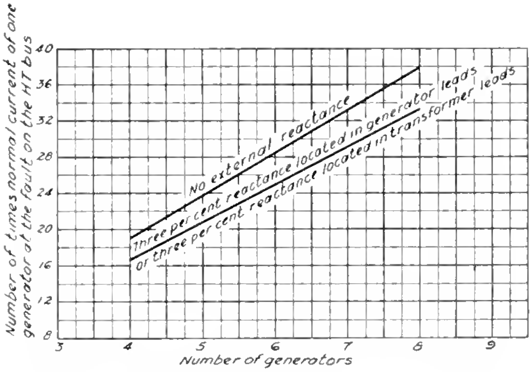


Fig. 4. Curves showing the Amount of Current that will flow in a system such as that of Fig. 3 without reactance, and with three per cent reactance located at various points

Single L. T. bus; Single H. T. bus; Generators, each 15 per cent reactance; Transformers, each 6 per cent reactance; Fault on the L. T. bus.

Taking the case of dividing the high tension bus into three sections, Fig. 8, with no external protective reactance, we find that the instantaneous current at a fault $X$ on the high tension bus is 36 times the normal current of one generator, whereas if the high tension bus is not sectionalized the current is 57 times the normal current of one generator. With the high tension bus sectionalized as shown and 3 per cent reactance introduced into the generator leads the current at the fault X is reduced about 9 per cent from what it is with no reactance; if in the low tension bus at points *A* and *B* it is reduced about 15 per cent and if in the low tension transformer leads it is reduced about 20 per cent.

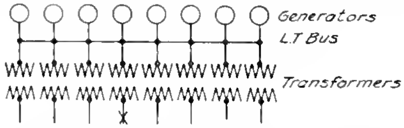


Fig. 5. Representation of a System of Parallel Generators feeding a bank of transformers, which are not paralleled on the high-tension side, in which a fault has developed in the high-tension side of one transformer

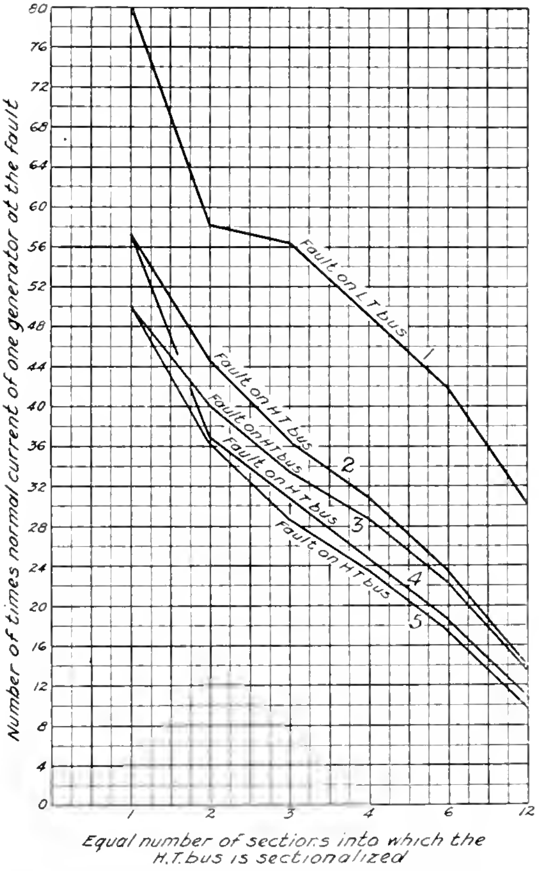


Fig. 7. Curves showing the Amount of Current that will flow at faults in a system in which the high-tension bus is sectionalized into different numbers of groups and which has no reactance or has three per cent reactance located at various points

Twelve Generators, each 14 per cent reactance
Twelve Transformers, each 6 per cent reactance
Single H.T. Bus sectionalized into equal number of sections
(No reactance)
(1)—L.T. Bus sectionalized into equal number of sections with 3 per cent reactance between sections
(2) L.T. Bus—no reactance, not sectionalized
(3)—L.T. Bus—no reactance, not sectionalized
(4)—L.T. Bus sectionalized into equal number of sections with 3 per cent reactance between sections
(5)—L.T. Bus, no reactance, not sectionalized, 3 per cent reactance in transformer leads

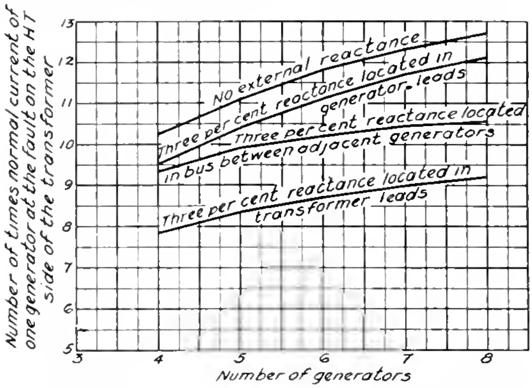


Fig. 6. Curves showing the Amount of Current that will flow at the fault in a system such as that shown in Fig. 5 with no reactance and with three per cent reactance located at various points

Single L.T. Bus; Outgoing Line from each transformer; Generators, each 15 per cent reactance; Transformers, each 6 per cent reactance; Fault on the H. T. side of the transformer

At first sight it appears from the above that the most favorable position for the reactance is in the low tension transformer leads, but there are required ten more reactances of the same size than if they were placed in the bus. In addition there is to be considered the increased losses due, not only to the greater number of reactances, but also, to the fact that reactances in the transformer leads means a constant loss in the reactance coils, whereas reactance in the bus means no loss in the coils, if the total system is operating with equal outputs on each section. Reactance in the bus also gives additional protection to the generators when a fault occurs on the low tension bus or in one of the generators.

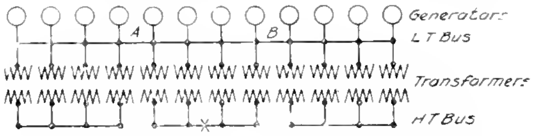


Fig. 8. Representation of a System of Paralleled Generators feeding transformers, the high-tension bus being sectionalized into three groups, fault assumed at *X*

When stating that twelve reactances in the generator leads are required to only two of the same size in the bus, we have assumed that the temperature rise is the same in either case, whereas the temperature rise in bus reactances may be greater, as the current is not normally flowing through them.

Assuming that it is desired in the above example to use bus reactance instead of 3 per cent reactance in the low tension transformer leads and to limit the current at the fault X to the same value as is obtained by the latter, it will be found by referring to Fig. 9 that the amount of reactance required in each of the two coils will be about 4.8 per cent.

If in the preceding system of twelve generators and transformers, it is desired to limit the current at a fault on the high tension bus to thirty times the normal full load current of one generator, the following (Table I) gives the number of protective reactances required and the comparative value of each expressed in terms of one generator, it being assumed that the maximum allowable number of high tension bus sections is four.

The importance of obtaining protection from high tension faults, by the division of the high tension bus into the same number of sections as there are outgoing lines, should be primarily considered, as from the preceding discussion the value of such sectionalizing is readily apparent.

The addition of reactance to systems already installed is often one of the most serious problems, as the existing layout will not always allow radical changes in the same on account of the expense and it is at times necessary to introduce reactance in both bus and generator or transformer leads, whereas if this question had been considered in the original design of the system, far better results could have been obtained at considerably less outlay.

In order to obtain the best results from the use of protective reactance, it is therefore necessary to consider each case on its merits, as the number and capacity of generators, transformers, and outgoing lines, together with the conditions under which the system will operate, have such an essential bearing on the amount and location of the reactance, that it is not possible to select any one location which will apply to all systems.

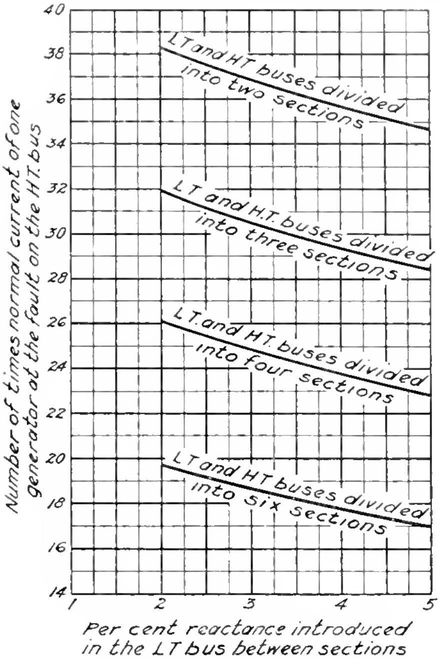


Fig. 9. Curves showing the Amount of Current that will flow at a fault on the high-tension bus of a system in which the low-tension and high-tension busses are sectionalized into equal numbers of groups with the reactance between the low-tension sections

Twelve Generators, each 15 per cent reactance
Twelve Transformers, each 6 per cent reactance
Single L.T. Bus sectionalized into equal number of sections, and reactance coils between sections.
Single H.T. Bus sectionalized into same number of sections as L.T. Bus (no reactance coils)

TABLE I

| Number of High Tension Bus Sections | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Reactances in generator leads | (12) 19 per cent | (12) 13 per cent | (12) 7 per cent | (12) 0.96 per cent |
| Low tension bus sectionalized by reactances into same number of sections as high tension bus | * | (1) 32.5 per cent | (2) 3.4 per cent | (3) 0.25 per cent |
| Reactances in transformer leads | (12) 19 per cent | (12) 6.5 per cent | (12) 2.3 per cent | (12) 0.24 per cent |

* As the high tension bus is not sectionalized, the current at the fault on it will be 57 times the current of one generator and the value of low tension bus reactance is useless as far as limiting the current at this fault is concerned.

# THE HYDRO-ELECTRIC DEVELOPMENT OF THE GEORGIA RAILWAY AND POWER COMPANY AT TALLULAH FALLS, GEORGIA

## PART I

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

This article constitutes a description of the most recently completed hydro-electric development in the South. The power plant will have an ultimate output of 60,000 kv-a., which will be generated by six units, five of which are now in place. This capacity is exclusive of two 3000-kw. units located at the dam to utilize the water released from the reservoir. Three of the main units supply power to the city of Atlanta and smaller municipalities; the remaining two being connected to the system of the Southern Power Company. The hydraulic head of 600 ft. is probably the highest that has been developed east of the Rocky Mountains, and is the highest in this country for which the reaction type of turbine has been employed. The present installment fully describes the hydraulic features and equipment of the development, the design of the power house, and the electrical equipment, including generators, exciters, transformers, oil switches and lightning arresters. The second installment will deal with the transmission lines and the large outdoor substations of the system.

—Editor.

Eric A. Lof

### General Description of System

THE Georgia Railway and Power Company was organized during the latter part of 1911 to take care of the growing demand for electrical energy in the State of Georgia and neighboring territory. It forms a distinct part of the vast network of interconnected hydro-electric power systems which are playing a most important role in the rapid development of the South, and is planned along lines similar to those of the Southern Power Company. Power will be generated in large quantities for the company's extensive light, power and railway service, and for municipalities and private corporations.

The company has taken over the properties formerly controlled by the Georgia Railway and Electric Company, which includes a large gas and steam station in Atlanta. Besides the new 100,000 horse power development at Tallulah Falls, it also owns two smaller hydro-electric plants at Bull Sluice and Dunlap, and several other water power sites which will be developed as the demand arises. Thus when ultimately completed the system will include ten developments with a total capacity of about 350,000 horse power.

The layout and general features of the development at Tallulah Falls is clearly shown by the map, Fig. 1. It comprises a diverting dam and intake a short distance above the Ladore Falls and close to the town of Tallulah Falls; a storage reservoir formed by the construction of this dam; a 6670 ft. tunnel terminating in a surge tank on the bluff above the power plant; five penstocks; and the power house with the tailrace. In addition, a large storage reservoir is under construction further up the river at Mathis, about seven miles from the intake works.

### Hydrography

The annual rainfall varies from 70 to 80 in., the driest months being September, October and November. Hydrographic records have been kept for the past fourteen years, and these show that the lowest average monthly stream flow was 135 sec. ft., while floods of from 5000 to 8000 sec. ft. are quite common in the spring season. A maximum flow of 15,000 sec. ft. has also been recorded during the month of March.

### Storage Reservoirs

The reservoir formed by the diverting dam has a capacity of 106,000,000 cu. ft. and an elevation of 1500 feet, with an available head of 606 feet. Of this capacity, 63,000,000 cu. ft. are available for the waterwheels, the drop in head caused by this release being 30 ft.

The large reservoir at Mathis will have a storage capacity of 1,000,000,000 cu. ft. It is formed by a reinforced concrete dam across the river bed, of the Ambursen type, 90 ft. high and about 700 ft. long, and a like dam of the same type across a depression about 50 ft. below the elevation of the water in the reservoir. The main dam is provided with three motor-operated 48 in. gate valves for draining the reservoir when necessary, and provision has also been made in the construction for housing a future auxiliary power plant. This will contain two 3000 kw. units, which will utilize the water power released from the reservoir, and this energy will then be transmitted to the main power house and there fed into the transmission system.

### Diverting Dam and Tunnel Intake

This dam, Fig. 2, is of the gravity type and is built of rubble concrete and arched to a radius of 900 ft. Its height is 110 ft. and the length along the crest 444 ft. The spillway is 280 ft. long, there being ten 28 ft. openings between the piers which support the highway bridge across the top of the dam. These openings, together with the two 5-ft. diameter sluices which are provided in the dam, give an overflow capacity of 20,000 sec. ft.

Flashboards are installed between the piers for all the spillway openings. Six of these are of the automatic type and are capable of taking care of ordinary spring floods, keeping the pond level within three inches of a constant elevation of 1500 ft. Thus, should the water rise three inches above this mark, the additional pressure on the flashboards will cause them to drop, and with an increased river flow they will continue to drop until they rest in a horizontal position on the dam crest. As the water subsides they will automatically return and maintain the water level in the pond at the same elevation. Each flashboard consists of a steel-reinforced timber panel hinged at the bottom and connected at the top to a 34,000 lb. concrete roller counterweight by two steel cables which are wound in grooves around each end of the roller. These rollers travel on inclined tracks, each end being provided with a geared drum which engages a rack to prevent slipping. The principle of operation is simply a balancing of the moments of force. The pressure on the flashboards is transmitted to the drums through the cables which act to roll the counterweight up the track, while its dead weight tends to roll it down; the two forces balancing each other when the water-

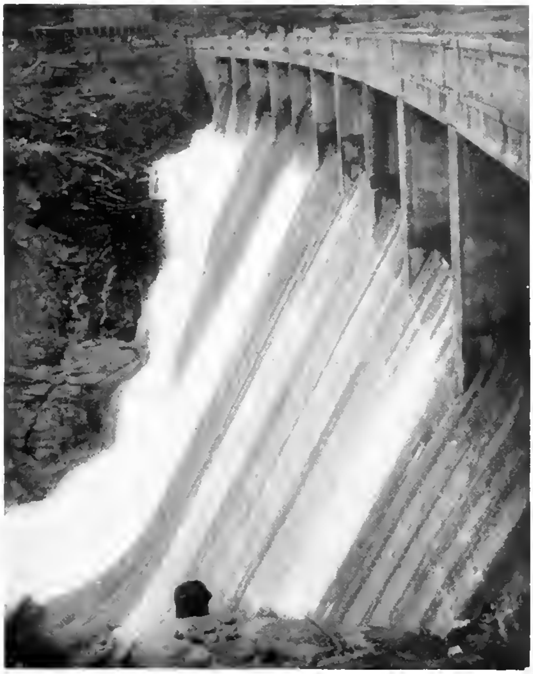


Fig. 2. Down Stream View of Diverting Dam

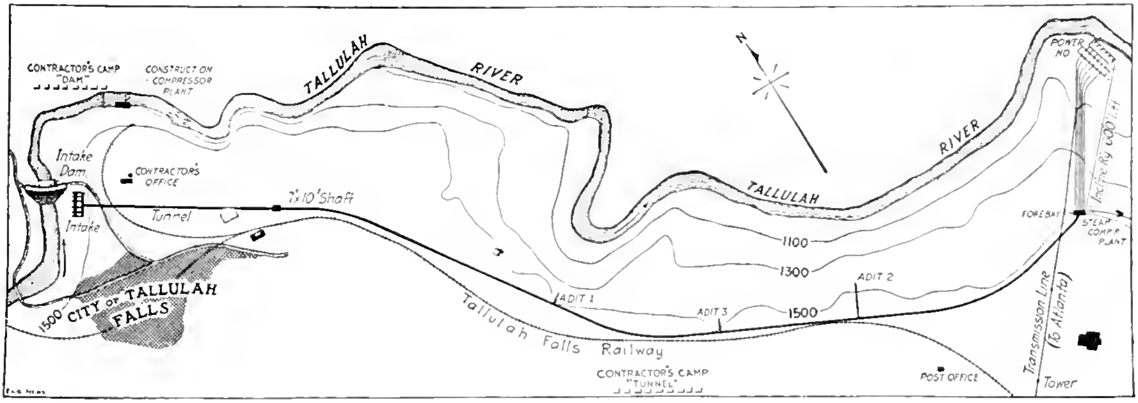


Fig. 1. Map of Tallulah Falls Development of Georgia Railway and Power Company

level is at the fixed elevation. Hand-operated winches are also provided for these flashboards, and their general construction is clearly shown in Fig. 3. The other four flashboards are of the ordinary stationary construction and are so designed that if the water in the pond rises one foot above the normal level the boards will give away.

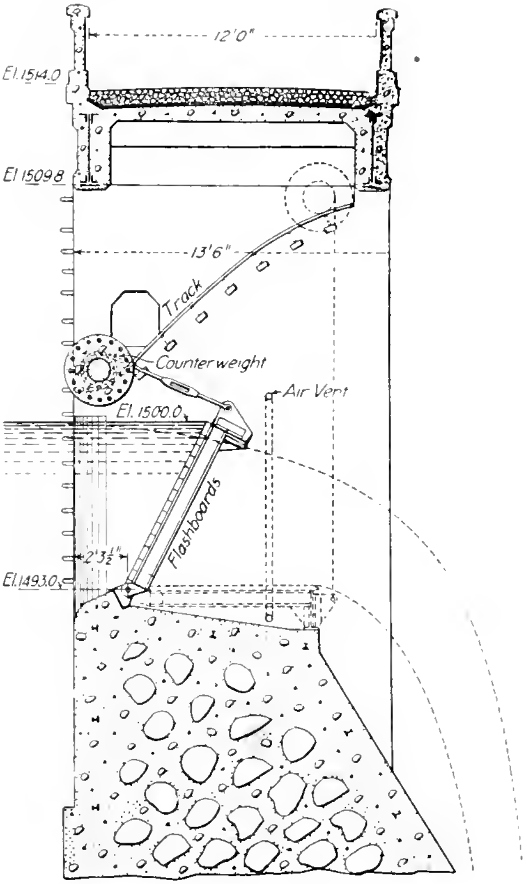


Fig. 3. Automatic Flashboards for Diverting Dam

The intake is a cassion-like self-contained concrete structure, divided by partitions into five sections in order to resist the stresses on the walls due to the hydraulic pressure when the intake is empty and the water in the pond is at its maximum elevation. At the rear of each division wall there is an opening which allows the water to pass to the tunnel entrance located at the center of the rear wall at the bottom. The location of the intake is such that it forms an angle of nearly 90 degrees with the dam. This arrangement has several advantages, among which are the ease with which logs, trees and other floating debris can be cleared away by simply opening one or two of the nearest flashboards. There are two kinds of racks, coarse and fine, the former being placed in front of the head gates outside the intake openings and the latter behind the gates in an inclined position. For three bays the fine racks are provided with rake cleaners which are operated at a speed of 3 feet per minute by a 5 horse power, 220 volt, three-phase induction motor. The five head gates are of structural steel and hand-operated through ordinary gate hoists.

The ground around the intake has been neatly graded and sodded, and electric lighting is provided both at the intake and along the highway bridge across the dam so as to facilitate any night operations that may be necessary.

### Tunnel, Surge Tank and Penstocks

From the intake, the water is led through a concrete lined tunnel which terminates in a surge tank located on the bluff above the power house. This tunnel has been excavated through practically solid rock strata and follows a comparatively straight route. It has a length of 6670 ft. and a cross-section of 151 sq. ft., the bottom being 46½ ft. below the high-water level in the reservoir. The gradient is 0.002, and the tunnel has a maximum capacity of 1555 sec. ft. with a water velocity of 10.3 ft. per sec. The normal flow

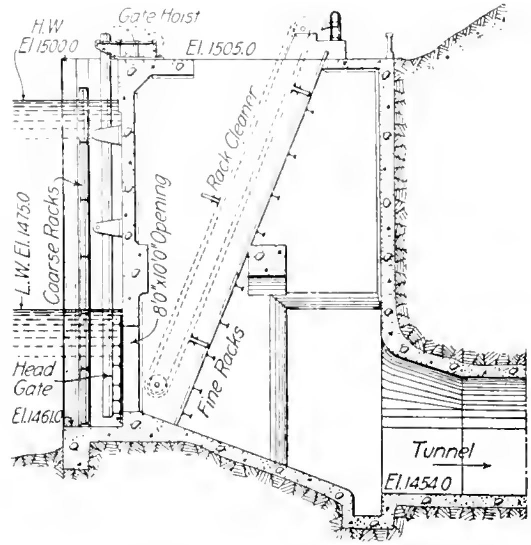


Fig. 4. Tunnel Intake, showing Racks, Rack Cleaners and Gates

with full load on all units in the station is 1160 sec. ft. and a velocity of 7.7 sec. ft.

The surge tank is of a heavy reinforced concrete construction, the bottom being about 63 ft. below the ground level. It is 93 ft. high, with an inside section of 30 ft. by 71 ft, and is designed to take care of the sudden surge that would be caused by closing all of the turbine gates with the machines at 25 per cent overload. At this load the water in the tank will be about 11.5 ft. below the elevation at the intake, due to the friction losses in the tunnel, and the sudden closing of all the gates will set up a surge which will cause the water in the tank to rise to a height of about 29 ft. above the water level at the intake.

From the surge tank five penstocks, ultimately six, run to the power house, 600 ft. below, Fig. 5. These penstocks are of riveted steel pipe for the upper half of the run, the lower part being of welded-steel pipe of German make. Their lengths vary from 1200 to 1258 ft., the diameter being 60 in. and the thickness varying from $\frac{3}{8}$ in. to $\frac{9}{16}$ in. There is one 8-in. air valve at the top of each pipe, and the thickness of the material in the pipes is such that it will resist any tendency to collapse at points below the influence of the vents. Heavy concrete piers are provided for anchoring the penstocks at each change of grade, and at intermediate points they are supported on concrete saddles. The grades exceed 70 per cent, the maximum being 150 per cent. Steel emergency gates are provided at each penstock entrance, hinged at the top side and held open by a chain and hand-operated mechanism at the surge tank. At the upper end of the penstocks 60 in. motor-operated valves are provided. These are equipped with limit switches and are controlled from the power house, the contactor panels being installed in a little house close

Fig. 5. Forebay and Penstocks

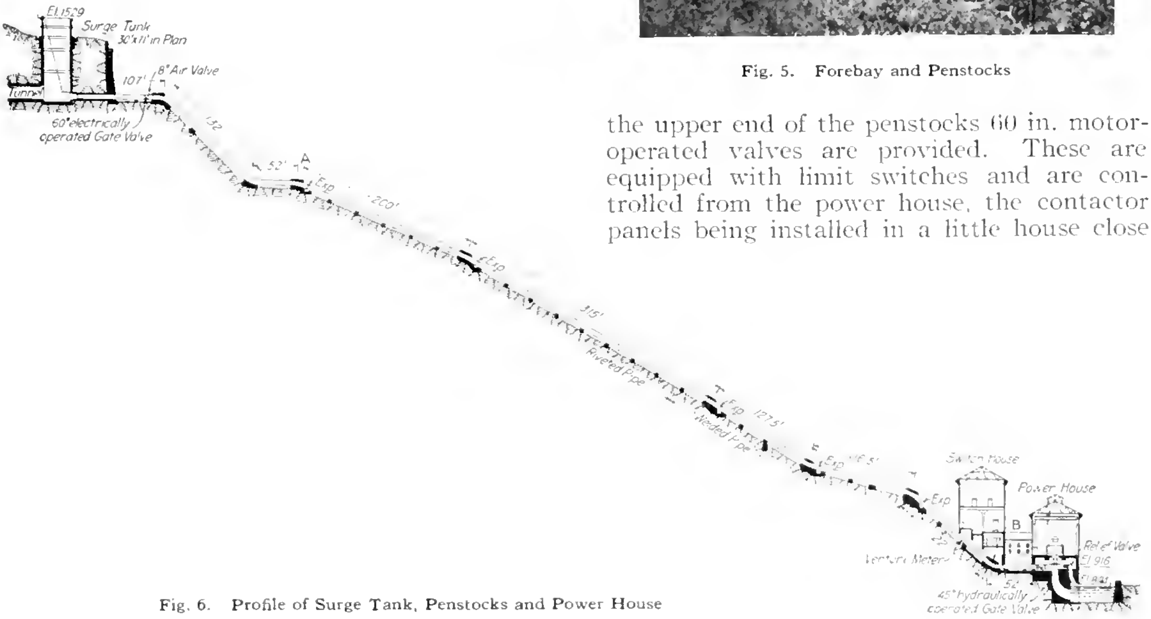


Fig. 6. Profile of Surge Tank, Penstocks and Power House

to the valves. Forty-four inch hydraulically operated gate valves are furthermore placed between each turbine casing and the penstock. They are furnished with pilot valves so that the gate can be held in any desired position during operation, the operating pressure being that due to the head of water in the penstocks. Just outside the switch house a venturi meter is placed in each penstock, the indicating and recording instruments for them being installed on a platform opposite the transformer bays in the switch house. By means of these devices the wheel efficiencies can readily be checked during operation, and for the same purpose a weir is also provided in the tail race channel. The general arrangement of the surge tank and penstocks is clearly shown in Fig. 6.

### Power House and Arrangement of Apparatus

The general design of the power house buildings and the arrangement of the apparatus are shown in Figs. 7, 8 and 9. As seen from these drawings, the power house layout resembles a letter "H" there being in reality two distinctly separate buildings, the power house and the switch house, which are interconnected by a small narrow building containing the control switchboard.

The power house, which faces the tail race, is 186 ft. long, 42 ft. 3 in. wide, and 49 ft. high above the generator room floor. Five generator sets, spaced 28 ft. center to center are installed with room for a sixth unit. The turbines with their pressure pumps, gate controlling mechanism, etc., are located below the generator room floor in the basement. A gallery with a stairway at each end runs along the rear wall of the generator room and leads directly to the control room. Below this gallery are located the exciter switchboard, the field switch panels, and the rheostat compartments. The foundations are of massive concrete, and large steel girders are provided in the generator room floor to distribute the heavy load of the generator frames and that of the revolving field and turbine runner elements, which are supported therefrom.

The building for the control switchboard is, as previously stated, located in the fifteen foot space between the power house and the switch house, forming a connection between the two. It is a two-story structure, the upper floor containing the control benchboard, telephone booths, etc., while the first floor, which is at the same elevation as the generator room floor, contains lavatories and lockers.

The switch and transformer house is a three-story structure, 244 ft. long by 46 ft. wide. The first floor, which is on the same level as the operating room, contains the low-tension switch equipment and busbars. On the second floor are located the transformers and oil filtering tanks, while the third floor contains all the high tension switches, buses and connections.

The buildings consist of a steel framework with the walls constructed of red brick with marble pillaster caps and window sills. The roofing is of reinforced tile construction, colored red to harmonize with the building walls, and a monitor extends nearly the entire length of the ridge of the power house roof. Rolling steel doors are provided at all principal entrances, and steel stairways and railings are installed at several places between the floors. A 60-ton traveling crane is provided in the generator room and an electrically operated trolley hoist has been installed in the switch house for lifting the apparatus to the upper floor.

Before work on the power house could be commenced it became necessary to build an inclined railway from the railway siding on top of the bluff to the power house site below, for lowering material and carrying the working force. The incline averages about 63 per cent grade, the maximum being 100 per cent. The car is at present operated by two steel cables from a steam-driven hoist located on top of the hill, although it is the intention to replace this with motor drive. A safety device is provided to hold the car should the hoisting cables suddenly break or release their pull. It consists of a clutch that will grip a stationary cable laid between the two track rails and securely fastened at the upper end of incline

### Hydraulic Equipment

The five vertical shaft turbines are of the Francis type, built by the S. Morgan Smith Company. They have a normal rating of 16,000 horse power at 580 ft. head when running 514 r.p.m. The runners are installed in cast iron spiral casings discharging into a steel plate draft tube, and the thrust bearing for supporting the generator field, turbine runner and shaft is placed on top of the generator frame. The exciter is mounted directly above the thrust bearing, its armature being direct-connected to the main turbine shaft. Each turbine unit weighs 300,000 lb., and the general design is as shown on page 532.

The spiral casing is made of cast iron in one piece, and the inlet, which has a diameter of 44 in., is connected to the hydraulically operated valve for cutting off the water in the casing from the supply pipe. The weight of the finished casing is 54,000 lb., and it was tested to a hydrostatic pressure of 400 lb. per square inch. Connecting the inner flanges of the spiral casing are twelve cast vanes through which are placed 2¾ in. vanadium steel bolts having a tensile strength of 200,000 lb. to the square inch. These bolts themselves have sufficient strength to carry the entire load of the longitudinal stresses due to the pressure of the water in the spiral casing.

On the inner diameter of the spiral casing is fitted a cast steel guide ring which serves to tie the inner flanges of the casting and to take part of the load of the longitudinal stresses due to the water pressure in the casing. In this cast steel guide ring there are heavy guides or vanes through which are cored large openings so that the water which passes through the upper running joint of the runner can pass from the upper chamber over the runner and through these guide vanes into the lower chamber under the runner and into the draft tube. This relieves the accumulation of water above the runner and so eliminates the thrust due to water pressure on top of the runner. The vanes in the guide ring coincide with those in the spiral casing, so that a smooth surface is obtained in the water passages.

The steel gates of the turbine are of the wicket type with stems forged on and finished all over, while all faces coming in contact with the water are polished. There are twenty-four gates for each runner, the stems being 2¾ in. in diameter with a ½ in. hole drilled the entire length of the stem. Fitted in the top of this hole is a large grease cup which forces grease through the stem and out of the radial openings into the bearings of the gate stems. These bearings are of bronze and are made renewable. On the top of the gate stem is keyed the crank arm which connects the gate to the gate ring. The hub of the gate arm on the gate stem is split, and is held by means of two tension bolts so that when it is necessary to take off the gate arm the tension bolts are relieved and a wedge driven in the split. This opens the hub a small amount, and the gate arm can be easily removed from the stem.

The top and bottom plates of the turbines are made of cast iron and the water faces are fitted with renewable bronze facing plates so that they can be replaced in case of erosion. These plates are also fitted with bronze packing boxes for the gate stems, which pass through the water chambers in the top and bottom plates in such a way that all leakage of water around the gate stems passes through these water chambers and the guide casting into the draft tube, and, as shown by actual operation, there is no leakage water on the outside of the turbines whatever.

The runner is of the central discharge or Francis type, and is made of hard bronze, 88 per cent copper, 10 per cent tin and 2 per cent zinc. It has 18 buckets and is 56 in. in diameter. It was made in one continuous casting by means of cores, and on the crown of the runner is fitted a flange by means of which it is bolted to a forged flange on the shaft. One of the runners and gates complete was sent to Holyoke and tested by the Holyoke Water Power Company. It developed a maximum efficiency of over 88 per cent, and from past experiences in testing high head wheels in place these runners should actually develop over 90 per cent efficiency.

The shaft of the unit is made of nickel steel in two sections. The lower section, which is fitted to the turbine, is 14 in. in diameter and is provided with a forged flange on each end, while the upper section, which is fitted to the rotor end of the generator, has a nominal diameter of 16 in. The complete shaft weighs 20,000 lb.

On the top plate and directly over the runner is mounted a lignum-vitae bearing, which is lubricated by means of a supply pipe from the spiral casing, the water passing through this bearing into the chamber above the runner and out through the guide vane into the draft tube. This bearing is made of lignum-vitae strips 2 in. square placed in a cast iron casing similar to that of the stern bearing of a steamship, and bolted to the top plate.

For supporting the generator rotor, shaft and turbine runner there is placed on top of the generator an oil pressure thrust bearing of the standard type. This bearing was designed for a pressure of 200 lb. to the square inch. There is, however, no pressure-regulating device employed in the oiling system whatever and dependence is placed entirely on the distance or clearance between the disks. The pumps are run at a constant speed and supply a constant quantity of oil to the bearing, the pressure being automatically regulated by the film of oil separating the disks. If the

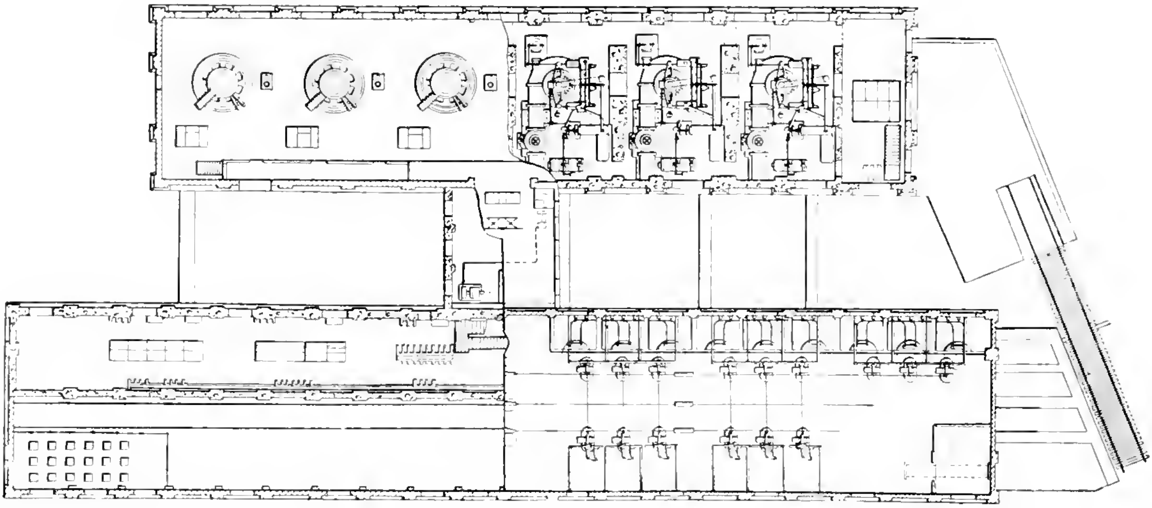


Fig. 7. Plan View of Power House

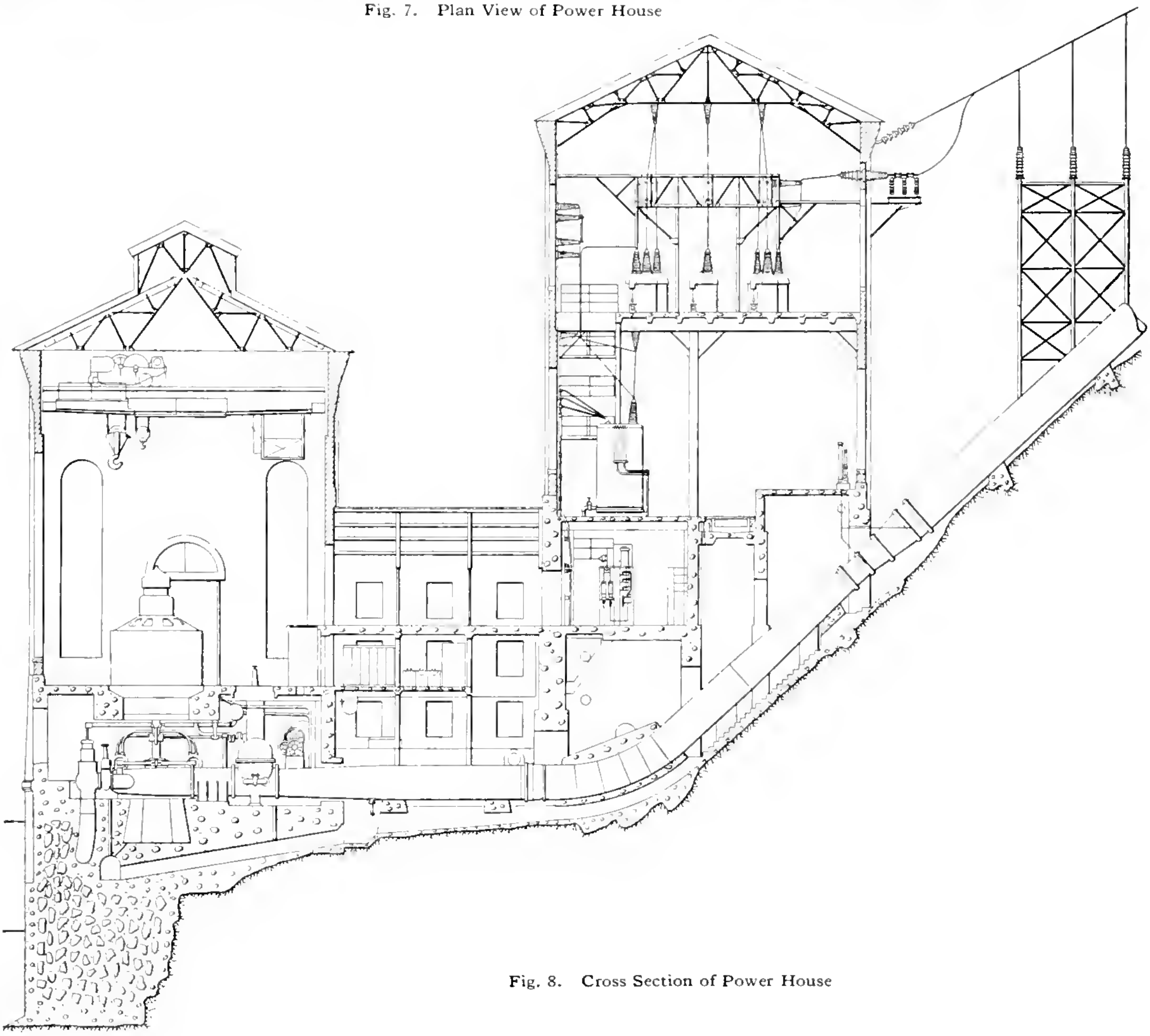


Fig. 8. Cross Section of Power House

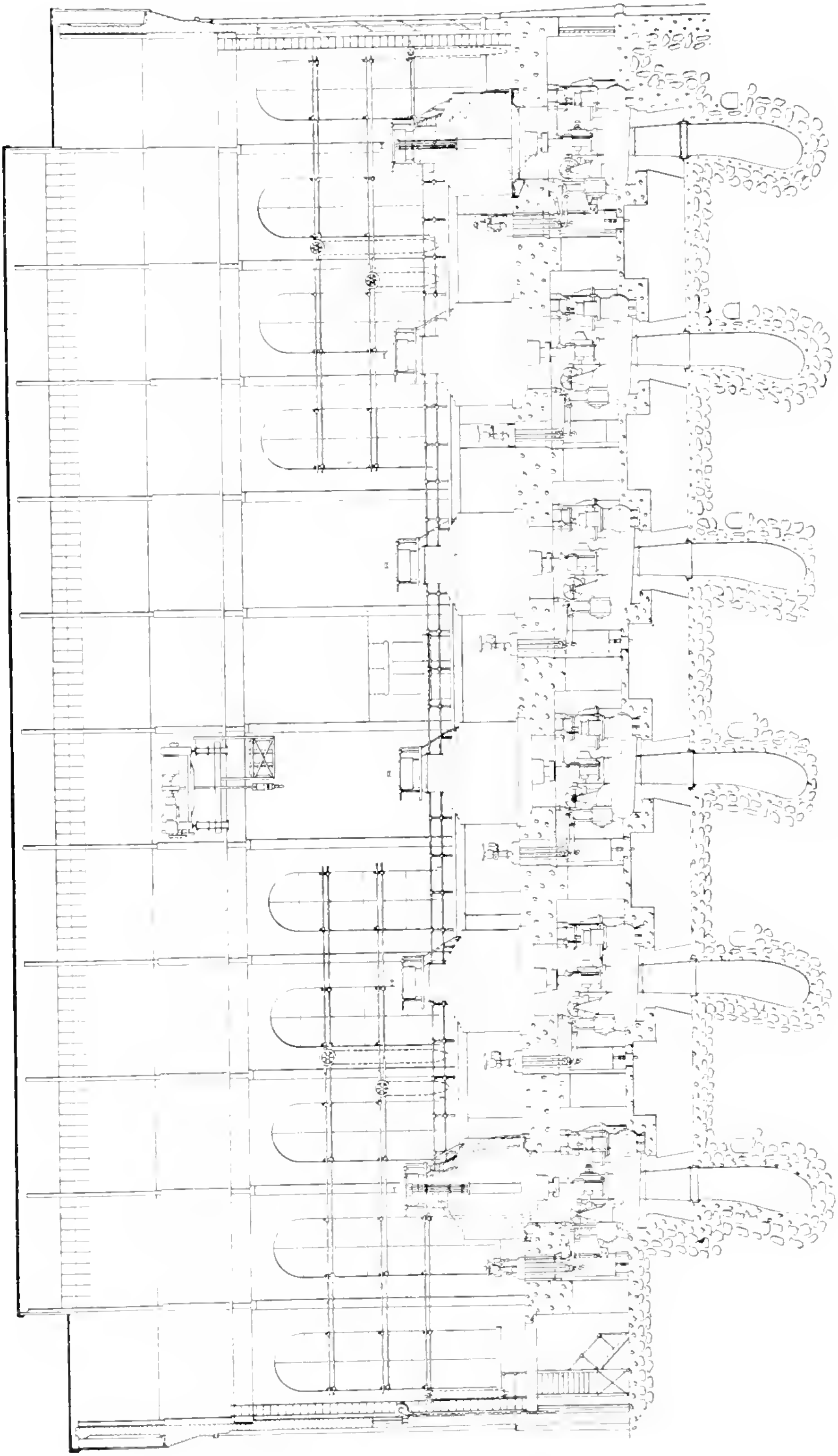


Fig. 9. Longitudinal Section of Power House

load increases the disks are brought closer together, decreasing the area of discharge between the disks and consequently raising the pressure between the disks and equalizing the load. The disks are placed in a suitable housing fitted with a drain pipe which conveys the oil from the bearing back to the receiving tank of the pump.

Fig. 10. Five of the 10,000 Kv-a. Main Generating Units

Each unit is equipped with an independent oil pressure system which consists of two triplex pumps having a normal capacity of 75 gallons per minute each. The pumps discharge the oil into a pressure tank, from which it is piped to the thrust bearing and governor cylinders. It then flows to a common pump tank from which it is again returned to the pressure tank by the pump. One of the triplex pumps is driven direct from the vertical turbine shaft by means of spiral gears and a Morse silent chain drive and the other pump is driven by a 35 h.p. electric motor. In order to insure an absolutely uninterrupted oil supply to the pressure bearings, both pumps are in commission all the time. It is found in actual operation that the oil pressure required in the thrust bearing varies from 140 to 160 lb. per square inch, and as this pressure is also sufficient to operate the gates of the turbines, it is not exceeded in any part of the oiling system. All the piping is equipped with flanges, and all fittings and valves are of the flange type.

The turbines are regulated by oil pressure governors, the actuators of which are placed on the generator floor, and the operating cylinders on the turbine casing. There are two cylinders for each unit, each having a diameter of 24 in. and an 8 in. stroke. Both cylinders are capable of developing a combined effort of 120,000 ft.-lb. at 200 lb. pressure. The piston rods of these cylinders are connected by hardened steel pins to a cast steel walking beam bolted to a cast steel gate ring which revolves on bronze bearings on the top plate. The cast steel gate ring has twenty-four machined slots and into each is fitted a bronze crosshead. These bronze crossheads are connected to cast steel cranks on the gate stem by means of an eccentric pin which allows a small movement of the gates by turning the pin so that they may be finely adjusted independently of one another, thus enabling the gates to be made tight when closed. The oil in the cylinders is controlled by the actuator or governor top, which is placed on the floor of the generator room.

The actuators for controlling the operating cylinders are of the relay valve type, and are equipped with electric speed control. The fly balls are mounted on ball bearings and are driven by means of spiral gears connected to a vertical shaft, which is belted to the main generator shaft. They are connected to a floating lever, one end of which is attached to the compensating arm by means of a dashpot; the other end being connected to the primary valve by a connecting rod and another floating lever, one end of which is connected to the secondary or main dis-

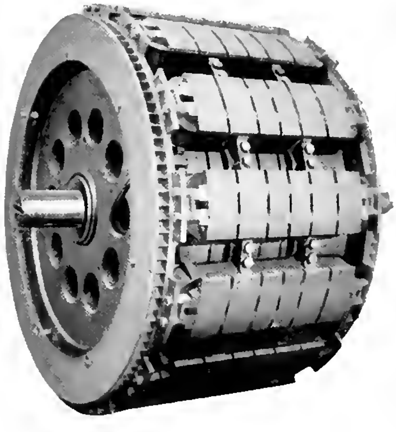


Fig. 11. Revolving Field of Main Generators

tributing valve. The main valve is always under control of the primary valve, which is controlled by the fly ball and the compensating mechanism. The electric speed control is connected to the main floating lever, and is so arranged that the speed can be changed direct by hand or by the electric control.

Each unit is equipped with a 22 in. mechanically operated relief valve, which is connected to the gate-operating mechanism by means of cranks and connecting rods, and so arranged that when the turbine gets below half gate the relief valve is thrown into operation. This valve is equipped with a dashpot and slow closing device. The valve will discharge 115 per cent of the full capacity of the turbine.

The upper portion of the draft tube is of cast iron and the lower part of steel plate imbedded in the concrete sub-structure. The connection between the cast iron draft tube and steel draft tube is made by means of a packing ring and hemp packing. This was done to overcome any discrepancy that might arise during construction. The total length of the draft tube from tail water to the center line of the spiral casing is 22 ft. It is circular in section, being 3 ft. 3 in. in diameter at the top and 8 ft. in diameter at the bottom. A quick closing valve is provided so that if necessary the vacuum in the tube may be broken. This valve is located on the turbine room floor.

**Generators**

The ultimate installation will comprise six main generators, five of which are installed at present (Fig. 10). They are of the three-phase, 60 cycle, vertical revolving field type, having 14 poles and operating at a normal speed of 514 r.p.m. They have a guaranteed normal continuous rating of 10,000 kv-a. at 6600 volts and a 25 per cent overload capacity for 2 hours. When operating at 80 per cent power-factor the temperature rise will not exceed 40 deg. C for normal load or 55 deg. C. for 25 per cent overload for 2 hours. The guaranteed efficiencies were as follows:

| | 1¼ Load | Full Load | ¾ Load | ½ Load | ¼ Load |
|---|---|---|---|---|---|
| 10,000 kv-a. 1.0 p.f. . | 96.0 | 95.5 | 94.5 | 92.0 | 86.0 |
| 10,000 kv-a. 0.8 p.f | 95.0 | 94.5 | 93.0 | 90.0 | 83.0 |

When delivering the normal load of 10,000 kv-a. at unity power-factor and 6600 volts, about 140 amperes will be required for the field excitation, while when delivering 10,000 kv-a. at 80 per cent power-factor and a 10 per cent over voltage (7260 volts) 200 amperes will be required. Under these conditions the excitation pressure will not exceed 250 volts. The field is furthermore so designed that with constant speed and 100 per cent power-factor, the load may be varied from normal rated current to no load and vice versa, and the voltage will not rise or drop more than 10 per cent.

The armature winding consists of form wound interchangeable coils, heavily insulated and tested between conductor and frame at 14,000 volts for one minute. They are Y-connected, the neutral being brought out and grounded through a 3.08 ohms resistance. Only one generator is grounded at one time, but provision is made so that by means of disconnecting switches any one of the generators can be grounded.

The revolving field structure is designed to withstand a runaway speed of 1.7 times normal for one hour. For this reason it became necessary to construct the rotor of rolled steel disks securely bolted together, the laminated pole pieces being dovetailed to them. The field coils are of strap copper wound on edge and substantially insulated so as to withstand a test between coil and core of 2000 volts for one minute. Spacing blocks are provided between the coils to prevent the winding from bulging out as a result of the heavy centrifugal force, and the connections between the coils are also securely fastened to prevent them from working loose.

The generator is furnished with two guide bearings, and the field rotor, as well as the waterwheel runner and exciter armature, is supported from the previously-described oil pressure bearing, this being mounted on the top bracket of the generator below the exciter.

For ventilating the machine, circulation of the air is brought about by small fans furnished at each end of the rotor and also by the natural fanning action of the field structure, ample air ducts being provided to secure a directed and uniform ventilation of the field coils. The air is drawn in at the bottom and discharged at the top after having been forced through the ventilating ducts in the core.

The over-all diameter of the generator is 13 ft. 8 in. and the height from the floor to the top of the exciter 17 ft. 8 in. Its total weight without the shaft is about 76 tons and the flywheel effect ($WR^2$) of the rotor approximately 1,250,000.

### Exciters

A six-pole compound wound commutating pole exciter is direct-connected to each main generator, Fig. 10. These exciters have a normal continuous rating of 100 kw. at 250 volts and a 25 per cent 2-hour overload capacity Each exciter is therefore capable of exciting two generators in case of emergency, and provision is made in the switching equipment so that the machines may be operated in parallel on the field bus, or any unit may be connected to the auxiliary bus as desired. On account of certain changes in load conditions which have taken place since the commencement of operation, it has been found necessary to divide the generating equipment in two sections, each requiring a somewhat different excitation. In order to readily accomplish this and provide a more flexible system, some slight changes are contemplated in the connections so that by simply adding double-throw field switches the exciters can, if desired, also be connected directly to the fields of their respective generators without being operated in parallel.

The machines are designed to withstand a 70 per cent over-speed, as are the generators. They are compounded to give 250 volts from no load to full load and their guaranteed full-load efficiency is 90.0 per cent. Each machine weighs complete about 8000 lb.

### Transformers

For each of the five generator groups there is a bank of three single-phase oil-insulated water-cooled transformers of the shell-type construction. Each transformer has a normal continuous rating of 3333 kv-a. with a temperature rise not exceeding 40 deg. C., this being based on an ingoing cooling water capacity of 12.5 gallons per minute at a temperature of 15 deg. C. They also have a 25 per cent 2-hour overload capacity with a temperature rise not exceeding 55 deg. C., based on a water supply of 15.7 gallons per minute.

The low-tension 6600 volt windings of the three transformers are delta-connected, while the 63,500 volt high-tension windings are Y-connected, this arrangement giving a transmission pressure of 110,000 volts. The neutrals of all the banks are connected through disconnecting switches to a common ground bus, which is grounded through a 127-ohm resistance. The primary windings of all the transformers are furnished with three 5 per cent taps, corresponding to voltages of approximately 60,300, 57,200 and 54,000. They are heavily insulated and the transformers have been submitted to the following high potential tests:

Primary to secondary and core, 220,000 volts for one min.

Secondary to core, 13,200 volts for one minute.

Across the full primary winding, 127,000 volts for five minutes.

The guaranteed efficiencies were:

| | |
|---|---|
| 1¼ load | 98.7 |
| Full load | 98.7 |
| ¾ load | 98.7 |
| ½ load | 98.4 |
| ¼ load | 97.2 |

The regulation:

| | |
|---|---|
| 100 per cent power-factor | 0.9% |
| 80 per cent power-factor | 4.3% |

The transformer tanks are cylindrical and are built of heavy steel plate with cast iron bases and covers. They are all mounted on trucks, which facilitates easy removal from the compartments, of which there is one for each transformer bank.

The cooling coils are of seamless brass tubing and designed to withstand a hydraulic test pressure of 250 pounds per sq. in. A sight flow indicator is installed in the piping for every transformer, and the cooling water supply is obtained from the penstocks through a reducing valve which is installed in a stand pipe on the hillside back of the switch house.

Fig. 12. 10,000 Kv-a. Transformer Bank

Each transformer requires approximately 2800 gallons of insulating oil and a piping system is installed so that the oil can be pumped to a large storage tank and filtered by means of a filter press. This latter is of the portable type and can also be used for filtering the oil of any transformer when in operation. A quick acting valve is provided at the bottom of each transformer tank which allows the oil to be quickly emptied into the tail race in case of fire. The discharge pipes for this run on brackets outside the switch house wall so as to reduce the fire risk to a minimum.

Each transformer is provided with oil gauges and capillary tube thermometers equipped with contact devices for ringing an alarm bell at the annunciator board in case the temperature should reach a dangerous value.

The over-all diameter of each transformer is 8 ft., the height to the top of the cover 13½ ft., and the height to the top of the high tension leads 16½ ft. The total weight, including the oil, is approximately 23 tons.

### Switching Equipment

The system of connections, as illustrated by the diagram, Fig. 13, has been slightly modified owing to the recent addition of a double-circuit transmission line which ties in with the Southern Power Company at Easley, S. C. The voltage required for this line is approximately 90,000, while 110,000 volts is used for the two Atlanta circuits. This fact has necessitated a sectionalizing of the system, and as operated at the present time generators Nos. 1, 2 and 3 are used for supplying energy for the Georgia Railway & Power Company service in Atlanta and other places, while Nos. 4 and 5 are used for the Southern Power Company's load.

As seen from the diagram, the generators are connected directly to their respective transformer banks, a transfer bus being the only connecting link on the low-tension side. The primary windings of the transformers are, however, paralleled by a high-tension bus, while a tie bus is installed on a structure outside the station.

The generators are connected through the low-tension oil switches on the first floor of the switch house to the transformer deltas on the floor above by two 1,000,000 c.m. varnished cambric insulated single conductor cables carried through ducts.

The delta-connection is made of 1¼ in. bare copper tubing mounted on post insulators supported on a pipe framework on the rear wall of the transformer compartments. The low-tension transfer bus consists of two rectangular bare copper bars 3 in. by ¼ in. mounted on insulator supports in brick compartments back of the switches.

There are three low-tension switches for each unit, the generator and transfer switches being of the non-automatic type and of 1200 amperes capacity. The transformer switches, however, are of the automatic type, provided with inverse time limit relays arranged so that they will trip both the low and high-tension transformer switches simultaneously. These switches also have a current carrying capacity of 1200 amperes, and the relays are energized from three 1500 ampere current transformers inserted in the transformer connections.

All the 6600 volt oil switches are of the H-3 motor-operated type with cell construction. Disconnecting switches are provided for isolating each main switch in case of repair. The sectionalizing of the transfer bus is also accomplished by a set of disconnecting switches.

The star connections are made on the high-tension side of the step-up transformers, the neutral points being connected through disconnecting switches to a ground bus which is mounted on the wall of the switch room on post insulators. This bus extends the length of this room and then down to the second floor, where it is connected to the grounding resistance. The other transformer connections are carried through high-tension oil switches located on the switching floor to the high-tension bus, and from there again through high-tension oil switches through wall bushings to the outside tie bus. Disconnecting switches are furnished, as shown by the diagram, for isolating the oil switches and for sectionalizing the high-tension bus, which, besides, is sectionalized in the middle by an oil switch.

The high-tension busbars and connections are of approximately one inch copper tubing spaced 8 ft. apart and mounted on post insulators, the buses being suspended from the roof trusses in the high-tension room directly above the switches. The trusses are of special design in order to give sufficient clearance for the wiring. By this type of truss it is possible to considerably cut down the height of the building and utilize the waste space for wiring.

The high-tension oil switches are of the K-15 solenoid-operated type, one magnet being furnished for each pole. They have a current capacity of 150 amperes. The transformer switches are, as previously mentioned, automatically tripped simultaneously with the low-tension transformer switches, while in closing they operate independently. Inverse time-limit series relays are provided on post insulators for automatically tripping the outgoing line switches, while the bus sectionalizing switch is of the non-automatic type.

An eight-panel direct current switchboard is located on the main floor of the generator room directly under the control board, and contains the switch and instrument equipments for the five exciters and the auxiliary direct current apparatus in the station. Each exciter panel is provided with a 600 ampere, single-pole, hand-operated reverse current circuit breaker with shunt trip attachment, a three-pole double-throw 600 ampere quick break knife switch, an 800 ampere ammeter, a rheostat handwheel, and potential receptacles. Two of the panels contain automatic generator voltage regulators, and two voltmeters are mounted on a swinging bracket at the end of the board. There is also a high and low voltage cutout relay which operates in conjunction with the regulator to lower the excitation by cutting in a resistance in the exciter field circuits should the voltage tend to rise 15 per cent or drop below 50 per cent as in the case of short circuits. The busbars are mounted on the rear of the board and the connections to the exciters as well as those to the generator fields consist of 750,000 c.m. single conductor varnished cambric weather-proof cable installed in conduits.

Generator field panels are installed in front of each generator on the main floor under the gallery. These are equipped with single-pole solenoid-operated field discharge switches and motor-operated rheostat dials, the resistances for which are located in compartments on either side of the exciter board under the gallery. The panels also contain push button switches and lamps for signalling with the operator in the control room.

The main control board is located in the operating room on the top floor of the switch-control house, which, as before stated, joins

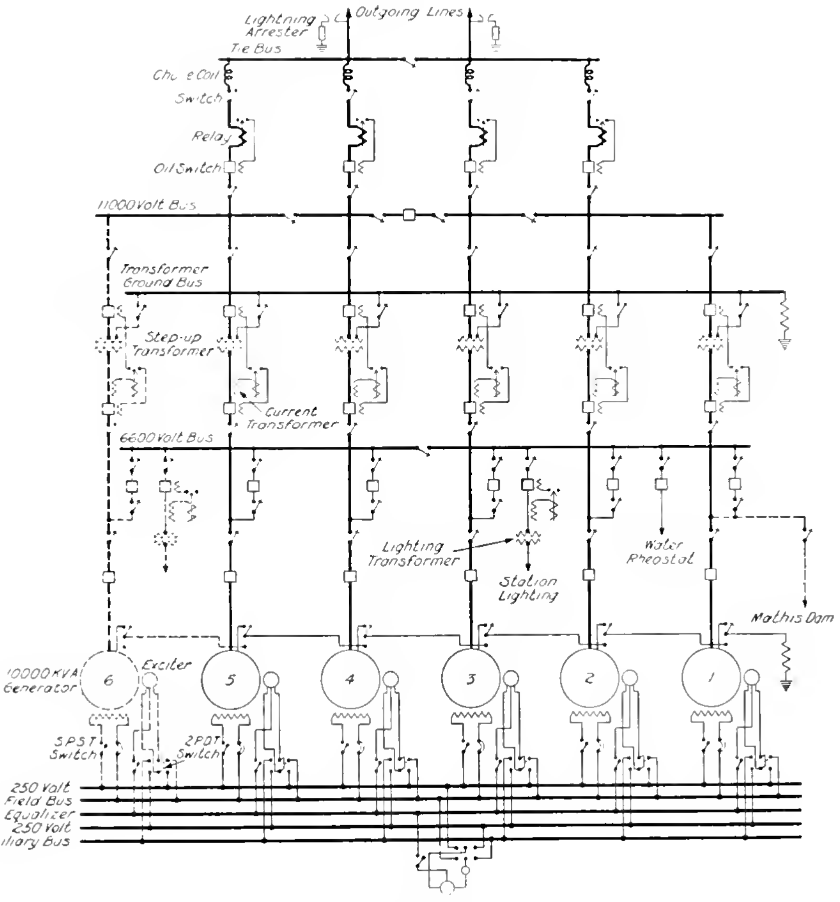


Fig. 13. Wiring Diagram of Power House

the generator building to the switch house. It is of the ordinary benchboard type, made of black slate, the desk containing all the control switches, signal lamps, potential and synchronizing receptacles, mimic buses, etc., while the instruments and meters are mounted on the vertical panels.

The instrument equipment for each generator consists of three a-c. ammeters, one voltmeter, one polyphase indicating wattmeter, one polyphase watthour meter, one power-factor meter and one field ammeter. For each transformer bank there is one ammeter, while a voltmeter and frequency meter are installed for each of the two low-tension bus sections. There are two synchroscopes, one of of them, which has a 36 in. dial being mounted on the wall of the generator room opposite the control board. Each of the outgoing line circuits is furthermore provided with three series ammeters mounted on post insulators. All the current and potential transformers are installed in compartments in the bus structure.

Fig. 14. High Tension Switch Room

### Lightning Arresters

Two sets of electrolytic lightning arresters with choke coils are provided for the two outgoing Atlanta lines, and similar equipments will soon be supplied for the other two lines. They are of the outdoor type mounted on a structure located on the side of the hill adjoining the switch house. Each arrester consists of four tanks, three of which are connected to the line wires through horn gaps, while the fourth tank is connected between the other three and ground.

Fig. 15. Lightning Arrester Equipment

### Station Lighting and Service Equipment

Energy for station lighting and power is supplied from the low-tension bus through a bank of three 20 kw. single-phase transformers stepping down from 6600 to 460 or 230 volts. On the first floor of the switch control house there is also a 125 h.p. Pelton waterwheel, fed from one of the penstocks and governed by a Lombard governor, which drives a 50 kw. 250 volt direct current generator. This can be connected to either the field or auxiliary station bus and is intended for emergency use, such as for providing light and power during shutdown periods of the main units.

A portable high potential transformer is provided and there is a large water rheostat outside the station, means being provided so that either generator can be connected thereto for testing purposes. There is also a small motor-driven air compressor for cleaning and performing other services about the station. The lighting is done by 100 c-p. mazda lamps.

In the following issue there will be a description of the transmission lines and the large outdoor substations of the system.

The construction work for this development has been done by the Northern Contracting Company under the able supervision of Mr. C. O. Lenz, Chief Engineer, 71 Broadway, New York; Mr. C. G. Adsit, Engineer at Tallulah Falls; Mr. C. E. Bennett, Electrical Engineer, and Mr. E. Lauchli, Hydraulic Engineer The entire electrical equipment was furnished by the General Electric Company.

# DRILLING AND PUMPING OIL WELLS BY ELECTRICITY

By W. G. Taylor

Power and Mining Engineering Department, General Electric Company

The methods of drilling and operating oil wells are described and illustrated in sufficient detail to give a clear conception of the requirements of motor drive, and the description and advantages of the electrical equipment are covered in a manner intelligible to oil men. Probably no other induction motor application has been obliged to contend with as complex conditions as the oil well motor; but the saving it effects in time, labor, and expense more than justifies the special features which make the equipments so versatile. The author submits valuable power and cost data obtained from the actual operation of oil well motors in the California oil fields.—Editor.

W. G. Taylor

It is no simple task to drill a hole in the earth half or three-quarters of a mile deep and from four to twenty inches in diameter, and then keep it free from shale and sand month after month while a pump is kept in operation at the bottom of the hole. Yet these are conditions imposed in the production of petroleum, and they have been successfully met at more than 176,000 wells now producing oil in the United States. There are a few wells in the Appalachian and California fields considerably more than a mile in depth, and the improvements being made from time to time in drilling methods indicate that wells of such depth may soon be numerous, as the drilling of new wells is started almost daily.

The steam engine did most of this work. A simple slide-valve type was adapted to this special service long before the electric motor was put into general commercial use, and yet the latter has supplemented steam and gas engines, or has been the initial type of drive installed, on more than 1020 wells during only three years' operation in the California oil fields alone. A number of motors have been in use in the Pennsylvania and West Virginia fields for several years longer, but these were not suitable for the widely different conditions encountered in California, and it was necessary to develop an improved type of motor which was more generally applicable to oil well operating methods of any character.

Several things combined to prevent the earlier adoption of motor drive. The lack of power lines in the fields was due to the fact that the power companies could not anticipate much revenue from them until a motor could be produced which would in every way satisfy the oil operator as well as did his time honored engine. Early trials of various types of motors indicated the special features that were necessary in the electrical equipment and indicated also the most suitable sizes of machines. The results obtained demonstrated clearly that electric drive would effect large savings in operating expenses. However, this saving was not a matter to which the oil producer paid much attention until the falling price of oil awakened his lively interest in the subject. Although oil and natural gas had always been the fuel used for both drilling and pumping, rarely had an oil producer charged to his operating expense the market value of the fuel consumed, and in some cases he had no accurate idea of the quantity used. Under such circumstances it is not surprising that the oil men were at first reluctant to pay cash for power when they could obtain it "free" from their own wells.

.Induction motors were used from the first, not only because the available power supply was alternating current, but because this type of machine was recognized as having the sturdiness and overload capacity necessary to withstand oil field service. Motors were first developed for use on producing wells, and electrical drilling was not attempted until considerable progress had been made on pumping motors. All the operations of drilling are handled by a machine installed at the time the rig is erected, which is replaced by one of smaller capacity when the well is "brought in" as a producer and is "put on the beam." The drilling motor is then transferred to the next new rig.

### Motors for Pumping, Pulling and Cleaning the Well

The principal work of the pumping motor is to pump the oil from the well, this being continuous duty day and night except when it becomes necessary to pull out the rods and tubing to make repairs or clean out the well, and then replace them to resume pumping. It was soon recognized that on the majority of wells all of these operations would have to be performed by the same motor in order to compete at all with the steam engine. On account of the wide range of duty thus imposed, motor equipments of exceptional versatility have been perfected.

To the ordinary observer, the oil well derrick and other parts of the rig make a crude-looking affair, but for convenience of manipulation they can hardly be improved upon. The motor is generally belted to a countershaft, as in Fig. 1, which in turn is belted to the band-wheel. The latter transmits the power through a crank to the walking beam, as is shown in Fig. 2. The well is lined wholly or in part with jointed iron or steel casing, within which a "string" of tubing of small diameter is lowered to the depth at which the pumping is to be done. The lower end carries the pump barrel within which the plunger works with a vertical reciprocating motion imparted to it by the beam, through jointed rods extending down within the tubing and attached to the end of the beam. Suitable check valves in the barrel and plunger govern the flow of oil through the pump.

When it is necessary to pull out the rods and tubing to clean out the well or replace broken rods, worn pump plungers, etc., the bull-wheel, Fig. 2, is operated by rope-drive from the band-wheel and the hoisting line is wound on the bull-wheel shaft, while the walking-beam is disconnected from the crank. The calf-wheel is used only for handling the casing in a similar manner during drilling, and is driven from the band-wheel by a sprocket and chain. The bull-wheel and calf-wheel are each equipped with a powerful hand-operated band brake.

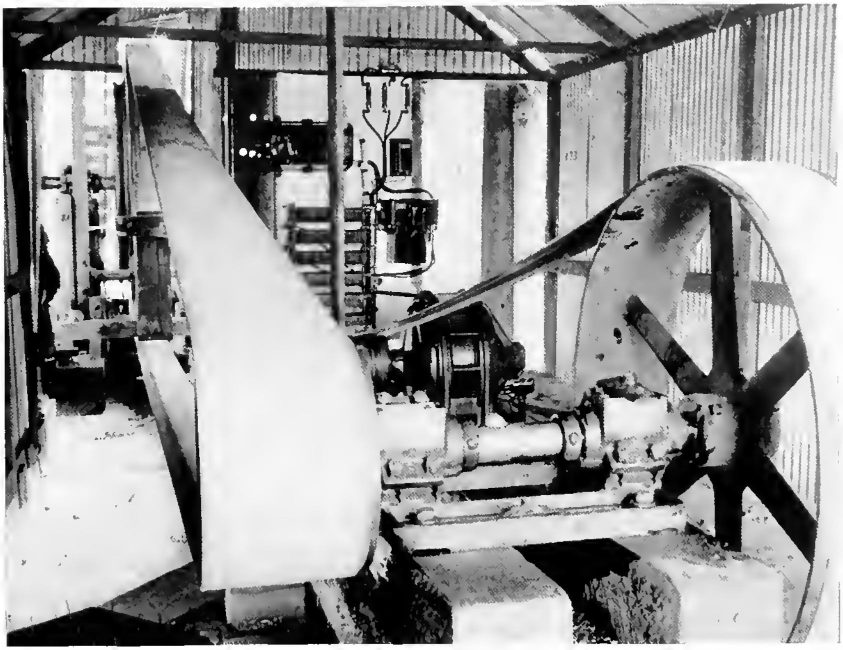


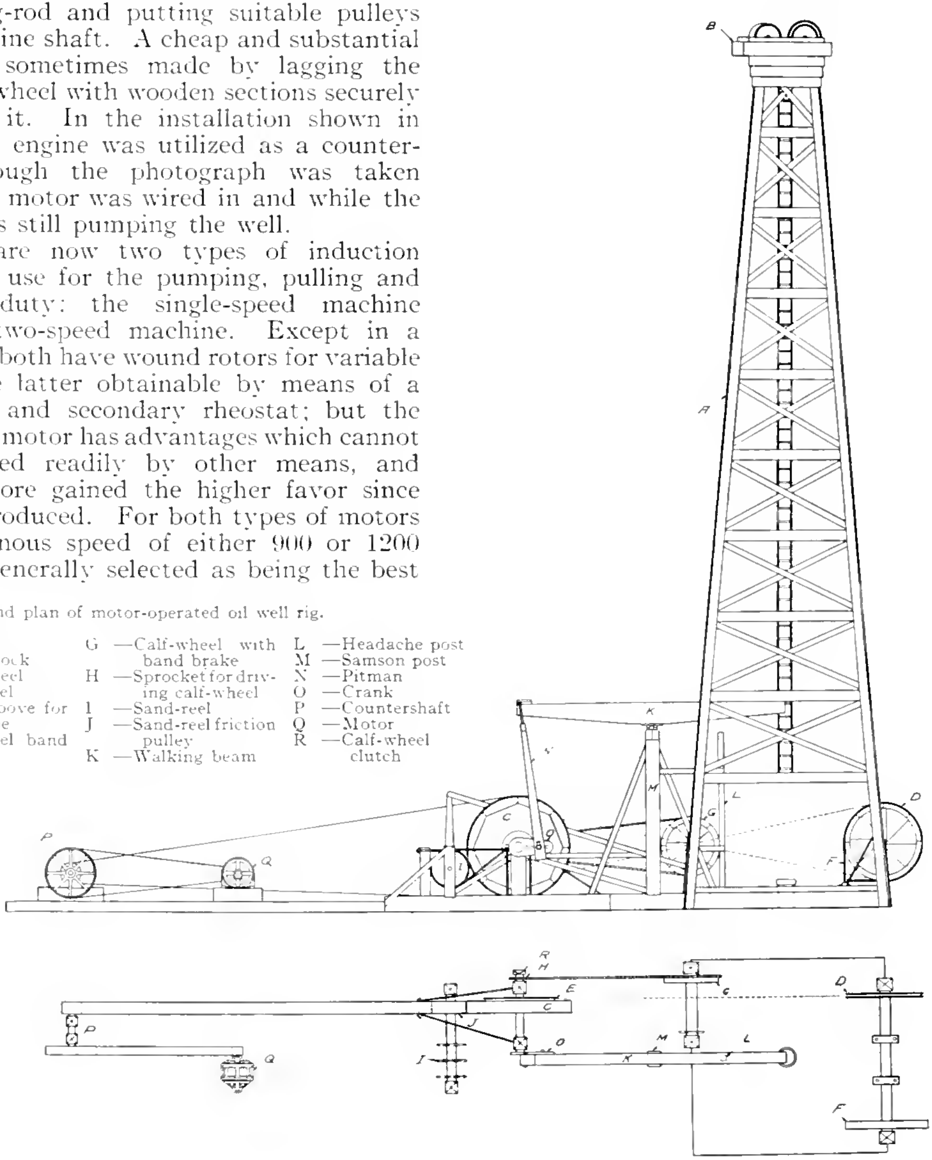
Fig. 1. Two-speed Motor with Countershaft for Pumping, Pulling and Cleaning a California Oil Well

When a well is cleaned, the mixture of sand, mud, and oil at the bottom must be bailed out. The bailer, a long tube with a check valve in the bottom, is handled by a single line on a drum called the sand-reel, which is driven by a friction pulley in contact with the band-wheel. Occasionally light drilling must be resorted to before the sand can be sufficiently loosened to be bailed out.

The oil well pumping motor installations are of two general types, belted and back-geared, by far the larger proportion of them being belted because of their more quiet running qualities. The backgeared motor is generally mounted on the old engine block and the backshaft belted directly to the band-wheel, Fig. 3 showing a typical installation with this arrangement. When a belted motor is used an intermediate countershaft is necessary, the latter being mounted on the engine block and the motor belted to it, as is seen in Fig. 1. Occasionally it is found advantageous to use the old steam engine as a countershaft, disconnecting the connecting-rod and putting suitable pulleys on the engine shaft. A cheap and substantial pulley is sometimes made by lagging the engine flywheel with wooden sections securely bolted to it. In the installation shown in Fig. 4 the engine was utilized as a countershaft, though the photograph was taken before the motor was wired in and while the engine was still pumping the well.

There are now two types of induction motors in use for the pumping, pulling and cleaning duty: the single-speed machine and the two-speed machine. Except in a few cases, both have wound rotors for variable speed, the latter obtainable by means of a controller and secondary rheostat; but the two-speed motor has advantages which cannot be obtained readily by other means, and has therefore gained the higher favor since it was introduced. For both types of motors a synchronous speed of either 900 or 1200 r.p.m. is generally selected as being the best compromise between a motor with too small a pulley and one with a high cost.

In the California fields particularly there is a great necessity for a variable pumping speed, as it is influenced by varying conditions, such as the rate of flow of the oil, the amount of sand accompanying it, the amount of gas or water in the oil, the viscosity of the fluid and the condition of the pump itself. A well is pumped at what the operator considers its maximum economical rate, but this may be limited by the rate at



Elevation and plan of motor-operated oil well rig.

A —Derrick
B —Crown block
C —Band-wheel
D —Bull-wheel
E —Rope groove for bull-rope
F —Bull-wheel band brake
G —Calf-wheel with band brake
H —Sprocket for driving calf-wheel
I —Sand-reel
J —Sand-reel friction pulley
K —Walking beam
L —Headache post
M —Samson post
N —Pitman
O —Crank
P —Countershaft
Q —Motor
R —Calf-wheel clutch

Fig. 2. Elevation and Plan of Motor-Operated Oil Well Rig

which the oil will flow into the well from the surrounding strata, or by the rapidity with which the rods and plunger will drop in the oil on the return stroke. On the average well the band-wheel speed may vary from 18 to 30 r.p.m. and the motor must consequently be capable of a similar range in speed. However, for the hoisting work necessary when "pulling" the well and cleaning it out, a band-wheel speed of twice this amount is used, and is obtained by changing either the motor pulley or the internal motor connections.

On the single-speed motor the desired hoisting speed can be obtained by putting on a larger motor pulley, which must, however, be replaced by the small one for pumping again. This change of pulleys is so irksome to the oil men that it is seldom made, and in many cases where it is tried the pulleys are soon damaged. The slow hoisting speed obtained with the small pulley materially lengthens the time required to "pull" the well and put it back "on the beam," and this means loss of production to the operator. An expedient for obtaining high hoisting speed is to lag the bull-wheel shaft on which the line is wound. This greatly increases the strain on the rig and for that reason is not considered a safe method by most operators. Furthermore, it does not increase the speed of the sand-reel and thus much time is lost when hoisting the bailer.

Fig. 3. Back Geared Pumping Motor in the Kern River Oil Fields, Bakersfield, Cal. At the right is the weight which counterbalances the rods in the well

Another operation which is impossible unless the motor pulley is changed on the single-speed motor is "shaking up" a well. When sand gets in, it very frequently clogs the pump-valves, but by speeding up the walking-beam sufficiently they may often be cleared without resorting to the expensive process of pulling the well. On the other hand, if the motor is shut down long enough to change the pulley, the well in the meantime may sand up completely, making a pulling job absolutely necessary, the work requiring one or two days time depending on the depth of the well, and thus entailing a considerable loss in production. Occasionally a well requires shaking-up several times a day, and it would be obviously impractical to change pulleys each time.

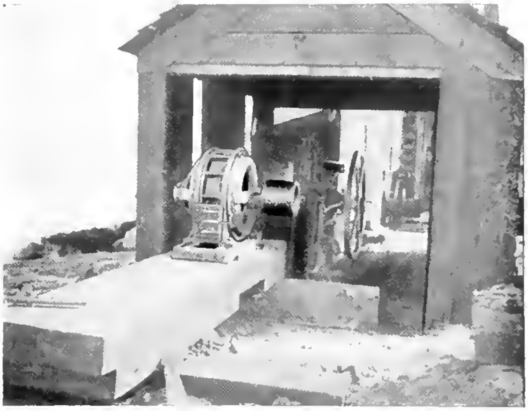


Fig. 4. One Method used by the General Petroleum Co., Taft, Cal. of installing a two-speed pumping motor for belting to the engine shaft

All of these drawbacks have resulted in the extensive adoption of the two-speed variable-speed machine. By a pole-changing switch mounted on the motor frame, the synchronous speed may be instantly changed from 600 r.p.m. to 1200 r.p.m. or back at any time desired, making the high speed at once available for shaking-up, bailing or handling rods and tubing. This method appeals to the oil man on account of its simplicity, and does not have the objections which have been offered to sliding-gear boxes and belt-shifting devices, the operation of which is soon impaired by the wear and tear of heavy duty. On the light redrilling work often necessary when cleaning out a well, the two-speed motor is especially suitable for the wide range of speed and load frequently desired.

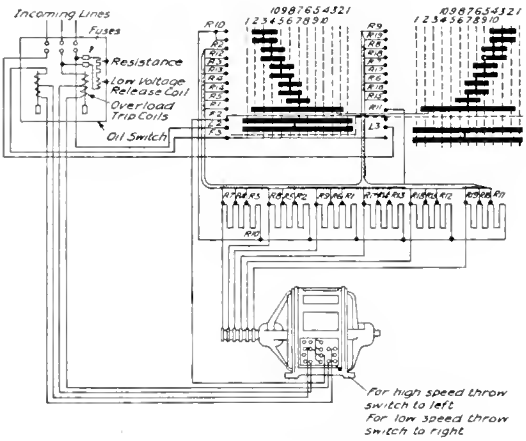


Fig. 5. General Connections for Two-Speed Pumping Motor Equipment

A 25 h.p. motor, rated 8 h.p. on the pumping speed, is the size suitable for the majority of wells. The deeper wells are generally equipped with a 30 15 h.p. machine. As indicated by Table 1, the motor on pumping duty is required to deliver an average of 4 h.p. but this may vary from 1 to 6 or 7 h.p., or higher. A well in the Midway fields in California has been known to require 16 to 17 h.p. for a considerable time for pumping, this heavy demand apparently having been due to a heavy flow of sand with the oil. The power input will vary from day to day and even from hour to hour, and may increase considerably in a short time when the well is sanding up. For this reason the motors are given the liberal ratings stated.

For handling rods and tubing the motor may be required to deliver from 35 to 80 h.p. for short periods on the average well, and even higher in some cases, especially in emergencies and on some of the special operations which are occasionally necessary to maintain the well as a good producer. This is many times greater than the power required for pumping, but it has been successfully obtained by designing the machines with a maximum momentary overload capacity of 300 to 450 per cent of their high speed rating.

As pumping is a continuous day and night load, good efficiency and power-factor on this work are of importance to the consumer and power company. To obtain these on the single-speed motor the windings are arranged to be Y-connected for pumping and delta-connected for pulling, the change being made by a double-throw switch on the motor. The rated capacity is thus increased in the ratio of 1 to 3, and excellent characteristics are obtained on either connection. On the two-speed machines it has already been mentioned that the pole-changing switch accomplishes both a change in speed and capacity, and this change in like manner produces the good characteristics particularly desired when pumping.

### TABLE I

### POWER REQUIRED FOR PUMPING 213 OIL WELLS IN CALIFORNIA

| | Bbl. per Well per Day | Depth of Wells | Kw-Hr. per Well per Day | Kw-Hr. per Bbl. Pumped |
|---|---|---|---|---|
| Max. | 230 | 3110 | 123.4 | 5.843 |
| Min. | 10 | 900 | 27.7 | 0.414 |
| Average | 122 | 1430 | 80.8 | 0.683 |

#### Motor Control for Producing Wells

The controller and rheostat are located near the motor rather than at the derrick, and the former is operated by a rope wheel instead of a handle, with a wire rope running to a similar wheel on the "headache-post" in the derrick within easy reach of the operator, and in all respects similar to the throttle control of the steam engine. But as all speed variation and reversing is done by the controller, the reverse lever used with steam engines and gas engines is not required, so

Fig. 6. Motor-driven Rig showing Counterbalance

that the operator has less effort in controlling the motive power and can give better attention to the work at the well.

In addition to the drum controller and rheostat, the equipment is provided with a wall-mounted oil switch with inverse time limit overload trip coils and low-voltage release. Motor protection is required on either its low or its high rating, and is obtained by the use of double-wound overload trip coils so interlocked with the pole-changing switch on the motor that the proper protection is automatically obtained for either connection of the motor. The method of doing this will be at once seen by reference to the wiring diagram, Fig. 5.

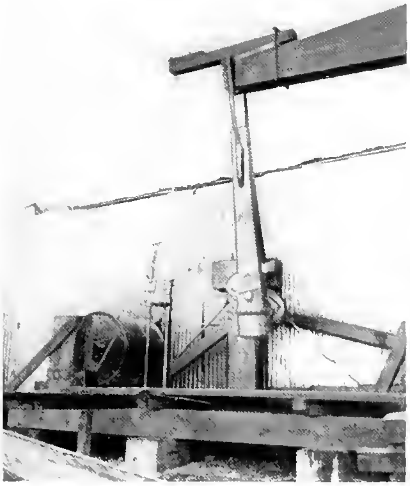


Fig. 7. Tail-Pump Operated by the Walking-Beam

The work of pulling out rods and tubing as well as replacing them requires that they be unjointed and handled generally in 60 foot lengths, and occasionally in 20 foot lengths, and this involves considerable manipulation by the motor with frequent reversals at high speed. The best results are obtained by making use of the high torque capacity of the motor, the full benefit of which is obtained on the intermediate controller points. A number of equipments are now provided with a device which entirely relieves the operator of the necessity of keeping this matter in mind on every reversal, as it automatically stops the controller at the most advantageous point until the input has fallen to a value at which the remainder of the resistance is no longer necessary in circuit. The device also acts as a protection to the motor, as it lowers considerably the average current input while reversing.

### Counterbalances

With the advent of the electric motor in the oil fields and the ease of measuring the power input, attention was directed to some economies which could be effected by minor changes in the rig. The chief improvement was the use of a weight to counterbalance the rods on the beam and thus relieve the motor of the necessity of hoisting the full weight of rods on each stroke. The usual type of counterbalance is shown in Fig. 6. It is installed at a nominal cost, and tests on a large number in use show a saving in power of 8 to 22 per cent, depending upon the depth of the well, weight of rods, etc.

### Tail Pumps

Fig. 7 shows a type of pump operated from the tail-end of the beam, frequently used for transferring oil from the sump to the storage tank or pipe-line. Such a pump increases the power demand from the motor approximately 1.5 h.p. under average conditions.

### Cost of Pumping, Pulling and Cleaning

The greatly diversified conditions encountered in the oil fields cause a wide variation in the costs of operation, though these check closely for similar conditions. The depth of well, the quantity and rate of production, the size of pump, the distance between wells, the number of wells operated and the gravity of the oil all have their influence. In general, pumping a well with

Fig. 8. Power-Head Driven by a 20 h.p. Motor in the Sherman Salt Lake Oil Fields, Los Angeles, Cal.

### TABLE II

### COST OF ELECTRIC POWER FOR PUMPING WELLS ON SEVERAL PROPERTIES IN THE CALIFORNIA OIL FIELDS

| No. of Wells | Average Depth | Rate per Kw-Hr. | Cost per Well per Day |
|---|---|---|---|
| 4 | 800 | $0.015 | $0.80 |
| 2 | 950 | .015 | .65 |
| 15 | 1000 | .015 | .71 |
|  | 1100 | .015 | 1.08 |
| 2 | 1100 | .015 | 1.21 |
|  | 1400 | .015 | 1.05 |
| 1 | 1500 | .015 | 1.13 |
| 62 | 1600 | .01 | .69 |
| 1 | 1700 | .015 | 1.11 |
| 110 | 750–2700 | .01 | .84 |

### TABLE III

### COST OF PUMPING 8 WELLS, DEPTH 1000 TO 2800 FEET, IN THE CALIFORNIA OIL FIELDS

|  | STEAM OPERATION |  | ELECTRIC OPERATION |  |
|---|---|---|---|---|
|  | Sept. 1912 | Oct. 1912 | Jan. 1913 | Feb. 1913 |
| Water | $449.99 | $457.83 | $71.00 | $53.90 |
| Fuel, oil at 50 c., per bbl. | 469.00 | 305.50 |  |  |
| Fuel and electric power at 1½ c. per kw-hr.. |  |  | 340.00 | 329.90 |
| Labor | 448.00 | 448.00 | 450.00 | 383.50 |
| Boiler compound and lubricating oil | 30.00 | 30.00 |  |  |
| Lubricating oil |  |  | 17.50 | 17.50 |
| Totals | $1396.99 | $1241.3 | $863.50 | $784.80 |

Average per well per day—steam . . . . . . $5.41
" " " —electricity . . . 3.49

Saving by electricity over steam $1.92 per well per day.

### TABLE IV

### COST OF PUMPING 12 WELLS, AVERAGE DEPTH 1100 FEET, OIL 15.5° BAUMÉ CALIFORNIA OIL FIELDS

|  | PER WELL PER DAY |  |
|---|---|---|
|  | Steam | Electricity |
| Labor pumping | $1.15 | $1.18 |
| Electric power at 1½ c. per kw-hr. |  | 1.07 |
| Fuel oil | 1.47 | .42 |
| Water | 1.95 | .95 |
| Repairs to boilers and engines | .25 | .06 |
| Repairs to motors, transformers and power lines | None to Date | None to Date |
| Oil, waste and packing | .27 | .17 |
| Totals | $5.09 | $3.85 |

Saving by electricity over steam $1.24 per well per day.

### TABLE V

### COST OF PUMPING 107 WELLS, AVERAGE DEPTH 800 FEET, OIL 13.5° BAUMÉ CALIFORNIA OIL FIELDS

|  | PER WELL PER DAY |  |
|---|---|---|
|  | Steam | Electricity |
| Maintenance pipe-lines, wells, pumps, rigs, boilers, motors, transformers, and transmission lines | $0.95 | $0.70* |
| Labor, including pumpers, boiler men, electricians and well-gang | .65 | .45 |
| Fuel oil at 35 c. per bbl. | 1.17 | .12 |
| Water, waste and lubricating oil | .52 | .13 |
| Electric power at 1 c. per kw-hr. |  | .57 |
| Totals | $3.29 | $1.97 |

Saving by electricity over steam $1.32 per well per day.

* Estimated repairs are added for electrical equipment, as there were none for period covered.

a steam engine requires the following items per well per day.

Fuel oil . . . . . . . . . . . . . . . . . . . . . . 3½ to 10 bbl.
Water . . . . . . . . . . . . . . . . . . . . . . . . 25 to 80 bbl.
Lubricating oil, waste, packing, etc. 15 to 40 cents
(the higher figure is for gas-engines)
Repairs to boilers and engines . . . . 20 to 40 cents

With electric drive the requirements per well per day are about as follows:

Electric power . . . . . . . . . . . . . . . . 45 to 200 kw-hr.
Water . . . . . . . . . . . . . . . . . . . . . . . . . 1 to 20 bbl.
Lubricating oil . . . . . . . . . . . . . . . . . . 1 to 3 cents
Repairs to motors, transformers and transmission lines . . . . . . . . . . . . . . 3 to 6 cents

These figures take no account of the cost of labor, which varies greatly even when other conditions are similar. In general one pumper can look after 8 to 12 gas or steam engines or 15 to 20 motors.

Tables 2, 3, 4 and 5 give actual comparative operating costs for a considerable range of conditions and indicate the excellent results being obtained. The figures are all for wells on the beam and operated by individual motors. In the three latter tables it will be noted that for electric operation a charge is included for fuel and water, this being required for washing and heating the oil, also for domestic purposes, and in some cases for shipping the oil. There are a few leases where steam has been entirely dispensed with, the only water used being for domestic purposes. The oil produced on these properties requires no washing, while motor drive is used for the shipping pumps.

## TABLE VI

### POWER REQUIRED FOR PUMPING OIL WELLS BY PUMPING-JACKS IN CALIFORNIA OIL FIELDS

| No. of Motors | No. of Wells | Average Kw-Hr. per Well per Day | Kw-Hr. per Bbl. Pumped |
|---|---|---|---|
| 1 | 7 | 39.7 | 2.52 |
| 1 | 8 | 37.6 | 2.30 |
| 1 | 14 | 31.9 | 1.41 |
| 1 | 8 | 37.1 | 1.67 |
| 1 | 8 | 29.1 | |
| 1 | 8 | 30.4 | |
| 1 | 9 | 28.2 | |
| 1 | 12 | 26.3 | |
| 1 | 23 | 15.7 | |
| 1 | 22 | 17.2 | 1.43 |

## TABLE VII

### COST OF ELECTRIC POWER FOR DRILLING IN CALIFORNIA OIL FIELDS

POWER RATE 1.5 CTS. PER KW-HR.

| Depth of Well, Ft. | Cost of Power per Foot Drilled |
|---|---|
| 735 | $0.1074 |
| 1495 | 0.1025 |
| 945 | 0.0915 |
| 1356 | 0.1060 |
| 824 | 0.0570 |
| 732 | 0.1040 |
| 1175 | 0.0848 |

### Pumping-Jacks

When the production of several adjacent wells is so low that it is unprofitable to pump them by individual motors, they are operated together by one motor from a central point, providing that they are comparatively free from sand and water troubles. The power-head, as shown in Fig. 8, carries one or more eccentrics, to the yokes of which are attached cables or rods extending to a bell-crank or "pumping-jack" at each well, and by this means imparting the vertical reciprocating motion to the sucker rods. An ordinary constant speed squirrel cage motor is belted to the power-head through a jack-shaft, the latter generally being provided with a friction clutch. A quarter-turn belt connects the latter with the power-head. The outfit is simple and the installation very cheap as no special electrical apparatus is required other than the standard motor and compensator for starting it. When the well is cleaned a portable hoisting equipment is employed, such as is shown in Fig. 9.

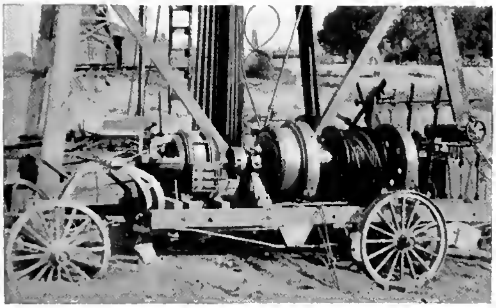


Fig. 9. Portable Electric Hoist used for Pulling and Cleaning Oil Wells Pumped by Pumping-Jack in the Kern Field, Bakersfield, Cal.

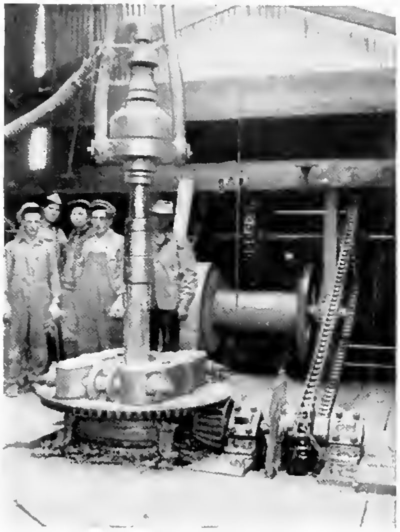


Fig. 10. Rotary Drilling Rig and Crew

The power required for pumping wells by this method depends considerably upon the effectiveness with which the wells are balanced against each other, and is affected also by variations in the depth of the wells, the height to which the fluid rises in the well, the gravity of the oil, the diameter of tubing used and the speed of pumping, as well as the general condition of the wells with respect to sand, gas and water content. A low pumping speed is maintained, generally from 10 to 20 strokes per minute. In Table 6 are given figures taken from the records of several oil companies in California which give a general indication of the motor capacity necessary.

### Motors for Drilling

The two principal modern methods of drilling oil wells are the standard cable-tool method and the rotary process, although in a few instances a combination of these two is used. In cable drilling a heavy stem and bit are suspended from the walking-beam by a steel wire or manila rope, and are raised and dropped on the bottom by the movement of the beam. The drillings are mixed with water in the hole and are removed at intervals by a bailer. In the rotary process a bit is located at the lower end of a rotating column of pipe, which is lowered into the well as drilling progresses. The pipe is held and turned by a turntable as shown in Fig. 10. By means of the so-called "slush-pump" a mixture of thin mud is circulated down through the stem and up outside of it, serving to wash out the drillings and plaster up the sides of the hole to prevent caving.

Fig. 11. Two-Speed Pumping Motor and Control Equipment Installed by the Kern Trading and Oil Co., at Shale, Cal.

As drilling proceeds the well is lined with iron or steel casing unless the strata passed through are so firm that no caving will occur. The casing is inserted in approximately 20 foot lengths, screwed together, and its handling imposes heavy duty on the drilling motor. As has been mentioned, the calf-wheel is used for this casing work. In lowering a string of casing into a well the friction of the sides of the hole caused by the pressure of the surrounding formations may so impede it as to prevent it from sinking farther until relieved by "spudding" the casing. This consists in repeatedly raising and lowering it a few feet until a clear passage is obtained, and requires a very liberal intermittent overload capacity in the motor. Its ability to exert a high torque in an emergency is often the means of freeing a string of casing which may have become "frozen," and which might otherwise have to be "landed" in the hole, and thus necessitate drilling being resumed with a smaller string.

On account of the heavy strains to which the equipment is subjected, the motor for cable drilling is preferred without backgears, and a belted countershaft is therefore used as with pumping equipments. A few installations have been made using a two-speed change-gear countershaft to obtain more economical speed variation, but they have nearly all been discarded because of their rapid depreciation under the severe service. It has also been found that the operators frequently failed to make use of the device because of the time and trouble involved, and furthermore that the tremendous pull obtainable with the low gear was more than the average rig and casing could withstand without injury.

The range in speed required is approximately the same as for producing wells and is obtained by insertion of resistance in the rotor circuit. Other methods requiring more expensive equipment have been tried, but the standard type of variable speed slip-ring motor with the special control described in a subsequent paragraph has met the most general favor. It is natural that this should be the case, as the various operations follow so closely upon each other during the day that the driller is seldom willing to take the trouble to throw switches or shift gears each time, and will not do so if he can get fair results without it.

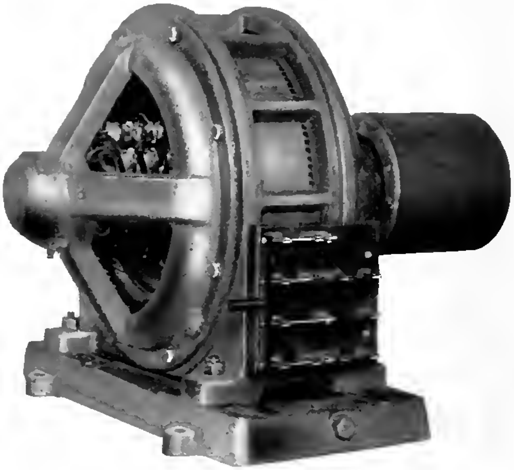


Fig. 12. Two-speed Oil Well Motor for Deep Wells, rated 15 h.p. for pumping and 30 h.p. (continuously) for pulling and cleaning work

The power required for the numerous operations in standard drilling varies considerably. Drilling itself is a fairly steady load on the motor, while the load imposed by the other operations, especially the manipulation of casing, is very intermittent in character, requiring high torque and frequent reversals. A 50 h.p. machine has been found to have sufficient capacity for all drilling work on most wells of moderate depth, but 75 h.p. may be necessary in many cases, particularly for greater depths. The size of motor in any specific case depends, as in pumping, upon the local conditions encountered.

For the rotary process the same type of motor used in cable drilling is well suited for driving the turntable and also the slush-pump. Heavy duty is required of the turntable motor in raising the drill-stem to change bits, and in putting in casing, so that high overload capacity is a necessity.

Fig. 13. 35 H.P. 1200 R.P.M. Constant Speed Motor Driving the Power-head for Pumping 23 Jack-wells in the Kern Field, Bakersfield, Cal.

### Motor Control for Drilling

In cable drilling the bit must fall freely on the down stroke to get the most effective blow, and to accomplish this the motor must slow down when lifting the bit and speed up when dropping it. This "series characteristic" is obtained by so proportioning the pulleys that some secondary resistance will be in circuit when the motor is operating at the correct drilling speed.

Fig. 14. Well No. 3 of the Midway Pacific Oil Co., Fellows, Cal., drilled entirely by electric power. Depth 1900 feet. The transformer installation is typical of the oil fields

The speed of cable drilling requires a very fine adjustment so that the movement of the beam will accord with the natural period of vibration of the drilling line due to its elasticity, as this period changes with the deepening of the well. Deviation from the right speed will not only result in deadening the movement of the bit but may seriously strain the line and the beam. Some of the first motors installed for this work were equipped with a 10 point controller, but it was found that the speed control was not fine enough. This trouble was overcome on later equipments by supplying an auxiliary controller designed to cut in between points on the main controller. A very smooth control with an infinite number of points may be obtained with a liquid rheostat, but this requires good water and close attention for satisfactory operation, neither of which can be given it under average conditions. For this reason it has been discarded by most

California oil men who have tried it, and drum controllers are now given the preference. They are operated by wire ropes extending to the "headache-post" as previously described for producing wells.

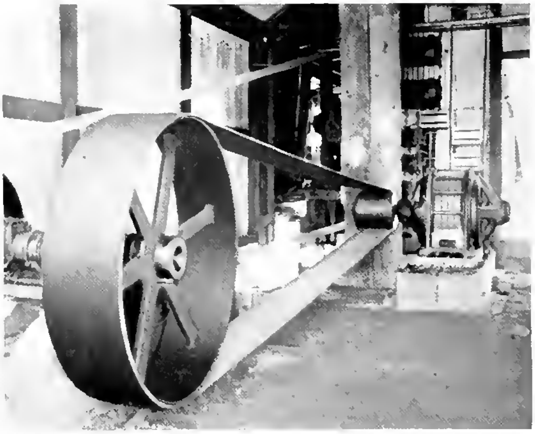


Fig. 15. 50 H.P. Drilling Motor Operating Standard Cable Tools at the Well Shown in Fig. 14

Rotary work also needs a fairly close speed adjustment because of the fact that for each different formation encountered there is a certain speed at which the bit will cut most effectively. The same type of control equipment used in cable drilling is therefore suitable. The slush-pump must also be operated at variable speed, owing to the changing pressure and flow required as the underground formation changes and the depth increases.

Fig. 16. Electric Oil Well Pumping is now used Exclusively Here on the Property of the Indian and Colonial Development Co. in the Desert of the San Joaquin Valley, Cal.

### Cost of Drilling

The cost of power is more variable for drilling than for pumping, as it depends upon the amount of trouble encountered and will be particularly high if there is any casing trouble. The figures given in Table 7, which have been determined from the actual power bills for drilling each of the wells in question, are representative of fairly good operating conditions in which no exceptional difficulties were encountered.

Fig. 17. An Electrically Operated Rig with Crew, for Drilling by the Standard Cable Method. The motor is controlled from the handwheels on the headache-post at the left.

### Summary of Motor Advantages

(1) Considerable saving in time is effected. The work is not necessarily done faster than with engines, but there are fewer delays from engine, steam and boiler troubles, from getting up steam, cleaning boiler tubes, making repairs, etc. The motor pulls the first "stand" of tubing as fast as the last one, while an engine will slow down considerably.

(2) Operating expenses are decreased. No boiler feed water is required, and the losses from leaky engine valves and piping are eliminated. The cost of lubrication and attendance is lower.

(3) Production is increased by the saving in fuel oil and by the steadier pumping motion secured.

(4) There is no power consumption when idle.

(5) Steady speed control is obtained by the steadier power supply. Speed fluctua-

tions due to varying steam pressure are eliminated.

(6) The motor has greater reliability, as it can always be depended upon to respond as expected and give the same speed on the same controller point for similar load conditions.

(7) The motor has a uniformly continuous torque and therefore never has to be "kicked off center."

(8) No time and efficiency are lost due to water choking the steam-pipes after an idle period.

(9) The motor is always ready at a turn of the controller and the speed is not only very easily varied, but is accurately controlled for "spotting" rods and tubing when screwing sections together.

(10) The control is simplified by the omission of the reverse lever required with an engine.

(11) Repairs are fewer and boiler depreciation, which is always high in the oil fields, is reduced or eliminated.

(12) Greater safety of operation is obtained, as the motor cannot run away when the rods part or a hoisting line breaks under heavy load.

(13) Explosions are eliminated and the fire risk reduced, particularly when the boilers are entirely done away with and electric lights are installed.

(14) The power consumption can be accurately measured and thus indicates the condition of the well and the most advantageous operating conditions from the standpoint of cost.

(15) The belts and the motor house in general can be kept cleaner and as a consequence there will be less rapid deterioration of the machinery and rig.

# WHERE FREIGHT IS MOVED BY MUSCLE

By R. H. Rogers

Power and Mining Engineering Dept., General Electric Company

The manner in which freight is handled at transfer and storage points is treated in a particularly interesting way in the following article. The item of cost is the all important factor to be considered when studying this subject, and consequently forms the theme of the article. The methods and figures involved in the movement of freight at railway sheds and at docks are presented. A few years ago muscle was practically the only power used. Today, however, there are installations of electrical equipment which to a certain degree have replaced the former muscle methods, and which have effected a considerable saving. Freight handling by muscle cannot be replaced by handling by machinery under certain conditions and an analysis of these conditions is clearly presented by the author.—Editor.

"Black Han', Black Han', uptown!
Blue Bottle. 'Cross de road! 'cross de road!
Red Boid, Red Boid, down town!"


R. H. Rogers

THIS is the 'sorter directing the toiling coffee bearers to over two hundred consignment piles on the wharf, each pile being distinguished by a flag, showing some well known emblem. As each carrier passes by with a 135 lb. bag of green coffee beans on his head the 'sorter glances at the complicated stenciled "mark" and conjures up in his mind the flag and its location that he has previously assigned to that mark. All day, and day after day, he directs at the rate of fifteen flags per minute with no errors and still has time to skylark, "pat juba" and curse the slow or stupid members of the gang.

The coffee is assembled in rope slings in the ten bag "drafts" in the hold, hoisted on deck by one steam hoist, swung out onto a hand truck on the pier by another steam hoist, dragged back under the shed by two men and there lifted onto the heads of the distributers.

From one hatch twenty-five men and two of the ship's hoists will discharge 750 bags per hour. At another hatch in the same ship the hand trucks were displaced by about 125 feet of portable electric conveyor sections and twenty-five men were discharging 1800 bags per hour. By extending the conveyors into the hold, the work of assembling the drafts would have been avoided and the two steam hoists would have been stilled.

The electricity for discharging the entire 5000 ton cargo as far as the 'sorter would cost the stevedore $14. We venture to predict, however, that the distribution to consignment piles, when they number over ten, will continue by the muscle method until there is some radical change in shipping methods or some new device or process is invented.

Wherever deep sea ships, coasters or river boats are discharging or receiving their cargoes of packages, and in some cases of bulk material also, we find freight being moved by muscle between the remote corners of the dark holds and the far side of the piers, outside bulkheads, "farms" and warehouses. The vertical lifts at the hatches are made by the ship's hoists, for which steam must be kept up, and the long hauls to and from warehouses are usually made by mules. The laborers are paid from thirty to forty cents per hour and mules are rented for sixty cents per hour, driver thrown in.


Tramp Steamer Light at High Tide Showing Difficulties of Mechanical Freight Handling

To take a specific case, we will look at burlap, which we import in enormous quantities for bagging, wrappers, etc. The bales weigh from 1200 to 1800 lb. each and are as hard as a rock. To hand-truck these from the ship's side to the consignment pile in the pier is laborious and no attempt is made to tier them up; to load the mule trucks from the pile is more laborious. The trip to the warehouse is slow and the load small. Then the trucks must be unloaded and the heavy bales tiered up to save the floor space that rents for 35 cents per square foot. What a lot of muscle! The work is now only half done, for when a bale is ordered out the whole process is repeated, in reverse, with a lighter, car or dray as the delivery point.

A standard electric freight handling machine, the battery truck crane, costing all-told $5.00 per day including operator, has eliminated 90 per cent of the muscle represented above and does the same amount of work at a saving of $48 per day.

Wherever freight cars discharge at terminals and receive their quota of outbound freight, there is much labor employed to effect the internal movements—some of it is amply justified, much of it is not.

Take a regular railroad transfer terminal, where less than car load lots are transferred from car to car to make up full cars for long hauls—here hand labor is used exclusively and is justified by the complexity of the work. With a setting of two hundred cars there are 40,000 different possible and probable routes along which to move freight by muscle, because a trucker may go from any car to two hundred different destinations. This complexity excludes any fixed trackage system. The consignments average 490 pounds (a very moderate hand truck load) and as the consignments have to be handled individually nothing can be gained by using a vehicle of greater capacity. The variations in height of car floors, lack of room in cars and passageways, and concentration of work in restricted areas at certain hours exclude any but the elastic, versatile, self-loading simple old hand truck.

The total cost of handling L. C. L. freight in a certain representative transfer terminal is 57 cents per ton, not including overhead, and of this only 17.2 cents per ton is chargeable to labor, so even a considerable reduction in the 30 per cent labor cost would not materially reduce the over-all cost of handling freight for that terminal where over three hundred men pull hand trucks.


Transferring Cargo from Lighter to Freight Car by Hand. One of the many steps in transferring about New York Harbor

Luckily all transfers are not so complicated and the extenuating circumstances are absent. The transfer of package freight from a wagon platform to the spacious main deck of a sound or river steamer is no job for muscle today, for the little electric industrial truck can be easily loaded from a suitable platform with one or two tons of freight (if it is not too bulky) and run through the pier up or down the gangway across the crowned deck to the edge of the carefully tiered freight. An equipment of twenty-one of these trucks in New York is credited with saving $63 per day over the old muscle method.

Where a wide wharf lies between the railroad tracks and the berths of the deep sea ships, one hears from afar the long drawn call of "Oh, dra-a-a-ag 'er! Oh, dra-a-a-ag 'er!" and there is seen a long line of men straining on a rope-fall pulling a log up skids out of a gondola car—gaining two inches on the "dra-a-a-ag" and losing one and three-quarters on the "Oh," until after half an hour the log topples over the edge and falls onto the wharf deck usually between the bumpers placed there to receive it, with consequent superficial or permanent damage to the fabric.

Then follows a mighty struggle with cant hooks, arms and legs and voices, as it is rolled onto a "dollie" a foot high mounted on six wheels. All hands shove the log across the wharf to a pile only two logs high where it is deposited with the aid of much shouting, muscle and perspiration. A few days later the operation is repeated, for the log must be urged and cajoled from the pile to the ship's side where the ship's tackle and hoist can lift it aboard. What an opportunity is here presented for the portable electric crane! Time to be saved, labor to be dispensed with, damage stopped.

In Main Hold of Tramp Steamer showing Part of Her 81,000 Bag Cargo

There seems to be always that intermediate piling of freight in all our terminal operations (with the exception of transfer terminals) consequent to breaking bulk for change of carriers to place in temporary storage.

When a ship discharges flaxseed to be transported inland in canal boats, it seldom goes into the canal boat direct, because of inspection and weighing by the customs officials, and again by the consignee, and because the canal boat is not there at the time. Car loads of manufactured goods or what not for foreign ports must be held in a warehouse, in an outdoor pile or on the pier until the ship is ready to receive it.

Two Men with Hand Truck Handling Coffee in Nine Bag Loads. There were 81,000 bags in this cargo

Even when coffee or sugar is going from a ship to a nearby warehouse piling intervenes, and often expensive hand terraced piling on account of the limited space. The operations of discharging the ship, piling the cargo, tearing it down, and drawing it away are going on simultaneously, the piles acting largely as reservoirs to take up the lost motion between mismated methods of freight handling.

There is an astonishing bulk of material in a ship's cargo and when it is loosely piled on a pier, with aisles between the various consignments, one wonders how it could all have come from the hold of one ship. There are four things that limit the height to which freight can be piled, viz., ability of the material to withstand pressure, head room in the pier shed or warehouse, the load capacity per square foot of floor area, and the cost of high piling by hand as compared with the cost of hand trucking out over a large area. When the pier is small, it is often necessary to pile freight up to the roof if the other conditions permit. This is usually done by relays of men working on terraces, rehandling every item from two to five times. This makes a very expensive process and one that is avoided wherever possible. Where the pier has a liberal area or where there is a large open space inshore, usually called the levee, "farm" or "beach," the freight is trucked, carried, or rolled to great distances and left shoulder high. Space along the water fronts of harbors is very valuable, and when a ship's inward bound cargo is allowed to cover all the neighboring coast there is no room for assembling and handling her outward cargo without excessive amount of trucking unless she is moved to another berth. At the same time other steamers are berthed at the same or in adjacent spaces, each discharging and receiving, adding to the confusion, double and triple handling, and causing delays and congestion.

**Battery Truck Crane Towing Fifty Bags of Coffee from Wharf Building to Warehouse. The rope slings are for hoisting the bags to upper floors**

The cargo of a 10,000 ton ship, allowing 40 cubic feet per ton, equals 400,000 cubic feet. Piled four and one half feet high with aisles occupying one-third the space, we find that the spacious holds have evicted some three acres of freight. Somewhere in the immediate vicinity there must be made ready another three acres of cargo outward bound.

To avoid this obviously inefficient use of valuable area and to reduce the cost of placing a cargo on the pier, there are available several ingenious types of portable stackers that are used independently or in connection with horizontal portable conveyors, industrial trucks, tractors and trailers, hand trucks or "backers," i.e., back loads. On ordinary material these machines will stack a ton per minute up to twelve or fifteen feet high and with a well planned layout on the floor the work can go on practically without interruption hour after hour. The current consumption is small. The power required for a 14 ft. lift at the rate of 136 tons per hour is only 4 h.p. These stackers are among the most valuable tools for supplanting muscle in freight handling, for they are great conservers of space at the same time.

Where large quantities of package freight are placed in storage it is usual to resort to horses and mules for the hauling. The restricted spaces are crowded with animals and their drivers, much damage is done to freight and accidents are not infrequent. On a half mile haul an electric tractor will tow three or four mule trucks twice as fast as a mule will walk, delivering 600,000 lb. of cotton, for instance, in one day, or at the rate of fifteen ton miles per hour, or "a bale-a-mile-a-minute." The cost for a half mile haul per bale, not including loading or unloading the trailers, is less than half a cent.

The question of conveying freight to and from freight houses and piers in cities by other than animal power is a vexing one. The streets in the neighborhood of piers and freight houses become congested during the popular shipping hours and vehicles are subject to long delays that are expensive or disastrous to power trucks. We sometimes see a line of drays waiting for ferry boats, the line frequently being made up of enough drays to load four boats; hence, a team may wait an hour and a half in the line. The load factor, or per-

**Loading a Freight Car by Hand under the Brooklyn Bridge**

centage of full load for full time, is apt to be low in freight hauling service both to and from terminals. A team taking one-quarter load one way and returning light would show a load factor of 12½ per cent and if the team were delayed altogether enough to double its time the load factor would fall to 6¼ per cent. Where industrial concerns have no sidings, but have enough traffic each way to insure a reasonable load factor and care is taken to avoid the rush hours, power trucks possess a great advantage over horses and they have become popular in many cities. However, in West Street, New York, which is a marginal street along piers, the percentage of power trucks is very low—4 per cent according to published observations. The average load one way was 71 per cent, making the load factor 35½ per cent if there were no delays. It is interesting to note in this connection the load factor of freight cars. Droege in his "Freight Terminals and Trains," says that only 55 per cent of the capacity of freight cars is utilized and that they are loaded only 70 per cent of the mileage; hence, the load factor for freight cars is only 38½ per cent.

We learn that the average freight haul is 138 miles and the average cost per ton mile is three mills, making the cost of the average haul 41 cents per ton. How does this compare with the cost of the muscle work required to supplement the locomotive? Twenty-five cents at the receiving station, 25 cents at the delivery station, 17 cents each at two transfers making a total of 85 cents for handling by muscle against 41 cents for hauling by steam. The railroads maintain a standing army of freight handlers three times as large as the standing army of the United States. They have a freight handler for every mile of road in the country. To these must be added the vast unknown army of marine freight handlers or longshoremen, and the still greater number of men and horses that are hauling freight to and from freight houses and piers.

Four Mules Drawing Fourteen Bales of Cotton Three Miles per Hour

Battery Truck Crane Towing Twenty-four Bales Five Miles per Hour

A straight line is the shortest distance between two points, but commerce always prefers to follow the "line of least resistance," which deviates from the straight line by very great amounts on apparently small provocation. The free flow of commerce is opposed by the friction of terminals. The friction of hauling is now very low. Take the case of any of our seaports: Friction begins when the engineer applies the air brakes on entering the city and continues until the ship drops her pilot beyond the bar. To hold and increase its commerce a seaport must make the "line of least resistance" run through that port and no item of lubrication that is needed to overcome the friction of the port is too small to be scrutinized with a view to its reduction or elimination.

The following table shows the charges, exclusive of coaling and provisioning, that must be met by a steamer entering, discharging cargo, receiving cargo and clearing from one of our most prominent sea ports. The ship is rated 3279 tons net, 5154 tons gross, 5780 tons dead weight and 351,760 cubic feet of cargo space. She arrived with 3550 tons of general cargo, on which $12,646.15 was collected for freight, and cleared with 5337 tons of general freight on which $29,493.37 was collected for freight.

| | |
|---|---|
| Custom house entrance $5.70, clearance $2.70 | $8.40 |
| Tonnage due at 6 cents per net ton | 196.74 |
| Officers' night work | 25.00 |
| Noting and extending protest on inward cargo | 15.00 |
| Consular fees | 15.65 |
| Customs' bond on inward cargo | 1.00 |
| Pilotage per ft. on deepest draft bar $4.00, river $1.50 | 268.13 |
| Towage on steamer to 5 berths | 750.00 |
| Harbor fees | 15.00 |
| Wharfage 6 cents per ton for 3 days, 3 cents for 3 additional days and 30 days free | 463.86 |
| Shed charge, 1½ cents per gross ton | 77.31 |
| Watchman on dock for inward and outward cargo | 187.50 |
| Cooperage on inward cargo | 70.65 |
| Cotton inspection, 1½c. per bale | 11.67 |
| Brokerage on outward cargo | 340.12 |
| Grain fittings | 144.10 |
| Damage for packing cargo | 30.00 |
| Stevedore (freight handling) | 3837.80 |
| Total | $6133.78 |

**Portable Conveyor Carrying Coffee from Ship's Deck to Wharf Building at Rate of 1800 Bags per Hour**

Of the above twenty charges, nineteen aggregate 26 cents per ton, while the remaining one, moving freight by muscle, amounts to 43 cents per ton. It is easy to point to the item of friction most worthy of study and attack. Every cent that can be cut off the port charges brings the "line of least resistance" thirty miles nearer. Thirty-three cents reduction will deflect the line 1000 miles in favor of the port. The efficiency of a ship as compared with men and animals is so great that it can carry a ton of freight 1200 miles for what it cost to carry the same amount 200 feet by muscle.

When we learned the rules of spelling and the numerous exceptions to those rules, we were at a loss to know why the exceptions were not the rule and the rule the exception. A similar condition prevails in freight traffic, the exceptions seem to far outweigh any rule of procedure that can be laid down. The manner of handling traffic in a given terminal will be diametrically opposite that in an adjacent terminal.

The obvious disposition of various commodities can be easily imagined, but observation will show that some apparently trivial detail has been overlooked and the actual practice differs materially from your carefully built up theory. It is the unexpected that always happens. Wholesale traffic conditions are not comparable with local peddling traffic, and machinery and methods adapted to the one would be a total failure in the other. Radical changes take place in the whole industry by seasons and by terms of years. An elaborate system and necessary apparatus was designed to handle the terminal work incident to the importation of a certain grain which was arriving every month in the year and in large quantities. Before it was placed in operation it rained, or did not rain, or both, in various countries, and like the turning of the tide the United States became a great exporter of this grain, effectually putting the whole plan out of joint.

Highly specialized machinery is to be avoided, for unless the conditions are very exceptional the load factor measured by the year will be very low. Machinery of general application, versatile like the hand truck, capable of coping with variable conditions and commodities, will be the successful machinery, for it must compete with the most elastic of all tools—"the gang."

There is great reward in store for those ports and terminal authorities who will vigorously attack this tremendous friction item by substituting carefully designed and intelligently selected electric freight handling machinery for the present almost universal aggregation of muscle.

# OUTDOOR SUBSTATIONS AT WARE AND MILLBURY

By A. E. Pope

Electrical Engineer, Connecticut River Transmission Company

The author writes a valuable article on the construction and first year's operation of two outdoor substations, and many interesting construction features are noted. The same standard steel sections used in constructing the transmission lines were used in building the substation, and the type of transformer selected had to provide for efficient cooling in summer and against freezing in winter. Some results of operation are discussed, and the relative cost of constructing substations of similar capacity of the indoor type are touched upon. The operation has been most successful, and the author sees no objection to outdoor substations when up-to-date apparatus specially designed for this purpose is used.—**Editor.**

During the past few years the subject of outdoor substations has been so thoroughly and vigorously discussed by the engineering fraternity that any further comments would at first sight seem futile. So many of these discussions, however, have necessarily been founded only upon hypothetical conditions and preliminary estimates that the following few comments upon an already overtaxed subject may possibly be excused by the fact that they are based upon actual results obtained from the construction and first year's operation of the two stations under consideration.

During the summer of 1913 a tower line designed for 110,000 volts was completed for the Connecticut River Transmission Company, connecting its generating stations at Shelburne Falls with the terminus of its original 66,000 volt line at Millbury, thus completing a double circuit loop. The two outdoor substations were, of course, designed for the higher voltage, but to date both line and substations have been operated at only 66,000 volts.

The substation at Ware is located midway between Shelburne Falls and Millbury, about thirty miles from the former. Due to its location, this station will eventually act as a line switching and transfer station as well as a substation. Arrangements for switching and interconnecting the lines by means of disconnecting switches have already been made, and the entire station is so laid out that oil switches can be installed for this purpose as soon as the load upon the line becomes sufficient to justify the expense. The station is designed for an ultimate capacity of 9000 kw., but only half this capacity, three 1500 kw. units, is installed at present.

Millbury Substation is located about six miles south of Worcester, at the junction of the new line, mentioned above, and the original line from Vernon to Millbury. As the line to Providence will start from this point, and as the difference in voltage will ultimately have to be taken care of here, it will be seen that the function of this station is somewhat diversified. It will act both as a tie-in and equalizing station between the 110,000 volt and 66,000 volt systems, and also as a step-down substation, taking power from either or both systems and delivering it at 13,200 volts. Due to these facts, and also to its geographical location, it has been selected as the operating and dispatching center of the system. The present capacity is 15,000 kw., of which 3000 kw. is converted to 25 cycle current for railway use. The ultimate equipment will be approximately 25,000 kw.

At both Ware and Millbury the selection of the outdoor type of substation was based upon the very obvious fact that for 110,000 volt construction there is no question but that a very appreciable saving in first cost is accomplished, even were the stations to act as substations only. The saving in first cost was also considerably increased by the requirement for switching and interconnecting the high tension lines and also by the necessity for providing space for the future installation of oil switches for accomplishing this switching. This latter advantage of outdoor substations is often overlooked in making a comparison between them and the indoor stations, and is one which should be given due consideration. The desirability of making the investment consistent with the immediate load conditions and increasing this investment only at a rate justified by the increase of load is a feature which must not be ignored in selecting the type of station to be built. The cost of real estate at both locations was practically negligible and the location of the real estate directly on the transmission line lent itself most favorably to the type of station selected. While the idea of placing the low tension apparatus outdoors was taken into consideration, no justification whatever could be found for so doing. Speaking very roughly, a decision such as this may be reached by comparing the increased cost of the outdoor apparatus with the cost of the cubical contents of a building required to house this apparatus. This ratio of building cost to increased cost of apparatus, on switches alone, drops from approximately 250 per cent in the case of 110,000 volt apparatus to 50 per cent in the case of 13,000 volt apparatus. When the further requirement for protecting instrument transformers is considered, the answer is obvious.

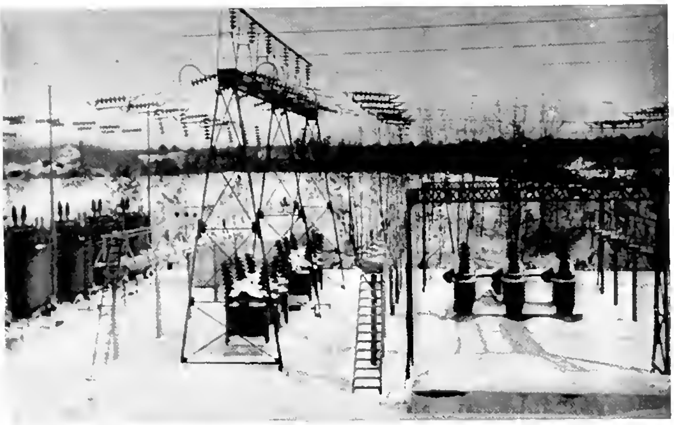


Fig. 1. View of Millbury Outdoor Substation after a blizzard. Note that the snow on the transformers has been melted by their heat, but not that on the oil switches

Considerable study was given to the general type of outdoor layout which would be adopted, particularly the type of supporting steel structure. In working this out, the following ideas were kept in mind: First, that the steel, in weight, factor of safety and method of erection, need be only consistent with the corresponding figures used in the transmission line. Second, that a special design for each substation be avoided and that the steel be so designed in units that different combinations of these units can be used for all outdoor substation work, both in present and future stations. Third, that all high tension overhead work used in substation design, such as insulators, fittings, conductor, etc., should be the same as those used on the transmission lines. As a result of the above, the design adopted consists of square towers, two-legged towers and standard box girders for connecting between these structures. The two bus elevations selected were thirty feet and eighteen feet, and supporting structures were made accordingly. From the above three units practically any required combination could be made up, and each combination was erected independently. In other words, no attempt was made to tie together the entire substation structure. It is believed that the resultant flexibility in the entire substation layout is more reliable than the more or less rigid construction which would have resulted in a special steel structure designed for each substation. The cost is unquestionably less. In many cases where it was necessary to support the suspension type disconnecting switches in the middle of a span, the stress upon the steel structures was greatly decreased by stringing galvanized strands over these switches and supporting the latter from the catenary by a single string of insulators. In most cases, the station layout was so arranged that this messenger wire could be supported from the same steel as the high tension conductors. In one or two instances steel trolley poles were used for such support.

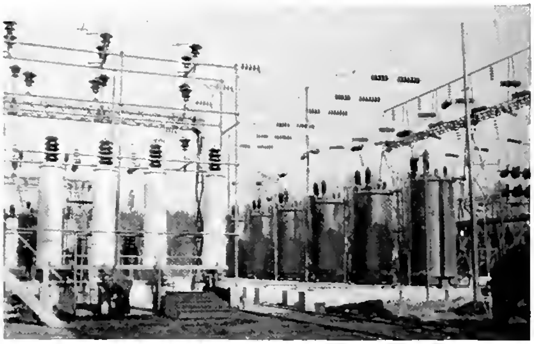


Fig. 2. A View of a Bank of Transformers and Lightning Arresters at the Millbury Outdoor Substation

Fig. 3. A View of a Bank of Transformers, Oil Switches and a Lightning Arrester at the Millbury Outdoor Substation

The question of bringing the low tension conductors into the substation building was carefully looked into, and in the case of Millbury a complete underground system was worked out. The cost of such a system proved to be very much greater than the corresponding overhead system, and a study of its operating advantages as compared with the overhead system resulted very unfavorably to the former. Accordingly, in spite of its somewhat neater appearance, the scheme for coming into the station underground was abandoned and the 13,000 volt lines were brought in overhead in a manner similar to the outgoing distributing lines. The results have been most satisfactory, and the possibility of underground troubles due to water conditions and cable breakdowns has been avoided.

The type of transformers to be used was determined largely by the size of the units involved, this being 1500 kv-a. at Ware and 2000 kv-a. at Millbury. While the possibilities of trouble with the water-cooled type in a northern climate were fully appreciated, yet the difference in cost between these and the self-cooled units, amounting to about 25 per cent net, could not be ignored. The water-cooled units do away with all external oil circulating pipes, and also have the advantage of operating at a much more even temperature throughout the year, with no decrease in capacity during the very hot weather in summer. A study of the possibilities of obtaining cooling water at both station sites showed that the cooling systems could be so arranged and protected that practically all possibility of freezing during the winter months could be eliminated, the result being that the water-cooled type was selected in both instances.

Fig. 4. A View of the Oil Switches at the Millbury Outdoor Substation after a heavy fall of snow

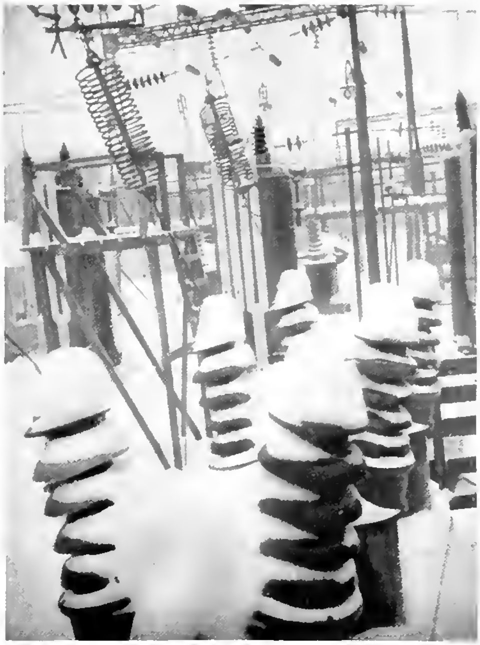


Fig. 5. A Near View of the Snow Covered Oil Switch Insulators. Two Choke Coils are shown in the upper left-hand

At Ware a deep well was driven and a deep well pump installed to supply the make-up water, a cooling basin being constructed in the near vicinity. During the summer the deep well pump is operated almost continuously through the daytime, the surplus water from the cooling basin discharging over a crest. The customary forms of sprays are used during this season for cooling. During the coldest months of the winter the deep well pump is not operated, the sprays are taken off and the discharge pipes turned under the surface of the cooling basin, so that the only cooling effect is from surface evaporation.

The station at Millbury is located practically on an island, with the Blackstone River on one side and the raceway for the Worcester Consolidated steam plant on the other. As the water in this river is entirely too muddy for use in cooling coils, a shallow well was dug near the transformers, about twelve feet in diameter and from ten to twelve feet deep. By this method the surrounding earth, which is a good gravel, was utilized as a natural filter and the water obtained in this manner has proven entirely satisfactory.

Circulation through the transformers is obtained by triplex pumps in a small isolated pump-house located directly above the well. The discharge from the transformers is piped into the river, with a tap discharging back into the well. By means of valves in the two discharge pipes, the water can be returned either to the river or to the well, or divided between the two, with the result that it has been possible to regulate the temperature of the cooling water in the well at all times of the year.

In both stations the water piping is laid below the frost line and the exposed parts running up to the transformers were lagged in a manner similar to steam piping. Special valves were also provided for connection with the compressed air system, in case it became desirable to blow out the cooling coils at any time when it might be impossible to keep the bank of transformers energized. All transformers are so located that they can be run into the station on trucks for any repair work, hoists being provided inside the stations for this purpose. A piping system is also provided for draining the oil from any transformer or switch into a storage tank, and the customary arrangement for treating the oil from this tank or at the transformers is utilized.

The operating results at these two stations during the winter just passed have been very

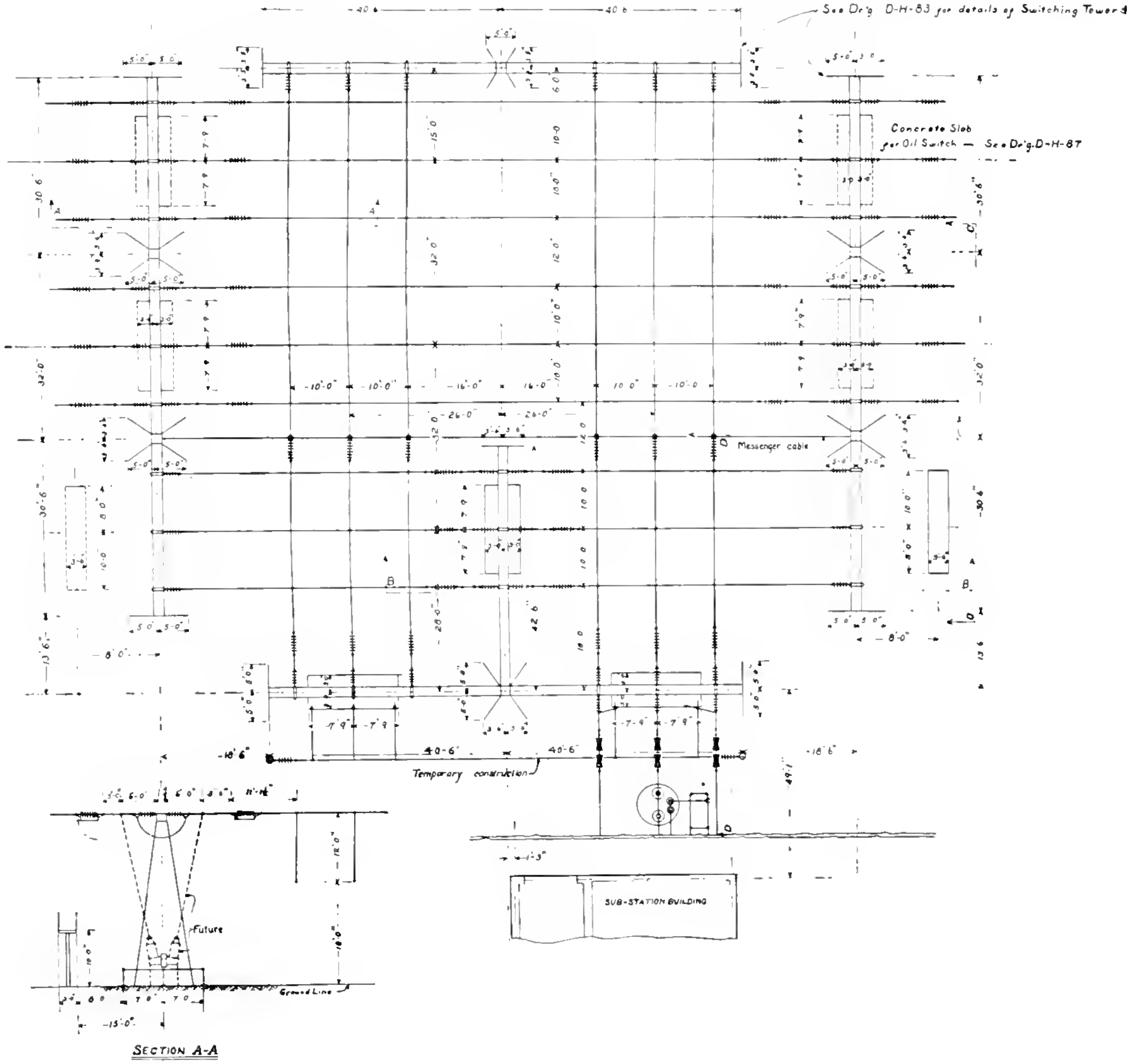


Fig. 6. General Plan of Outdoor Switching Apparatus, Ware Substation

interesting indeed. At Millbury substation the temperature of the ingoing cooling water has been held during the entire year at between fifteen and twenty degrees Centigrade, this regulation being obtained by diverting a part of the discharge back into the well as described above. During the two cold snaps of last January and February, when for periods of three and four days at a time the temperature at night went down to eighteen and twenty degrees below zero, the entire discharge from the transformers at Millbury was diverted into the well, and the cooling water was held at twenty-two degrees Centigrade. During this excessively cold weather the idle bank of transformers was energized in all cases at night, and during the daytime when necessary. The corresponding results at Ware were consistent with the above, although the regulation of cooling water temperature at this station was not as perfect as at Millbury. During the coldest nights at the latter station the minimum temperature of the cooling water was approximately ten degrees above freezing. At both stations, temperature records have been kept on the cooling water during the entire winter and the results carefully noted in conjunction with the transformer temperatures, etc. Both stations have been through a number of sleet storms during the winter, none of which, however, have been very serious, the maximum amount of sleet probably not being over a quarter of an inch. The most serious difficulties encountered during these storms consisted in one case of a solenoid plunger becoming frozen to the concrete switch base, and in another of some trouble in closing a set of disconnecting switches due to the formation of ice around the clips. Both difficulties were minor and did not interfere in any way with the operation of the station.

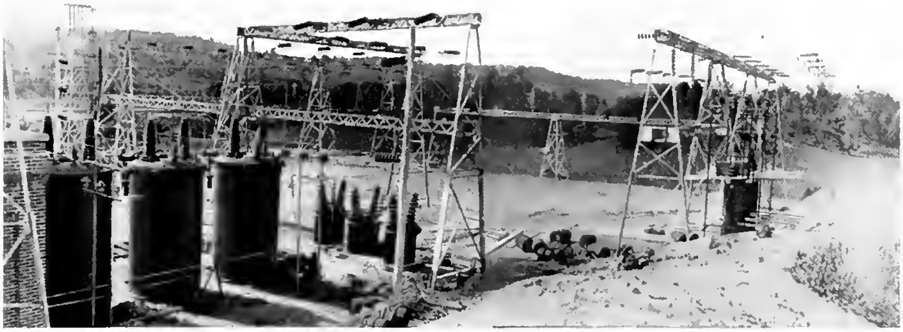


Fig. 7. A Panoramic View of a Portion of an Outdoor Substation showing Overhead Connections, Lightning Arresters, Oil Switches and Transformers

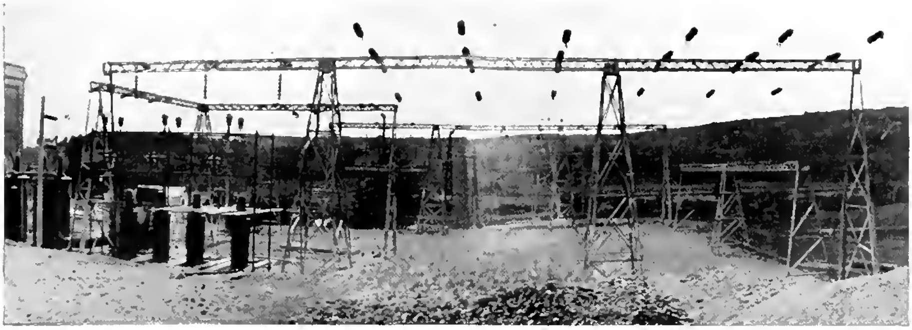


Fig. 8. A Panoramic View of an Outdoor Substation showing Several Transformers and Lightning Arresters at the Left

On February 14th both stations were subjected to a severe blizzard, with high winds and a snowfall of nearly two feet. The temperature of the transformers was such that practically no snow piled up on them, and the accumulation on and about the oil switch bushings caused no trouble whatever.

A comparison of first costs between indoor and outdoor stations is so dependent upon local conditions, upon the function of the station, and the design of either type, that it is very hard indeed to make any general statement which will apply. On the system mentioned above, such a comparison of actual costs between the indoor and outdoor types, corrected for similar local conditions and use and based upon an ultimate station capacity of approximately 10,000 kw. at 66,000 volts, shows a saving in favor of the outdoor type of from 10 to 15 per cent. This difference is not large, and is almost entirely dependent on the type of outdoor construction. Accordingly, the preliminary estimates for stations of this capacity and voltage must be very carefully made, as local conditions may easily result in an almost identical first cost for either type, in which event the choice would rest with the individual. For conditions similar to the above, except for increased capacity and 110,000 volts, the saving would probably run between 20 and 25 per cent. In both of these cases, the estimates have been based upon a simple substation layout without considering any line switching. In the case of Millbury, with its requirements for line switching, the actual saving is estimated at about 25 per cent, but this percentage is reduced by the comparatively high cost of the frequency changer set and building required to contain it. If this feature were eliminated and the station consisted only of the switching and step-down transformer substation, the saving would amount to 30 or 35 per cent.

In practically all discussions of outdoor substations, it has been claimed that all considerations from an operating point of view are unfavorable to this type of construction. While this is to some extent true, yet there are certain advantages of outdoor construction which should at least be given reasonable credit. The simplicity of arrangement and increased spacing throughout invariably tend

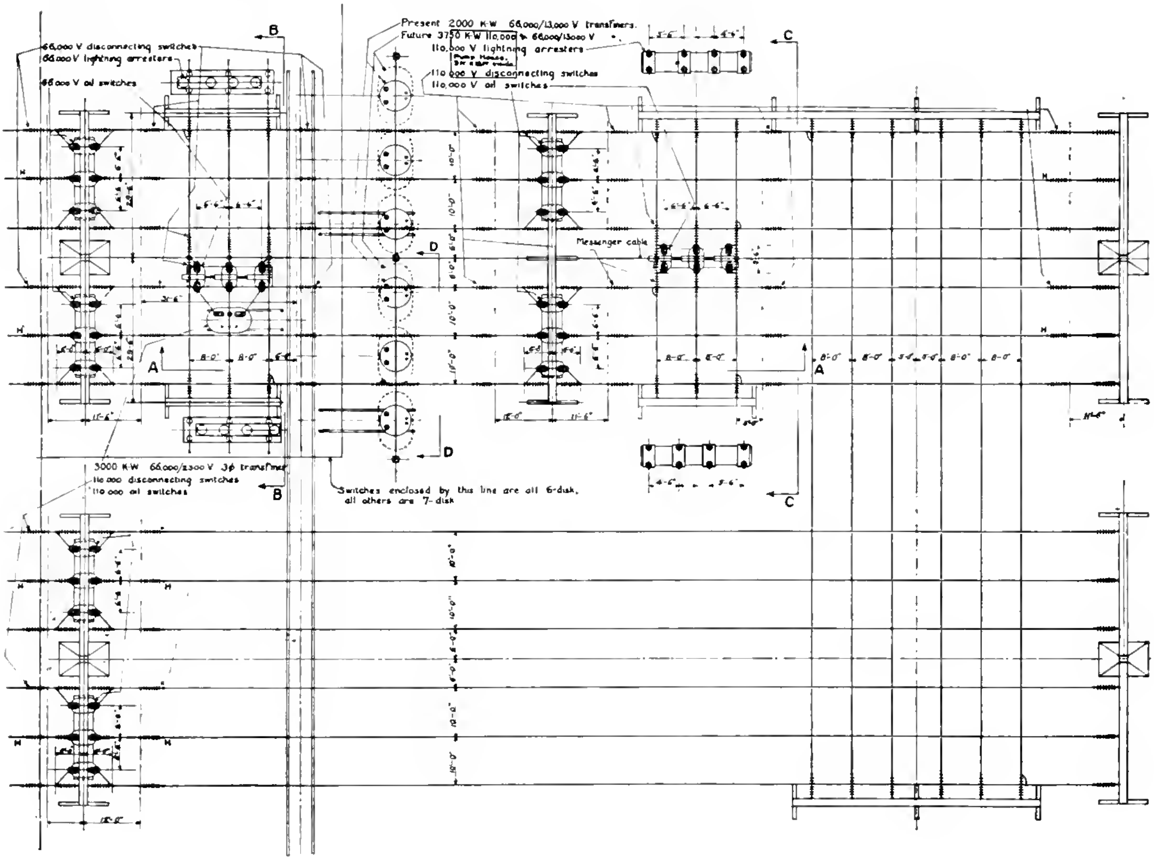


Fig. 9. Millbury Substation Arrangement of Outdoor Equipment

toward freedom from mistakes in handling disconnecting switches and switching by means of them. The outdoor layout also permits the use of standard suspension insulators throughout and eliminates the use of any type of post insulator or entrance bushing on 110,000 volt work. The freedom from fire risk and saving in cost of special fire protection is also a feature which should be taken into consideration. While it is undoubtedly true that the outdoor stations require more constant attention and care on the part of operators, yet it should be borne in mind that this does not necessarily result in increased operating expense, and with the comparatively high-grade class of operators which would be required for any substation of the size and voltage under consideration, it is questionable whether or not this requirement for constant attention to the entire station can be considered a disadvantage. There is quite as much ground for assuming that it will tend toward the more successful and satisfactory operation of the entire system.

From the experience gained in the design and construction of the stations mentioned above, and the results of their operation through a winter as severe as has been experienced for several years, it may be stated that for 110,000 volt work or for 66,000 volt stations where more or less line switching is necessary, the outdoor type of construction is unquestionably justified. For the more simple layouts of 66,000 volt stations, the question is one which must be decided by very careful preliminary estimates based upon the particular conditions involved. In cases where there is some doubt and where the outdoor operation of transformers is unfavorably thought of, a reasonable and very satisfactory compromise could be effected by housing the transformers in compartments adjacent to the operating building, leaving the remainder of the high tension equipment outdoors. With the latter arrangement, the transformers would be practically outdoors for the greater part of the year, but could be enclosed in heated compartments during the more severe weather.

Possibly the most significant feature of the above is the successful operation of water-cooled units in a northern climate. Beyond this, the information will simply add another link in the practical application of the outdoor design. The results which are being obtained from this type, and the constantly increasing number of them which are being installed in all parts of the country for the higher voltages, would seem to prove conclusively that they are practicable and in most cases cheaper. While some of the more conservative engineers still argue against them on the basis of jeopardizing service, it is believed that the operating results of the more modern stations employing the switching and protective apparatus recently developed by the manufacturing companies will in time prove this argument to be groundless.

# ELECTRICITY IN MINES

By K. A. Pauly

Power and Mining Engineering Department, General Electric Company

Each succeeding day it is becoming more fully recognized that the employment of electricity in mining is one of the factors which contributes largely to economical operation. The reasons which have made the application of electricity desirable, the means of procuring this power, and the manner of utilizing it at the mine are the divisions of the subject treated in this article. In the section on the application of electric motors to the equipment of the mine, discussions of the following subjects are included: Suitable voltages to be used; and the drives of pumps, fans, drills, locomotives, hoists and mills. A very interesting and valuable table presents the data on a large number of electrical mine hoisting equipments that have been installed.—Editor.


K. A. Pauly

THE mining industry differs from most others in one essential detail, its location is fixed. Those engaged in many other industries can avail themselves of the advantages to be gained by being located near an abundant supply of comparatively cheap power, and the nucleus of many of our country villages and even cities is the grist mill or saw mill so placed as to take advantage of a small water power. The great electro-chemical plants centered around Niagara Falls are modern examples of the tendency of industries to migrate toward cheap power centers.

Mining operations, because of the location of the mineral deposits, are usually carried on where the conditions are very unfavorable to the development of cheap power, coal mining being an obvious exception, however. Fuel and labor are high, and water suitable for use in boilers is frequently scarce and expensive. The necessity of subdividing mining operations into a large number of small units, necessarily operating at a low load factor, tends to further increase the cost of power. Many mines are operating today with a boiler plant supplying steam for a hoisting engine, a small compressor for supplying air for drills and small underground gathering pumps, with possibly a main steam pump at the foot of the shaft and a ventilating fan on the surface. The coal consumption in pounds per horse power hour of work done will often exceed the steam consumption of a modern efficient plant. Attempts, which no doubt have been successful to a limited extent, have been made to reduce the cost of power by supplying two or more shafts from one central steam plant, but the area supplied from such a steam plant is extremely limited owing to its first cost and inefficiency. The accompanying illustration, Fig. 1, will serve to indicate what distribution of power by steam means, although it fails to reveal the miles and miles of steam pipe hidden underground.

If we can not locate our mines where the conditions are favorable for developing power, we can usually take comparatively cheap power to the mines. Because of the high efficiency with which large quantities of power as electric energy can be transmitted over long distances, power can be placed at the disposal of the mine operator at a price usually considerably below his cost of developing it at the mine. But in addition to this, electricity offers other and important advantages. Extensions in the power equipment, to meet developments in the workings, are possible at a lower cost and with less inconvenience than otherwise. Increased output, which means lower cost of production, always follows the introduction of electric power. Materials are handled with a minimum of delay, especially underground, by the electric locomotive. In those processes of ore extraction in which the speed affects the percentage extraction, the three-phase induction motor with its practically constant speed is an ideal motive power.

Until very recently, at least, the application of electric power to mining operations on a large scale has been less extensive than to most, if not all, other industries: why is this so, if electrification means increased production and lower costs? It has been due to two principal causes. First, the speculative nature and uncertain life of metal-mining operations have not been looked upon with favor by capitalists interested in electric power development. Neither were the mine operators themselves, with few exceptions, in a position to install large central stations at a considerable distance from their mines, owing to the smallness of their power requirements. Second, because the chief advantage of electricity was looked upon as being largely one of improvement in efficiency; coal miners with waste coal at their disposal saw little to be gained by electrification further than the installation of small direct current generators at each mine for lighting and for supplying power to locomotives where lack of gas permitted their use.

But conditions have changed: mining is becoming less speculative, small operators are being united into large companies, and grades of coal once considered worthless now have a considerable value. There are no less than 65 power companies serving mining districts, many of which are largely dependent on the mining industry for a load. As examples of these might be mentioned the Montana Power Company supplying the Butte copper mines, the Virginia Power Company and the Appalachian Power Company in the bituminous coal fields, and the Lehigh Navigation Electric Company serving the anthracite coal fields. In addition to these we have a considerable number of large power systems owned and operated by independent mining companies; for example, the power systems of the Calumet and Hecla Mining Company in Michigan copper fields, the Cleveland Cliffs Iron Mining Company also in Northern Michigan, the D. L. & W. Coal Company and Consolidation Coal Company in the anthracite and bituminous coal fields respectively, and the Calumet & Arizona Copper Company at Bisbee, Arizona.

With power in large quantities available at most of the large mining camps the question often arises, and rightly so, as to whether the large companies should purchase power or make it themselves. This is a very broad question with important advantages pro and con, and each case must be settled on its merits after a thorough analysis of all the elements affecting the problem. The decision for or against purchasing power is usually based on a comparison between an estimated cost of producing power locally and of purchasing it at a definite price. In making power cost estimates great care must be taken not to base them on erroneous assumptions which may result in wrong conclusions. Although the independent plant may appear from the estimate to be more economical, and it may be within the bounds of possibility to operate it within the estimated cost, yet it must be remembered that we have on the one hand a mining company whose efforts are devoted to the production of coal or ore at a minimum cost, in which cost the item of power plays but a minor part. In addition to this, the power cost is handicapped by a low load factor, resulting in high fixed charges and operating costs which combine to give a power cost often higher than estimated. On the other hand, the one object of the public service corporation is that of developing cheap and reliable power. It maintains a competent corps of engineers who devote their entire time to the problems incident to the development of cheap and reliable service. They have at their command the necessary capital to introduce improvements and make extensions which tend toward lower power cost. Assisting them in their efforts, they have the greatest diversity of loads to bring up their load factor. To sum up, so to speak, the one is a coal or ore manufacturer and the other a manufacturer of power.

Fig. 1. An Example of what Distribution of Power by Steam means. Note the long line of exposed pipes

In general the conditions affecting the design of a power system for supplying a mining district do not differ materially from those governing the installation of a similar system for serving an industrial district.

Probably, however, in no other industry is continuity of service so important a consideration; and one of the important factors which is largely responsible for the recent rapid increase in the application of electric power to mining operations is the improvement in the design of electrical machinery and the construction of transmission lines and their successful protection against outside disturbances. Apart from the consideration of production, unless the pumps of wet mines are kept in service a serious and expensive flood may result while the stopping of the ventilating fans of the gaseous coal mine, if but for a short period only, may endanger the lives of many hundreds of men underground. Obviously long interruptions in the power supply might seriously inconvenience the complete underground force, if it occurred at the end of a shift. Wherever possible the transmission system should be laid out on the loop principle, power being supplied at each end of the loop thus reducing to a minimum interruption due to line breakage.

It is coming to be generally recognized that, on account of men working underground where the temperature is rather high and the body frequently wet with perspiration and especially at high altitudes where they are more susceptible to injury by electric shock, 250 to 300 volts is the proper operating potential for underground equipment where the operator is in danger of coming in contact with live parts or wires, although higher potentials have been and can still be safely used when the conditions are favorable. Where there is no danger of the operator coming in contact with live parts, the potential of any apparatus may be made as high as is consistent with reliable service from the machinery involved. Experience seems to indicate that, with present methods of insulating motors, they should not be operated underground at potentials much in excess of 2300 volts; and that unless the operating conditions are favorable motors wound for this potential may prove rather unreliable, especially so if the service is of such an intermittent nature that the windings are alternately heated and cooled at comparatively frequent intervals.

As previously stated, one of the most vital parts of a mine equipment is its pumping plant. Wherever possible, the underground workings are so laid out that the water flows from the face to the main sump usually located near the shaft. Gathering pumps are used where this plan is not possible. These gathering pumps are usually small and are of the direct-acting type, similar to boiler feed pumps, and are driven by compressed air taken directly from the air system supplying the drills. Centrifugal pumps are not suitable, owing to the necessity of priming them each time they loose their vacuum. Where electric power is available, motor-driven pumps will show a very considerable saving over air-driven units which are very extravagant in the consumption of air. They are, however, handicapped by a higher first cost, but except where the conditions are otherwise unfavorable this difference is small in comparison with the improved efficiency.

Motor-driven centrifugal pumps are very generally used for pumping from the main sump, although there is a very pronounced doubt in the minds of many large operators as to whether this is really the best practice, the contention being that the higher efficiency obtainable with plunger pumps warrants their use at a much higher first cost. Where, as is frequently the case, the sump capacity is inadequate to protect the mine against a flood in the event of an interruption in the pumping, except for very short intervals, it is extremely advisable to provide spare pumping units and to use the spare unit alternately with the others, also to provide a drying transformer for supplying just enough current to the windings of the idle motor to keep it dry when at rest. The first cost of such a transformer and the cost of the energy consumed are insignificant in comparison to the insurance that they afford, especially so if 2300-volt motors are used for driving the pumps. Special ventilation may frequently be provided to advantage, for keeping pump chambers cool where there is a tendency for the air to become stagnant.

Because of the nature of the underground workings and the presence of poisonous and explosive gases in many coal mines, it is necessary to provide large quantities of air by forced ventilation. In non-gaseous mines the fans may be run at reduced speed, except when the shift is underground, and an occasional interruption of the air supply during working hours will not cause serious inconvenience. With a gaseous mine it is entirely different. An interruption in the air supply, if only for a comparatively short time, may endanger the lives of all working in the affected area. The miners appreciate the danger so well that they will leave the mine immediately there is a stoppage or material reduction in the air supplied. It is obviously then of the utmost importance that every pre-

# APPROXIMATE LIST OF ELECTRIC MINE HOIST D-C. MOTORS 200 H.P. AND ABOVE

| Name of Company and Location of Mine | Surface or Underground | Name of Mine | Product Hoisted | Inclination to Horiz. | Max. Depth in Ft. | Hourly Tonnage (2000 Lb.) | Material per Trip in Lb. | Wt. of Skip or Cars and Cage | Rope Speed in Ft. per Min. | Rope Diam. in In. | First or Second Motion | Type of Drum | Single or Double Drum | Drum Diameter in Ft. | Hoist Motor Rating in H.P. | Hoist Motor Speed in R.P.M. | MOTOR-GENERATOR SET | | | | | | | | Type of Control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | Motor | | | | Generator | | Flywheel | | |
| | | | | | | | | | | | | | | | | | Voltage | Cycles | Rating in H.P. | Speed in R.P.M. | Rating in Kw. | Voltage | Weight in Lb. | Dia. in In. | |
| Winona Copper Co., Winona, Mich. | Surface | Winona No. 4 Shaft | Copper ore | 70° | 1500 | | 5,000 | 2,500 | 1200 | 1⅛ | Second | Cylindrical | Double | 7 | 200 | 430 | 2080 | 60 | 450 | 600 | 340 {170<br>170} | 575 | 80,000 {40000<br>40000} | 120 | Generator field control |
| Winona Copper Co., Winona, Mich. | Surface | King Phillip No. 1 Shaft | Copper ore | 70° | 1500 | | 5,000 | 2,500 | 1200 | 1⅛ | Second | Cylindrical | Double | 7 | 200 | 430 | | | | | | | | | |
| Calumet & Hecla Mining Co., Calumet, Mich. | Underground | | Copper ore | | | | | | | | | | | | 225 | | 2080 | 25 | 300 | 750 | 185 | 250 | | | Generator field control |
| * Colorado Fuel & Iron Co., Florence, Colo. | Surface | Coal Creek Mine | Coal | 90° | | | | | | | First | Conical | Double | | 250 | 90 | 440 | 30 | 125 | 900 | 220 | 260 | 6500 | | Generator field control |
| * Knight Power Co., Eureka, Utah | Surface | Iron Blossom Mine | Silver ore | 70° | 3200 | | | | 1000 | 1⅜ | First | Cylindrical | Double | | 300 | 65 | 440 | 60 | 240 kv-a | 720 | 165 | 600 | Syn. motor | | Generator field control |
| * Silver King Coalition Mines, Park City, Utah | Surface | Silver Hill | Silver ore | 90° | 1100 | | 6,000 | 3,300 | 1630 max. | 1 by ⅜ | First | Reels | Double | 3½-8 | 300 | 65 | 2200 | 60 | 240 kv-a. | 720 | 165 | 600 | Syn. motor | | Generator field control |
| Osage Coal Mining Co., McAlester, Okla. | Surface | | Water | 90° | 720 | 250 | 8,350 | 5,500 | 1140 | 1⅛ | Second | Cylindrical | Double | | 350 {175<br>175} | 350 | | | | | | | | | Series parallel |
| * New River & Pocohontas Consol. Coal Co., Herberton, W. Va | Surface | | Coal | 90° | 420 | 225 | 3,000 | 8,000 | 2200 max | 1¼ | First | Conical | Double | 5½-8 | 380 | 88 | 2200 | 60 | 850 kv-a. | 720 | 300 | 275 | Syn. motor | | Generator field control |
| * Inspiration Consol. Copper Mining Co., Miami, Ariz. | Surface | | Copper ore | 90° | 630 | 500 max. | 24,000 | 15,000 | 750 | 1¾ | Second | Cylindrical | Double | 10 | 580 | 264 | 2200 | 25 | 825 | 750-635 | 1000 {500<br>500} | 575 | 19,700 | 112 | Generator field control |
| * Inspiration Consol. Copper Mining Co., Miami, Ariz. | Surface | | Copper ore | 90° | 630 | 500 max | 24,000 | 15,000 | 750 | 1¾ | Second | Cylindrical | Double | 10 | 580 | 264 | | | | | | | | | |
| * Cinderella Consol. G. M. Co., Witwatersrand, So. Africa | Surface | | Men and material | 90° | 3600 | 57 | 5,400 | 7,600 | 2056 | 1⅜ | First | Cylindrical | Double | 11½ | 700 | 55 | 6300 | 50 | 850 | 750 | 570 | 300 | | | Generator field control |
| * Christopher Coal Co., Christopher, Ill. | Surface | New North Mine | Coal | 90° | 687 | 643 | 9,000 | 11,000 | 2400 | 1⅜ | First | Cylindrical | Double | 7 | 1150 | 109 | 2300 | 60 | 650 | 600-510 | 880 | 550 | 22,600 | 130 | Generator field control |
| * Peabody Coal Co., Nokomis, Ill. | Surface | | Coal | 90° | 687 | 874 | 16,000 | 19,000 | 1950 max | 1½ | First | Conical | Double | 9-11 | 1300 | 57 | 2300 | 60 | 950 | 514-435 | 1000 | 750 | 33,000 | 142 | Generator field control |
| * New Modderfontein G. M. Co., Ltd., Witwatersrand, So. Africa | Surface | | Gold ore | 90° | 2220 | 360 | 12,000 | 20,000 | 4050 max | 2 | First | Cyl.-conical | Single | 15-24 | 4000 {2000<br>2000} | 53.5 | 2000 | 50 | 5000 | 375 | 3300 {1650<br>1650} | 550 | | | Generator field control |
| * Crown Mines, Ltd., Witwatersrand, So. Africa | Surface | South Rand Shaft | Gold ore | 90° | 3540 | 335 | 16,000 | 8,700 | 3500 max | 2 | First | Cyl.-conical | Double | 12-20¾ | 4000 {2000<br>2000} | 53.5 | 2000 | 50 | 5000 | 375 | 3300 {1650<br>1650} | 550 | | | Generator field control |

Equipments marked with a (*) have been purchased since January, 1912

# APPROXIMATE LIST OF ELECTRIC MINE HOIST INDUCTION MOTORS 250 H.P. AND ABOVE

| Name of Company and Location of Mine | Surface or Underground | Name of Mine | Product Hoisted | Inclination to Horizontal | Maximum Depth in Feet | Hourly Tonnage (2000 Lb.) | Material per Trip in Lb. | Wt. of Skip or Cars and Cage | Rope Speed in Ft. per Min. | Rope Diameter in In. | First, Second or Third Motion | Type of Drum | Single or Double Drum | Drum Diameter in Ft. | Hoist Motor Rating in H.P. | Hoist Motor Speed in R.P.M. | Hoist Motor Voltage | Hoist Motor Frequency | Type of Control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Consolidation Coal Co., Acosta, Pa. | | Mine 123 | Coal | 90° | 440 | | 3,500 | 10,100 | 1225 | 1⅛ | Second | Conical | Double | 6½-8½ | 250 | 450 | 2300 | 60 | Contactor |
| Boston & Corbin Copper and Silver Co. | | | | | | | | | | | Third | | | | 250 | 600 | 2200 | 60 | Contactor |
| Melones Mining Co., Melones, Cal. | | | | | | | | | | | | | | | 250 | 600 | 2200 | | Squirrel cage motor |
| * Cleveland Cliffs Iron Co., Ishpeming, Mich. | | | | | | | | | | | | | | | 250 | 600 | 2200 | 60 | Squirrel cage motor |
| * Cananea Consol. Copper Co., Cananea, Mexico | | | Copper ore | | | | | | | | | | | | 250 | 450 | 2200 | 60 | Contactor—with dynamic braking |
| * Consolidated Mines Co., Goldfield, Nev. | | | | | | | | | | | | | | | 250 | 600 | 440 | 60 | |
| * Knight Central Gold Mining Co., Witwatersrand, So. Africa | Underground | | Gold ore | 30° | 4500 | | 6,000 | 4,000 | 1440 | ⅞ | Second | Cylindrical | | 7 | 275 | 300 | 2000 | 50 | Contactor |
| * Falcon Mines, Ltd., Rhodesia, So. Africa | | | | | | | | | | | | Cylindrical | Double | | 275 | 300 | 500 | 50 | Contactor |
| * Anaconda Copper Mining Co., Butte, Montana | Surface | Butte & London Hoist | Copper ore | 90° | 2000 | | 3,000 | 2,400 | 1475 | 1 | Second | Cylindrical | Double | 6 | 275 | 600 | 2200 | 60 | Contactor |
| * Pennsylvania Coal Co., Dunmore, Pa. | Underground | Underwood (Big Vein Slope) | Coal | 3½°-9° | 2775 | 158 | 71,000 | 33,000 | 500 | 1 | Third | Cylindrical | Single | 6 | 300 | 450 | 440 | 60 | Contactor |
| * Pennsylvania Coal Co., Dunmore, Pa | Underground | Underwood (Clark Vein Slope) | Coal | 3½°-9° | 3535 | 125 | 71,000 | 33,000 | 500 | 1 | Third | Cylindrical | Single | 6 | 300 | 450 | 440 | 60 | Contactor |
| * Pennsylvania Coal Co., Dunmore, Pa. | Underground | Underwood (Dunmore Vein Slope) | Coal | 5°-11° | 4930 | 112 | 71,000 | 33,000 | 500 | 1 | Third | Cylindrical | Single | 6 | 300 | 450 | 440 | 60 | Contactor |
| * Pittsburg Coal Co., Pittsburg, Pa. (3 Equipments) | Surface | Montour Nos. 1, 2 and 3 | Coal | 90° | 220 | 480 | 8,000 | 12,000 | 800 | 1½ | Second | Conical | Single | 7½-9 | 300 | 300 | 2300 | 60 | Contactor |
| * Greensburg Coal & Coke Co., Greensburg, Pa | Surface | | Coal | 90° | 190 | 353 | 4,500 | 13,650 | 1140 | 1¼ | Second | Conical | Double | 6½-8 | 300 | 450 | 2300 | 60 | Contactor |
| * Halifax Tonopah Mining Co., Tonopah, Nev. | Surface | Jumper Mine | | 90° | | | | | | | | | | | 300 | 450 | 440 | 60 | Contactor |
| * Anaconda Copper Mining Co., Butte, Mont. | | | | | | | | | | | | | | | 300 | 600 | 2200 | | Contactor |
| * J. K. Deming Coal Co., Clinton, Indiana | Surface | Mine No. 1 | Coal | 90° | 274 | 300 | 3,400 | 6,200 | 1370 | 1⅛ | Second | Cylindrical | Single | 5 | 300 | 514 | 2200 | 60 | Contactor |
| * Keystone Mines, Amador, Cal. | Surface | | | 90° | | | | | | | | | | | 300 | 450 | 440 | 60 | Liquid rheostat |
| * Arizona El Paso Copper Co., Ltd., Clifton, Ariz | | | | | | | | | | | | | | | 300 | 450 | 2200 | 60 | Liquid rheostat |
| * Witherbee Sherman Co., Mineville, N. Y. | Surface | Harmony A and B | Iron ore | 90°-30° | 1500 | | 7,000 | 3,800 | | | Second | Cylindrical | Four | 10 | 300 | 250 | 440 | 25 | |
| * Witherbee Sherman Co., Mineville, N. Y. (4 Equipments) | Underground | | Iron ore | 90° | | | | | | | | | | | 300 | 500 | 440 | 60 | Contactor |
| * Witherbee Sherman Co., Mineville, N. Y. | Surface | | Iron ore | 90° | | | | | | | | | | | 300 | 375 | 3300 | 25 | Contactor |
| * Consolidated Indiana Coal Co., Knoxville, Iowa | | | | | | | | | | | | | | | 300 | 450 | 2200 | 60 | Contactor |
| Consolidation Coal Co., Jenner, Pa. | Underground | | Coal | | | | | | | | Second | | | | 300 | 450 | 2200 | 60 | Liquid rheostat |
| Victor American Fuel Co., Trinidad, Colo. | | Gray Creek Mine | | | | | | | | | | | | | 300 | 600 | 440 | 60 | Contactor |
| * Central Coal Co., Kimberly, Ala. | | | Coal | | 575 | | | | 800 | | Second | | | | 300 | 600 | 220 | 60 | Contactor |
| Victor American Fuel Co., Gallup, N. M | | Weaver Mine | | | | | | | | | | | | | 300 | 600 | 440 | 60 | Contactor |
| Stepto Valley Mining & Engineering Co. | | | | | | | | | | | | | | | 300 | 514 | 550 | | |
| * Alabama Fuel & Iron Co., Margaret, Ala | | | | | | | | | | | | | | | 300 | 450 | 220 | | Liquid rheostat |
| * Witwatersrand Deep, Ltd., Witwatersrand, So. Africa | Underground | | Gold ore | Slope | 4500 | | 8,000 | 6,000 | 1500 | | Second | Cylindrical | Double | 8 | 350 | 273 | 2000 | 50 | Contactor |
| Coregum Gold Mining Co., India | | | Gold ore | | | | | | | | | | | | 350 | | | 25 | Contactor |
| * Campania de Santa Gertrudis, Pashucha, Hildalgo, Mexico (5 Equipments) | | | | 90° | 2500 | 79 | 9,000 | 6,000 | 1000 | 1⅛ | Second | Cylindrical | Double | | 375 | 375 | 440 | 25 | Liquid rheostat |
| Victor American Fuel Co., Hastings, Colo. | | | | Slope | | | | | | | | | | | 375 | | | | |
| * Cananea Consol. Copper Co., Cananea, Mexico (3 Equipments) | | | Copper ore | | | | | | | | | | | | 375 | 450 | 2000 | 60 | Contactor |
| * New River Co., McDonald, W. Va. | Surface | Whipple | Coal | 90° | 453 | 252 | 4,200 | 6,700 | 1680 | 1⅛ | Second | Conical | Double | 6-9 | 400 | 600 | 2300 | 60 | Contactor |
| * New River Co., McDonald, W. Va. | Surface | Cranberry | Coal | 90° | 467 | 216 | 3,600 | 6,000 | 2000 | 1⅛ | Second | Conical | Double | 6-9 | 400 | 600 | 2300 | 60 | Contactor |
| * New River Co., McDonald, W. Va. | Surface | Carlyle | Coal | 90° | 483 | 180 | 3,000 | 6,100 | 1780 | 1⅛ | Second | Conical | Double | 6-9 | 400 | 600 | 2300 | 60 | Contactor |
| * New River Co., McDonald, W. Va. | Surface | Scarbro | Coal | 90° | 422 | 198 | 3,300 | 6,600 | 1780 | 1⅛ | Second | Conical | Double | 6-9 | 400 | 600 | 2300 | 60 | Contactor |
| Cleveland Cliffs Iron Co., Michigan (5 Equipments) | | | | | | | | | | | | | | | 400 | 360 | 2100 | 60 | Contactor |
| * Cleveland Cliffs Iron Co., Michigan (2 Equipments) | | | | | | | | | | | | | | | 400 | 360 | 2100 | 60 | Contactor |
| * Cinderella Consol. Gold Mining Co., Witwatersrand, So. Africa | Underground | | Gold ore | 42° | 1850 | 136 | 10,000 | 7,000 | 1500 | 1⅛ | Second | Cylindrical | Double | 7½ | 450 | 500 | 500 | 50 | Liquid rheostat |
| Crown Mines, Ltd., Witwatersrand, So. Africa (2 Equipments) | Underground | | Gold ore | | | | | | | | | | | | 450-225 | 360-180 | 2100 | 60 | Liquid rheostat |
| Nourse Mines, Ltd., Witwatersrand, So. Africa | Underground | Shaft No. 1 | Gold ore | 42° | 2240 | 111 | 6,000 | 4,800 | 2000 | 1 | Second | Cylindrical | Double | 8 | 500 | 375 | 2000 | 50 | Liquid rheostat |
| * Witherbee-Sherman Co., Mineville, N. Y. | Surface | Joker Shaft | Iron ore | 78° | 1000 | | 7,000 | | 900 | 1⅛ | Second | Cylindrical | Double | 10 | 500 | 250 | 440 | 25 | Liquid rheostat |
| * Cleveland Cliffs Iron Co., Ishpeming, Michigan | | Cliffs Shaft | | 90° | | | | | | | | | | | 500 | 600 | 2200 | 60 | Contactor |
| * Vandalia Coal Co., West Terre Haute, Indiana | Surface | Mine No. 82 | Coal | 90° | 280 | 540 | 6,000 | 7,000 | 1560 | 1⅛ | Second | Cylindrical | Single | 6 | 500 | 450 | 2200 | 60 | Contactor |
| * Woodward Iron Co., Woodward, Ala. | Surface | Slope No. 2 | Iron ore | 27° | | | | | 800 | 1¼ | Second | Cylindrical | Single | | 500 | 375 | 3300 | 25 | Liquid rheostat |
| Crown Mines, Ltd., Witwatersrand, So. Africa (2 Equipments) | Underground | Shafts Nos. 1 and 2 | Gold ore | 22° | 2800 | 120 | 6,000 | 1,800 | 3000 | 1 | Second | Cylindrical | Double | 6 | 550 | 375 | 2000 | 50 | Liquid rheostat |
| Van Ryn Gold Mines Estate, Ltd., Witwatersrand, So. Africa | Surface | No. 2 Shaft | Gold ore | 30°-45° | 2720 | 100 | 10,000 | 7,000 | 1500 | 1¼ | Second | Cylindrical | Double | 10 | 550 | 187.5 | 2100 | 50 | Liquid rheostat |
| * Lehigh Valley Railroad, Tufts Farm Pier, Buffalo, N. Y. | Surface | | Loaded cars | 7° | 525 | 60 cars (loaded) | | 160,000 (loaded) | 600 | 1½ | | | | | 550 | 375 | 2200 | 25 | Contactor |
| Bantjes Consolidated Mines Ltd., Witwatersrand, So. Africa | Surface | East Shaft | Gold ore | 34° | 2500 | 105 | 6,000 | 4,600 | 2000 | 1 | Second | Cylindrical | Double | 6 | 600 | 375 | 2000 | 50 | Liquid rheostat |
| * D. L. & W. Coal Co., Nanticoke, Pa. | Surface | Truesdale Slope No. 1 | Coal | 4½°-30° | 4000 | 200 | 40,000 | 15,000 | 1200 | 1¼ | Second | Cylindrical | Single | 8 | 600 | 400 | 440 | 60 | Liquid rheostat |
| * Keystone Coal & Coke Co., Greensburg, Pa. | Surface | Crow's Nest Mine | Coal | 2½°-3½° | 8750 | 300 | 240,000 | 100,000 | 1000 | 1¼ | Second | Cylindrical | Single | | 700 | 300 | 2200 | 60 | Liquid rheostat |
| * Woodward Iron Co., Woodward, Ala. | Surface | Slope No. 2 | Iron ore | Ave. 24° | 1800 | | 33,600 | 30,000 | 1800 | 1½ | Second | Cylindrical | Single | | 700 | 300 | 3300 | 25 | Liquid rheostat |
| * Lehigh Coal & Navigation Co., Lansford, Pa. | Surface | No. 5 | Coal | 90° | 900 | 80 | 11,000 | 17,000 | | 1¾ | Second | Cylindrical | Double | | 750 | 360 | 2200 | 60 | Liquid rheostat |
| D. L. & W. Coal Co., Hampton, Pa. | Surface | Hampton Central | Water | 90° | 550 | 1020 | 34,000 | 17,000 | 740 | 2 | Third | Cyl.-Conical | Double | 10-16 | 800 | 225 | 2200 | 60 | Contactor |
| South Eureka Mining Co., Sutter Creek, Cal. | | | Gold ore | 68° | 3500 | | 10,000 | 3,500 | 900 | 1¼ | Second | Cylindrical | Double | | 800 {400<br>400} | 450 | 440 | 60 | Contactor |
| Rose Deep, Ltd., Witwatersrand, So. Africa | Surface | Shaft No. 3 | Gold ore | 37° | 2880 | 124 | 8,000 | 6,300 | 2000 | 1⅛ | Second | Cylindrical | Double | 10 | 900 | 375 | 2000 | 50 | Liquid rheostat |
| Bantjes Consolidated Mines, Ltd., Witwatersrand, So. Africa | Surface | Central Shaft | Gold ore | 34° | 2500 | 175 | 10,000 | 7,000 | 2000 | 1⅛ | Second | Cylindrical | Double | 6 | 900 | 375 | 2000 | 50 | Liquid rheostat |

Equipments marked with a (*) have been purchased since January, 1912.

caution be taken to prevent the possibility of an interruption in the power supplied to a fan, and until recently many have questioned the advisability of electrifying the fans of gaseous mines. With the development of our larger power systems, many of which are consolidations of smaller independent stations, the feeling of uncertainty is gradually disappearing because of the remote danger of complete interruptions in the service.

Until within the past year fans when electrified have been driven by either variable-speed direct current motors or by induction motors, speed variation over a considerable range being required to provide for increased air pressure as the workings are extended. Provision is usually, if not always, made to provide for a considerably increased air pressure for rapidly clearing the mine of the poisonous gases following an explosion. While, where direct current is available, fans may be driven at variable speed efficiently by varying the fields of these motors the efficiency of the induction motor, except under special conditions, is low. Recently a variable-speed three-phase alternating-current motor has been developed which possesses all the advantages of the direct-current motor, from the standpoint of field control, and thus avoids the necessity of conversion of power to direct current. Speed control is obtainable over a very wide range by simply shifting the brushes on the commutator.

Although the power required by the electric drill is only one fifth that of the air drill, no other piece of machinery used in connection with mining has so completely resisted all efforts of the designing engineers to bring about its electrification, although the ordinary air drill is extremely inefficient from a purely power standpoint. Many electric drills have been produced, some of which have been more or less successful under special conditions, but there has been one recently developed which bids fare to have a very wide application. Rapidly repeated hammer blows are delivered to the drill as in hand drilling. In early tests trouble was experienced with the drills, but improvements in the steel have practically eliminated this.

One can hardly imagine a more inefficient system of underground haulage than are some which are in actual operation in some of the large mines. There are hoisting engines located near a boiler plant on the surface with the haulage rope carried for long distances above ground and then down a bore hole to the head of the slope. In such an installation the friction is often a large part of the work done. Many small air engines, or "puffers" as they are frequently termed, are used where the grades are too steep for mule haulage. These engines take air full stroke and as the air is used cold they have an efficiency not over 15 per cent.

With the development of the gathering locomotive, loaded cars can be taken from the rooms, placed in an underground yard, and the empties returned without the necessity of stringing the trolley wire to the face. From the yard the cars are taken in trains by electric locomotives, where the grades permit their use or by slope hoists where the grades are too steep, to the shafts or out of the mine through tunnels.

Mining conditions impose very severe limits to the design of locomotives. The track gauge varies from 24 inches to standard, the curves are made at a very short radius, the grades are frequently excessive, and with shallow veins the head room is very small. Great ingenuity has been exercised in the design of electric "motors," as the locomotives are called, with the result that there are today rugged, thoroughly reliable, and efficient locomotives suitable for operating under most exacting conditions.

Air locomotives, although very inefficient, have been and will continue to be used, at least for some time in coal mines, although abroad the slope hoist air engine is giving way to the fire-damp-proof motor in gaseous mines. These motors, which are designed on the Davy safety lamp principle to prevent the communication of an explosion within the motor to the surrounding atmosphere, have not been introduced to any considerable extent in this country, although tests at the Pittsburgh Testing Plant of the Bureau of Mines indicate that, with the addition of a simple automatic cut out to disconnect them from the line after the first internal explosion, they should be entirely safe.

Electric shaft hoisting on a large scale was first introduced in Europe, although at an early date scattered installations of quite considerable magnitude were made in America. About two years ago there appeared to be a simultaneous appreciation of the advantages of the electric hoist on the part of American miners and America bids fair to soon rival Europe in the number and size of its electric installations. About five years ago the Eckstein interests in South Africa started to convert their existing steam hoists to electric hoists on a scale which has not been even approached elsewhere, and today there are more and larger shaft hoists in South Africa than in any other equal area. It is worthy of note in this connection that, while America has lagged behind Germany and South Africa in the magnitude and number of its installations, an American company has built the electrical equipment for many of the larger foreign hoists among which are those of the Crown Mines, Ltd., and the New Modderfontein Gold Mining Company, which are the largest electrically-driven hoists in the world, and which require peak loads of approximately 7000 horse power during acceleration.

Many systems of electric hoisting have been proposed, some of which have a very general application and others designed to meet very special conditions, but owing to the many questions involved it will be impossible to attempt to discuss the merits of the several systems in an article of this kind. However, a few remarks with reference to a few important considerations affecting to a more or less degree all types will not be out of place. This subject is discussed more in detail in an article "Some Advantages of the Electric Hoist over the Steam or Air Hoist," by the author, which appeared in the April issue of the GENERAL ELECTRIC REVIEW.

In general, although there are many exceptions, the simplest system is preferable, and in units of 500 horse power and less the variable-speed induction motor geared to the drums by any of the quiet running gears will give entire satisfaction. For equipments involving motors of 1500 horse power and larger, the direct-current motor direct-connected to the hoist drums will usually offer sufficient advantage over the simple induction motor to warrant its adoption, in spite of the additional expense of the motor-generator required with the direct-current equipment. The intermediate range of capacities is the transition field and special local conditions may and will usually be the deciding factor in the choice of either the one or the other type.

The relative capacity of the power system serving the hoist or, if power is purchased, the basis upon which the rate is determined, i.e. the effect of peak demands on the price for power, must always be taken into consideration and, where peaks are heavily penalized or the generating capacity small, a considerable saving in cost of operation can usually be made by relieving the power system of excessive fluctuations by the use of a flywheel.

The great advantage of the electric hoist, and especially of those driven by direct-current motors, over all its competitors is greater safety which, although it usually is difficult to capitalize, may represent a saving during its life quite equal to its first cost.

Greater economy, all factors considered, is a second important advantage of the electric hoist. No better evidence can be offered in support of this fact than the extent to which the electrification of mine hoists has been carried out in coal fields where, if anywhere, efficiency in-so-far as it affects the coal consumption only is of minor importance. Increased production resulting from decreased delays, with its corresponding reduction in the mine overhead charges, is one of the most important factors which is responsible for the adoption of the electric hoist in coal districts, where it has been given a test on a thoroughly commercial scale. Considerable savings result from lower maintenance and repair costs, no inconsiderable item of which are the savings due to increased life of the rope, and to the reduction in cage and shaft guide repairs due to the uniform torque of the electric motor.

As an indication of the rapid strides which are being made in the electrification of mine hoists in this country and the part which we are playing in the development abroad, a partial list of the equipments of 300 horse power and over which have been built by the largest electrical manufacturing company in America is given as Table I, most of which installations it will be noted have been purchased during the past two and a half years.

Electricity is very extensively used wherever power is required in the treatment of minerals from the time they reach the surface until the finished products are placed on the market and, with few exceptions, the standard industrial power motor has very satisfactorily met the requirements in this field of application. Consequently no attempt will be made to discuss each of the several processes in detail, to do which would involve considerable unnecessary repetition. Reference is made, however, to two applications which are of interest because of their bearing on the design of the electrical machinery involved.

Anthracite coal, before it is marketable, must be reduced in rolls to a certain maximum size, and separated by screening into a large number of sizes from the smallest bucket wheat to steamboat coal. Mechanical pickers are used to remove the slate which is present in all coal as it comes from the mine. Probably no motors used in the industrial field, with the exception of those found in steel mills, are subjected to as severe operating conditions. Constant vibration tends to crystallize the shafts, loosen the laminations, break the bars of squirrel-cage rotors and chafe the insulation on the coils. The atmosphere surrounding the motor is filled with a fine sharp coal dust which works its way into the insulation and while this dust is a very good non-conductor so long as it is dry it becomes a very good conductor immediately it is moistened, which may occur as water is used in the process of separating the slate from the coal. By far the greater part of bituminous coal is shipped as run of mine or screened only, but the value of washed coal is being recognized and washeries are installed throughout the soft coal field. Motors applied in these washeries are subjected to conditions quite similar to those of the anthracite breaker.

To meet these severe conditions the coal-mine motor has been developed, the ruggedness of which is apparent from a comparison of it, Fig. 2, with a standard industrial motor of similar capacity, Fig. 3. This is truly a coal mine motor in the design of which some of the ablest and most experienced electrical engineers in the anthracite fields played an important part.

Pebble mills are being used more and more extensively in the process of preparing ores for the Wilfley or similar tables. The Hardinge mill, which is typical, requires motors of approximately 40 horse power geared to the mill which revolves at a very low speed. Because of the dirt and water present, the squirrel-cage motor is rather to be preferred, but when used it must be designed to give a high torque at starting, and its rotor must be capable of storing a large amount of heat without injury because of the severe starting conditions.

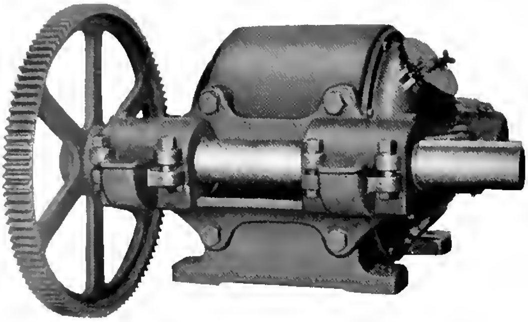


**Fig. 2.** Coal Mine Motor, showing sturdiness of construction

Although low-pressure turbines have not been as extensively applied in the mining field as has been the case in many other industries, in spite of the fact most mine engines are operated non-condensing, this is largely due to the lack of condensing water and the intermittent character of the load of some of the engines. Regenerators have been used in connection with the hoisting engines and a large portion of the energy of the exhaust steam conserved through a mixed-pressure turbine, but the cost of the installation is high under the most favorable conditions. The regenerator capacity required is very large, except where the hoisting is done uniformly and with comparatively short rests between trips. The most interesting installation of the kind in America is the 500 kw.-unit at the "D" shaft of the Newport Mining Company, Ironwood, Michigan.

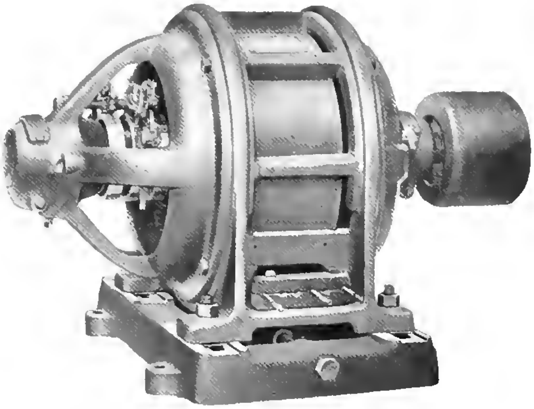


**Fig. 3.** Standard Industrial Motor, of same capacity as motor of Fig. 2

The steam stamps used throughout the Michigan copper country afford a large supply of exhaust steam which, through the low-pressure turbine, will develop sufficient power to perform all the work in connection with the extraction of the copper from the rock. The flow of the steam is uniform so that no regenerator is required and, as the remainder of the mill is always running when the stamps are, there is always a market for the low-pressure power. The largest installation of this kind is that at the stamp mill of the Calumet & Hecla Mining Company, which is operating a 7500 kw., low-pressure turbine-generator from approximately 30 stamps.

Treating a subject so broad as this in so small a space permits of touching only briefly on some of the most important points, although there are many others which must be taken into consideration when dealing with any specific problems. There is one consideration to which attention again is called, and that is the matter of safety. Equipment of the highest grade only should be used; the installation of all wires and cables if carrying currents of dangerous potential should be so installed that the miners can not come in contact with live parts; all apparatus should be thoroughly grounded and the equipment should be placed under the charge of a competent engineer with full responsibility.

# ELECTRIC FURNACES

By John A. Seede

Power and Mining Engineering Department, General Electric Company

The author points out that the power consumed by electric furnaces is constantly increasing and already figures appreciably in the income of power plants. Large electric furnace installations constitute power problems by themselves, and the load factors of such installations are generally higher than other industrial loads, approaching 100 per cent. While this is not true of the small electric furnaces used for heating forging bars, rivets, tools, etc., and for melting various metals, they will have a beneficial effect on the off-peak load. In connection with such furnaces it is interesting to note that the cost of heat utilized is lower with electric power than with fuel oil. The problem of obtaining the reclamation of worn, broken or defective metal parts by arc welding equipments is an application of great importance, and the use of these equipments is rapidly spreading.—Editor.

John A. Seede

In discussing the ability of any apparatus to compete with old and strongly established types, there are a number of things that must be considered that are not obvious at first.

In addition to possessing advantageous features that will enable it to compete successfully, this new apparatus must overcome a strong conservative element before it can come into general use. This is true of the electric furnace, and various reasons are given for its slow development, such as its reputation as a laboratory machine, imagined danger from electric shocks, probable high cost of operation, inability of ordinary workmen to operate it, small capacity limited to one special application, and numerous other equally indefensible objections of similar quality.

The electric furnace is a device in which electric power is transformed into heat with the intention of obtaining certain chemical or physical changes. In view of the high unit cost of heat from electric power the electric furnace appears to be greatly handicapped as compared to the cost of heat obtained from various fuels.

| Source of Energy | Cost | B.T.U. Per One Cent. | Ratio |
|---|---|---|---|
| Coal | $3.00 per ton | 97,000 | 28.4 |
| Fuel oil | 5 c. per gallon | 27,000 | 7.90 |
| Natural gas | 50 c. per m cu. ft. | 22,000 | 6.44 |
| Electric energy | 1 c. per kw-hr. | 3,420 | 1 |

In order to overcome the great differences shown in this table the electric furnace must be much more efficient if it is to compete successfully, and it is interesting to note that in certain operations, other conditions being equal, the electric furnace shows a saving of 15 to 30 per cent in cost of heat alone, as compared to oil furnaces, with oil and electric energy at approximately the figures given above.

With the increasing development of water power and other forms of natural energy, the relative cost of electric power will undoubtedly decrease as the various fuels are exhausted, and we may reasonably expect a rapid increase in the use of electric furnaces.

The power input to the electric furnace may be controlled automatically or by hand, and in either case a better temperature regulation can be obtained than in any other type of furnace. From the upper limit of 3500 to

4000 deg. C. down to the average operating temperatures of 1600 to 500 deg. C. we obtain a range suitable for nearly all metallurgical operations.

Considerable difficulties were first experienced in the early use of the electric furnace by the high temperatures exceeding the limits of commercial refractories, which was an experience entirely outside previous furnace practice. The difficulty was finally overcome by using the outer portions of the charge as a combined refractory lining and heat insulator.

This ability to develop and concentrate heat in the interior of the charge distinguishes the electric furnace from all other furnaces and makes possible the development and commercial manufacture of many products, such as carborundum, graphite, calcium carbide, etc. In addition the absence of large volumes of superheated gases and transference of heat through refractory walls increases simplicity and reliability and gives very much better operating conditions.

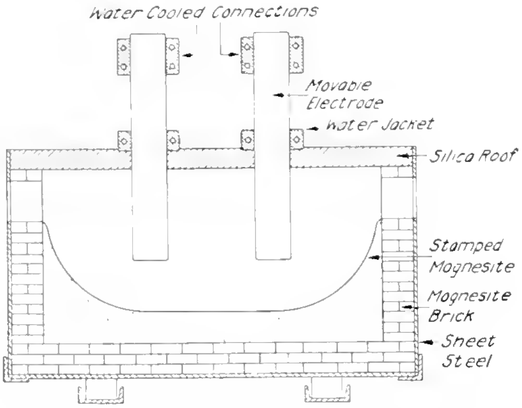


**Fig. 1.** Cross Section Direct Heating Arc Furnace. Current arcs from one electrode to charge and from charge to other electrode

With the early development of the successful calcium carbide furnace many more furnaces were installed than the natural consumption could take care of, with consequent loss to investors. In endeavoring to use these furnace equipments, in order to obtain some return on the investment, the manufacture of ferro alloys, and incidentally the refining of iron and steel, was brought about.

The electric furnace has been very successful in producing high class products from mediocre materials, and it may be said that while in any furnace the best results are obtained with the best raw materials, the electric furnace product is least affected by indifferent quality of raw materials.

The electric furnace of the stationary type consists of a refractory lining of the material being worked on in very high temperature work, or of magnesite, dolomite or silica at more moderate temperatures. This is held in place by a fire brick, silica or magnesia brick lining, which is usually supported by iron framework, except in very large resistance furnaces in which the supporting walls are sometimes of concrete.

In furnaces of the tilting type the steel framework is mounted on trunnions or rollers and is lined with magnesite brick, inside of which is the lining of crushed magnesite or dolomite stamped in place. The roof is usually silica brick through which pass the carbon or graphite electrodes. A water-cooled collar is provided where the electrode passes through the roof, and the electrode contacts are also water-cooled. These devices are necessary in order to insure continuous operation by preventing destruction of the roof, electrodes and electrode contacts.

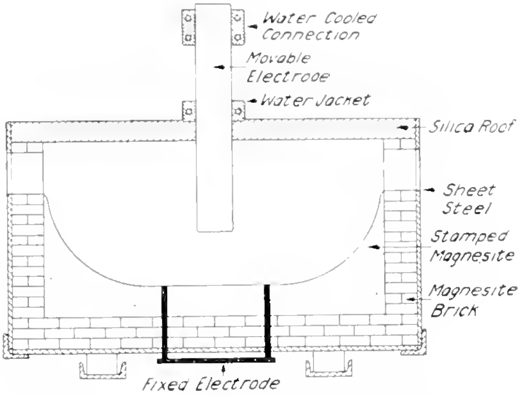


**Fig. 2.** Cross Section Direct Heating Arc Furnace. Current arcs from electrode to charge and then to lower fixed electrode

The carbon electrodes are made of a combination of anthracite coal, petroleum coke and other materials, requiring great care in order to produce a substance that will withstand the high temperatures and severe strains of the electric furnace operation. Nearly all electrodes are now made with screw joints so that very little is wasted, the electrode being fed continuously through the roof.

In electric furnaces the heat is generated by passing electric current through an arc, a resistance or a combination of these two. Accordingly we have two great classes, arc and resistance furnaces, with various combinations of these types. Arc furnaces may be classified as direct, indirect, and smothered.

In the direct type the arc extends from the end of the electrode to the charge, and heating is accomplished by conduction and radiation. In the indirect type the arc extends between the electrodes above the charge, and heating is accomplished by radiation. As examples of the above types we have arc furnaces for melting and refining metals.

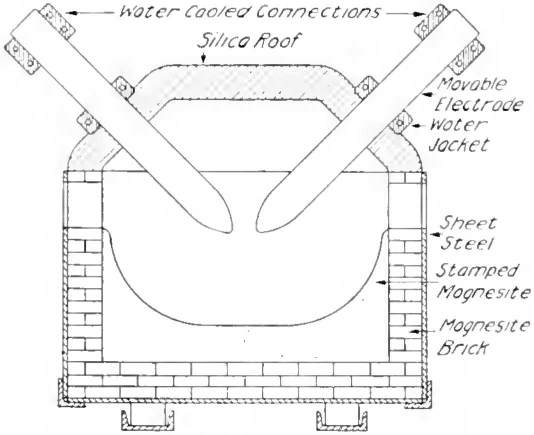


Fig. 3. Cross Section Indirect Heating Arc Furnace. Current arcs from one electrode to the other above charge

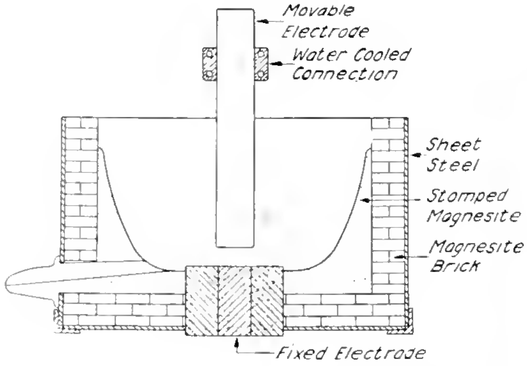


Fig. 4. Cross Section of Smothered Arc Furnace. Current arcs from the electrode to the charge in which the electrode is plunged and the current passes through the charge to the lower fixed electrode

In the smothered type the arc extends from the end of the electrode beneath the surface of the charge, and heating is produced in the charge by arc and resistance heating. Examples of this type of furnace are the ferrosilicon, calcium carbide and other similar furnaces. The resistance furnaces may be classified into direct and indirect types. In the direct type the charge is the resistor and the current is led to the charge by means of carbon or metal electrodes. Under this classification comes the only class of furnace that does not require electrodes, the induction furnace, in which the charge constitutes the secondary of a transformer surrounding an iron core and in inductive relation to a primary high voltage winding. In the indirect type the heat is generated in an internal or external resistor and is transferred to the charge by conduction and radiation.

In certain classes of work the internal graphite or carbon resistor carries the current at the start, but the charge soon becomes conducting and at the end of the run is carrying practically all the current.

In the contact resistor type, instead of developing heat by the ohmic resistance of a conductor, a large number of blocks are used, and the heat is developed by contact resistance. The resistance depends to a large extent on the pressure, and advantage of this principle is sometimes taken to effect a certain amount of regulation. This furnace is used in small moderate temperature work.

Fig. 4-A. Small Smothered Arc Furnace in Operation showing exterior bracing, upper movable electrode and connections to bottom electrode

The regulation of arc furnaces is accomplished by raising and lowering the electrode which lengthens and shortens the arc as required. In automatic regulation the electrode motor is controlled by contactors energized by a current operated relay.

In induction furnaces of moderate capacity and above, in order to keep the power-factor within reasonable limits, it is advisable to use low frequency, and in this case each furnace has its own generator. Under these circumstances we have the most flexible type of control, that is, through the field of the alternating current generator which gives as fine an adjustment as can be desired. Fig. 9 shows a 15 cycle generator driven by 60 cycle synchronous motor with direct connected exciter for use with a 2-ton single-phase induction furnace.

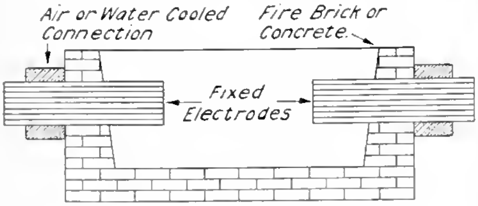


Fig. 5. Cross Section of Resistance Furnace. Current passes from one electrode through the charge to the other electrode

Fig. 5-A. Resistance Furnace partially dismantled showing electrodes, core of finished product in middle and raw product outside of core

Fig. 5-B. Resistance Furnace in Operation, showing gases burning above contact area between electrodes and charge

### Electric Smelting

In the practice of smelting, the ore, usually the oxide, is heated with a reducing agent producing carbon monoxide and the metal. The electric furnace has been used successfully to smelt tin, zinc, iron and other metals of which iron and zinc are probably the most important. The smelting of iron is making slow headway, and it is doubtful if the time will ever come when our present efficient methods will be entirely supplanted. The modern blast furnace is a very efficient, highly developed machine, while the electric smelting furnace has been experimented with for a few years only, and with limited capital and without the urgent situation that has forced the development of the blast furnace.

The present electric furnaces have a daily capacity of 25 to 30 tons with a possible immediate increase up to 100 tons as compared to the blast furnace with its daily output of 450 to 600 tons. The ordinary blast furnace consuming one ton of coke per ton of pig iron is to be compared to the electric furnace taking about $\frac{1}{3}$ of a ton of coke and 1700 kw-hr. This means that with coke at $4.50 a ton electric power must be supplied for about $12.00 per horse-power-year, other things being equal. If desired, the electric furnace product can be controlled so as to contain considerably less impurities than pig iron, and in this way be a better raw material for the manufacture of steel.

The electric smelting of zinc has been attacked by a number of investigators, and while conflicting reports are received in regard to the success of the different processes, there seems to be considerable basis for belief that a commercial furnace will soon be available.

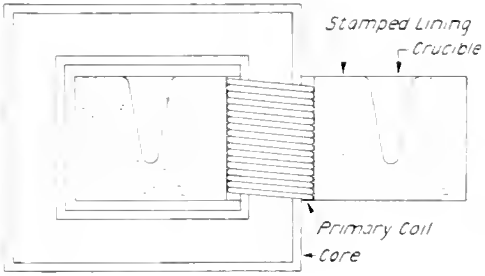


Fig. 6. Cross Section of Single Ring Induction Furnace

## Electric Melting and Refining

This large field covers many applications that are becoming of increasing importance, and we may soon expect to see an electric furnace in every up-to-date plant, not only for melting and refining steel but also brass and other non-ferrous alloys or metals.

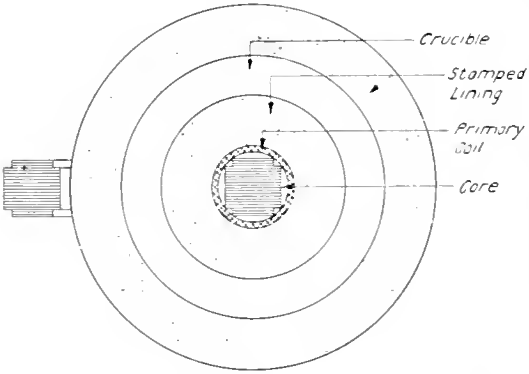


Fig. 7. Cross Section in Horizontal Plane of Single Ring Induction Furnace

Electric furnaces have been used in the manufacture of crucible quality steel for some time, and within the last three years the number has been greatly increased.

Contrary to the opinions of many iron and steel founders the electric furnace for melting and refining steel and iron is a very practical and efficient shop tool. When you consider that an electric furnace equipment requiring comparatively small floor space is available for producing crucible steel quality castings, in intricate shapes, for 5 cents a pound or less from steel scrap costing $10.00 to $12.00 per ton, it is evident that such an equipment should have a widespread use when its value is appreciated.

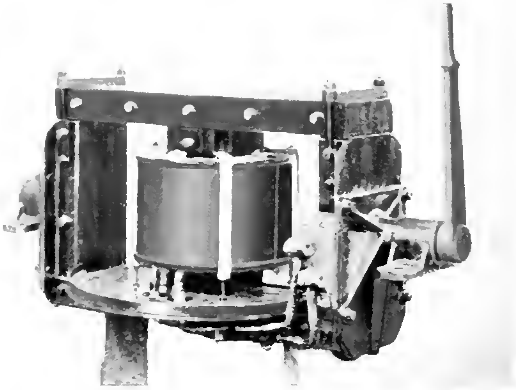


Fig. 6-A. Core and Primary Coil of Simple Induction Furnace ready for putting in refractory lining

Fig. 7-A. Induction Furnace assembled complete with crucible. Cover plates shown beneath furnace

While the induction furnace has been somewhat slower in its introduction than the arc furnace, it will soon hold the record for individual capacity in this country, when the 20-ton unit, now on order for the American Iron & Steel Manufacturing Company, is put in operation.

While these large furnaces are usually operated under the molten metal charging system, the smaller furnaces of 5 tons and below are usually operated with cold metal charging, especially where the demand is intermittent and the metal is used for making steel castings.

Another application requiring less skill and operation is in the making of fine iron castings from cast iron borings and scrap iron. This material, selling from $6.00 to $8.00 per ton, can be made into high grade castings equal to those made from high grade foundry iron and at a somewhat lower cost.

Copper, brass and other non-ferrous metals and alloys require separate treatment and form in themselves an application of great importance. Owing to the formation of poisonous vapors and other difficulties in other types of furnaces, the resistance furnace appears to offer advantages for this class of work. There are several equipments being developed at the present time, one of which not only maintains a constant temperature independent of the amount of material in the furnace but also allows of this temperature being varied according to the requirements of the process.

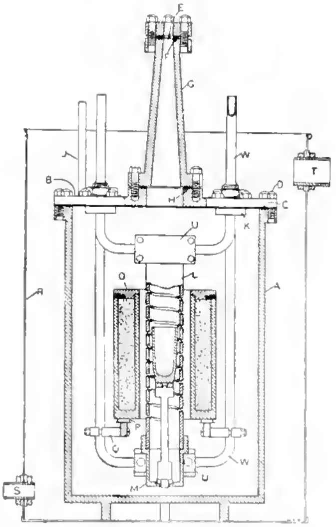


Fig. 8. Cross Section Arsem Vacuum Furnace showing crucible in center surrounded by resistor and radiation shield outside of resistor

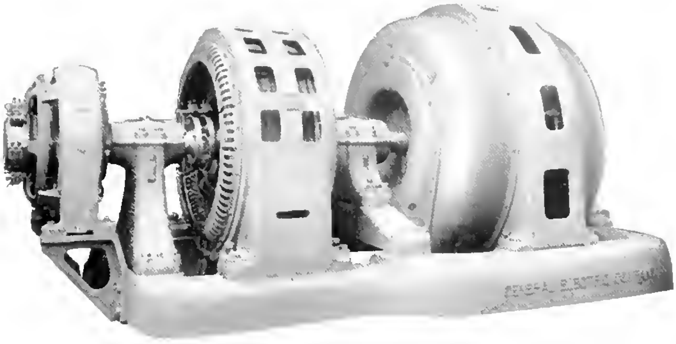


Fig. 9 Motor-Generator Set consisting of two-phase 60-cycle synchronous motor driving single-phase 2200 volt 15-cycle generator and direct connected exciter for use with two-ton single-phase induction furnace

The advantages of such a furnace, particularly where the non-crucible type is used, are many and will undoubtedly lead to a revolution in this kind of work in a short time. These might be listed as consistent even temperature, lack of oxidation products in the metal, small loss of volatile metals due to even temperature and no blast, etc. The absence of superheated gases enables the operator to use more care, increasing the quality of product and decreasing the loss due to metal being spilled from the crucible.

### Forging

The question of a successful electric furnace to heat metal for forging has occupied the attention of investigators for a long time. Such a furnace with slight changes would also be suitable for hardening and general heat treatment of tools, heating drills for sharpening, heating rivets, etc. Several types are now on the market, and in one of them the auxiliary equipment enables the operator to automatically maintain any desired temperature over a wide range, as would be needed with various metals, such as copper, brass, monel metal, nickel steel, wrought iron, etc. This furnace uses a resistor made of foundry coke and practically the only charges against the furnace, outside of overhead charges, are 10 to 20 lb. of coke per day and the electric energy. One of these furnaces was dismantled recently after running continuously six months and investigation showed that the operation could be continued with slight repairs for an indefinite period.

While it is not feasible to refer to all the experiments that have been made on this furnace, one example may be of interest. It is well known that the heating and forging of nickel steel presents many difficulties, and in this connection this type of furnace in competition with an oil-fired furnace, using the same material, operator and forging hammer, gave an increase of 15 to 20 per cent output with a superior product, showing about one-quarter of the scale and no loss of material due to over or uneven heating.

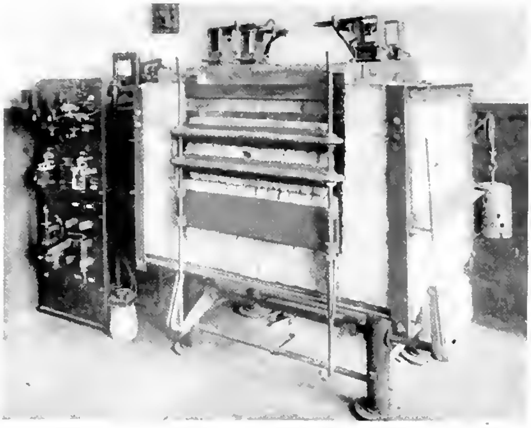


Fig. 10. Resistance Heat Treating Furnace with control panel for automatically maintaining constant temperature

### Drill Heating Furnace

In mining and similar work the expenditure of considerable time and expense is necessitated by bringing drills and other tools from the deep workings to the surface for forging and sharpening. Every time a load of drills is hoisted or lowered the hoisting capacity of the shaft is decreased and great care must be exercised in the prevention of accidents. This same type of furnace could be used in heating these tools in the mine, as there will be very little gas formed and absolute certainty of results which means keeping the producing capacity of the mine at its highest point.

A variation of this type of furnace could be used in melting and smelting the precious metal concentrates on the surface, especially in such situations where fuel is expensive and savings can be made by reducing the weight of the material to be transported.

The heating of rivets in all kinds of construction work offers another wide field that will be of great value.

### Electric Arc Welding

The subject of electric welding may not appear to belong under the subject of electric furnaces, but being an electro-thermic development is included in the list of applications.

Electric arc welding consists in utilizing the intense heat generated in the electric arc to unite various metals by small additions of metal melted in place. The process is chiefly applicable to steel but may be used for wrought iron, cast iron, copper and a few other metals. The electrodes consist of $\frac{1}{4}$ in. or smaller iron or other metal rods for metallic electrode work and of $\frac{3}{8}$ in. to $1\frac{1}{4}$ in. hard carbon for carbon electrode work. When using a carbon electrode the process somewhat resembles soldering, in which case an iron rod is held in one hand taking the place of the soldering stick, while the electrode holder is held in the other hand, taking the place of the soldering iron. When using the metallic electrode the iron rod is held in the electrode holder and serves both as an electrode for making the arc and to furnish metal for the weld. The process is from two to five times as rapid as the gas process and is much safer, as there is absolutely no possibility of injury by electric shock, explosion or asphyxiation. It is difficult for the operator to burn the weld, which can be easily done with the gas process.

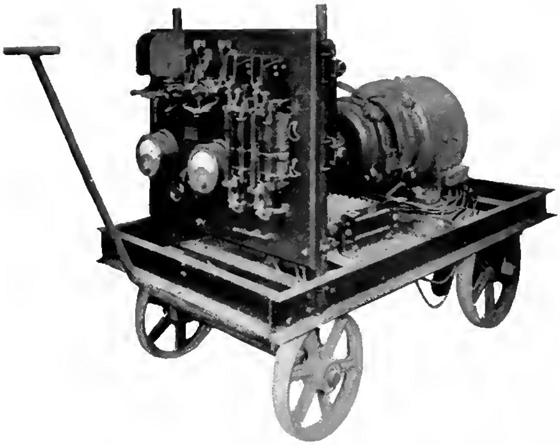


Fig. 11. 200 Ampere Arc Welding Motor-Generator Set with controlling apparatus mounted on truck to form portable equipment

It is generally recognized that metal electrodes give softer and tougher welds approaching the quality of mild steel, and that the limit of current per electrode for such work is 150 amperes. For heavy work the carbon electrode gives successful results and can work much faster, as the limit of current is approximately 600 amperes. In heavy cutting this can run up to 900 amperes or even higher values, depending on the endurance of the operator.

The arc welding equipment usually consists of a 60/75 volt flat compound wound direct current generator, belt-driven or direct connected to a suitable motor with controlling apparatus to vary the current in accordance with the character of the work and automatically protect the generator against overloads without making it necessary for the operator to leave his work. This is done by providing a rheostat in series with the electrode but normally short-circuited by a shunt contactor controlled by a series relay. (Fig. 14.)

On starting work the operator sets the rheostat switch at the proper value for the work and proceeds to weld in a normal manner. If, at any time, the current setting of the series relay is exceeded, the plunger rises slowly, and if the overload continues for one to two seconds the shunt contactor is de-energized throwing the preventive rheostat in series with the electrode and protecting the generator. The operator notices instantly that the current is cut down and lifts the electrode from the work, breaking the arc and restoring the circuits to the normal operating condition. In case of very unusual emergencies the circuit breaker affords additional protection.


Fig. 12. Operator Arc Welding with Carbon Electrode

The value of arc welding equipments in the repair and general upkeep of all kinds of machines has been thoroughly demonstrated and it is to be hoped that all manufacturers will complete their equipments by acquiring one or more in the near future. The removal of broken taps, ordinarily a difficult proposition, is easily taken care of by an arc welding equipment, taps broken off $2\frac{1}{2}$ inches below the surface being removed in 4 to 8 minutes without damage to the thread.


Fig. 13. Control Panel for use with 800 ampere arc welding equipment

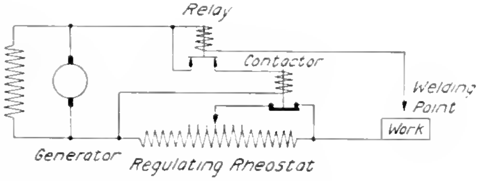


Fig. 14. Line Diagram of Control for automatically protecting generator against overloads

Electric welding equipments are used in: machine shops, to repair worn and broken machine parts and tools; in steam railroad shops, repairing broken engine frames, wheels, cylinders, welding seams and patches in locomotive fire boxes, welding flues; in electric railway shops, welding broken motor frames, gear cases, truck frames, building up worn rails and crossings, flat wheels; in steel mills, repairing broken frames, worn roll passes and wobblers; in steel foundries for cutting off gates and risers, cleaning out and filling slag and sand holes, filling blow holes and cracks; and in general the upkeep of all kinds of metal parts, much of which cannot be done by any other method.

As an example of the results to be expected from one of these equipments it might be said that this standard 500 ampere equipment was installed about three years ago and to date has paid for itself at least fifty times.

There is much that is necessarily left unsaid in an article of this general nature, and it is expected that some of the above applications will form the subject of a detailed discussion in the near future.

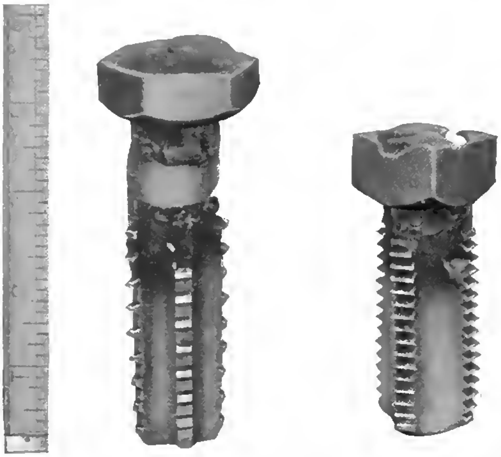


Fig. 15. Taps Removed by Arc Welding after being broken in work

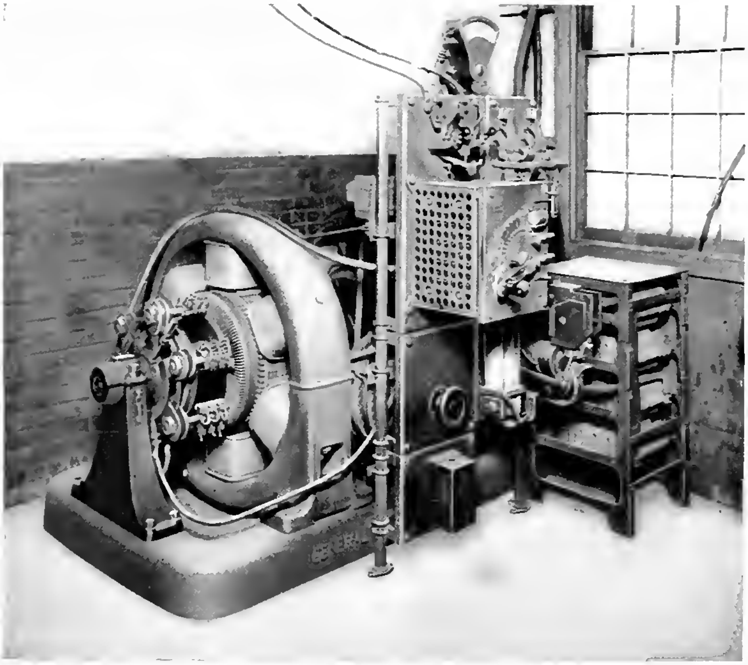


Fig. 16. 500 Ampere Arc Welding Installation

# THE CONTROL OF ELECTRIC MINE HOISTS

By M. A. Whiting

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The author of the following article has divided the subject of the control of mine hoists into its principal and secondary divisions, and under each has presented a very clear description of the equipments employed and their operation. The characteristics of the various commercial systems are discussed and the suitability of each for particular conditions is explained. A good conception of the matter treated may be gained from the main side-headings used in the article, which are: Speed characteristics of direct-current hoists; Speed characteristics of induction motor-driven hoists; Interlocking of electrical equipment with hoist brakes; and overwind protection.—Editor.


M. A. Whiting

THERE is a very limited class of mine hoists in which the motive power runs continuously and the load is accelerated on friction clutches. A hoist of this type can, of course, be motor-driven and the control problems will then be entirely mechanical. In the great majority of hoists, however, successful operation is dependent largely on the control system for the motive power, for if clutches are used they are thrown in or out as a rule only when the hoist is at rest.

This article is confined entirely to a discussion of the characteristics of motors and control equipments as applied to mine hoists, and the mechanical and electrical design of the various parts of the control equipments will not be taken up here.

The method of control whereby a flywheel motor-generator set is used to equalize the power demand of a direct-current hoist motor is of course important as it affects the degree of equalization which can be attained. The control of the hoist itself, however, is not affected in any essential manner by the equalizing control of the flywheel set (although in some cases the characteristics of the hoist may be somewhat dependent upon the size of flywheel selected). The equalizing control for flywheels can therefore most appropriately be discussed under the subject of equalization of power demands, and is not discussed here.

## SPEED CHARACTERISTICS OF DIRECT-CURRENT HOISTS

### (Driven from Individual Motor-Generator Sets by Generator Field Control)

The speed characteristics of this type of hoist can be deduced by bearing in mind the fundamental characteristic of the combined equipment. The shunt-wound direct-current hoist motor has its armature circuit connected directly to the armature of the generator from which it operates, including in this circuit the necessary commutating field winding, etc., also as a rule a circuit breaker and line switch, but without any rheostat in this armature circuit. The hoist motor field is excited always in the same direction and either maintained constant or in some equipments varied within definite limits; for purposes of explanation, however, it may be considered to be constant. The generator field excitation is varied from zero to a maximum in either direction by means of a controller which constitutes the hoist controller. With an equipment arranged in this manner, the generator voltage may be varied at the will of the operator and the hoist motor tends to run at a speed approximately corresponding to the generator voltage. If the hoist motor is pulling the load its speed will be slightly less, and if the load is pulling the hoist motor (as in lowering out of balance or in retarding rapidly) its speed will be slightly greater than this value. The amount of the variation in each case corresponds approximately to the CR drop in the armature circuit. When lowering out of balance or when retarding rapidly, the functions of the entire system are temporarily inverted and the mechanical power returned to the hoist motor by the hoist is converted into electrical power in the hoist motor (which is temporarily a generator). This power is delivered to the generator which therefore temporarily acts as a motor driving the alternating-current motor of the motor-generator set as a generator and as a result a large part of the power returned by the hoist is "pumped back" into the line (the remainder being dissipated as losses in the electrical machines). Over the entire range of controller positions and hoist loads, therefore, any one individual position of the controller gives very nearly the same speed irrespective of the load.

The results obtained in practical operation by the use of this method of control follow logically from the characteristics just described, but as these results may not be entirely obvious to those who consider this subject only occasionally, the results obtained under various typical hoisting conditions will be discussed somewhat in detail. The numerals used identify the conditions which correspond approximately to like conditions for the induction-motor hoist that will be discussed later.

### (1st) Hoisting In Balance or Out of Balance

The speed can be varied by varying the position of the controller. On any one position of the controller, the speed will be practically constant although the load may vary all the way from full load hoisted out of balance to full load lowered out of balance. An apparent exception to this occurs in case of widely varying loads handled at slow speeds. For example, assuming one drum unclutched, a heavy load on the other rope, the controller on the first point in the hoisting direction and the brakes released, the rope pull may be strong enough to revolve the motor in the lowering direction a ainst the motor torque, whereas, in handling a very light load on the same controller point the motor will hoist the load slowly. Even under these circumstances, however, the difference is more apparent than real, as the total difference in speed on this controller point (i.e., the lowering speed with an unbalanced load plus the hoisting speed with a light balanced load) is only a small percentage of the full hoisting speed. It is also to be noted in handling a heavy unbalanced load that although the first controller point in the hoisting direction may not hoist the load only a relatively small further movement of the controller in the hoisting direction is required to start the load.

### (2nd) Retarding and Holding an Ascending Trip

In approaching the dump with a balanced trip, the controller is moved gradually to the off position (or nearly so). This will result in the hoist retarding to a speed corresponding closely to the controller position. If, as is usually the case, the energy stored in the moving system is so large compared with the net rope pull that the hoist does not tend to coast to rest as rapid'y as the controller is turned off, the motor will exert a retarding effort on the hoist to bring it to rest. If the controller is turned back to a partial speed point, instead of all the way to the off position, the hoist will be retarded to a speed corresponding to this controller point, and will continue to run at this speed until the controller is turned farther off or on.

In some of the coal fields it is a common practice, where a high rate of retardation and the utmost economy of time are required, to move the controller gradually back to the off position and then for an instant to about the first or second reverse position. By this time the ascending cage will be entering the dumping horns. The controller is put over to the first or second hoisting point about at the end of the trip; this serves, if necessary, to prevent the trip from stopping too short, and in any event serves to hold the cage into the dump while the coal is spilling without the necessity of using the brake.

### (3rd and 4th) Lowering

With an induction motor-driven hoist, there are two entirely different ways in which an unbalanced load may be lowered by the motor, viz., (3rd) *lowering on counter-torque*, (4th) *lowering above synchronism* (referred to later). With the direct-current system (generator field control), a single method of handling the controller provides a more advantageous control for lowering out of balance than is obtained with an induction motor by the use of either the "counter-torque" or "above-synchronism" methods or a combination of both.

With the direct-current equipment, a heavy load may be lowered out of balance by releasing the brake, and holding the controller on the off position. If the lowering speed thus obtained is slower than desired, the controller may be moved in the lowering direction which will allow the load to overhaul the motor at a rate more rapid than on the off position, but under equally close control. If the unbalanced load is exceptionally heavy and it is desired to lower it at the slowest possible speed, the controller may be moved to about the first or second position in the hoisting direction.

On whatever position the controller is held, when lowering out of balance, if the torque exerted on the motor by the load is greater than the motor torque, the motor will be overhauled a little more rapidly, up to a speed at which its resisting torque has increased to a value equal to the torque exerted by the load.

## SPEED CHARACTERISTICS OF INDUCTION MOTOR-DRIVEN HOISTS

### (1st) Hoisting In Balance or Out of Balance

When hoisting against a certain resisting torque, the speed can be varied by varying the position of the controller; on any one partial speed point of the controller (part of the rheostat cut in) the speed varies with a variation in load; on the last point (all resistance cut out) the speed is nearly constant irrespective of load.

### (2nd) Retarding and Holding an Ascending Trip

When hoisting in balance, the controller may be reversed thereby using the motor to retard the load. (The same thing can of course be done when hoisting out of balance but is practically never necessary as even a small load entirely out of balance will coast to rest very quickly.) In cases where the empty skip or cage rests on bottom at the end of the trip, the motor may be used to hold the loaded cage into the dump without applying the brake.

### (3rd) Lowering on Counter-Torque

An over-balanced or entirely unbalanced load can be lowered against the torque of the motor at practically any speed below full speed. To do this the controller is moved to a point in the hoisting direction on which the torque developed by the motor will be insufficient to lift or even hold the load. The hoist mechanism will therefore revolve the motor backward against its own torque. As the speed at which the motor is pulled in the backward direction increases (the controller being held on a fixed point) the torque exerted by the motor increases until it balances the torque exerted on the motor by the hoist mechanism, and the hoist will then run at this speed. If this speed is too low the controller may be brought nearer the off position, weakening the motor torque so that the load will accelerate the hoist to a higher speed before the motor torque increases to a value sufficient to balance the torque exerted by the hoist mechanism. Similarly the lowering speed may be decreased or the hoist retarded to rest by moving the controller farther toward the full-speed hoisting position.

This method of lowering requires as much power to be taken from the line as if the motor were exerting an equal torque under the ordinary condition in which the motor hoists the load. The full amount of the electrical energy, which the hoist motor takes from the line during this operation, is transformed through the induction motor (less a small fraction dissipated as internal losses in the motor) and is delivered from the collector rings to the rheostat in which it is dissipated. In addition, the mechanical energy developed by lowering the load is converted into electrical energy in the rotor and is likewise delivered from the collector rings to the rheostat. The sum of these two components of energy is manifested as a secondary current proportional to the percentage of full-load torque exerted upon the motor by the hoist and a secondary voltage which is in excess of the standstill secondary voltage by a percentage proportional to the speed in the backward direction.

This method of lowering out of balance is obviously wasteful of power and if used for frequently repeated lowering trips requires a very heavy rheostat. The principal use for this method occurs therefore in vertical shafts for changing levels, also for lowering an occasional heavy load, which it is desired to lower slowly as a matter of safety. The judicious use of a partial application of the hoist brake, in conjunction with the counter-torque of the motor, will provide an additional element of safety and a somewhat greater precision of control; it will ordinarily be unnecessary, however, to apply the brakes except during a portion of the trip, and only at low pressures, so that the resulting wear on the shoes will be very slight.

### (4th) Lowering Above Synchronism

An over-balanced or entirely unbalanced load can be lowered at a speed very slightly above full hoisting speed in the following manner. The brake is released and the controller thrown in the lowering position. The acceleration of the hoist will of course be very rapid, as it is due to the unbalanced rope pull *aided by the motor*. The controller should reach the full-speed position by the time the hoist is up to speed; this is important because, *when lowering out of balance above synchronism the more resistance in the secondary circuit the higher the speed*, which is the opposite effect from that obtained under ordinary conditions. As soon as the load has accelerated the hoist to a speed at which the motor is being driven above synchronism, the motor will begin to generate power which is "pumped back" into the line. This regeneration of power limits the speed, and with the controller in the full running position the speed will not exceed more than about 5 per cent above synchronism. The ideal method of retarding the trip is to apply the brake, and as soon as the brake has taken hold sufficiently, the controller may be brought to the off position and the hoist brought to rest by the brake. Or, if desired, as soon as the brake has sufficiently taken hold, the controller may be thrown to a hoisting position so that the motor and the brake are both used to bring the hoist to rest. Ordinarily it is not entirely safe to retard the trip merely by reversing the controller, as in so doing, there is an appreciable time, while passing from forward to reverse connections, during which the motor has no torque. Unless the unbalance in load is slight it is therefore advisable to have the hoist brake partly applied before reversing the motor.

The foregoing comments apply more particularly to the case of a vertical shaft, or to an incline which approaches the vertical. In case of a typical slope, particularly within about 30 deg. of the horizontal, considerably more latitude is allowable in controlling a descending unbalanced trip. The friction losses, of course, absorb a considerable percentage of the energy developed by the descending empties; furthermore, the acceleration of gravity for a body on a slope is less (in proportion to the per cent grade) than for a body falling vertically. As a result, therefore, the hoist can momentarily be allowed to run free of brake and motor torque, without danger of suddenly reaching so excessive a speed as to incur the risk that the brakes will not take hold properly or that the reversal of the motor will be too severe a shock. Subject to ordinary care in handling the equipment, the method of lowering on the motor above synchronism is therefore particularly suitable for long slopes.

## INTERLOCKING OF ELECTRICAL EQUIPMENT WITH HOIST BRAKES

On any hoist, which is provided with an emergency brake, it is advisable to interlock the electrical equipment with the emergency brake, or brakes. By emergency brakes is meant either a separate emergency brake or simply a mechanism for making an emergency application of the brakes used for ordinary service. This interlocking should be so arranged that whenever the main circuit breaker or oil switch opens, or whenever the voltage fails, an automatic emergency application of the hoist brake (or brakes) will occur. Where the hoist brakes, instead of being applied by a weight and released by air, are applied directly by hand, there is ordinarily no emergency mechanism, and the electrical apparatus, of course, cannot be interlocked so as to make an emergency application of the brakes. However, hand-operated brakes can be designed so as to provide an emergency application by means of a weight that can be tripped out in an emergency in practically the same manner as in an air-operated brake.

## OVERWIND PROTECTION

The subject of overwind protection for mine hoists is one on which there has been a wide variation of opinion and an equally wide variation of practice among mine operators in various regions. The attitude of some has been to put the entire responsibility for overwinds forcibly "up to" the hoist operator and hold him accountable accordingly. This, of course, eliminates any carelessness on the part of the operator which might arise from a sense of dependence on the overwind devices. The opposite attitude has been to use overwind devices that protect as completely as possible. In the latter case it is assumed (not unreasonably) that if the hoist operator becomes less careful on account of the presence of the overwind devices, this is more than compensated for by the protection afforded by the overwind devices. It is, however, not particularly difficult in applying overwind devices, to arrange so that an unmistakable record is made (by breaking a seal or otherwise) for the Superintendent's benefit, that an overwind has occurred. When supplemented by severe discipline for overwinding, this will probably be effective in preventing the hoist engineer from becoming careless about overwinds, on account of the presence of overwind protective devices.

In determining the form of overwind devices to use it is necessary to consider closely the type of electrical apparatus used and the arrangement of the hoist. For induction motor-driven hoists it is necessary to consider also the characteristics of the hoist load in the manner which will appear in the later discussions.

### Head Room

It is obvious that the cost of a head frame increases with the height, and this increase in cost is probably in a greater ratio than the increase in height, which is naturally a very strong consideration in the design of a head frame. But however perfect a system of overwind protection may be, it is of course impossible to arrange so that in case of overwind under all conditions of load and speed the automatic devices will always bring the hoist to rest at exactly the same point in the travel of the ascending cage. It is therefore necessary to have a reasonable amount of head room above the dump, i.e., sufficient to allow for the difference in rate of retardation under emergency conditions according to the characteristic of the load at that time. With a direct-current hoist the head room required is relatively small. With an induction motor hoist the provision for a liberal amount of head room increases greatly the degree of protection which can be obtained by the use of any form of induction motor overwind device.

### Clutched Drum Hoists

For an equipment to operate from several levels, the overwind problem is not appreciably more difficult than for a single level. a certain segregation of the overwind equipment is necessary so that one part can be geared to one drum (or depth indicator), and the other part to the other drum (or depth indicator). Each side of the overwind mechanism therefore maintains a constant relation with its own drum, and therefore with its own rope. The overwind adjustments are therefore not disturbed and do not require any attention due to clutching and unclutching the drums in changing levels.

### Direct-Current Hoists

By virtue of the fact that a direct-current hoist (operated by generator field control) is positively retarded to rest by moving the controller to the off position, as explained at length in discussing the speed characteristics, a very effective overwind protection can easily be provided. This consists of a mechanical device connected to the hoist drum or to the depth indicator, by which as either cage approaches the dump (or the collar, as the case may be) the travel of the hoist drum gradually turns the controller toward the off position, thereby retarding the hoist. Control circuits are also provided whereby, if the cage over-runs the normal maximum height by more than a predetermined amount (which by virtue of the overwind device on the controller can happen only at a low speed), an emergency application of the hoist brakes will be made. (It is taken for granted that on any hoist of sufficient size or importance to be direct-current driven with generator field control, the brakes will be arranged for emergency as well as for service application.) The use of this form of overwind protection provides two things, (1) principally it automatically reduces the speed at a safe rate even if the operator fails to begin retarding in time, (2) incidentally if the hoist operator is standing where he should, with his hands on the levers, the automatic motion of the controller toward the off position reminds him that he is letting the hoist over run.

When particularly required, overwinds for direct-current hoists with clutched drums (generator field control) can be provided so that, in lowering entirely out of balance, the hoist can be retarded automatically, in such a manner that the cage or skip cannot land on bottom except at a greatly reduced speed. This, however, ordinarily requires more mechanism and should not be specified unless it is a distinct advantage.

Good practice recommends that *for direct-current hoists with generator field control the overwind devices be quoted and supplied by the electrical manufacturer.* The reasons for this are principally as follows.

*1st:* If overwind protection is not provided, there is danger that the operator, if the hoist begins to overwind and he becomes excited, will pull the controller instantly to the off position. This, in most instances, will cause the hoist motor to "pump back" into the motor-generator set at an enormous overload which not only may be excessively severe on the descending rope, hoist mechanism, and commutators, but will probably open the circuit breaker, thus losing the services of the hoist motor for completing the retardation and putting this duty entirely on the hoist emergency brake.

*2nd:* The overwind protection afforded by moving the generator field controller automatically to the off position is superior to the protection afforded by any purely mechanical overwind device.

*3rd:* The overwind mechanism for the method referred to (2nd), must practically be built as a mechanical part of the generator field controller itself, and the connection of this overwind mechanism to the drums (or depth indicators) is a simple matter.

### Induction Motor-Driven Hoists

As will be understood by a consideration of the speed characteristics of the direct-current motor with generator field control, in comparison with the speed characteristics of the induction motor, it is impossible to provide so ideal a system of overwind protection for an induction motor-driven hoist as for a direct-current hoist with generator field control. However, by one of the methods which will be described (embodying a centrifugal governor), a high degree of perfection of overwind protection can be attained with an induction motor-driven hoist. It is especially important to bear in mind that any degree of overwind protection, which can be attained with a steam hoist, can be attained to an equal degree (by a similar but usually somewhat simpler means) with an induction motor-driven hoist.

The most obvious method of protecting an induction motor-driven hoist against overwinds is to use a limit switch which cuts off the power entirely and makes an emergency application of the brake. Where the rope speed is low, the head room ample, and where the weight of the descending rope is not excessive, this method may meet all requirements. Suppose, however, the characteristics of the hoist in these respects are particularly unfavorable. In order to be sure the brakes will stop the hoist under the worst conditions (coming up at full speed with a light load, cages balanced) in time to prevent the ascending cage from going into the head sheave, it will be necessary for the overwind to cut off the power and apply the emergency brakes while the cage is still below its normal position in the dump (or at the collar). Coming up at reduced speed, or with a heavy load, or worst of all if out of balance, the operation of the limit switch will then stop the cage short of the dump (or collar).

A refinement of this method, which is often used, is to arrange the limit switch so that resistance is cut into circuit, and the torque of the motor reduced thereby. This tends to cause the hoist to slow down and to continue running at a reduced speed till the position is reached at which the limit switch cuts off all the power and applies the emergency brakes. The introduction of this slow-down feature extends the usefulness of this general method of overwind protection, making it adaptable to a greater variation of operating conditions. However, in hoisting a very light load at full speed, in balance, if the descending cage and rope approximately balance the ascending cage and load, the cutting-in of resistance will have very little effect since the load itself gives very little retarding effort, and the hoist therefore will tend to coast along at nearly full speed until the emergency goes on.

There is an entirely different method of providing overwind protection for an induction motor-driven (or a steam-driven) hoist. A centrifugal governor is used to actuate one portion of the overwind mechanism, and another portion of the overwind mechanism is driven (using a screw, worm, or equivalent means) by the travel of the hoist drum. The results achieved are most easily explained by an example. Suppose that under the worst condition, the hoist can be retarded from full speed to rest in the last 100 feet of travel by a service application of the hoist brakes or by the reverse torque of the induction motor. The overwind will be adjusted so that if the hoist operator has not begun to retard the hoist by the time the 100 foot level is reached, the overwind will trip out, thereby cutting off the power and making an emergency application of the brakes. If the hoist passes this point at a sufficiently reduced speed, say at 80 per cent speed, the emergency will not trip out at this point, and the hoist can continue to run till the next setting of the overwind device is reached (say at the 60 ft. level). If the hoist passes this second point at 80 per cent speed the emergency will trip out, whereas if the operator has reduced the speed to, say 60 per cent, the emergency will not trip out. In like manner other settings may be provided at properly reduced tripping speeds. At the end is provided a setting which will trip at any speed, set to operate just above the dump.

The net result attained by this type of overwind device is that if the operator properly retards the hoist all the way in approaching the dump, the overwind device will have no effect at all. But, if the operator lets the ascending cage run too far up at any speed, the emergency will go on in time to retard and stop the hoist from that speed and position of the ascending cage in the shaft before the cage goes into the head sheave.

This type of overwind mechanism embodying the governor is the best overwind protection for an induction motor-driven shaft hoist where the conditions in regard to overwind are at all exacting. The device is almost entirely mechanical in its nature, and therefore it is outside the field of electrical manufacturing concerns to supply this device. Such overwind devices are in the market, however, and are well known to the mine hoisting trade.

For direct-current motor hoists, operated by generator field control from their own motor-generator sets, this governor type of overwind could, if necessary, be applied and made operative. There is no advantage in this, however, as the action obtained with a generator field control by turning the controller automatically to the off position affords ideal overwind protection, as previously explained.

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# NOTES ON ELECTRIC SHAFT-HOISTING

By F. L. Stone

Power and Mining Engineering Department, General Electric Company

Coal operators are driven by competition to investigate the merits of the use of electricity in and around the mines. The result of such investigation has been most flattering to this class of machinery. The electrifications of the main hoist has received serious consideration. The following article deals with the methods of handling one set of conditions which frequently face the engineer.—Editor.


F. L. Stone

THE subject of electric shaft-hoisting has been so thoroughly gone over from a technical standpoint that it is not necessary in the present article to touch at any great length upon the actual calculations of the ordinary hoisting problems.

As near as can be learned the first electric shaft hoist of any importance was installed in this country in the mines of the Hecla Mining Company, approximately 14 years ago. The progress made by the manufacturers since that time, up to within the past two or three years was extremely slow and discouraging. Many very attractive propositions came up, but were awarded to the steam engine builder or the compressed air man, because of the operators' lack of confidence in what was comparatively a new and untried method of hoisting in this country. Fortunately this is not the condition today. We have in successful operation in this country a great many electric hoists on both slopes and shafts.

At one time, when a hoisting problem came up for solution, the electric drive was not given serious consideration; fortunately, things have changed and today there is hardly a hoist installed where the electric drive is not given very serious attention.

Without entering into a discussion of the relative merits of steam and electric drive it is sufficient to say the standby losses of the steam hoist mount up most astoundingly, particularly if the hoist is located any appreciable distance from the boiler plant. Fig. 1 is a record showing a continuous indicator card of a typical steam hoist operating in the hard coal region. The conditions of hoisting are approximately as follows:

| | |
|---|---|
| Weight of coal | $3\frac{1}{2}$ tons. |
| Weight of car | $2\frac{1}{2}$ tons. |
| Weight of cage | $4\frac{1}{2}$ tons. |
| Depth of hoist, approximately | 600 ft. |

This was a comparatively new 30 by 60 twin first motion hoist. For the first nine revolutions the hoist takes steam at practically full stroke; and on the remaining ten revolutions there is hardly any work done. The cards were taken simultaneously on the crank end of each cylinder. Cards were also taken on the head ends which show that the valves were properly set. The other indicator card shows the operation of this hoist while men are being raised. It is evident that as the depth of the mine increases the efficiency of the steam hoist improves, and when bodies of ore at such great depths as five to eight thousand feet have to be raised, and Corliss compound condensing engines can be used, the comparison between the electric and steam hoists becomes much more interesting.

When the all-day efficiency is considered, that is to say, when the total pounds of steam evaporated in 24 hours (properly chargeable to the hoist) is divided by the foot-pounds of energy expended in the shaft, the water rate is very high. In all probability in the great majority of cases the steam consumption will be over 100 lb. of steam per shaft h.p.-hr.

Assuming that it has been decided to use electric drive, the question naturally comes up: What is the best arrangement for the operator so that his power bill or his station demand will be the minimum? Will he use induction motor drive, or will he use a direct current motor with generator voltage control, either with or without a flywheel? Shall he use conical or cylindrical drums or a combination of the two?

The question of whether or not the flywheel shall be used depends almost solely upon the rate at which power is to be charged for or the station capacity from which the hoist is to be operated. If instantaneous peaks are to be penalized as is the case in some localities, and the hoisting is to be done with a fair amount of regularity, it would seem as though the flywheel would be the proper arrangement to consider.

By way of illustration assume a set of hoisting conditions which will approximate fairly well the conditions met in many shallow shafts, viz.,

| | |
|---|---|
| Depth of shaft | 220 ft. |
| Weight of cage | 6000 lb. |
| Weight of car | 2000 lb. |
| Weight of coal per car | 2000 lb. |
| Tonnage per hour | 480 ton. |
| Rest period | 5 sec. |
| Size of rope | $1\frac{1}{4}$ in. |

In working up the duty cycle without any reference to the system to be used for the hoist, it will be found that it consists largely of accelerating and retarding in order to get the tonnage. The cycle as calculated is shown in Fig. 2.

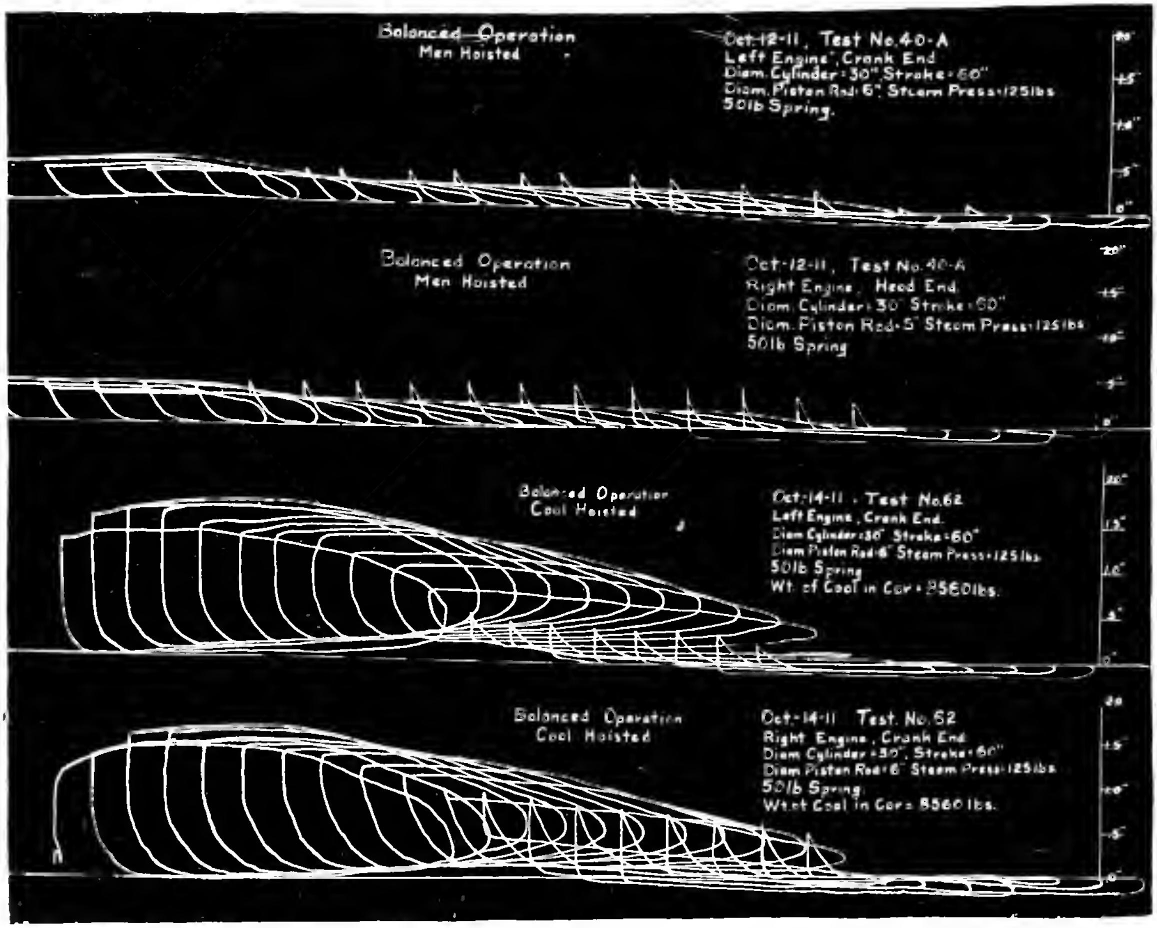

Fig. 1. Continuous Indicator Diagram for Steam Engine-Operated Coal Mine Hoist

This cycle requires approximately 1365 h.p. for 5 seconds, and approximately 330 h.p. for one second, at which point current will be thrown off and the brakes applied to the extent of 800 h.p. torque for four seconds; or the motor could be reversed and the braking done electrically, which of course would be approximately 800 h.p. demand on the line for four seconds. The efficiency of such a duty cycle would be extremely low and everything about it undesirable.

The possibilities of improving such a duty cycle should at once be considered. The obvious way is to reduce the running speed and increase the loads, by double decking the cages or by widening the cages so that two cars per trip may be carried, thus increasing the tonnage per trip to four instead of two. This gives a cycle with a peak of 350 h.p. and an average running of about 210 h.p. as shown in Fig. 3. It will be noted that this permits an increased period of rest. Further improvement might be attained by making the drums conical, to reduce the acceleration peak to 320 h.p. and give the cycle as shown in Fig. 4. The drums in this case were 7 ft. 6 in. to 9 ft. The advantage derived from the use of conical drums in this case is a slightly reduced peak.

All the cycles are plotted to the same scale and form a very good illustration of what can be accomplished by the use of a little foresight in selecting loads, etc. In some instances it might be difficult and even impracticable to carry two cars per trip. Where the breakage of ore is not of great consideration, skips carrying two or three pit-car loads per trip could be considered.

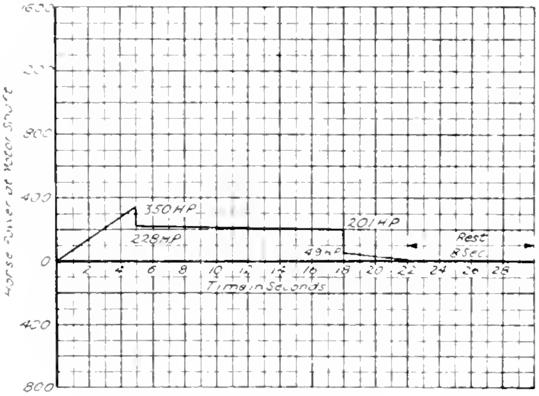

**Fig. 3. Vertical Hoist**

Depth, 220 ft.; tons per hour, 480; tons per trip, 4; max.rope speed, 756 ft. per min., cylindrical drum; trips per min., 2.

The advantages of the conical drum are perhaps not as well exemplified in this cycle as in the case of some other instances where the acceleration is very excessive. Fig. 5 shows an excellent illustration of what can be accomplished in this direction.

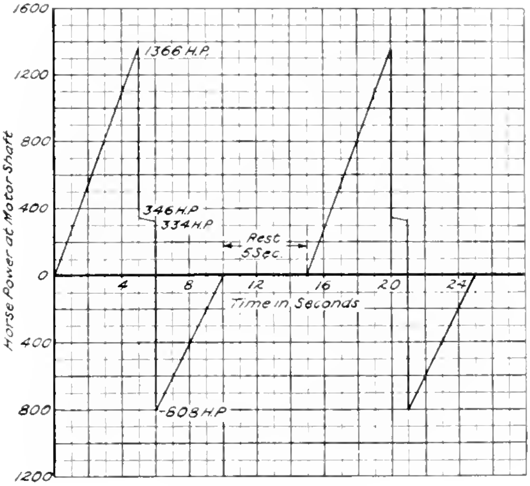

**Fig. 2. Vertical Hoist**

Depth, 220 ft.; tons per hour, 480; tons per trip, 2; max. rope speed, 2400 ft. per min.; trips per min., 4

In general, in regard to conical drums there are instances where they have a slight advantage over the cylindrical drum by virtue of reducing the peak, although this is occasionally off-set by their increased cost and increased weight. Many of the South African installations use a combination of the cylindrical and conical drum, particularly when hoisting from very great depths. This

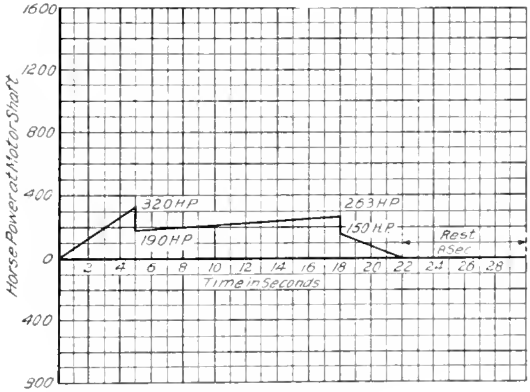

**Fig. 4. Vertical Hoist**

Depth, 220 ft.; tons per hour, 480; tons per trip, 4; max. rope speed, 780 ft. per min.; drums conical, 7 ft. 6 in to 9 ft.; trips per min., 2.

is done to reduce the peak and also to assist in overcoming the enormous weight of rope which becomes a very important factor in deep mine hoisting.

After deciding on the cycle of operation best suited to all conditions we will proceed to examine the three systems used in shaft hoisting; namely, the geared induction motor, the flywheel motor-generator set with direct current motor and generator voltage control, and the synchronous motor-generator set with direct current hoist motor and generator voltage control.

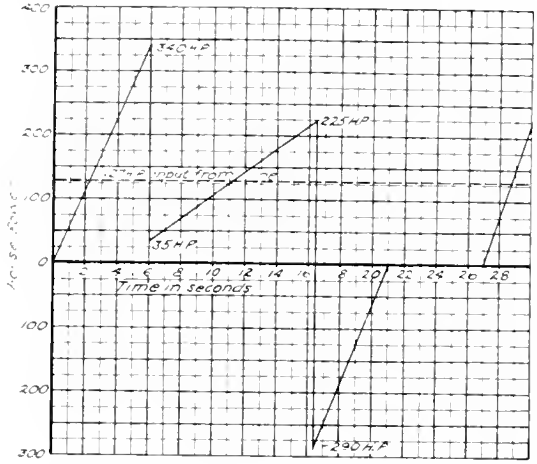

Fig. 5. Balanced Hoist

Depth, 452 ft.; ore per trip, 2400 lb.; drums conical, 5 ft. to 7 ft.; flywheel m-g. set; weight of wheel, 7000 lb.

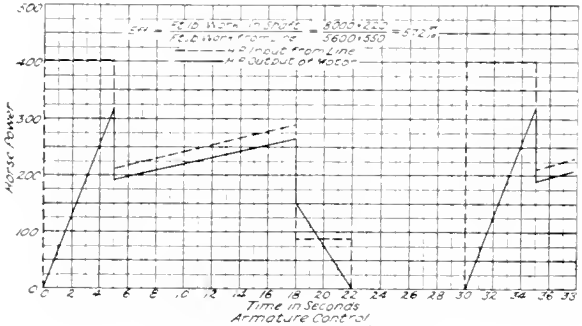

Fig. 6. Induction Motor Hoist

Depth, 220 ft.; tons per hour, 480; horse power seconds per trip, 5600; kw-hr. per trip, 1.162.

The fundamental cycle in all cases is identical and includes no armature acceleration or retardation. With the induction motor, Fig. 6, it will be noticed that the peak will run up to 402 h.p. and hold at this point for 5 seconds. The area above the diagonal line represents the energy wasted in the rheostat. The acceleration and retardation of the hoist motor armature is included. At the end of the accelerating period the consumption drops to 212 h.p. and on account of the conical drums increases from 212 to 287 h.p. at the end of 18 seconds. At this point the retardation has begun, and the input drops to 87 h.p. which is held for 4 seconds, at which point the current is thrown off. The area of this cycle under the dotted line represent the h.p. seconds consumed per trip, which in this instance is 5600, or in terms with which we are more familiar, 1.162 kw-hr., and the overall efficiency from input to motor to ft.-lb. of work done in the shaft is 57 per cent.

The next instance to be considered is the flywheel equipment shown in Fig. 7. As stated before, the only reasons for considering this are: First, a possible penalization of instantaneous peaks or a limited power station capacity, or a very distorted cycle which shows enormous peaks in proportion to the average horse power.

A flywheel equalizing equipment consists of an induction motor driving a flywheel and direct current generator, and finally a direct current hoist motor. The speed of the hoist motor is controlled by controlling the generator voltage; the armatures of the two being tied together electrically with no intervening resistance of any sort. The flywheel is calculated on the basis of operating at 300 ft. per second maximum speed, and the energy given out by the wheel is, to a certain extent, proportional to its drop in speed. In addition to this moving apparatus there is what is known as a slip regulator, which in reality is a current limiting device which prevents the current in the induction motor

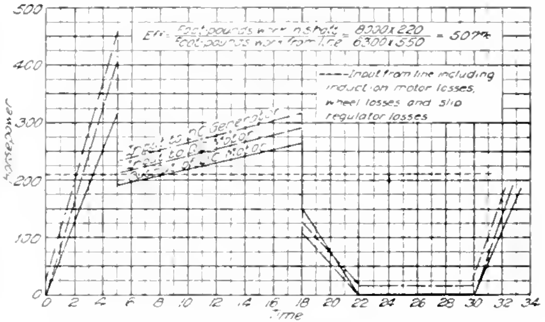

Fig. 7. Flywheel Motor-Generator Driving Hoist

Depth, 220 ft.; tons per hour, 480; horse power seconds per trip, 6300; kw-hr. per trip, 1.307.

from exceeding a predetermined value, and, therefore, the induction motor can deliver only a given torque and everything in excess of this amount must be given up by the wheel. The wheel in the instance shown has approximately 4500 lb. effective weight at 300 ft. per second; and a drop in speed of 7 per cent will take care of all peaks above the average. The actual weight of this wheel will be approximately 9000 lb. The input to the induction motor driving the set is 210 h.p. or 6300 h.p.-seconds consumed per trip, making 1.300 kw-hr. per trip. The overall efficiency in the case of the induction motor will be 50.7 per cent.

The third arrangement is a synchronous motor-generator set with the voltage control for both the generator and motor as shown in Fig. 8. In this instance the input to the hoist motor and the input to the direct current generator are omitted as they will be identical with that shown in the case of the flywheel. The input to the synchronous motor is vastly different, however, from that of the induction motor and flywheel since its peaks and load follow identically the duty of the hoist. The peak demand on the line is approximately 500 h.p. The overall efficiency, including losses when running light during the idle period, shows 56.8 per cent.

The question now comes down to the relative merits of the synchronous motor driven set and the induction motor hoist from an operating standpoint. In order to intelligently select the better of these two equipments it is necessary that we have more information in regard to the actual mining operation than that which has been given. For instance, is there much night work to be done, which of necessity must be an intermittent characteristic. With the synchronous motor-generator set it will be necessary to keep it running all night at no load in order to make a few light trips; while the induction motor stands ready at all times to perform its work with no standby losses. On the other hand, if there is much slow speed running to be done it can only be accomplished by a great sacrifice in efficiency on the part of the induction motor, the efficiency being almost proportional to the present reduction in speed. For instance, half speed must of necessity give less than 50 per cent efficiency.

In regard to hoist operation for individual plants of limited capacity where a flywheel might prove effective, it is questionable if it would not be better engineering to install additional station capacity which would be available for other purposes when the hoist is idle; while the extra money spent for the flywheel set could be used only when the hoisting is actually done.

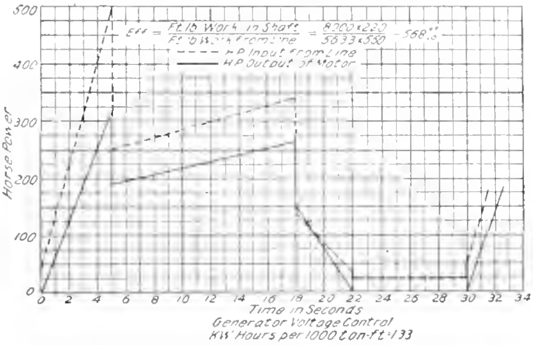

**Fig. 8. Synchronous Motor-Generator Driving Hoist**

Depth, 220 ft ; tons per hour, 480; horse power seconds per trip, 5633; kw-hr. per trip, 1.17.

A hoisting equipment has recently been installed at one of the New River and Pocohontas Mines, in which the hoist motor proper is direct connected to conical drums, and driven by a synchronous motor-generator set using generator voltage control. In addition to driving the generator for operating the hoist, the synchronous motor also drives a third generator, which is used for underground direct current power. There is also a two unit generator set installed in the hoist house which acts as a spare and also operates at night when it is not necessary to run the hoist. All three direct current armatures are interchangeable so that in case of accident to the generator driving the hoist, either one of the other two armatures can be removed from the shaft and put in place of the damaged armature.

The interest displayed in electric mine hoisting from both the theoretical and practical standpoints is decidedly encouraging. It is unfortunate that no hard and fast rules can be laid down for the guidance of operators in the selection of systems and types of apparatus to be used. Practically all cases require the special attention of some one experienced in this line of work. There are usually quite a number of different ways of accomplishing the same result, namely, of getting the material to the surface, and if a mistake is made in the selection of the best method it is liable to prove very expensive for the operator when the life of the apparatus is considered. When power rates are based on the kw-hr. consumption only, the electrical manufacturers are frequently asked to guarantee the kw-hr. per ton of material hoisted, or the kw-hr. per trip. This they are naturally very reticent to do, as the efficiency of the mechanical parts of the hoist intervene between the work done in the shaft and the input to the motor. Guarantees, when so made, must necessarily be safe from the manufacturer's standpoint, and statement should be made of the assumed mechanical efficiency of the hoist proper. In many instances the hoist proposition can be badly handicapped by the selection of incorrect acceleration and retardation values. There are some cases where the size of the motor could be reduced from 10 to 15 per cent by a readjustment of these values. Finally, with regard to the ratings of the hoist motors, it is likely that all hoist motors over 200 kw. should be given their continuous ratings, and temperature rise at which they will operate at these ratings. This rating should be approximately the root mean square of the duty cycle. If this method were in vogue it would make the matter of comparison much simpler than it is at the present time. Occasionally hoist motors will be rated on an intermittent basis, which has little meaning.

# ELECTRICITY AND THE COAL MINING INDUSTRY

By W. W. Miller

Power and Mining Department, General Electric Company

This article points out that, while only a few years ago steam and compressed air were used almost entirely for the power requirements of coal mine operations, electricity has shown such marked advantages over these two systems that it is reasonable to suppose they will be replaced by it within the next few years. In such work the electric motor is now largely used for driving mine pumps, coal cutters, ventilating fans, hoists, gathering locomotives, etc. The author mentions the principal features of each class of service and the type of motor that has been found to give the best results.—Editor.

W. W. Miller

The coal mining industry of the world comprises a yearly production of coal of over a billion tons, and in the United States alone more than five hundred million tons are mined. If this were placed on regulation railroad cars, it would make a train that would reach around the world, without the locomotives necessary to haul it.

In the United States 750,000 coal miners are employed, and the yearly output constitutes approximately 50 per cent of the traffic of the railroads. In the State of Pennsylvania alone there are employed more than 300,000 coal miners, and the output equals that of Great Britain. It is interesting to note that it is estimated that there still remains unmined in the world four million million tons of bituminous coal, and it is approximated that of this amount 271,080 million tons are in America. In the State of West Virginia alone the excavation incident to three years' mining is greater than the excavation in eleven years required to build the Panama Canal.

A careful consideration of the above data makes it evident that electricity must be an important factor in the economic production of coal. In the early days steam and compressed air were used entirely, but the first installation of electricity at once proved its flexibility and value, as well as its superiority.

At the present time every operation incident to the production of coal can be accomplished by the use of electrical apparatus, and while animal haulage and compressed air are still used to a certain extent, it is fair to assume that within the next five years these two systems will be replaced by electricity.

One of the difficulties met with in all mining operations is the disposal of the water found underground. In the anthracite mines of Pennsylvania there is pumped out yearly one billion tons, or approximately three hundred billion gallons of water. The importance of this condition can be appreciated better when it is realized that in many mines ten tons of water are pumped to every ton of coal mined. Where feasible the common practice is to drain the water to a sump, and pump the water from the sump with centrifugal or reciprocating pumps equipped with direct or alternating current motors, varying in capacity from five to one thousand horse power.

Practically all mining installations are made underground, and due to the fact that the mining laws in the several states require substantial housings, this apparatus is placed in concrete compartments; these provisions allow the use of high potential motors.

For parts of the mine which are below the sump level a large number of small portable mine pumps, driven by motors, are used. They are made portable to meet the different requirements incident to the constantly changing conditions. These outfits can be lowered down a shaft, and hauled to any portion of the mine, and immediately put in service. Some companies have as many as three hundred of these pumps in daily operation.

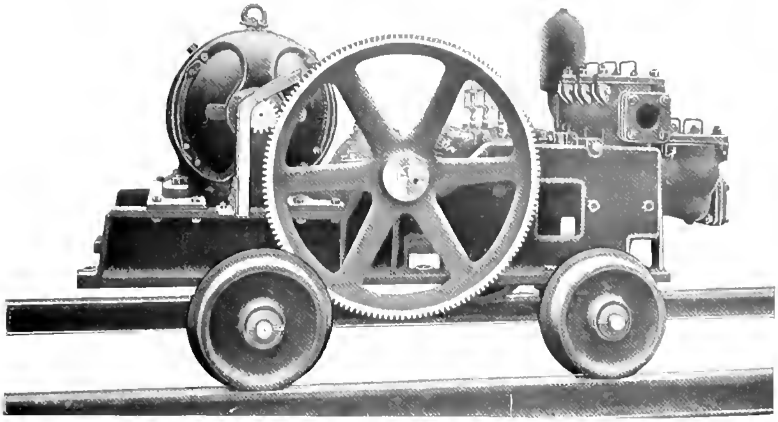

Fig. 1. 7 1/2 h.p. 925 r.p.m. CQ Motor Driving Portable Mine Pump

Formerly coal cutters were all driven by compressed air, but a modern type of coal

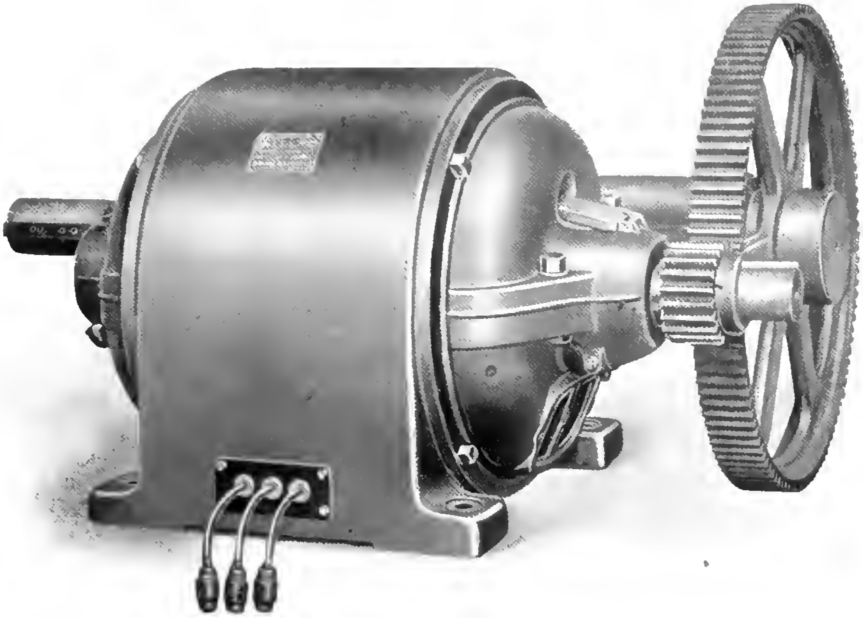

Fig. 2. Back Geared Mining Induction Motor showing Ventilating Inlet on Lower End Shield

cutter, Fig. 4, is mounted on its own truck and is self-propelled and all of its operations are accomplished by its own power, rather than by hand labor. This type of machine was originally equipped with direct current motors, but owing to the general use of alternating current, there has been a large number of alternating current machines built, which are now in successful operation. It was also believed that coal cutters were adapted to mining bituminous coal only. Experiments during the last two years have demonstrated that anthracite coal can be mined by this type of machine, and in the last eighteen months several hundred machines have been placed in successful operation in the State of Pennsylvania.

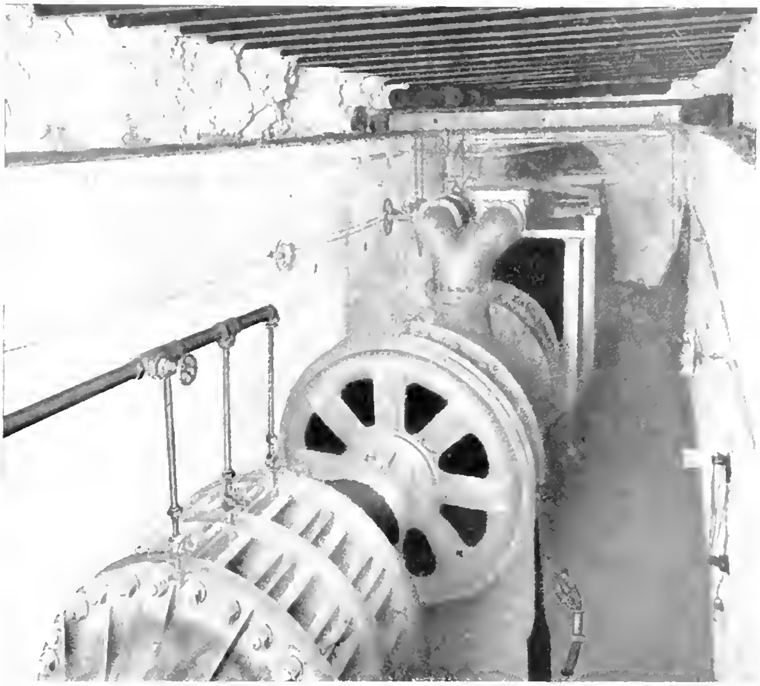

Fig. 3. 1000 h.p. 2300 Volt 720 r.p.m. Induction Motor Direct Connected to 5000 g.p.m. Six-stage Centrifugal Pump Operating Against 500 Ft. Head, Located at Hampton Water Shed Sump. D., L. & W. R. R. Co. Mining Dept.

There are several schemes for mining coal, but the one most generally adopted is the room and entry system, where the coal is mined in the rooms, and then taken from the rooms to the entries or main haulage ways. Formerly this was taken care of by hand power or mules, but the rapid introduction of electricity demonstrated a considerable saving. This hauling is now done by a type of electric locomotive known as a gathering locomotive.

In many mines it is not feasible to install trolley wire and to bond the rails into the room or working faces. To use electric locomotives successfully meant the production of the cable reel locomotive. This was first taken care of by driving the cable reel by a chain and sprocket from the locomotive axle. About 1907 the electric motor driven cable reel was introduced; the use of this reel enables the locomotive to be operated at distances up to 750 feet from the source of supply.

In some mines, owing to physical conditions; severe grades are encountered, in fact so severe that the ordinary locomotive would not operate satisfactorily. This necessitated the development of the wire rope reel or what is known in mining parlance as the "crab." This is simply a motor-driven hoist, placed on the locomotive. In the last eighteen months a storage battery locomotive has been successfully used for gathering, and it is believed by many to be the practical solution of the gathering problem.

After the cars are delivered to the cross or main entry they are made up into large trains, and hauled either to the surface or to the shaft. This service requires, in some cases, the use of locomotives up to twenty tons capacity. Some of the larger mining companies have as many as three hundred gathering and haulage locomotives in daily service.

Ventilation in mines is of vital importance owing to the presence of "coal gas." It is interesting to note that in many mines very little of this deadly gas is found, while in others there is an abundance, varying in quantity from time to time. Most of the ventilating fans are driven by variable speed, direct current motors, two speed alternating current motors, or variable speed alternating current motors of the brush shifting type.

The geological formation of the veins of coal requires different methods of bringing it to the surface, after it is mined. In some cases shafts are sunk to a depth of 1200 ft. In other cases openings are made in the side of the hill, and the coal is either lowered or raised by a type of hoist known as the slope hoist. Most of the shaft hoists have heretofore been driven by steam engines. Installations made during the last two years, especially of the Ilgner System, have demonstrated the flexibility and saving in power secured by the application of electric motors. Most of the slope hoists require motors of such capacity that they can be successfully driven by wound rotor type of motor.

The next stage is the preparation of the coal for market. In the anthracite field this is taken care of in a coal breaker, and in the bituminous field by tipples. Formerly the usual practice was to belt motors to the steel belt conveyors, crushers, shaker screens and car loaders, but the efficiency of the modern motor has resulted in a marked tendency towards direct drive. Most of the operations in these breakers and tipples are of such a nature as will require an extremely substantial motor. A typical type of motor is shown in Fig. 2.

Power at the mines is obtained from turbines or engine-driven units, or from substations with rotary converters, or synchronous motor-generator sets. Many companies operating a number of mines have found it economical to install central stations. Large public service companies are campaigning actively to secure mining loads, and in fact some of them have built central stations, the total load being entirely of a mining nature.

A very considerable tonnage goes to make up the seaboard coal traffic. Coal is hauled to the piers, and loaded in colliers by electrically operated car dumping machines, and at the destination is handled by electrically operated unloading machines.

This article is meant to show that electrically operated machinery is used in every operation in connection with the mining of coal, and that almost every type of electrical apparatus manufactured by large electric companies is used.

Fig. 4. Sullivan Coal Cutting Machine in Operation

# DIRECT CURRENT ELECTRIC DRIVE ON CRANES

By R. H. McLain

Power and Mining Engineering Department, General Electric Company

Overhead travelling cranes are employed for various kinds of work which differ greatly in service requirements, ranging from a heavy lift for a few minutes at long intervals, to continuous operation on all sorts of loads; while others are required to work in highly heated locations and therefore have to be specially insulated. The severity of the service for the kinds of work considered is increasing in the order given, the soaking pit cranes having to operate under the most trying conditions to which such apparatus is subjected. The author discusses the design of motor best suited for each class of service, and goes into considerable detail respecting the best methods of speed control and of braking, whether dynamic, solenoid, mechanical, or a combination of these. The most suitable motors and brakes for the trolley and bridge motions are indicated, and some remarks included on protective devices.—Editor.

R. H. McLain

During recent years many improvements have been made in the electrification of cranes with direct current apparatus, both in regard to the manufacture and the design of the electrical material and in the proper selection of equipment to meet the specific requirements. The service conditions for the various classes of work have been shaped into very definite channels. In some cases a motor is required which will hoist tremendous loads for five or ten minutes at a time and then lie idle for long periods. In other cases, a motor is required to occasionally hoist a very heavy load for a short time and in addition is required to keep busy most of the time hoisting moderate loads. Some industries require a motor to operate in a very hot location, and, therefore, demand special non-combustible insulation.

The controller requirements are classified very much along the same lines; but many new possibilities in controllers have recently been worked out. Dynamic braking for lowering is becoming more popular in order to save the expense, wear and adjustment on mechanical brakes and to gain more refined speed control. In some cases motors, control and solenoid brakes must all be used together to obtain the best conditions for extreme overloads on hoisting, high speed on lowering, and refined speed control. These three pieces of apparatus must be so corelated that the life of none is impaired under extreme operating conditions. The "Safety First" movement has invaded cranes and brought about a demand for absolute protection for the operator; this involves the protection of the motor and equipment as well as of the load on the hook.

### Power House Cranes

About the simplest and cheapest class of crane is the one which is used for setting up machinery in a power house. Once the heavy machinery is set in place the work of the crane is done, except for a few repairs or alterations which must be made at rare intervals. Such a crane may lie idle for weeks. A low hook speed is required and therefore no speed control refinements are necessary. All the control and protective apparatus should be made as simple as possible so that it will be easy for an untrained operator to manipulate and so that it will not get out of adjustment when not in use. The apparatus should be made as inexpensive and small as is consistent with the extremely heavy load which must be handled when the power house is first built or when additions to the power house are made. While the apparatus should be strong no especial expense need be incurred to make it stand wear.

### Machine Shop Cranes

The class of crane which serves machine shops comes next above the power house crane in point of severity of service. They have at rare intervals very heavy loads to hoist but are on duty at all times serving the machines, bringing up raw material and holding parts in place on the assembly floor and so on. High speed in these cranes is not so important merely for the purpose of moving material rapidly, but is frequently important when the crane occupies such a place that its slowness would keep high priced mechanics idle while waiting for the crane. Such a crane requires a series wound motor which can stand extreme overloads, can speed up on light loads, will wear well, and which is light and accessible for repairs. Interpoles come in well on such a motor, because of the overloads and high speeds; split motor frames and large convenient openings to the brushes are well worth while so as to enable repairs being made easily and quickly. Such a motor must be built both for strength and wearing qualities.

A good easily operated controller of the manual type with no live parts exposed to the operator is best adapted to this class of work. Ordinarily there is not enough work done in lowering heavy loads to make it necessary to use dynamic braking; but, if it is used, the controller and especially the motor must give high speeds when lowering so as to speed up the work. To obtain this high speed the controller must have a large number of points and the resistance steps must be just as carefully laid out as is the resistance in the field circuit of an adjustable speed, shunt wound, motor; because the crane motor is connected very much like a shunt wound motor or generator when lowering dynamically.

The motor had best be of the interpole type, although a well designed non-interpole motor can lower at 50 to 75 per cent above its hoisting speed. If correctly proportioned interpoles are used and if the brushes are securely and accurately held at the "neutral" position the motor can easily lower at twice the hoisting speed. An improperly constructed motor either sparks at the commutator or is unstable in speed. In the majority of cases no especial refinements in speed control are needed and ordinary rheostatic control is sufficient; but where very exact work is to be done, such, for example, as requires a uniform speed less than 15 per cent of full load hoisting speed, it is wise to obtain this creeping speed by connecting resistance in shunt with the motor as well as in series with it on the first point of the controller.

Such a connection definitely limits the motor speed to any desired low speed regardless of the load on the motor and makes a most desirable condition for such cranes as are required to do delicate work with heavy loads. Foundry cranes whose hook speed is above twenty feet per minute, frequently use this connection so as to take care of pattern drawing. Hand-operated controllers are good enough for this class of work unless careless operators are employed or the motor capacity is greater than 50 to 75 horse power. Automatic current limit controllers prevent the abuse of the motors and are better able to stand up to service requirements on large motors than hand-operated controllers.

On this class of cranes the solenoid brake is usually series wound instead of shunt wound so as to get quick action, to reduce the number of trolley wires and because a series wound coil uses heavier and, therefore, more substantial wire than a shunt wound coil. If a mechanical load brake is used the solenoid brake need have only sufficient retarding torque to bring the armature smoothly to rest, because the braking action for holding and lowering the load is all supplied by the load brake. About 50 per cent or less of the normal rated motor torque is all the solenoid brake need exert on the shaft of the motor. More torque would produce too violent a stop. If dynamic braking is used, no mechanical load brake is necessary, and, therefore, the solenoid brake must not only retard the armature but must also retard and hold the load. Owing to the fact that the friction losses in the crane machinery help to prevent the load from falling, the brake need only have about 70 per cent of the torque which is required on the motor when it is hoisting its *maximum* load. The exact value required depends on the amount of friction loss in the crane hoist.

Powerful action on the part of the brake does not necessarily produce violent stopping, because ordinarily the dynamic braking really stops the motor and the solenoid brake only has to hold the load, although in case dynamic braking should fail to operate the solenoid brake would have to stop the load as well as hold it. Violent action does take place in the hoisting direction, but this is not objectionable because the weight of the load helps so much with stopping that the violent action is not felt. Still if a very powerful brake is used it will be objectionable in this respect at times, and, for this reason, too much retarding torque should not be demanded of a solenoid brake. It is far better to have a brake just powerful enough, but with ample wearing surfaces so as to be reliable.

### Yard Cranes

The class of crane, as regards greater severity of service, next to the machine shop crane is the shipping yard crane around steel mills. Here speed is everything. Large amounts of raw material must be moved rapidly and on schedule time. The motors and controllers are kept so busy that they should not be worked anywhere near their extreme limits else their life will be impaired. Dynamic braking should be used for lowering and, on motors above 40 to 50 horse power, automatic control should be employed. In fact, for dynamic braking it is far more important to have automatic control than for reversible work because it is easier for a careless operator to damage the motor. In very many places it is profitable to put automatic control on all motors so that the crane can make the greatest speed with the least abuse to the motors, and with the least care and skill on the part of the operators.

Special cranes for handling sand, clay, etc., in buckets or lifting magnet cranes work the motor so hard and so regularly, both when hoisting and when lowering, that the temperature rise is the limiting feature. If these motors are not exposed to the weather it will be economical to use open type motors provided a smaller motor could be used without its being too much overloaded at the commutator. Owing to the fact that the maximum loads are easily determined the motors can be selected with certainty. Dynamic braking for lowering should be used and since the loads do not vary much from a fixed condition the controllers and resistances should be designed for the particular condition so as to get the highest speed possible at all times without abusing the motors. Automatic control should be used on motors above 40 to 50 horse power.

### Soaking Pit Cranes

About the severest crane on electrical apparatus is the crane in steel mills which not only works hard most of the time but works in a high temperature. Soaking pit cranes and some charging cranes come in this class. Here non-combustible insulation should be used in the motor and, wherever possible, on the wiring of the crane. Accessibility of all electrical parts is of vital importance. Automatic control should be used in all cases unless space or temperature forbid. In some cases there is not sufficient room for contactor panels and a small manual controller must be crowded in, although it may have to be repaired every few days. While temperature would have no worse effect on a contactor panel with fire-proof wiring than on a hand-operated controller yet the loss is greater in amount when the contactors are lost and, therefore, it would in extreme cases be better to use hand controllers.

### Trolley and Bridge Motion

Only the hoist motion has been discussed above. The trolley and bridge motion are simpler and usually require smaller motors. The motors should be series wound and similar in general characteristics to the hoist motor which is chosen for the crane. The motor should have as steep a series characteristic as possible so that, after exerting its full torque for starting or pulling over bad places in the track, it will rise to a relatively high speed and gain all the time possible. Simple reversing controllers are used for these motors. In most cases hand controllers are employed but on high speed cranes automatic controllers are used. No dynamic braking is needed but sometimes the motors are stopped by reversing them while they are running. If this is to be done, ample resistance should be used on the first point of the controller to limit the current under this condition and thereby permit of gradual stopping. This method of stopping is not dependable, because it would be ineffective should power fail. Where the trolleys are used for pulling or shoving cars it is advisable to use automatic control to prevent the operator from turning too much power on the motor when it is overloaded. Where automatic control is used for such purposes there should be at least two hand control points on the master controller so that the action of the motors will not be too jerky. Where no such work is required, the trolley motor need have only one point hand control, but the bridge motor should have two points hand control, because the bridge track is usually uneven and consequently if only one point hand control were used it would have to provide sufficient power for starting on an up-grade, and it would cause a jerk where the track is down grade. Ideal conditions are obtained by having two hand points, the first to admit a small current for starting down grade and the second to provide more current for up-grade.

On ladle cranes where the trolley motor is used for pouring hot metal it is often advantageous to have one positive creeping speed point on the controller. This point can be obtained by connecting resistance in shunt with the motor as well as in series with it; but no resistance should be connected in shunt with the armature because there would be a dynamic braking action by the motor if the master controller is thrown to this point after the motor has been running at high speed, and this action would cause the ladle to swing. Solenoid brakes are sometimes used on the trolley motor for stopping, but for satisfactory operation their retarding torque must just fit the needs of the case. Usually 10 to 30 per cent of the rated motor torque is all that is required of the brake. Too much torque would stop the trolley so quickly as to make the hook swing and jerk. Foot operated brakes are almost universally used for bridge motion because of the gradual stopping which can be obtained most advantageously in this way.

### Protective Devices

Crane protective devices have been standardized. On account of the expense and annoyance of replacing fuses they have been practically discarded on cranes; and overload relays in connection with contactor type circuit breakers are used instead. Short circuits and grounds on the crane are relieved by having one single pole breaker and one overload relay in each side of the line. Damaging overloads on the motors are prevented by having one overload relay in the circuit of each motor on the crane. Single-pole knife switches for each motor are frequently used so as to provide a convenient means of tracing out troubles in the wiring. A main line double-pole knife switch is used for disconnecting the crane entirely from the line and, in order to insure that this switch remains open while repairmen, oilers and painters are on the crane, a staple for locking the switch open is used. Any man who goes on the crane can protect himself by locking the switch with his own padlock. Space for several such padlocks is provided so that each individual can insure his own protection with his own padlock and thus prevent accidents due to carelessness or misunderstanding on the part of other people.

Safety for the load is obtained by an emergency switch which is installed within easy reach of the operator. The emergency switch should be convenient to operate and so constructed that an operator can open it quickly without exposing himself to live parts or electric arcs. A back-of-board-switch operated by a front-of-board-knob is best for this purpose and the switch should be double-pole so as to open both lines. The function of this emergency switch is to shut off all power from the crane and allow the solenoid to set. On dynamic brake controllers it gives extra safety to have the motor hold back in an emergency such as occurs when the solenoid brake fails to hold. Hand-operated dynamic braking controllers always have the motor connected to brake dynamically on the lowering side and at the "off" position but not on the hoisting side. If there is a case where a great degree of safety is required a normally closed contactor should be used which would establish dynamic braking connections when power fails even if the controller handle is on the hoisting side. Contactor automatic hoist controllers which give dynamic braking should always be equipped with the normally closed contactor. Hot metal cranes and many others are equipped with more than one solenoid brake so as to get additional protection for emergencies.

Unfortunately there is one problem on the crane hoist which has not been solved to the satisfaction of all users. This is the limit switch for preventing over-travel in a hoisting direction. It is, of course, disastrous to hoist too high as the ropes may be broken and the hook with its load dropped. In many places it is necessary to hoist very near the limit so as to clear obstructions over which the load is to be carried. Therefore the operator must use great care. Two types of limit switches are used but each is objectionable. First is a limit switch which shuts off power and sets the brakes when the hook is raised too high. The switch provides no means of getting power to the motor for lowering the hook and thus penalizes the operator for his carelessness by making it necessary for him to go to considerable trouble to get the hook down. The trouble with this type of limit switch is that much time is wasted every time it is tripped. Incidentally, some one in anger is liable to do something which will prevent the switch from working as designed and thereby defeat the whole usefulness of the switch. The second type of limit switch is one which not only cuts off power when the hook is hoisted too high but also provides a return circuit so that the operator can return the hook simply by reversing his controller. Such a limit switch will function many times without the operator even knowing it and for this reason is liable to wear out quickly or lose its proper adjustment. The result is likely to be an accident because the operator is trained to use the switch and thinks nothing of hoisting too high. It seems that the only way out of the difficulty is to use the second type of switch, see that it is most substantial in construction and, above all, to inspect its condition and its operation at frequent and regular intervals. The very best switch which can be built should not be left unnoticed to do its work. On one point regarding these limit switches there seems to be a consensus of opinion, and that is, that the switch should open the main line power circuit close to the motor and not depend on some control circuit to open a circuit breaker in the operator's cage.

# THE APPLICATION OF ELECTRIC MOTORS TO SHOVELS

By H. W. Rogers

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Owing to the existing difference of opinion regarding the proper type of motor to be used on electric shovels the author has endeavored to show that the direct-current series motor is not only better adapted to this service but possesses marked advantages over the alternating-current motor both as regards size and power consumption.—Editor.


H. W. Rogers

It often happens that men are slow to adopt new methods and this may be attributed to three causes; first, because they are satisfied with the old methods; second, because they hesitate to abandon a method which they know is good for one which they think is questionable; third, because of the increased investment of capital which is sometimes necessary.

Unlike the hydraulic dredge, which is largely used for contracting work, and which is considerably cheaper when electrically operated than when steam operated, the electric shovel calls for a larger investment of capital than the steam shovel, but the reduced operating expense will warrant the increased investment.

It is hardly necessary to treat with the first reason as those who are familiar with the history and development of the steam shovel during the past fifty years will acknowledge that it is a machine which has not only proven its worth but has probably reached its highest stage of development and efficiency. Any further improvement, therefore, must of necessity be along different lines and with the rapidly increasing power developments throughout the country which make cheap electric power available the electric shovel is logically the next step.

That it is a possibility cannot be denied as there are at present from twelve to eighteen shovels in operation in this country. Some of these are of the type commonly called "friction electric," and although the initial cost and operating expense is low they do not compare favorably with the steam shovel as regards speed. Others are of the "three" or "four-motor type" with automatic control and although they compare very favorably with the steam shovel in all respects they have not all been equipped with a full knowledge of the conditions to be met or the characteristics of the steam engines which the motors replaced. It is very important that the motors be applied with a full knowledge of existing conditions as any misapplication will not only be detrimental to the individual shovel involved but also to future advancement in this field of engineering.

Granting that the electric shovel is a possibility, the fact still remains that its first cost is higher than that of the steam shovel and it must be proven that the saving in operating expenses will warrant the increased investment of capital.

There is probably no class of machinery that presents a duty cycle as severe as that of the shovel, which is very short, varying from 7 to 12 seconds on the hoist, 7 to 12 seconds on the thrust, and from 10 to 18 seconds on the swing, making a complete cycle in from 17 to 30 seconds, and the motor to meet these requirements must have a sufficiently low inertia to permit of rapid acceleration and quick reversals with small power.

It should also be a motor of substantial design, as it must be subjected to severe overloads, shocks and frequent reversals. This is especially true of the hoist motors and, to a lesser degree, of the swing motor; the thrust motor being practically stalled during the digging operation, its duty being to hold the dipper to the bank, although it may revolve or overhaul according to conditions, and is operated at full speed only after the hoisting operation is completed.

A considerable advantage may be gained by using two motors of small capacity instead of one large motor on the hoist as the power required to accelerate is much smaller. This fact will be appreciated by comparing one 150 horse power, 425 r.p.m. motor, which requires 117 horse power torque to bring it to full speed in one second, with two 75 horse power, 500 r.p.m. motors, which require 32.3 horse power torque each or 64.6 horse power torque to bring both motors to full speed in one second. The saving in power represented here is approximately 45 per cent.

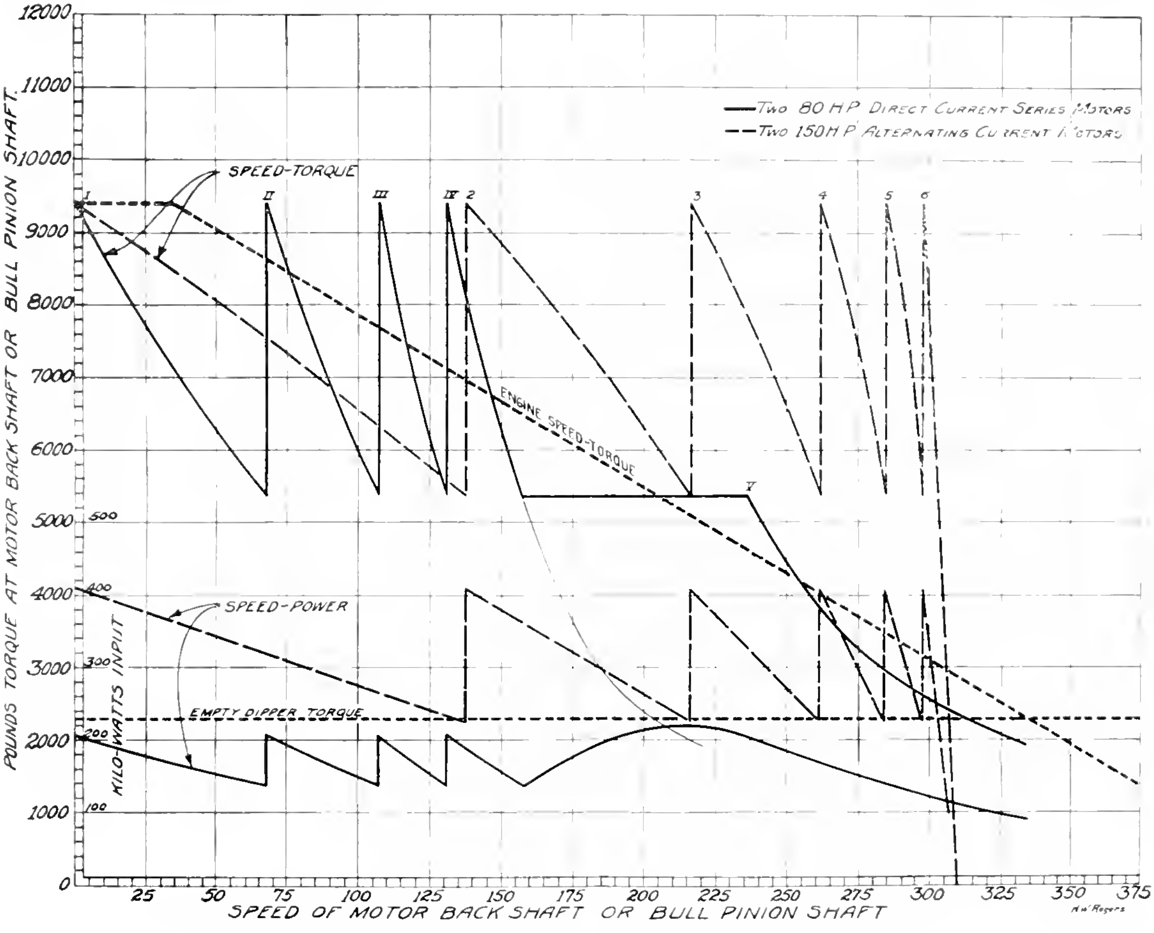

Fig 1. Comparative Size, Characteristics, and Power Consumption of an Instance of Direct and Alternating Current Motors which will accomplish the same results in electric shovel operation

The question naturally arises as to the type of motor that is best adapted to this class of service and without careful consideration of conditions it is natural to assume that either direct or alternating current would be equally satisfactory, but this is not true, as a study of the steam engine and motor characteristics will show.

As the bulk of electric shovels will undoubtedly have to operate from an alternating current source and as there still exists a difference of opinion as to the advisability of using direct current series motors or alternating current slip-ring motors, the curves of Figure 1 have been plotted between speed and torque and between speed and power for two 80 h.p., 500 r.p.m. direct current series motors operating in multiple and two 150 h.p., 450 r.p.m., 60 cycle, slip ring induction motors operating in multiple. The full line represents the speed-torque curve on the series motors with a gear ratio of 3.31 to 1.0 which gives the maximum pull required at 150 per cent normal current, while the broken line represents the speed-torque curve on the induction motors with a gear ratio of 1.45 to 1.0 which gives the maximum pull required at 170 per cent normal current. This corresponds to the torque given on the series motors with 150 per cent normal current and although the gear ratio could be increased to give the required pull at 150 per cent current it is not desirable as it would reduce the maximum speed.

The direct current series motor has the characteristics of the steam engine, in that it gives its heaviest torque on starting, speeds up under light loads, and slows down under heavy loads. It is much easier to control and requires considerably less apparatus, in so far as the control is concerned, than the alternating current equipment.

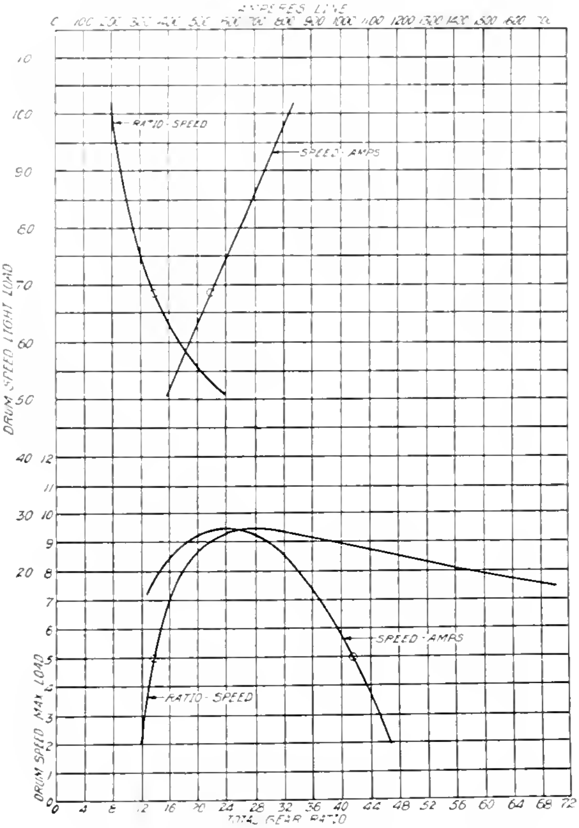

Fig. 2. Curves showing the Effect of Change of Hoisting Machinery Gear Ratio on Speed and on Power

This characteristic is clearly shown on the curve, which represents a five-point control, four of these points being used to cut out the armature resistance and the fifth to weaken the series field, which results in a very high light load speed.

Although sufficient starting torque may be obtained on the alternating current motors, the light load speed, which is very important, is limited by the synchronous speed, and the only means of improving this disadvantage is to reduce the gear ratio or use a higher speed motor. Either of these methods would mean an increase in the motor capacity and an increase in the power required, accompanied by an increase in the armature inertia and a slower acceleration, both of which are very undesirable. This feature will be appreciated from the following data applying to the motors used in plotting the curves.

| | Total $WR^2$ | Diam. Rotor Inches | Per Cent Torque to Bring to Speed in 1 Second |
|---|---|---|---|
| Two 80 h.p., 500 r.p.m. series motors | 444 | 16 | 43 |
| Two 150 h.p., 450 r.p.m. induction motors | 2480 | 30 | 98 |

Under these conditions the natural result is a much larger kv-a. capacity in transformers for the induction motors than kw. capacity of motor-generator set for the direct current motors.

In laying out an electric shovel drive there are four things to be considered; namely, the speed at maximum torque, the speed at light load, the power required by the motors and the gear ratio. Any increase in the gear ratio results in a decrease in the power at both light and heavy loads, an increase in the speed at heavy loads and a decrease in the speed at light loads; and taking all of the variables into consideration the gear ratios used in the foregoing comparison seem to give the most satisfactory results. The effect of the gear ratio on other conditions is clearly shown on the diagram, the light load curves representing a weakened field condition without armature resistance while the maximum load curves represent a strong field with armature resistance.

These curves apply to direct current series motors only.

The saving in operating expense of the electric shovel over the steam shovel will depend somewhat upon the comparative cost of coal and electric power and will vary for different localities, but the greater saving will be effected through the elimination of the fireman, the watchman, the coal passer, teaming for ½ day, the use of water and considerable waste. The natural increased wear and tear of parts having a transverse motion as compared with those having a rotary motion and the elimination of boiler trouble should also be considered.

As an illustration, consider a 120 ton shovel which is ordinarily equipped with a 5 cu. yd. dipper and has an average capacity of approximately 2500 cu. yd. per 10-hr. day. This capacity is based on an average working time of 55 per cent and an average dipper capacity of $3\frac{3}{4}$ cu. yd., or 75 per cent.

With a good grade of coal the steam shovel will require approximately $3\frac{1}{4}$ tons per 8-hr. shift and will make an average of two complete cycles per minute. For the purpose of comparison, however, the maximum capacity of the shovel is taken; i.e., three cycles per minute. Under these conditions either the steam or the electric shovel will have a total working time during one shift of $8 \times 60 \times 0.55 = 264$ min. during which time it will make $264 \times 3 = 792$ complete cycles, and will handle $792 \times 3\frac{3}{4} = 2970$ cu. yd. of material.

The direct current shovel would be equipped with two 80 h.p., 500 r.p.m., 230 volt series motors on the hoist, one 40 h.p., 550 r.p.m., 230 volt series motor on the swing, one 60 h.p., 550 r.p.m., 230 volt, series motor on the thrust, and one 150 kw., 900 r.p.m., 250 volt, direct current generator direct connected to a 225 h.p., 900 r.p.m., 2200 volt induction motor, with four-point reversible automatic control on each motor.

The estimated power consumption during each cycle will be as follows:

| | kw-seconds |
|---|---|
| Hoisting | 1379 |
| Swinging | 522 |
| Crowding | 547 |
| Total | 2448 = 0.68 kw-hr. |

Fig. 4. Interior View of the Shovel of Fig. 3 showing the control panels

The input to the motors equals $792 \times 0.68 = 539$ kw-hr. per 8-hr. shift, or, taking into account the efficiency of the motor-generator set, 657 kw-hr. per 8-hr. shift.

As the shovel is working only 55 per cent of the time, the motor-generator set will be running light 45 per cent of the time, or $8 \times 60 \times 0.45 = 216$ min.

Fig. 3. A Sixty-Five-Ton Electric Shovel equipped with four 550-volt direct current series motors

The power consumption of the set when running light will be approximately 16.77 kw.

$$\frac{216 \times 16.77}{60} = 60.4 \text{ kw-hr. loss per 8-hr. shift.}$$

Therefore the total power consumption equals $657 + 60.4 = 717.4$ kw-hr. per 8-hr. shift when working under the maximum cycle.

The power consumption per cubic yard excavated equals $\frac{717.4}{2970} = 0.241$ kw-hr.

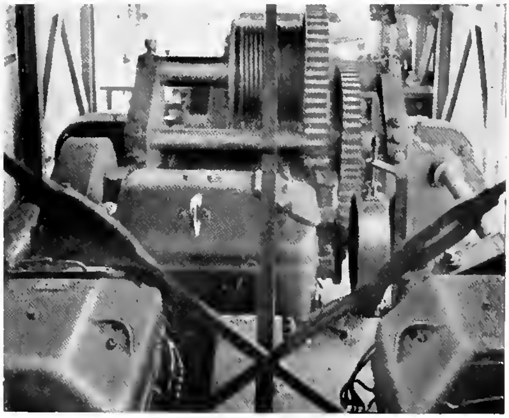

Fig. 5. Interior View of the Shovel of Fig. 3 showing arrangement of the motors

The alternating-current shovel would be equipped with two 150 h.p., 450 r.p.m., 440 volt motors on the hoist, one 50 h.p., 720 r.p.m., 440 volt motor on the swing, one

75 h.p., 600 r.p.m., 440 volt motor on the thrust, and three 125 kilovolt-ampere, 2200-480 volt transformers, with five-point reversible automatic control on each motor.

The estimated power consumption during each cycle will be as follows:

| | kw-seconds |
|---|---|
| Hoisting . . . . . . . . . . . . . . . | 2040 |
| Swinging . . . . . . . . . . . . . | 759 |
| Crowding . . . . . . . . . . . . . . . | 750 |
| Total . . . . . . . . . . . . . . | 3549 = 0.987 kw-hr. |

The input to the motors equals 792 × 0.987 = 782 kw-hr. per 8-hr. shift, or, taking into account the efficiency of the transformers, 796 kw-hr. per 8-hr. shift.

The no-load losses on the transformers will be approximately $\frac{216 \times 3.6}{60} = 13.0$ kw-hr. loss per 8-hr. shift.

Therefore the total power consumption equals 796 + 13 = 809.0 kw-hr. per 8 hr. shift.

The power consumption per cubic yard excavated equals $\frac{809}{2970} = 0.273$ kw-hr.

| Labor per Shift | Steam | Electric |
|---|---|---|
| Shovel runner . . . . . . . . . . | $6.00 | $6.00 |
| Craneman . . . . . . . . . . . . . | 4.00 | 4.00 |
| Fireman . . . . . . . . . . . . . . | 2.50 | |
| Six pitmen at $1.75 . . . . . . . . | 10.50 | 10.50 |
| One watchman . . . . . . . . . . . . . . | 1.75 | |
| One coal passer . . . . . . . . . . . . . | 1.50 | |
| Teaming (½ day) . . . . . . . . . . . . | 2.50 | |
| Oil and waste . . . . . . . . . . . . . . . | 1.50 | .75 |
| Total . . . . . . . . . . . . . . . . . . | $30.25 | $21.25 |
| Saving, electric over steam . . . . | 21.25 | |
| | $9.00 per shift | |

For convenience in comparing the costs of operation on steam and electric shovels, the costs are all reduced to a day basis.

| | Steam | ELECTRIC | |
|---|---|---|---|
| | | Direct Current | Equivalent Alternating Current |
| Interest at 6 per cent | $5.20 | $7.75 | $10.85 |
| Depreciation at 4 2 3 per cent . . . . . . . . . | 4.03 | 6.00 | 8.43 |
| Repairs at 10 per cent | 8.66 | | |
| Repairs at 6 per cent . . | | 7.75 | 10.85 |
| Labor per shift . . . . . . . | 30.25 | 21.25 | 21.25 |
| Total cost per shift . | $48.14 | $42.75 | $51.38 |

It has been assumed that, owing to weather conditions, delays, etc., the shovel working year consists of 150 days and the above figures are based on this assumption; also that the shovel is only working one shift a day.

If the shovel works three shifts a day instead of one shift a day, the interest and depreciation will remain the same, provided the shovel is kept in repair. It is reasonable to assume that the repairs will increase when working three shifts, but not in direct proportion; therefore, this item has been increased 50 per cent.

| | Steam | ELECTRIC | |
|---|---|---|---|
| | | Direct Current | Equivalent Alternating Current |
| Interest at 6 per cent | $5.20 | $7.75 | $10.85 |
| Depreciation at 4 2 3 per cent . . . . . . . | 4.03 | 6.00 | 8.43 |
| Repairs at 15 per cent | 13.00 | | |
| Repairs at 9 per cent . . | | 11.63 | 16.28 |
| Labor (three shifts) . . . | 90.75 | 63.75 | 63.75 |
| Total cost (three shifts) . . . . . . . . . . | $112.98 | $89.13 | $99.31 |

Disregarding the cost of coal and electric power, the saving of the direct-current shovel over the steam shovel would be $810 per year for one-shift operation and $3580 per year for three-shift operation.

The alternating current shovel when working one shift a day would show a loss of $486 per year. On the other hand, if this shovel worked three shifts a day it would show a saving of $2050.50 per year. Any greater saving than that shown would, of necessity, depend upon the comparative cost of coal and electric power, but as this is variable it can only be shown by dealing with each case individually.

Disregarding the cost of fuel, it is evident that the electric shovel is a better proposition than the steam shovel; that the direct-current equipment is far superior to the alternating-current equipment; and that the saving in operating expense will warrant the increased investment.

The control on either the direct or the alternating current equipment is reversible and entirely automatic, all panels being equipped with automatic acceleration, the hoist and crowd panels being also equipped with a "jam" relay which inserts resistance in the circuit in case of very heavy overloads, but does not open the circuit, the resistance being automatically cut out again by the same relay when the overload disappears. The master controllers are located similarly to the operating levers on a steam shovel so that a steam operator will be entirely at home on an electric shovel.

In selecting a shovel equipment it should be remembered that although it is possible to operate with alternating current, it is cheaper to use the direct-current equipment, even with a motor-generator set, and have an outfit which more nearly approaches the characteristics of the steam shovel, and has much simpler control apparatus and requires considerably less power to operate it than the alternating equipment with transformers. In addition to this, any change in the frequency would mean a complete change in the equipment of an alternating-current shovel while it would mean only a change in the induction motor of the motor-generator set, with possibly a change in the generator fields on a direct-current equipment.

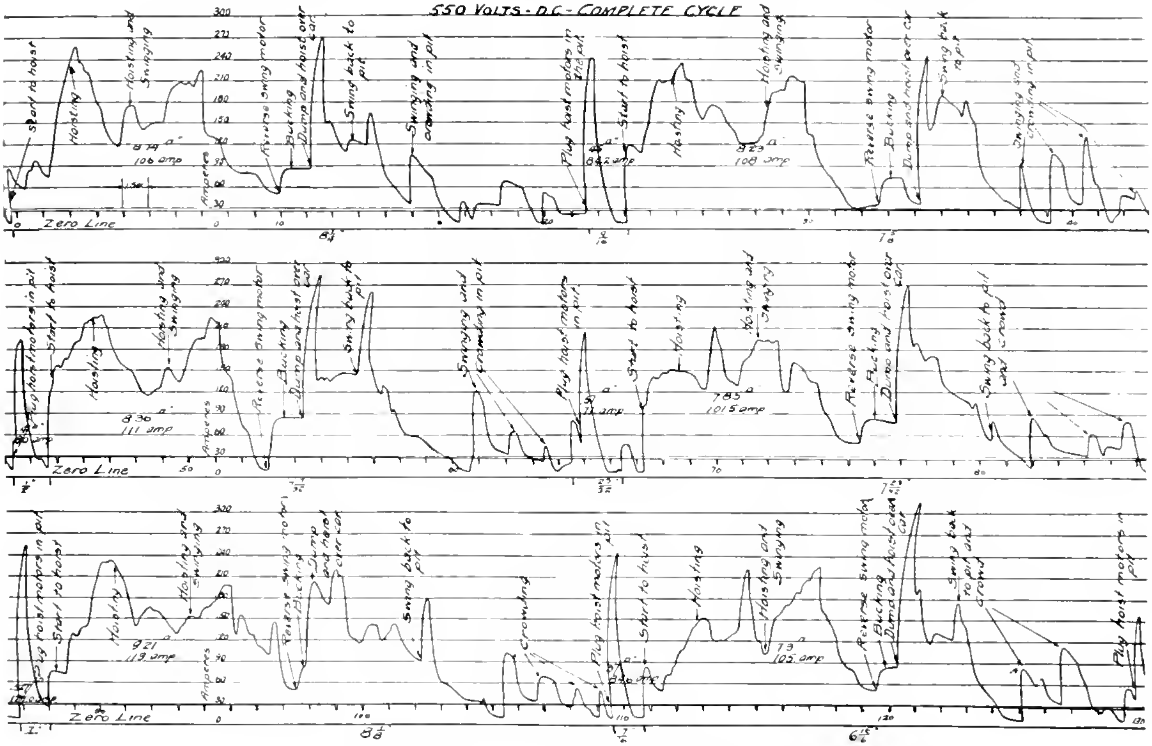

Fig. 6. A Graphic Recording Ammeter Record of the current input to the shovel shown in Fig. 3 taken over a period of six complete cycles

# SOME FACTORS GOVERNING THE SELECTION AND APPLICATION OF INDUSTRIAL MOTORS

By W. L. Merrill

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The following article calls attention to one of the vital points in the selection of direct current motors for adjustable speed work and shows the fallacy of using the compound wound adjustable speed motor. We hope to have the author treat of other phases of motor application, both from the technical and practical side, in subsequent issues of the Review.—Editor.


W. L. Merrill

In discussing the various questions which arise, concerning the application of electric motors to industrial uses, it should always be borne in mind that there is no one type of motor which is suitable for all requirements. Unless a careful study is made of the specific requirements in each individual case and the correct motor selected to meet the service conditions, very serious mistakes may be made. Both the electric and mechanical features of the motor have to be given due consideration and a correct selection cannot be arrived at until the many various factors have been duly considered.

Before discussing the selection of the correct motor for any given service, it is well to study the different classes and types of motors available.

The tabulation on the opposite page gives the general types of alternating current and direct current motors, classified according to their windings.

From this, it will be seen that a very great variety of motors can be built by combining the electrical and mechanical features, and the list of possible motor designs is extended enormously when we consider the different kinds of bearings available; e.g., oil ring, waste pack, anti-friction, ball, roller, and bearings arranged to take thrust or arranged for vertical drive. In fact, there are so many possible combinations that there is a constant tendency to complicate the individual motor by including too many of the possible features and not limiting the selection to those features which are called for by the service conditions under which the motor is to operate. For instance, if a motor is required to operate under such conditions that acid-proof windings are desirable, after having specified such a winding, it is not necessary to use an enclosed motor for the purpose of protecting the windings from acid fumes, as provision has already been made for this in the type of insulation selected.

### The Fallacy of Compound Wound Adjustable Speed Motors

The tendency to use adjustable speed motors with compound windings is apparently due to a lack of knowledge of the characteristics of such a motor; the benefits gained by this use are in most cases imaginary.

There are two separate and distinct applications of adjustable speed motors: the first, generally used; the second, occasionally. The first case is in connection with machinery in which the load is nearly all dead load and friction, such as ordinary machine tools and the like, requires speeds of 2 to 1, 3 to 1, 4 to 1, and occasionally higher. On this class of machinery not only is no advantage gained by compounding the motor, but it is a positive detriment to its successful operation.

Assume, for example, a motor with a speed range from 300 to 1200. It is inherent in the design of such a motor that at full field or slower speeds, the motor has a heavy flux and the magnetic circuits are well saturated. If a certain amount of shunt winding is removed and replaced by a series winding giving the same ampere turns on the pole pieces with full load current passing through the motor, it will at once be seen that the torque is the same as if it were the original shunt motor. If, however, 100 per cent shunt winding is supplied on the motor and additional turns are supplied as a series winding, very little increased torque will result for the reasons mentioned above, that is, the magnetic circuits of the motor are nearly saturated under such conditions.

The same holds true if the motor is compounded as first mentioned and the control so arranged as to allow more than full load current to pass through at the time of starting.

Assume a shunt motor with a full field speed of 300 and a weak field speed of 1200. The field current at full load is 2 amp., and at weak field 0.45 amp. The regulation of this motor is shown in Fig. 1 as "A." It will be seen that, throughout the speed range of the motor, the speed remains practically constant for any variation or fluctuation of load at any particular setting of the control. This is very essential in the majority of classes of work, and particularly true with machine tool applications. It can readily be seen that, if an irregular casting, for instance, is being turned and the tool cutting at its maximum cutting speed and engaging the work for only a part of the periphery, the tool must not enter the work at a higher speed than it should cut. If it does, the tool will have a very short life. If the speed increases during the interval of light or no cuts, it will be readily seen that, during the remainder of the revolution, the machine speeds up at the interval of light or no cuts and it will be necessary to readjust this speed to the maximum cutting speed desired on the tool, and then when the tool enters the work the machine will slow down of its own accord and the cutting speed will be below normal. This leads to a loss of production. This is exactly what happens when an adjustable speed motor is supplied with compound winding and curves "B" on Fig. 1 show the regulation of such a motor having 80 per cent shunt winding and 20 per cent series winding. It will be seen from the curve that, with this motor running at no load, 1200 revolutions, the speed would slow down to about 600 revolutions under full load, and of course when the load was removed it would again return to 1200, while at the full field speed there would be little effect, due to the series winding.

ALTERNATING CURRENT

- Squirrel Cage
  - Single speed
    - High torque
    - Low torque
  - Multi-speed
    - High torque
    - Low torque
- Collector Ring Type
  - Single speed
    - Starting
    - Regulating
    - Adjusting
  - Multi-speed
    - Starting
    - Regulating
    - Adjusting
- Internal Resistance.
- Synchronous.

DIRECT CURRENT

- Shunt
  - Constant speed
  - Adjustable speed
- Series
- Series Shunt
- Compound Wound
  - Adjustable speed[*]
  - Accumulative
  - Differential

The different types of motors, classified according to their mechanical features are listed below. These mechanical features may apply to both a-c. and d-c. motors and any of the windings mentioned above may be used in conjunction with any of these types:

- Open
- Mechanically protected
- Semi-enclosed
- Totally-enclosed
- Enclosed externally ventilated
- Enclosed self ventilated
- Moisture-proof
- Splash or water-proof
- Acid-proof
- Submergible

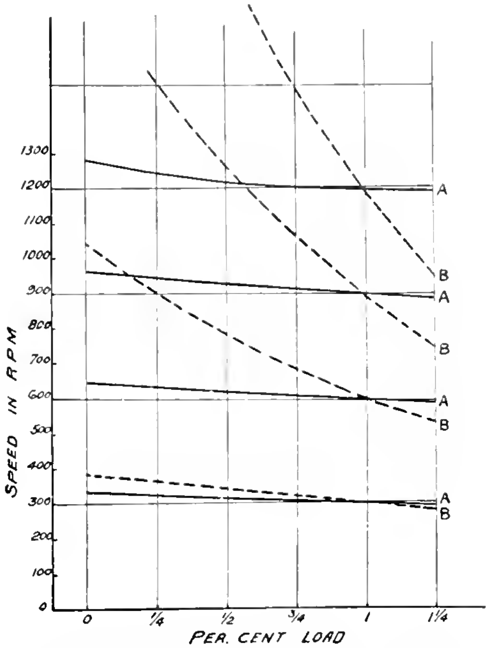

Fig. 1. Curves showing speed regulation of shunt and compound wound variable speed motors. A, shunt motor; B, compound motor.

On the other hand, assume that the motor was adjusted at the full load condition for approximately 1200 revolutions and then the

---

[*] The limitations of this type of motor are discussed in this article.

load was removed. The speed would follow the curve "B," which indicates a run away.

It is even suggested that this would be overcome by using a motor wound with a normal 100 per cent shunt and 20 per cent series winding. Under this condition a motor of this type would follow identically the same curves as shown, for if the motor were adjusted 1200 revolutions at full load, we must have the same flux in the poles, therefore, proportionately less current per turn, since there are the same number of series turns as above. It is therefore evident that the characteristics of a motor of this type is that of the shunt wound motor at full shunt field, gradually approaching the characteristics of the series wound motor at weak field.

To avoid the difficulties mentioned above, it is often suggested by those unfamiliar with the characteristics of such motors that series winding be cut out after the motor is started. First, this materially complicates the control; second, as noted above, little if any added starting torque is given the motor by this type of winding. Therefore, the absurdity is evident of applying such motors with compound winding to increase starting torque with a given current and then cutting this series winding out after the motor is up to speed.

It is often thought necessary to supply such motors with compound windings so that they can be started under weak field conditions; that is, wherever the field control rheostats happen to be left. With ordinary drum controllers as supplied for this service, it is impossible to shut the machine down from high speed to low speed without bringing the field to its full strength. Therefore, for use with such controllers this is unnecessary. With certain types of automatic control it is possible to start motors under weak field conditions where the starting arrangement and the field regulating control are separate.

Ordinarily, motors with speeds of $1\frac{1}{2}$ or 2 to 1 and in many cases higher, can be started equally as well on weak field as on full field and with the higher ratios of speed variation this can be readily taken care of by the use of the so-called "fluttering" relay in the circuit, which gives much better starting conditions than any combination of series winding which is cut in and out during starting.

The second class of applications mentioned above would be where an adjustable speed motor was to drive machinery in connection with a flywheel or heavy inertia load, where it was desired that the motor should speed up and slow down a certain amount with the change in load. Compound winding under such conditions may be advantageous in many cases, but the speed variation of such motors by shunt field control is usually very limited, say $1\frac{1}{4}$ or $1\frac{1}{2}$ to 1 and seldom 2 to 1. Under such conditions they are useful.

Of course, there are exceptions to all rules, and there are very special cases, such as some types of elevator applications, reversing motors for planers, and the like, where it may be necessary to accomplish certain desired results, not conflicting with the above conditions, to use compound wound windings, but these are very limited and for all other classes of work where adjustable speed motors are used, compound windings are not necessary and in the majority of cases are not only an added complication but are a detriment to the equipment as a whole.

## QUESTION AND ANSWER SECTION

### ANNOUNCEMENT

The pages of the Question and Answer Section have been omitted from this issue of the REVIEW on account of space limitations in this our largest number to date.—EDITOR.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## THIRD HARMONIC

If three auto-transformers, Y-connected with the neutral grounded as the only ground, are used to step up the generator voltage, abnormal potentials to ground may result. These excess voltages are not measured by a voltmeter but may be by indicated static discharges on the leads, or by a spark gap connected between one line and the ground. The reason for this is that the effective value of the voltage read by the voltmeter is not greatly changed, but only the maximum value of the wave is increased which is indicated by a spark gap, or by a stress on the insulation. The cause of the voltage distortion is as follows:

When a sine wave e.m.f. is applied to a transformer, the resulting magnetizing current wave cannot be a sine wave but must follow the changing permeability of the iron; this current wave is a distorted wave containing a third harmonic. The current and voltage waves can never be the same, but if the magnetizing current is a sine wave, the voltage wave must then contain a third harmonic. Hence, if anything prevents or suppresses the third harmonic the voltage must then become distorted.

In a three-phase transformer the currents are 120 deg. apart for the fundamental frequency, or 3×120 or 360 deg. apart for the third harmonic—that is, in phase. Thus for Y-connected auto-transformers the triple frequency magnetizing currents to the neutral must be in phase. The sum of the three currents flowing to a point must be zero. Hence, as the third harmonic magnetizing currents are all in phase, they must be zero to satisfy these conditions—that is, they must be suppressed. This means that the voltage to the neutral cannot be a sine wave but must be distorted, or peaked, or contain the third harmonic, which appears as increased voltage to the neutral and causes extra iron and insulation loss. A distortion does not appear in the voltage between lines because the distortion between one line and the neutral is cancelled by that of the other two lines. The voltage distortion may be eliminated by supplying a path for the triple frequency exciting current; that is, in this case, by connecting the transformer neutral to the generator neutral. This supplies a single-phase circuit for the triple frequency through the line and generator. A current of the proper phase relation flows and the distortion disappears.

If before the connection is made to the generator the transformer is connected to a transmission line a path is supplied for the triple frequency current through the capacity from line to ground. This capacity offers three single-phase circuits. A triple frequency current thus flows, but it has not the proper phase relation for the triple frequency excitation current and instead of eliminating the voltage distortion it greatly increases it. Two or three peaks may occur in the fundamental voltage wave and an increased iron loss result. This distortion, however, also generally disappears when the auto-transformer neutral is connected to the generator neutral. Without this interconnection the distortion is greater in the case where the transformer is connected to a capacity. The peak of the wave may be several times normal. There are other ways of supplying this third harmonic current; for instance, by a closed delta in the transformer.

The transformer third harmonic is a "constant current" effect—that is, the voltage drops when triple frequency current, with the proper phase relation, flows.

There may also be a third harmonic in the generator wave, due to the relations of the windings, which has a "constant voltage" effect and which may produce a very heavy triple frequency current when improper connections are used, or when a path is afforded for these currents. Precautions are thus necessary where several generators are connected in parallel and the neutrals grounded. If all of the generators are of an identical design, very large triple frequency excitation currents may flow unless the field excitation is the same on all the generators. If the generators are not of an identical design dangerously large triple frequency currents may result. When a number of generators are operated in parallel and the voltage is stepped up by auto-transformers, it is often practicable to ground only one generator at a time and to connect this to all of the transformer neutrals.

Whenever auto-transformers are used it is necessary to investigate the possibilities of trouble for the particular case under consideration. Their use is generally not to be recommended. F.W.P.

# IN MEMORIAM

Henry Augustus Pevear, the first and only President of the Thomson-Houston Electric Company, died at his home in Lynn, Mass., on May 14th, of heart failure. His death was not unexpected, as he had been failing for weeks.

Mr. Pevear was in his 86th year, as he was born in Tewksbury, Mass., on September 13, 1828. He is survived by four sons and one daughter, twelve grandchildren and thirteen great grandchildren; Mrs. Pevear and a daughter died a few years ago. He had been a successful morocco manufacturer for forty-five years, and he was one of the group of men who purchased the American Electric Company, re-organized it as the Thomson-Houston Electric Company, and moved it to Lynn in 1883. He was made president of the new company.

Henry Augustus Pevear

During the succeeding ten years, the Company was successful and important progress was made in electrical development. Mr. Pevear retired from the presidency when the Company was consolidated with the Edison General Electric Company. He was president of the Lynn five-cent Savings Bank and a director of the City National Bank for a number of years. He retired from active business about twenty years ago, and devoted himself to charities, to which he has made large donations.

The most notable of his philanthropies was the gift of his large summer estate at Barre, Mass. as the Stetson Home for Orphan Boys, endowing it with $250,000 in memory of his mother. As a memorial to his wife, there is now being erected a children's ward, provided by Mr. Pevear, as a part of the Lynn hospital.

Mr. Pevear combined scrupulous honesty, well balanced conservatism, and straightforward business dealing. He leaves many friends, among whom are men now prominent in the electrical field who worked with him in the Thomson-Houston Company, and who cherish the memory of the association.

# GENERAL ELECTRIC REVIEW

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Sixteen mule team hauling seven reels of aluminum cable for the transmission lines of the Big Creek development, Pacific Light & Power Corporation. Fifteen hundred reels of this cable weighing 4,890,000 lbs. were required.

# GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

The thirty-seventh convention of the National Electric Light Association was held in Philadelphia during the first week in June. All who attended many of the sessions must have been profoundly impressed with the progress of the industry, and this impression was much intensified by those papers and reports that compared present activities with those of earlier periods.

The report of the committee on progress, with T. C. Martin as the committee, seems to lend strength to the old adage that when real business is to be accomplished there is nothing like a committee of two with one member sick in bed. Mr. Martin's report is an astonishing document and leaves one somewhat bewildered by the mass of facts and figures that he has so ably marshalled to give a really comprehensive picture of the progress made. The following quotations are from Mr. Martin's report:

"The figures as given for the continental United States show general and remarkable gains for the decade 1902–12. The number of commercial stations or plants increased from 2805 in 1902 to 3659 in 1912, or 30 per cent. The number of municipal plants increased from 815 in 1902 to 1562 in 1912, or 92 per cent, but their relative proportion in the industry has declined. The total income for 1912 amounted to $302,115,599, as compared with $85,700,605 in 1902, or an increase of 252 per cent. The total expenses, including salaries and wages, in 1912, amounted to $234,419,478, as compared with $68,081,375 in 1902, or an increase of 244 per cent. The total number of persons employed in 1912 was 79,335, as compared with 30,326 in 1902, or an increase of 162 per cent. The total horse power of the steam engines and steam turbines was 4,946,532 in 1912, as compared with 1,394,395 in 1902, or an increase of 255 per cent. The horse power of the waterwheels was 2,471,081 in 1912, as compared with 438,472 in 1902, or an increase of 464 per cent. The output of stations amounted to 11,502,963,006 kw-hr. in 1912, as compared with 2,507,051,115 in 1902, or an increase of 359 per cent. The estimated number of arc lamps wired for service in 1912 was 505,395, as compared with 385,698 in 1902, or an increase of 31 per cent. Incandescent and other varieties of lamps wired for service, however, numbered 76,507,142 in 1912, as compared with 18,194,044 in 1902, or an increase of 320 per cent. The horse power rating of the stationary motors served with electricity amounted to 4,130,619 in 1912, as compared with 438,005 in 1902, or an increase of 843 per cent."

It is particularly noted that in the above the term "station" may represent a single station or a number operated under the same ownership and that the electric railway stations are treated under another head by the Census Bureau report and are not included in the total number of 5221 establishments shown above. Such statistics speak more eloquently of progress made than volumes of platitudes and generalities.

It will surely astonish many people to learn that "there were engaged in the manufacture of electrical machinery, apparatus and supplies in the United States in 1909, a total of 1009 establishments."

In dealing with the security of public utilities as investments, the report shows a very promising state of affairs. Mr. Martin in quoting a paper by Mr. Oldham says:

"Mr. Oldham gave instances to show that while municipal and railroad bonds have depreciated somewhat in value in the last ten years, public-utility bonds have generally appreciated in value. A computation was made by the author to show the comparative returns from the three classes of bonds between 1901 and 1912. Representative public-utility, municipal and railroad issues were selected, and every effort was made to make a fair investigation. It was shown that the purchaser of $1,500,000 of public-utility bonds would have received an income on his total investment from date of purchase to July 1, 1912, of $487,500 and a gain in market value of $27,377, or a total of $514,877. From the municipal bonds the income was $326,551, and the loss due to depreciation, $106,989, leaving a net return of $219,562. Income from the railroad bonds was $399,691 and the loss due to depreciation $70,065, leaving a net return of $329,626. Therefore, the net difference in favor of public-utility over municipal bonds was $295,315 and over the railroad bonds was $184,891."

Much of our modern progress can be traced to the scientific study of ways and means effecting economies in every branch of the industry and in finding new fields for the use of energy. The report quoting from an address of Mr. Insull, says:

"Only about 40 per cent of the coal burned per unit generated ten years ago is now required for the same output. He exhibited a diagram showing that from 1896 to 1912 the business of the Commonwealth Edison Co., had grown about $1,000,000 a year to about $16,000,000, the latter figure being divided into $8,000,000 for lighting, a little more than $4,000,000 for industrial motor service and a little less than $4,000,000 for energy for transportation purposes. Improvements in lamp efficiency helped to decrease the cost of electric light. As to the wholesaling of electrical energy, backed by the courage of a body of investors which has stood behind him for more than twenty years, Mr. Insull tried out several experiments, with the result that he has been able to bid for classes of business not until recently supposed to be within the reach of electric-service companies. The problem is to keep the investment working for as many hours of the day and as many days of the week as is possible. About 1902 this effort to fill up the valleys in the load curve as much as possible was begun, and it was so successful that by 1912 the Commonwealth Edison Co. was using its investment 31 per cent more of the time than ten years before."

# RECENT VIEWS ON MATTER AND ENERGY

## Part I

By Dr. Saul Dushman
Research Laboratory, General Electric Company

This is the first installment of a series of articles by Dr. Dushman on our modern views of matter and energy. Modern investigations point to a monistic view of all natural phenomena. The atomic theory, which was originally developed to "explain" the structure of matter, has been extended to electrical phenomena, as the electron theory, and more recently still we have seen the development of an atomic theory of energy or quantum theory. The author discusses here the evidence which has led to the formulation of the electron theory of conduction in metals and gases. The subsequent installments will deal with the atomic view of energy, as well as its application in widely different fields of investigation; and will in conclusion discuss the application of the electron and quantum theories to the development of a theory of the structure of atoms and molecules.—Editor.

## INTRODUCTION

"The close of the old and the beginning of the new century has been marked by a very rapid increase of our knowledge of that most important but comparatively little known subject—*the connection between electricity and matter.* No study has been more fruitful in surprises to the investigator, both from the remarkable nature of the phenomena exhibited and from the laws controlling them. The more the subject is examined, the more complex must we suppose the constitution of matter in order to explain the remarkable effects observed. While the experimental results have led to the view that the constitution of the atom itself is very complex, at the same time they have confirmed the old theory of the discontinuous or atomic structure of matter. The study of the radio-active substances and of the discharge of electricity through gases has supplied very strong experimental evidence in support of the fundamental ideas of the existing atomic theory. It has also indicated that the atom itself is not the smallest unit of matter, but is a complicated structure made up of a number of smaller bodies."[1]

Upon these atomic theories of electricity and matter there has been superposed in the last few years an atomic theory of energy which promises to alter radically all the ideas that have been held hitherto on the nature of energy and its mode of transmission. The experimental observations on the laws of distribution of radiant energy have led to conclusions that are apparently opposed to the electrodynamical equations deduced by Maxwell from the principle of least action. It has been shown that the view that energy is emitted and absorbed continuously is unable to explain the variation in distribution of radiant energy with the frequency of the radiation when this frequency is very high. An atomistic view of energy—or *quantum theory*, as it has been designated, is necessary not only in order to account for the observations of Lummer and Pringsheim and others on the distribution of intensity of radiation in the ultra-violet and visible portions of the spectrum, but this theory also leads to conclusions that are strikingly confirmed by observations in such vastly different fields of investigation as those of specific heats, the photo-electric effect and the production of X-rays.

And piling Pelion upon Ossa, the scientific iconoclast finally concludes that matter in itself has mass only in virtue of the motion of its constituent electrons, thus robbing us at once of what we had hitherto supposed to be a fundamental attribute of matter.

Never in the history of science has there existed such a period as the present: A period in which discoveries have multiplied more rapidly and the scientific imagination has risen to higher flights. It is an epoch.

"When every morning brings a noble
chance,
And every change brings out a noble
knight."

Within the past two decades we have seen the discovery of X-rays and radio-active phenomena on the one hand, and the evolution of the electron and quantum theories on the other. It has been found necessary to discard the old idea that the atoms of the elements are permanently stable and to replace this by the view that the atoms of the radio-active elements are "unstable dynamical systems," while it is quite probable that the atoms of all the elements are more or less unstable.

One of the first conclusions drawn from the application of the theory of energy quanta was that regarding the nature of X-rays. A large amount of experimental evidence has been obtained in the last two years confirming this conclusion and now we have every reason to believe that X-rays as well as gamma rays are electromagnetic waves of extremely short wave length, the frequency of these radiations

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[1] E. Rutherford, Radio-active Substances and Their Radiations, 1913, p. 1.

being about ten thousand times as great as that of ordinary visible radiation.

Laue, the Braggs and others have shown how X-rays may be utilized to *determine crystal structures.* Mosely and Darwin have still more recently investigated the X-ray and gamma ray spectra of a large number of elements and their observations are most easily interpreted in terms of the atomic model which had been previously suggested by Rutherford and Bohr. Not only are we learning something about the manner in which the atoms and molecules arrange themselves to form crystal structures, but we seem to be on the verge of learning something about the innermost structure of the atom itself.

This is not all. The very concept of matter itself is being questioned. We have been familiar for some time with the notion that the electron possesses mass in virtue of its charge. Now the work of Marsden and Geiger on the scattering of $\alpha$-particles when passing through different substances led Rutherford to the suggestion that the mass of the positive nucleus itself may also be of electrical origin.

The most fundamental magnitude of physics and chemistry is therefore the unit negative charge or electron. Maybe there exists a positive electron corresponding to this unit of negative electricity and it is probable that the positive nucleus of the hydrogen atom is this long-sought-for unit of positive electricity. But the great outstanding fact is that all the investigations of recent years are converging towards a monistic view of natural phenomena. As mentioned above, we have atomic theories not only of matter and electricity but also of energy. Everywhere we are confronted with discontinuities in regions which have hitherto been assumed to be best represented by continuous functions.

The later conclusions must, however, be regarded as not being distinctly at variance with the older views but rather as an extension and evolution of the older theories which has been found necessary, owing to the accumulation of a large amount of new experimental evidence. We must never lose sight of this point, that the observations must always preceed the theory and while the latter may be in a state of continuous flux, the facts remain. To evolve a unitary concept which shall reconcile the known facts of the past with the results of recent investigations is a stupendous undertaking; but the difficulties are by no means insurmountable and judging from the vigor with which the whole problem is being attacked by the foremost scientists of the present time, it is quite certain that the next decade will see developments in physics even more startling than have been accomplished in the past two decades.

As yet the effect of these altered views has been felt mainly by the theoretical physicist. To the practical physicist, the engineer at large, the chemist, and interested layman, these new concepts are either unfamiliar or else disregarded because of a much advocated doctrine which may be labelled empiricism, pragmatism, or agnosticism, according as befits the philosophical views of each individual.

But just as the speculations of Carnot, Meyer and Clausius formed the foundation upon which the engineer of the present has developed methods of energy transformation, just as the almost incomprehensible flights of imagination of Maxwell were realized in the wireless waves as used commercially today, even so no doubt those atomistic theories of energy and electricity which we see under evolution at present will form the starting points for new developments by the engineer, whose happy function it has always been to realize in tangible form what the physicist beholds only as a vision.

It has been thought that an account of the results of the recent investigations might be of interest to that large class of readers whose daily labor is apt to get them out of touch with such developments. If, in the attempt to carry out this object, the writer shall have succeeded in imparting to his readers even a fraction of the information and inspiration that he has derived from the writing of the paper, he will deem his efforts amply rewarded.

## ATOMIC THEORY OF ELECTRICITY

### Charge on a Univalent Ion in Electrolysis

The ionic theory of solution has familiarized us with the idea that atoms or certain groups of atoms in solution carry electric charges which are integral multiples of that carried by a charged atom of hydrogen. These charged atoms or groups of atoms, known as ions, are the carriers of the electric current in the solution and liberate their charges at the electrodes during the process of electrolysis. Thus in the case of a solution of hydrogen chloride (HCl), the ions are $\overset{+}{\mathrm{H}}$ and $\overset{-}{\mathrm{Cl}}$, the positive and negative signs denoting that the hydrogen and chlorine ions are transported during electrolysis in the positive and negative directions of the current respectively.

From Faraday's law and a knowledge of the number of atoms contained in one gram-ionic weight[2] of a substance it is possible to calculate the charge per atom, or the *unit electric charge*. According to Faraday's law, the electric charge carried by 1.008 grams of hydrogen (one gram-ion) is 96,540 coulombs. The number of atoms contained in the above weight of hydrogen is the same as the number of molecules per gram-molecular weight. This is usually denoted by $N$ and according to the most accurate determination it has the value $6.06 \times 10^{23}$.

The unit electric charge as deduced from observations on conduction through electrolytes is therefore

$$\frac{96540}{6.06 \times 10^{23}} = 1.57 \times 10^{-19} \text{ coulombs.}$$

Since 1 coulomb is equal to $10^{-1}$ electromagnetic units (e.m.u.) or $3 \times 10^{9}$ electrostatic units (e.s.u.) the electric charge on a univalent ion in solution may be expressed as $1.57 \times 10^{-20}$ e.m.u. or $4.78 \times 10^{-10}$ e.s.u.

Furthermore, the ratio of the charge to the mass of a hydrogen atom in electrolysis ($e/m$) is $9.654 \times 10^{3}$ e.m.u. per gram.

### Cathode Rays. Ratio of Charge of Mass

In the case of the conduction of electricity through gases and metals, the same question arose as to the nature of the carriers of the electric charges. Obviously the conduction does not take place by means of charged atoms or groups of atoms as in the case of electrolytes. J. J. Thomson, continuing the experiments of Crookes on the nature of the electric discharge in high vacua, showed that the cathode rays observed in these experiments consist of *negatively charged corpuscles* which starting from the cathode move with very high velocities in straight lines and produce a vivid fluorescence wherever they strike the glass walls of the tube. Now it was shown a long time ago by Rowland that a charged particle in motion must produce the same effects as are observed in the case of a wire carrying current. In other words, the direction of motion of a charged particle will be affected by magnetic and electrostatic fields just as a wire carrying current. Furthermore the magnitude of the effects observed depends upon the ratio of the charge ($e$) to the mass ($m$) of the particles and upon their velocity. By observing the amount of deflection suffered by the cathode rays when subjected to magnetic and electrostatic fields, J. J. Thomson concluded that the negatively charged corpuscles constituting these rays have a value of $e/m$ of about the order of magnitude of $1.2 \times 10^{7}$ e.m.u. per gram. Later experiments have led to the more accurate value $1.76 \times 10^{7}$. The velocity of the corpuscles was found to vary from $10^{7}$ to $10^{9}$ cms. p.s.

Comparing the above values of $e/m$ with that obtained for hydrogen ion in electrolytic conduction ($9.654 \times 10^{3}$ e.m.u. per gram), the conclusion follows that either the unit electric charge is much greater in the latter case than in that of the cathode rays or that the mass of the negatively charged corpuscle is

$$\frac{9654}{1.76 \times 10^{7}} = \frac{1}{1835}$$

of that of the hydrogen atom.

Now, apart from the evidence obtained by a large number of experimenters that the corpuscles constituting the cathode ray beams must have masses much smaller than that of the hydrogen atom, there are definite reasons for believing that the unit electric charge in the cathode ray discharge has the same value as that possessed by the hydrogen ion in electrolytic conduction.

### Unit Charge in Gaseous Conduction

When X-rays pass through a gas they cause the latter to become conducting, that is ions are produced throughout the gas. These ions possess the property of acting as condensation nuclei for water-vapor in a supersaturated state and, by varying the conditions of the experiment, the condensation may be made to occur either on the positive or negative ions. By noting the rate of fall of the cloud formed by this condensation, measuring the total charge carried by the condensation produced and knowing the degree of supersaturation of the vapor, it is possible to determine the minimum charge carried by each ion, and consequently the unit negative charge concerned in gaseous conduction. This was the method adopted by C. T. R. Wilsons in 1898.

Within the past two years Prof. Millikan has, however, obtained much more accurate data by the "oil-drop method." In this method the ions produced by the action of X-rays attach themselves to oil-drops suspended between two horizontal plates which are connected to the terminals of a high

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[2] The gram-molecular weight of any substance is that weight in grams corresponding to its chemical formula. Similarly the gram-ionic weight is the weight in grams corresponding to the formula of the ion.

voltage battery, so that the rate of fall of the charged oil drops can be measured both in the absence of an electric field, and under the combined action of the latter and gravity. From observations on the rate of fall under these different conditions, it is possible to calculate the charge carried by the oil-drop. It was found by Prof. Millikan that in all his observations, the actual magnitude of this charge was always an integral multiple of that calculated for a hydrogen ion in electrolysis, viz.: $4.8 \times 10^{-10}$ e.s.u.; furthermore that while the charge on any oil drop under observation altered from time to time owing to collision with other ions or molecules, the magnitude of the change was never less than $4.80 \times 10^{-10}$ e.s.u. The most accurate value of this unit electric charge according to Prof. Millikan's most recent determinations is $4.77 \pm 0.009 \times 10^{-10}$ e.s.u.

These investigations thus lead to the conclusion that the unit electric charge is the same for both gaseous and electrolytic condition. Consequently the mass of the negatively charged corpuscle constituting the cathode-rays must be $\frac{1}{1835}$ of that of the hydrogen atom.

### Electron Emission from Hot Bodies. Photo-Electric Effect

The cathode-rays of an ordinary discharge tube such as is used for the production of X-rays is not the only case in which these negatively charged corpuscles, or *electrons*, as they have been designated, are obtained in the free state. O. W. Richardson[3] and his associates have shown that heated metals emit negatively charged corpuscles with the same value of $e/m$ as that obtained for cathode rays. The number of these electrons emitted per unit area of surface increases rapidly with the temperature according to the formula

$$i = A\sqrt{T}\epsilon^{-\frac{b}{T}} \qquad (1)$$

where $A$ and $b$ are constants and $i$ denotes the current per unit area.

Dr. W. D. Coolidge[4] has utilized this phenomenon in the construction of an X-ray tube in which the X-rays are produced by the bombardment of a tungsten anode by electrons moving with very high velocity. As source of electrons he used a heated tungsten filament.

In further elaboration of Richardson's work, Dr. I. Langmuir[5] has shown that under certain conditions the electrons emitted from the heated metal can produce a space charge outside the metal which prevents the emission of more electrons and quantitative confirmation has been obtained by the writer[6] of the conclusions deduced by him on the assumption that the thermionic currents obtained are due to the actual emission from heated cathode of charged particles having a ratio of charge to mass of the same value as that obtained for the electrons in cathode ray tubes.

Electrons are also emitted from all metals under the influence of ultra-violet light. This is the well-known photo-electric effect. The more electro-positive the metal, the lower the frequency of the light that is capable of causing photo-electron emission, and in the case of the alkali metals photo-electric currents of considerable magnitude are obtained even when ordinary light is used as a source of illumination.

In the case of both thermionic and photo-electric emission we are dealing with pure electron currents in a vacuum. There is an actual convection of negatively charged corpuscles from the heated metal or illuminated surface (which has to be charged negatively) to the anode. It is true that, within the past two or three years, doubt has arisen among a large number of investigators as to the existence of such pure electron currents in high vacua. The tendency has been to ascribe both thermionic and photo-electric effect to chemical reactions occurring at the surface of the metal. But the results obtained by Dr. Langmuir and his associates on the thermionic currents in very high vacua and by Millikan, Richardson, the writer and others on the photo-electric effect in the best vacua obtainable, only seem to confirm the older views that such pure electron currents actually exist *per ipse* and are not due to any secondary effects due to the presence of gases.

### Electron Theory of Conduction in Metals

The emission of electrons from heated metals and under the influence of ultra-violet light can only be explained on the assumption that at any temperature there are present in the metal a certain number of free electrons and that there exists an equilibrium between the concentration of these free electrons inside

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[3] Trans. Am. Electrochem. Soc. *22*, 69 (1912).

[4] Phys. Rev., *2*, 1913.

[5] Phys. Rev., *2*, 450, (1913).

[6] Phys. Rev., *3*, 65, (1914).

the metal and in the surrounding space. With an increase in temperature the concentration of free electrons in the metal increases and consequently the emission of electrons also increases. The electrons must therefore be regarded as an essential constituent of all atoms.

According to the most recent theory, that suggested by Bohr, the atom is considered as being composed of one or more rings of electrons which are in constant rotation about a positively charged nucleus, the total charge on the latter being equal and opposite to that on all the electrons external to it. Owing to the vibrations among the atoms themselves, some of these electrons acquire sufficient kinetic energy to enable them to travel out beyond the influence of the forces which ordinarily hold them at a fixed distance from the positive nucleus. The latter is consequently able to attract any other free electron that comes within its field of attraction. At any instant there are thus present a certain number of free electrons, and it is by means of these free electrons that both electric charges and heat are conducted through the metal. An electron theory of conduction was suggested even before the investigation of J. J. Thomson by Riecke and Drude. The latter was able in this manner not only to give a theoretical basis to the well-known Wiedemann-Franz relation, according to which the ratio of thermal to electrical conductivity at any temperature is approximately the same for all metals, but he showed that there exists an intimate relation between the electrical conductivity and the thermo-electric properties of any metal.

Regarding the actual number of free electrons present under given conditions, we are as yet unable to draw any definite conclusions. The electron theory of conduction is as yet in a far from completed state. Recent speculations[7] of Keesom and others indicate that a theory in harmony with all known observations will probably be developed in the very near future. But even in its present state the theory proves of considerable advantage correlating a large number of phenomena while simplifying a number of concepts that are prevalent in electrical engineering.

Considering an electric current in a metallic conductor as due to a convection of charged particles, it is seen that electrical resistance may be simply regarded as a frictional resistance tending to oppose the flow of current. It follows also that the energy which we ordinarily conceive as being used to establish a magnetic field is really the energy required to set the electrons in motion, in other words, to overcome the inertia of the charged corpuscles. The same amount of energy must be restored to the conductor when the stream of electrons is suddenly stopped. The physical significance of what is meant by inductance thus becomes apparent.

Again, if the electron is made to oscillate backwards and forwards, as in the case of an alternating electric current, the magnetic field at any point in space must vary correspondingly and since the electron also exerts an electrostatic force, the magnitude of this at any point in space must also vary in a similar manner. In other words, if the motion of the electrons in the wire is harmonic, there will be propagated into the surrounding space two linear harmonic disturbances at right angles to each other and to the direction of motion of the electron. One of these disturbances will cause variations in the magnetic intensity at any point in space, while the other will cause corresponding variations in electrostatic force. It is also evident that such disturbances will affect the electrons in other conductors and these elections will consequently execute harmonic vibrations of the same frequency as that of the original exciting electrons. That is, an electromagnetic wave is produced.

### Zeeman Effect. Explanation in Terms of Electron Theory.

The explanation of the Zeeman effect in terms of the electron theory must be regarded as one of the most important triumphs of this theory.

Assuming in accordance with Bohr's theory of the structure of the atom that light is produced by the vibration of electrons in the atom around a positive nucleus, it easily follows that the frequency of this vibration ought to be affected by a magnetic field, for the latter will exert a force which will either aid or oppose the centripetal force which is exerted by the positive nucleus on the rotating electron, according as the direction of rotation is either right-handed or left-handed with respect to the lines of magnetic force.

If now a source of monochromatic light emitting radiation of frequency $\gamma_0$ is placed in a magnetic field, the frequency of some of the electrons is increased while that of others is decreased. The consequence is that in-

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[7] Phys. Zeitschrift, *14*, 665, (1913).

stead of one line in the spectrum we perceive three lines, the two outer ones being due to the vibrations set up by the electrons whose orbits are affected in opposite senses, while the center line has the same frequency as the original light and is due to the electrons whose orbits are situated in a plane that is parallel to the direction of the lines of magnetic force.

Denoting the frequencies corresponding to the outer lines by $\gamma^1$ and $\gamma$ respectively, it was shown by Lorentz that

$$(\gamma^1-\gamma)\ \frac{2\pi c^2}{H}=\frac{e}{m} \qquad (2)$$

Here $c$ denotes the velocity of light and $H$ the strength of the magnetic field. The values of $e/m$ deduced by this method have been found to be in good accord with those obtained by measurements on cathode rays and are recognized as of equal weight with these other values.[8]

A similar explanation has been given of the observed rotation of the plane of polarization by a substance in a magnetic field (Faraday effect).

### Electron Theory of Magnetism

The electron theory of magnetism is one of the most important and most interesting applications of the new views. It is evident that the rotation of an electron about its nucleus must produce a molecular magnet having its axis perpendicular to the plane of rotation of the electron. This is the fundamental idea of the electron theory of magnetism. Langevin and Weiss have extended the theory to explain the phenomena of para- and ferro-magnetism. To explain the latter, Weiss has introduced the idea of magnetons or elements of magnetic moment corresponding to electrons.[9]

### Summary

The above are only a few of the many fields of application of the electron theory. It has proven of immense value in correlating a large number of observations, which is after all the prime purpose of any theory, and furthermore its application has led to the discovery of a large number of new phenomena which would not have been otherwise suspected.

Let us review then very briefly what we have learnt regarding the evidence upon which the theory is based and its main assumptions. The fundamental experiments upon which it is based are those of J. J. Thomson and others, showing that electrical conduction in gases takes place largely by means of small negatively charged corpuscles having a ratio of charge to mass which is 1835 times as great as that for hydrogen in electrolysis. Another line of investigation has led to the conclusion that the unit negative charge is the same in all cases. Consequently the mass of the negatively charged corpuscle or electron must be $\frac{1}{1835}$ of that of the hydrogen atom.

In other words, we are led to the conclusion that electricity is transported in multiples of a unit charge which has the magnitude of $4.8\times10^{-10}$ e.s.u. This may therefore be said to be an atomic theory of electricity, similar to the older atomic theory of matter.

The electron theory of the constitution of the atom gives a logical explanation of all the phenomena of conduction. According to this theory the atoms of all elements contain under normal conditions one or more negatively charged corpuscles together with a positive nucleus.

Under the influence of different re-agents, such as ultra-violet light, high temperature, X-rays, $\gamma$-rays, or an intense electric field, the atom may lose one or more of its electrons, and the latter are then emitted with velocities that vary from $10^7$ to $10^9$ cms. per second. These electrons travelling with high velocity are capable of detaching more electrons from gas molecules with which they collide and thus produce the phenomenon of ionization by collision. The positively charged residues or ions produced in this manner are attracted to the cathode of the discharge tube and bombard it with velocities sufficiently great to cause the emission of more electrons. We thus obtain the various phemonena of gaseous conduction which vary from the Geissler discharge to the arc.

Again, the drift of these electrons in metallic conductors under the influence of the electric force constitutes a current, and for the quantitative explanation of this phenomenon, it is only necessary to assume that, owing to the vibrations of the atoms in the solid, there is a continual separation of electrons from these atoms as well as a re-combination of the free electrons with the charged residues so that there is always present a small number of free electrons. On this assumption it is then possible to represent physically not only such electrical concepts as resistance and inductance, but also the mechanism by which electro-magnetic radiations are emitted and absorbed.

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[8] Kaye and Laby, Physical and Chemical Constants, pp. 99.

[9] E. H. Williams, the Electron Theory of Magnetism. Bull. 63, Univ. Illinois Engineering Experiment Station.

The electron theory of conduction enables us not only to deduce the relation between electrical and thermal conductivity of metals, (Wiedemann-Franz law) but also indicates relations between the electrical conductivity and thermo-electric properties.

Finally, the theory has also received splendid confirmation in the explanation of the Zeeman effect and other magneto-optical phenomena.

### References

For those who are interested in obtaining more explicit information on the subject the following references may be of interest.

1. *Fournier D'Albe. The Electron Theory,* 1906. Non-mathematical and popular exposition.

2. *E. P. Adams. Radio-activity.* A series of five lectures delivered before the American Institute of Electrical Engineers, New York, March and April, 1913. (Proc. Vol. 32, pp. 1159-1233.) The last two lectures deal especially with the electron theory and contain an excellent summary of the fundamental points. No difficult mathematics.

3 *N. Campbell. Modern Electrical Theory,* 1913. The best work in English on the whole field of recent physical developments. Mathematical in parts.

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# THE DUBLIN, IRELAND, THREE-PHASE FOUR-WIRE DISTRIBUTION SYSTEM

By Gilbert Archer

Assistant to Chief Engineer, Dublin Corporation Electricity Supply

We frequently find, in the various scientific papers, descriptions of the many pieces of apparatus installed in generating stations and the methods employed in regulating and handling these. Such descriptions are always welcomed by electrical engineers the world over, for it keeps them in touch with what is being done in centers other than those with which they are immediately concerned. It is not often, however, that one finds any description of the means used in the distribution of the power generated, from the time it leaves the switchboard at the generating station until the time it is delivered to the consumer in the workshop, business premises or private residence. The author has set out below the means adopted in Dublin, believing that it will be of interest to engineers who have charge of similar networks, or who are employed in designing and laying out systems of distributing cables for future use. The Dublin system is one of the largest three-phase, four-wire secondary distribution systems installed, the connected load being approximately 11616 kw. There is 4500 h.p. connected and the maximum load on feeders is about 5510 kw., the area served by the system being approximately 12 square miles.—Editor.

The city of Dublin receives its supply of electricity as three-phase alternating current, this being generated at 5000 volts. The location of the generating station (marked *A* on Fig. 1) is some $3\frac{1}{2}$ miles from the main distributing station (marked *B* on Fig. 1). From the switchboard at the generating station, trunk feeders—seven in number, at present, each having three cores of 0.15 sq. in. section—bring the supply to the main distributing station switchboard. These feeders are connected to the busbars of the switchboard through three-pole oil-break automatic switches fitted with reverse-current relays. These relays ensure the isolation at the distribution station end of any feeder developing a fault; while other relays in the generating station make equally sure of isolating it at that end. The reverse-current relays are set to operate at 10 per cent of the full load current.

The switchboard in the distributing station, Fig. 2, is divided into five sections, each section being fed by its own trunk feeder or feeders, which are connected by means of sectionalizing oil-break switches of the overload automatic-release type. Normally, the sectionalizing switches are in the "on" position, the five sections being connected together forming one large switchboard. Should the busbars on any section break down to earth or short-circuit, the sectionalizing switches at each end of this section trip out, on account of the rush of current through them, and thus isolate it from the remainder of the board.

From the busbars of the switchboard, subfeeders are led through automatic triple-pole oil-break overload type switches to the different substations erected in various parts of the town. The supply still remains at 5000 volts and the cables used are similar to the trunk feeders, being three-core, paper-insulated, and lead-covered. The cores in this case, however, are only of 0.1 sq. in. section.

Each substation is fed by either one or two high-tension sub-feeders and, in addition to this, certain substations are linked together by interconnecting cables. This makes it possible to feed a substation through another cable, in the event of one of its sub-feeders breaking down, by means of the interconnectors, or to assist one substation, should its own sub-feeder be overloaded, by coupling up the interconnectors and feeding partly from another substation or substations.

Fig. 1 shows the high-tension sub-feeders and interconnectors diagrammatically, *A* being the generating station, *B* the main distributing station and 1, 2, 3, etc., being the substations.

It will be noticed that substations 29, 4, 28, 25 and 23 are connected together with a "ring main," and that Nos. 29, 4 and 28 have two sub-feeders each connecting them with the main distributing station. Into this "ring main" transformer kiosks are connected (represented in the diagram by ■). These are used for supplying the outlying districts where the demand is not large enough to warrant the expense of building and equipping a substation, each kiosk being fitted for supplying 100 kv-a. These kiosks are portable and can be replaced by a substation at any time when the demand increases sufficiently to warrant the change. In this event the kiosk is then removed to some other district.

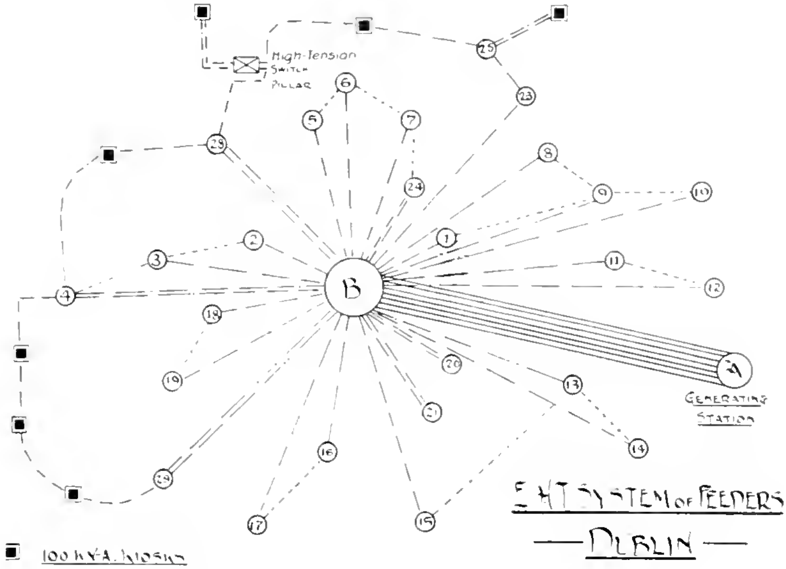

Fig. 1. Diagram Showing the Relative Location of Generating, Distributing and Substations and Connecting Feeders

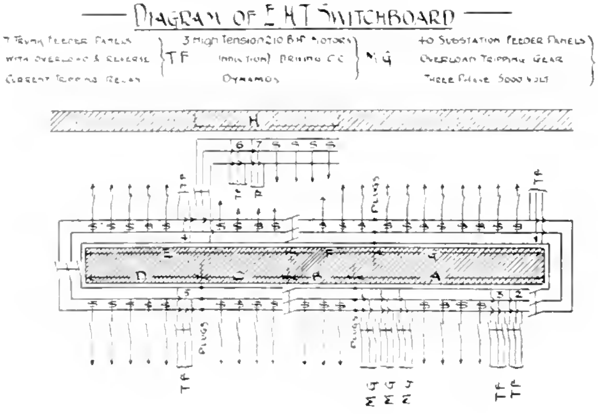

Fig. 2. Diagram showing the Layout of Circuits at the Distributing Switchboard

The high-tension (5000-volt) sub-feeder enter the substation and are connected to the substation high-tension switchboard through a triple-pole automatic oil-break switch of the overload release type.

The primary windings of the step-down transformers are connected to the high-tension busbars in △ through double-pole automatic oil-break switches of the overload release type (Fig. 3), thus ensuring the isolation of any transformer that may break down either in its primary or its secondary winding.

Four transformers are installed in each substation, the size of the transformers varying with the local load conditions. Three are "running" transformers and the fourth a "spare," provision being made so that the spare transformer can be connected up so as to replace any of the three running transformers that may fail (Fig. 4).

Should a transformer break down, it only affects one phase of the supply from that substation, and, when an assistant is sent out it only takes a few minutes to connect up the spare transformer.

The low-tension side of the transformers are connected to the low-tension switchboard in

Y through ammeters and circuit breakers, the spare transformer bus bar being arranged in such a manner that this transformer can be readily "plugged in" in the place of any one of the three running transformers.

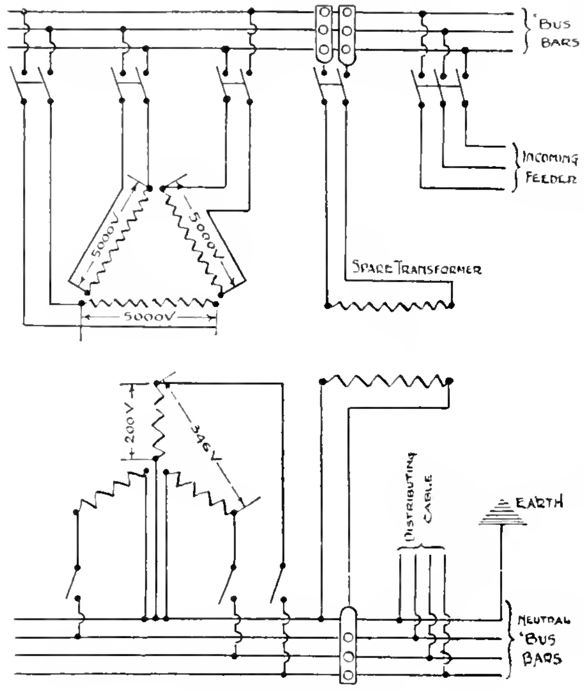

Fig. 3. Transformer Connections in Substation; High-Tension Above, Low-Tension Below

The center point of the "star" or Y connection is connected to an earth bar, which in its turn is connected to an earth plate through a recording ammeter arranged in such a manner that when the earth current exceeds a certain predetermined value this ammeter is automatically short circuited and the earth bar connected direct to earth, for the protection of the ammeters.

From the main transformer busbars of the low-tension switchboard, other bars are fixed horizontally. To these are connected sets of "Downe" fittings for connecting up the low-tension feeder cables which run out from the substation to the different feeding points. Fig. 6 shows diagrammatically the low-tension switchboard with "Downe" fittings and spare transformer bus. A photograph of a substation switchboard panel with "Downe" fittings is shown in Fig. 5.

The feeder cables are *four-core*, paper-insulated, and lead-covered; three of the cores are connected to the busbars of the low-tension switchboard by means of the "Downe" fittings, while the fourth core or "neutral" is connected to the earth bar.

One of the chief advantages of using the "Downe" fitting, Fig. 7, is that it does away completely with the necessity of using rubber insulated cables in the substation; the lead-covered cables are connected by means of a wiped joint to the bottom of the "Downe" fittings, the cores passing through the center of the fitting and each one terminating at a terminal connected with the proper "phase busbar," which is filled in with high-grade compound after all the cores are fixed in position. Each phase is also protected by a fuse and a copper removable link is provided in the neutral that can be removed when it is necessary to carry out any tests on a particular feeder.

The low-tension feeder cables from this switchboard run out to the different feeding points in the area fed by this substation and are connected into feeder pillars, "Downe" fittings being again used (Fig. 8). Three-core pilot cables are run back to the substation from these feeding points and are connected, by means of a three-phase multiple-way switch, to a pilot voltmeter.

In some districts, where the load on the feeders is heavy enough to make it advisable, variable-ratio transformers are installed.

These transformers have a regulating switch connected to taps on the low-tension winding, thus providing a means of boosting the voltage should the pilot voltmeter show that it has fallen below the minimum allowed.

It has been already pointed out that there are three separate transformers, one for each phase, so it is possible to boost the phases separately if required.

As it is only at times of maximum load that the feeders will be likely to be heavily loaded, it is not necessary to have an attendant constantly at the substations where variable-ratio transformers are installed; men are sent there at such times as boosting is required and come away when the necessity has passed.

Distributor cables radiate from the feeder pillars carrying the supply to the consumers' premises. These distributors are *four-core* cables, three of the cores being connected to the "phase" bars and the fourth to the neutral bar in the feeder pillar.

In some cases distributor cables have been run out direct from a substation—for purely local supplies—but it is better practice, and results in a more satisfactory voltage regulation, to arrange matters so that all the distributor cables radiate from definite feeding points.

Each substation has its own natural area assigned to it which under ordinary circumstances it feeds but, in order to meet any eventualities, section pillars are erected at the junction points of the different areas; and by means of these it is possible to connect the area of one substation to that of one, or more, adjacent to it; and in this way feed through the section pillars should any substation be put out of commission through a serious breakdown within it.

By linking up all the section pillars it is possible to make all the low-tension networks of the city into one large interlinked network, with all the substations feeding into it in parallel. It has not been found desirable, however, to adopt this course, and the network is arranged in such a manner that each substation deals with the supply in its own area.

Besides the section pillars, disconnection boxes are used at street corners and points from which a number of cables may radiate. The use of such boxes obviates the necessity of cutting a cable should tests have to be carried out, as any of the cables may be "deadened" by removing the links in the box. A brick pit is built in the pathway or road as the case may be, into which the disconnecting box is placed, and an iron framework round the top of the brick pit carries the pavement cover; thus the box is doubly protected. Fig. 9 illustrates the arrangement employed.

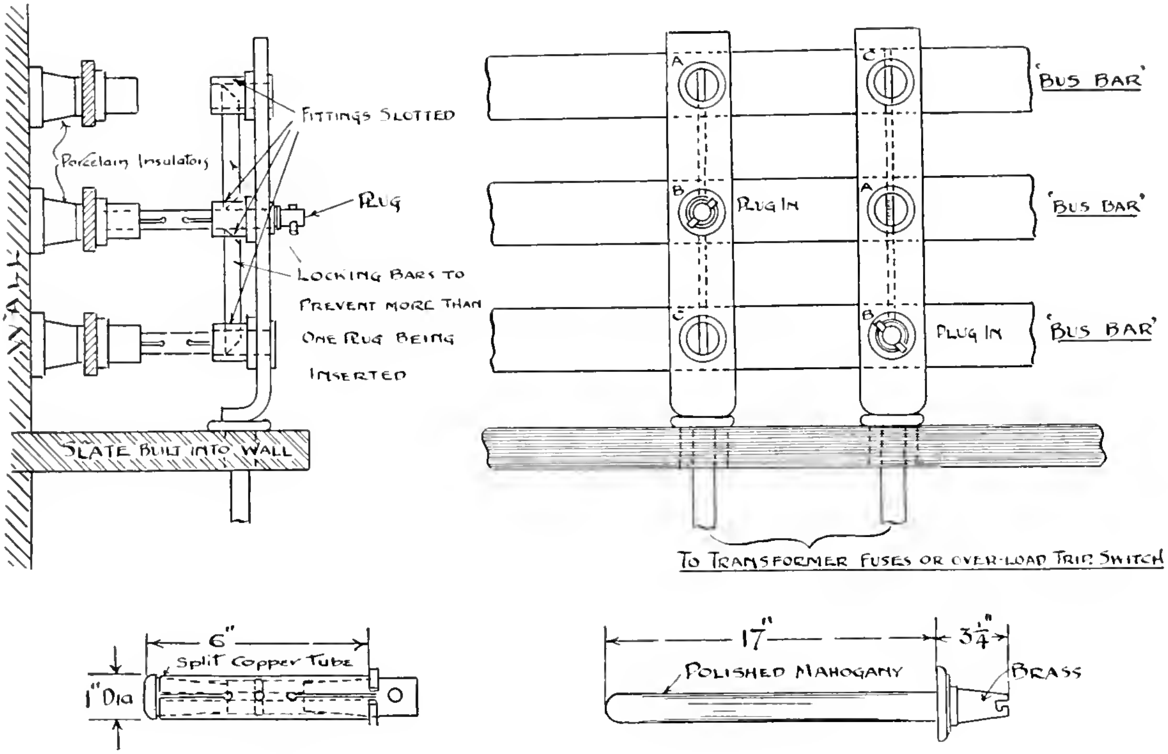

Fig. 4. Plug Connections in Substation for Replacing a Defective Transformer by the "Spare"

From the distributors are taken the house service cables. For these connections cast-iron service boxes are used, the service cables being jointed to the distributors by means of patent clip cable fittings which render it unnecessary to cut the cable, and which make it possible to make joints quickly and efficiently while the distributors are "alive." The construction of one of these service boxes and the location of the clip fittings are shown in Fig. 10; a detail drawing, Fig. 11, and a photograph, Fig. 12, show the method of attaching the clip to the cable.

When the connections are completed the service box is filled in with a special box compound.

All the cables, both high-tension and low-tension, are tested at twice the working pressure after being laid; no periodic high-pressure tests are made. Should a fault develop, it is finally located, after "pinning it down" at the feeding point through a process of elimination, by use of a wire bridge, battery, and galvanometer. The wire bridge employed is of a special construction which gives extremely accurate results, the wire being some 40 to 42 feet long and wound on a drum. This special bridge is made by The British Insulated and Helsby Cable Co., Ltd., Prescot, Lancashire, England.

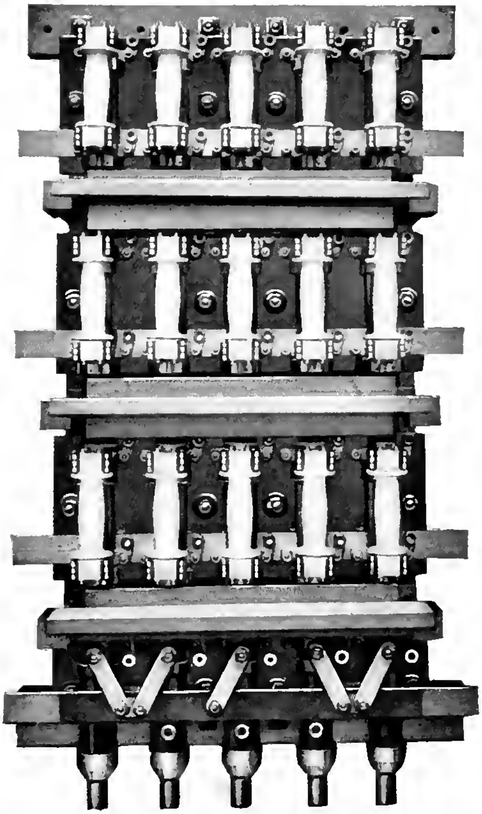

Fig. 5. Low-Tension Board with "Downe" Fittings

The method employed in laying the cables follows:

The cables, as already mentioned, are lead-covered and paper-insulated, the high-tension ones having three cores and the low-tension ones four cores.

They are laid in cast iron troughs with cast iron covers; the cable is supported every foot by creosoted wooden bridge pieces, the trough being filled up with pitch after the cable has been placed in position, and the covers are pressed down while the pitch is still hot. The cast iron troughs are treated with Dr. Angus Smith's solution, before laying.

The trenches in which the troughs are placed are usually about from 1 foot 6 inches to 2 feet deep and in the case of the distributors where more than one line of trough runs in the same trench, room is left between troughs to allow a service box to be put in on either of them.

After the troughs have had their covers placed in position, fine earth—i.e., earth free from any large stones—is filled into the trench to a depth of some 3 inches over the trough, and then a line of hard brick or concrete blocks is placed over the troughs as an indication to future excavators of the presence of electric cables.

The troughing varies in size with the size of the cable used, thus for

A 0.1 in. by 3-core high-tension cable, a 2⅞ in. by 2⅞ in. trough is used.

A 0.2 in. by 4-core low-tension cable, a 2⅞ in. by 2⅞ in. trough is used.

A 0.1 in. by 4-core low-tension cable, a 2½ in. by 2½ in. trough is used.

A 0.05 in. by 4-core low-tension cable, a 2¼ in. by 2¼ in. trough is used.

A 0.035 in. by 4-core low-tension cable, a 2 in. by 2 in. trough is used.

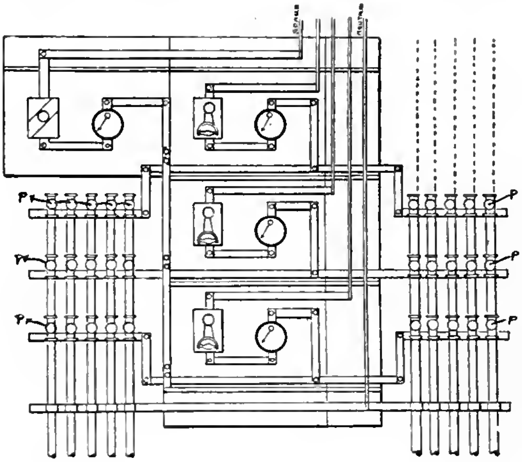

Fig. 6. Representation of Low-Tension Switchboard with "Downe" Fittings and Spare Transformer Bus

The thickness of metal is ¼ in. in all cases.

One important point that must be always borne in mind and receive careful consideration in connection with a three-phase system is the balancing of the loads on the three limbs, for the loads on the three phases must be kept as nearly as possible equal. This is done in Dublin by balancing one installation against another, one being connected between one phase and the neutral line, the next between the second phase and the neutral, etc. In the case of a very large installation a four-core service cable is run into the building and the installation is divided up into three equal sections, each section being connected to a phase and neutral. In order to have the matter of the balancing under easy observation a set of balancing cards is kept—one for each street, and also one for each substation. From these the mains' engineer can see at a glance to which phase a new consumer should be connected in order to preserve the balance.

This has worked out admirably in practice, the balance on the whole system being remarkably close.

Motors, with the exception of those of small power, ¼ h.p. to 4 h.p., are all three-phase and are connected to the phase wires, the neutral in this case not being made use of. The pressure for lighting is 200 volts and for motors 346 volts. There are certain rules in force as to the permissible starting current for motors and their power-factors.

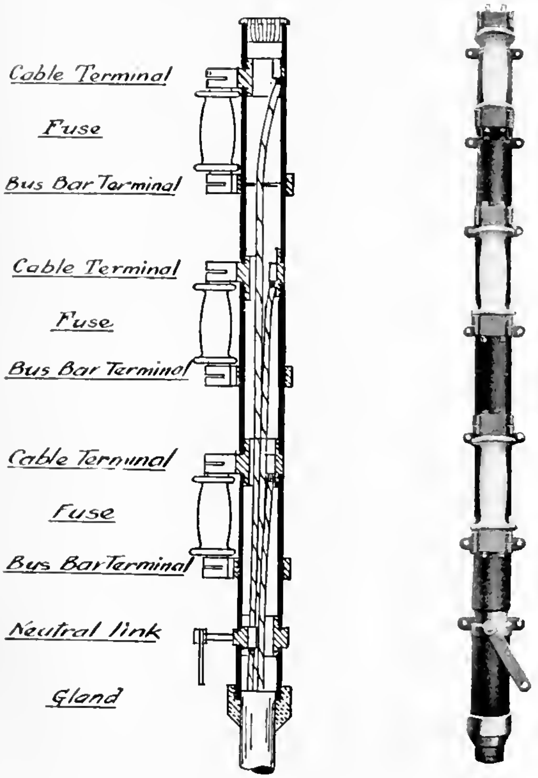

**Fig. 7. A sectional View of a "Downe" Unit and an Exterior View**

The solid system of cable laying which has been described is, perhaps, costly when only the initial expenditure is taken into account; but, when one considers the immunity from the effects of electrolysis which the use of the cast iron troughing gives, and the very exceptional freedom from cable faults that the Dublin system enjoys, the expenditures made on both cable and its laying is fully warranted.

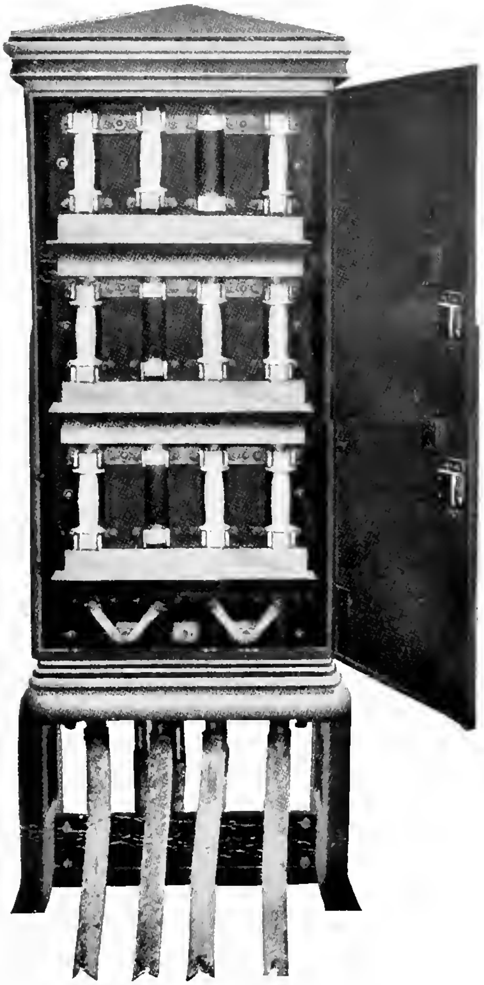

**Fig. 8. A Four-Unit Feeder Pillar**

Practically the whole of the cable laid was manufactured by the British Insulated and Helsby Cables Co., Ltd. Before it was shipped, stringent tests were carried out for insulation and capacity; and after laying the cable was again tested, this time under twice the working pressure, before being put into commission.

In any system of distribution the record of the mains is an important item. It will therefore perhaps be of interest to describe the network filing system adopted in Dublin. This is substantially a method in which the records of all connections in substations, feeder pillars, section pillars, network boxes, etc., can be easily and cheaply brought up to date and kept.

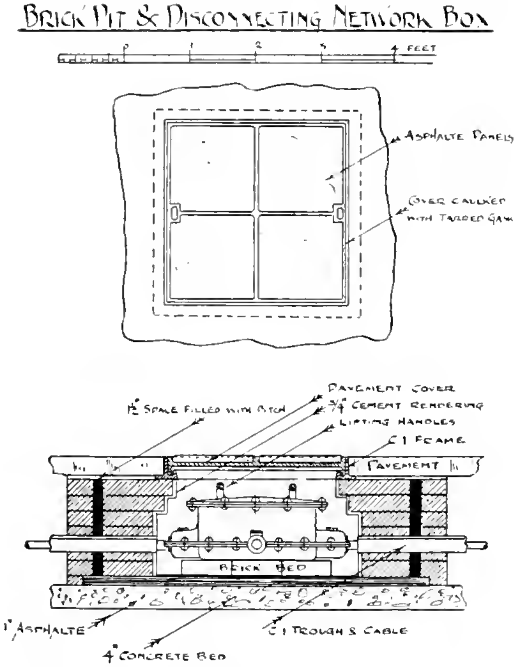

Fig. 9. Drawing Showing Disconnecting-Box and its Pit

Maps, more or less elaborate, are, of course, always made use of but, after all, these are only of use insofar as they are a record of the positions of the mains, it being impossible to mark on them the various possible connections and the changes made in the network connections from time to time.

Now it is obvious to any one, who has even a slight knowledge of the distribution of electrical energy, that alterations and additions have to be made to the mains in order to cope with the increasing demands, and that each alteration or addition may possibly introduce a complete new set of network connections, the old connections being either left as they were or modified to suit the altered conditions. When such alterations are made a record must be kept of them, otherwise the mains' engineer has to depend on his memory or the memories of his assistants. What this might possibly mean may, to a certain extent, be understood by taking a glance at the network supply in Dublin and its added areas. This consists of a network made up of two systems of mains—the older portion originally laid down for a single-phase supply, by the use of concentric cable, and the newer portion for the present three-phase supply—laid out for a certain maximum demand and having additions and alterations carried out from time to time so that the increasing demand could be dealt with. It considers the following points.

1. The system comprises twenty-eight substations with their high-tension switchboards, transformers, and low-tension switchboards; also six-way disconnecting boxes, four-way disconnecting boxes, two-way section pillars, four-way section pillars, six-way section pillars, high-tension three-phase transformer kiosks, radial high-tension feeders, and high-tension ring mains or interconnectors.

2. That it is possible (though perhaps not advisable) to link up the whole of the low-tension network so that it would be fed from all the low-tension substation boards in parallel, or all from one substation.

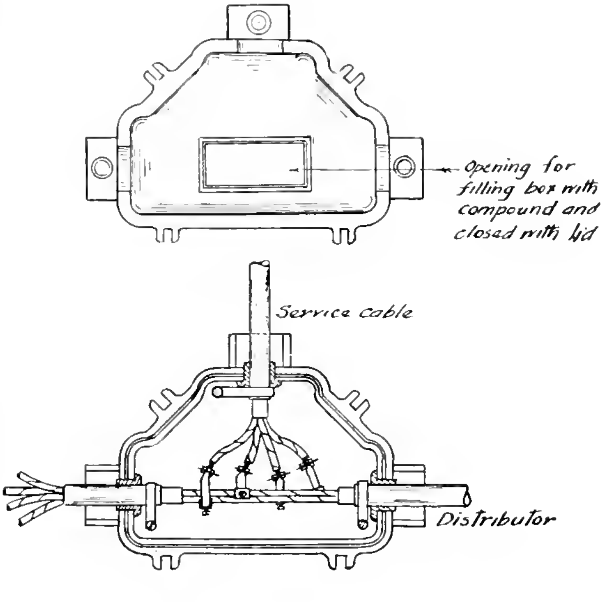

Fig. 10. Service-Box with Connections for Four-Core Service

3. That the substations can be linked together independently of the main station

on the high-tension side by the main distributing station high-tension interconnectors.

4. That alterations for one reason or another are made weekly, one might almost say daily. It then becomes obvious that it is an impossibility for any one to carry in his mind exactly how the connections and linking-up stand.

The system in vogue before the adoption of the present filing system was that of having written reports handed in of every change made in the network, such reports being duly filed for reference. This was all very well in its way; but when any further alteration had to be made or the exact method of linking up at a particular point was in question (perhaps in connection with a substation or cable fault), it became necessary to either trust to the memory of the mains' engineer or to hunt up the files of reports to obtain the necessary information and to make such sketches as were needed for use on the job. Thus a tremendous amount of valuable time was lost.

The originators of the filing system, recognizing the various difficulties attendant upon adequately recording everything attached to a large and complicated system of mains, set out to evolve some means by which records could be so kept that a glance would show exactly how the connections controlling any portion of the network stood.

It was first suggested that a large map should be mounted and that plug-holes should be drilled to indicate positions where it was possible to make connections and disconnections between sections of mains. Very little consideration was necessary to show the impracticability of such a scheme, for the map would have to be enormous to allow the possible alterations to be adequately indicated on, say, a three-phase four-wire system.

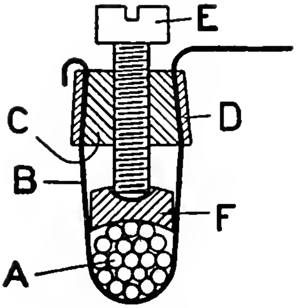

Fig. 11. Cross Section of Special Connecting Clip Used in Service Box

Further consideration of the question led to the decision that it was quite unnecessary to show the *whole* of the cable system when the only parts that allowed of alterations in the way of connections were the switching or the fusing points, and it then became apparent that all conditions would be satisfied if every point on the system, where linking up by links, switches, or fuses were possible, was reproduced diagrammatically and in such a manner that by some simple device it could be shown if a link, switch, or fuse was "in" or "out." Finally, it was decided that a small plug of bone or metal which could be placed in a hole indicating the position of a link, switch, or fuse was the best method to adopt. From this beginning the filing system developed.

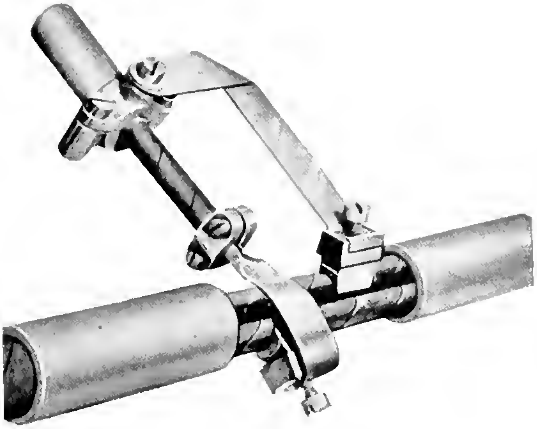

Fig. 12. View Showing Method of Attaching Special Connecting Clips

First of all, the various substations were taken into consideration, and what was the natural or normal network to be fed by each substation was decided upon. This being done, a diagrammatic plan was prepared for each substation network showing all network boxes and section pillars, etc., each carefully numbered, the points where linking up with another substation was possible being indicated. These were called reference plans. Fig. 13 represents such a plan, and it will be seen that it would be possible to link Substation No. 1 with Substation Nos. 2 or 8 in the six-way Box No. 1 at the corner of High Street and Church Road or with Substation No. 15 in the Section Pillar No. 1 at the corner of High Street and Rochester Road.

The next question was to represent the connections in the substation itself, and to do this a diagrammatic sketch was made of the high-tension and low-tension switchboards, plug-holes being provided where links, switches, or fuses were used. Fig. 6 represents one such card and is a diagrammatic representation of a low-tension switchboard (made in the workshops of the Corporation Electricity Department to designs worked out by the staff), the plug-holes being at *p*, *p*, etc.

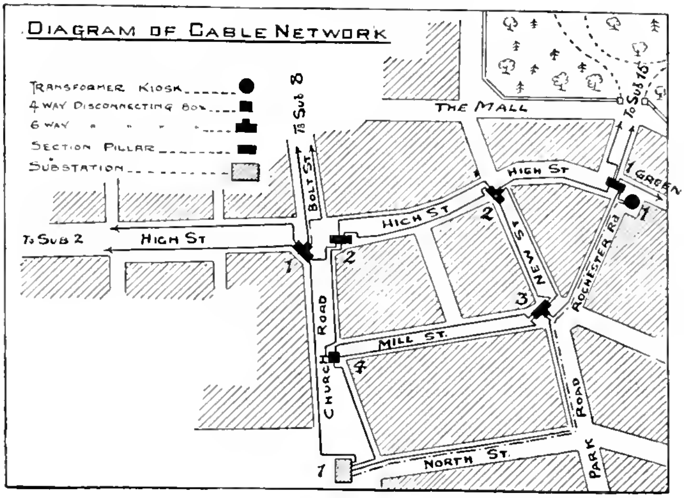

Fig. 13. A Map of a Section of Town Diagrammatically Showing Substation, Feeder, Etc., Layout

The position of the plugs on this diagram will indicate at once which circuits are being fed from the substation. For instance, take the line of cable to the extreme left, which in this case leads to Box No. 1 at the corner of High Street. If the plugs are in the holes marked *p*, *p*, *p*, it would show that this box is being fed from this particular substation; but if these plugs were *not* in, it would show that Box No. 1 was not fed from this substation, and, if the engineer wished to know which substation fed this box, he would have to look up Substations No. 2 and No. 8, as his diagram of cable network, Fig. 13, would show him that it might be fed from either the one or the other.

Provision is made on the substation card for miscellaneous information, such as size of transformers in use, inspections made, etc.

The substation switchboards and the cables radiating therefrom having been dealt with, each section pillar, network box, and transformer kiosk was treated in like manner.

Fig. 14 is a tray in the filing system representing a section pillar (No. 1 six-way), and the position of the plugs will, as in the previous case, indicate which cable is being fed through this section pillar. Thus, if the row of plugs above the line marked "New Street and High Street" are all *in*, it would show that the cable from this section pillar to the corner of New Street and High Street (which enters Box No. 2) is connected on at the section pillar; but if the plugs were *out*, it would show that this cable was disconnected at the section pillar. Likewise, if the plugs above the line "Feeder from Kiosk" were in, it would indicate that this section pillar was being fed from Kiosk No. 1, in which case it would possibly be working in parallel on its low-tension side with the low-tension of Substation No. 1; but this fact would be ascertained by looking at the diagram of those boxes where it was possible to disconnect the low-tension network. Such diagrams will be given later on.

Fig. 15 is a tray in the filing system indicating the low-tension connections in the transformer kiosk, plug-holes and plugs again being used to indicate how the cables leaving the kiosk are connected, the plugs being left out where a disconnection has been made.

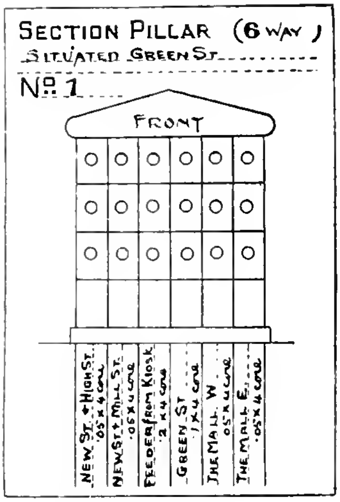

Fig. 14. A Plug-Diagram of a Section Pillar

Figs. 16 and 17 represent a four-way and a six-way network box respectively; let us say Box No. 4 and Box No. 1. It will be again seen that the presence or absence of the plugs in the plug-holes will show how the cables are connected in each box.

Having now made a full set of diagrams for the whole system—and these are very cheaply obtained by using diagrammatic forms, because photographic prints can be got of the various sets of diagrams required—these are firmly glued down onto trays or slides made of hard wood and holes are drilled wherever required for the reception of the bone or metal plugs.

Then a neat cabinet (Fig. 18), was made in which to house the completed trays, a drawer being provided for the plugs not in use and for the reference plans, the whole making a very handy and valuable addition to the records of the station.

The working of the system in actual practice is exceedingly simple. Say a change is made in any network, such as shutting down No. 1 Substation for repairs or alterations. The substation must be made "dead" on the high-tension and low-tension sides in order that the staff can work on the switchboards and transformers, but the low-tension network with its numerous consumers must be kept "alive." First of all, the engineer responsible takes the diagram of cable network and decides at which point to link up with another substation. Assume that by linking with *one* substation the requirements of the case can be met, and that he decides that No. 15 Substation shall take up the load for the time being. He then takes the diagram of No. 1 Section Pillar and sees if the cables to No. 15 Substation, via the Mall, W. and E., are connected at this section pillar. If they are *not*, these links or fuses must be put in, and he gives directions for this to be done, which puts Substations Nos. 1 and 15 in parallel on their low-tension sides. The next step is to take off Substation No. 1, and instructions are given for the high-tension switches to be drawn at the substation and the low-tension fuses to be drawn on all the cables leaving the substation. In the instance under consideration this would also necessitate the shutting down of the Kiosk No. 1, unless special arrangements were provided for feeding this from No. 1 Substation, irrespective of the high-tension switchboard feeding the transformers in the substation. Should the kiosk have to be shut down as well as the substation, its network must be fed from Section Pillar No. 1 also, and the links would have to be put in that would enable this to be done.

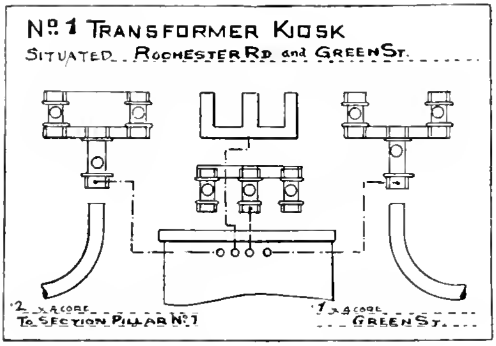

Fig. 15. A Plug-Diagram of a Transformer Kiosk

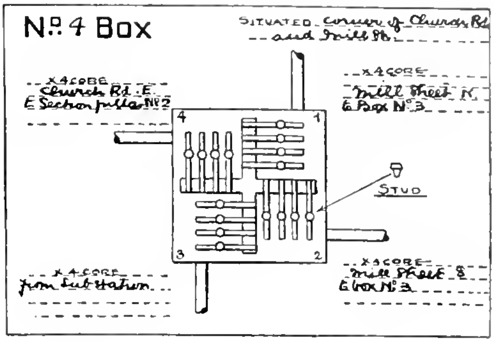

Fig. 16. A Plug-Diagram of a Four-Way Network Box

Having made all the disconnections necessary in the substation, the switch on the switchboard of the central station on the high-tension sub-feeder to Substation No. 1 is drawn, and the substation is "dead" and ready for the men to work on it. Stops are

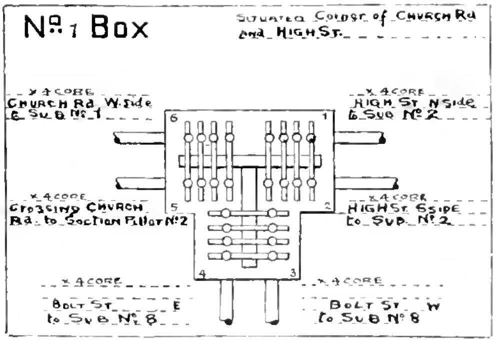

Fig. 17. A Plug-Diagram of a Six-way Network Box

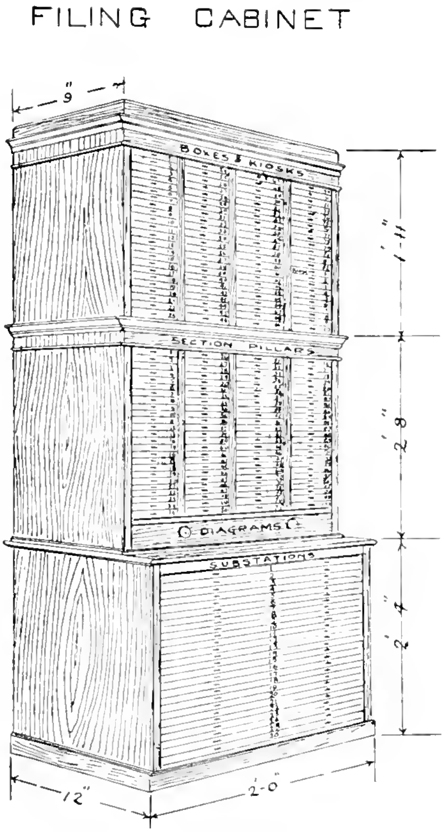

Fig. 18. Drawing of Complete Cabinet for Filing Trays Showing Records of Connections

inserted in the cable units of the low-tension board to denote that these are "alive" up to the fuse contacts on the cable side in order to prevent any one interfering with them. The switchboard, however, is "dead," and can be altered or cleaned as may be required. As each of these operations is carried out the plugs on the different trays affected by the changes are altered to suit the new conditions, and these are left as long as such conditions maintain.

At any time the whole of the conditions of linking and switching at any point of the system, either in the substation or on the network, can be seen at a glance, there being no necessity for hunting over files of papers to unearth remote reports, and trusting to memory is made unnecessary. As far as possible, all chances of mistakes being made are eliminated. As a further precaution against making mistakes, in the actual work of making changes in the substations, the cables are painted different colors; red, blue, and green being the colors used to designate the different phases, while the neutral cable is painted in stripes of all three colors.

Should additions or alterations be made at any time to either network, system, or substation, the cost of making the filing system conform to such alterations is but trifling, as, even if a substation is completely remodelled, it would only require that a new diagram be prepared and fixed to the tray reserved for that particular substation.

There is no doubt that further developments of the filing system are possible, and that the mains' superintendents in charge of networks differing from the one in Dublin would be able to modify it to suit their own purposes.

# HYDRAULIC EQUIPMENT OF THE GATUN HYDRO-ELECTRIC DEVELOPMENT, PANAMA CANAL

By Chas. A. Jackson

Mechanical Engineer, The Pelton Water Wheel Company

In the January, 1914, number of the General Electric Review we published eight articles describing the mechanical and electrical controlling devices of the Panama Canal lock machinery. The present number contains three articles which describe different stages of the production and distribution of electrical energy in the Canal Zone. The following article covers the hydraulic machinery of the installation and the features of its operation. In connection with this description see those by Mr. Eden and Mr. Bern.—Editor.

The permanent electric energy supply for lighting and power purposes on the Panama Canal will be derived from a hydro-electric plant which is being installed at Gatun spillway. The gross head available from Lake Gatun to mean tide level of the Pacific Ocean varies from a maximum of 91 ft. in the extreme flood times to a minimum of 79 ft., to which level the lake may possibly drop after three or four months of absolutely dry season.

The plant is therefore designed to develop the full power output when operating under an effective head of 75 ft. The station has a capacity of 6000 kw. and provision is made for the installation of an additional 6000 kw., the three necessary outlet pipes in the dam having been installed at the same time as the original pipe lines.

The water is taken from Lake Gatun through passages 12 ft. wide, fitted with wrought iron racks 29 ft. 7 in. high to prevent trash from entering the pipelines. Water is admitted into the pipelines through three head gates 10 ft. 6 in. in diameter. These gates are of massive cast iron construction, the seats where water tightness is required being made of bronze.

Each gate is equipped with two steel stems for raising and lowering. These stems are fitted with bronze nuts working in roller thrust bearings; and the nuts are fitted with steel bevel gears arranged to be operated by a 15-h.p., 220-volt, alternating-current motor with a speed of 750 r.p.m. The motor is placed between the stems and has shaft extensions on each side which carry two bevel pinions arranged to engage the bevel gears on the stem nuts. The stands which carry the stem nuts are equipped with hand-operating mechanism, arranged to be disconnected when the gate is operated electrically.

The gates are equipped with automatic control devices, consisting of a limit switch geared to one of the gate stems and a float switch actuated by the water in the pipe. The action of the control is as follows, the gate being closed and the pipeline empty: The gate motor switch is closed at the power house, which starts the motor and the gate begins to open. When the gate has opened a sufficient distance to fill the pipeline in about five minutes, the limit switch opens the circuit and stops the motor. The gate remains in this position until the pipeline is filled and the water rises in the 36-in. diameter air vent just below the gate. At this time it actuates a float switch and again closes the motor circuit, thereby causing the gate to be opened fully, when the limit switch again operates to prevent over-travel. The gate is closed by reversing the main switch at the power house, which causes the motor to operate, the limit switch again stopping the motor when the gate has reached the closed position. In case the electric power should fail, the gates can be hand-operated by two men.

Each of these gates is bolted to a pipeline 10 ft. 6 in. in diameter with an average length of 420 ft. The pipelines are made of $\frac{3}{8}$-in. steel plate in courses 8 ft. long, each course being made of three sheets to form the circumference. The center of each course is fitted with a 3-in. by $\frac{3}{8}$-in. Z-bar ring, which is also made in three sections. After the pipe was riveted together at the plant, the outside was covered with a layer of reinforced concrete to prevent rust.

The pipelines are led down to the rear of the power house on a uniform slope from the spillway, and are connected to the turbines in the power house through 90-degree bends having a radius of 70 ft. Each of the pipelines is arranged for attaching a Pitot tube testing apparatus while its unit is in service; and one pair of portable tubes for taking readings in planes of the pipe at 90 degrees from each other was supplied.

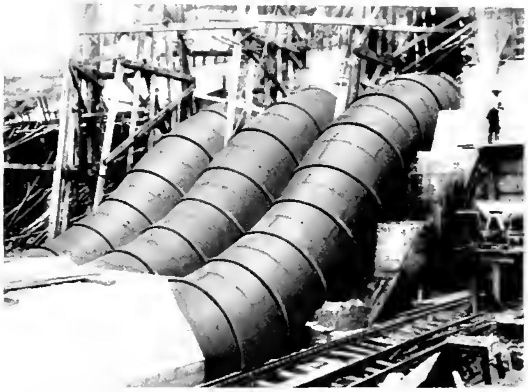

Fig. 1. Gatun Hydro-Electric Station. Close View of "Ogee" Curve Immediately below Headgates. Looking East

This is accomplished by fitting each pipe with two 6-in. saddle nozzle connections located 45 degrees on each side of the vertical center line of pipe. From these connections there are two Pitot tube supports placed across the pipe at right angles to each other with their thin sections pointing in the direction of the flow of water and fitted with guides for the Pitot tubes. These supports are bolted in the pipes and, while they are intended to remain permanently in the pipe, if desired, they can be removed very readily.

Each 6-in. outlet on the pipe is closed by a gate valve with tongued and grooved flanges which match the base on the Pitot tube apparatus. Each Pitot tube is arranged to measure both the static and velocity heads at practically the same point in the pipe, and readings are obtained by means of "U" tubes containing a colored liquid having a specific gravity of about 1.25. Carbon tetrachloride, thinned with gasolene to the proper specific gravity and colored red, is usually used for this purpose.

One end of each "U" tube is connected to the static and the other to the velocity side of the Pitot tube; the difference in height of the colored liquid columns is read, from which the velocity of flow in the pipe is calculated.

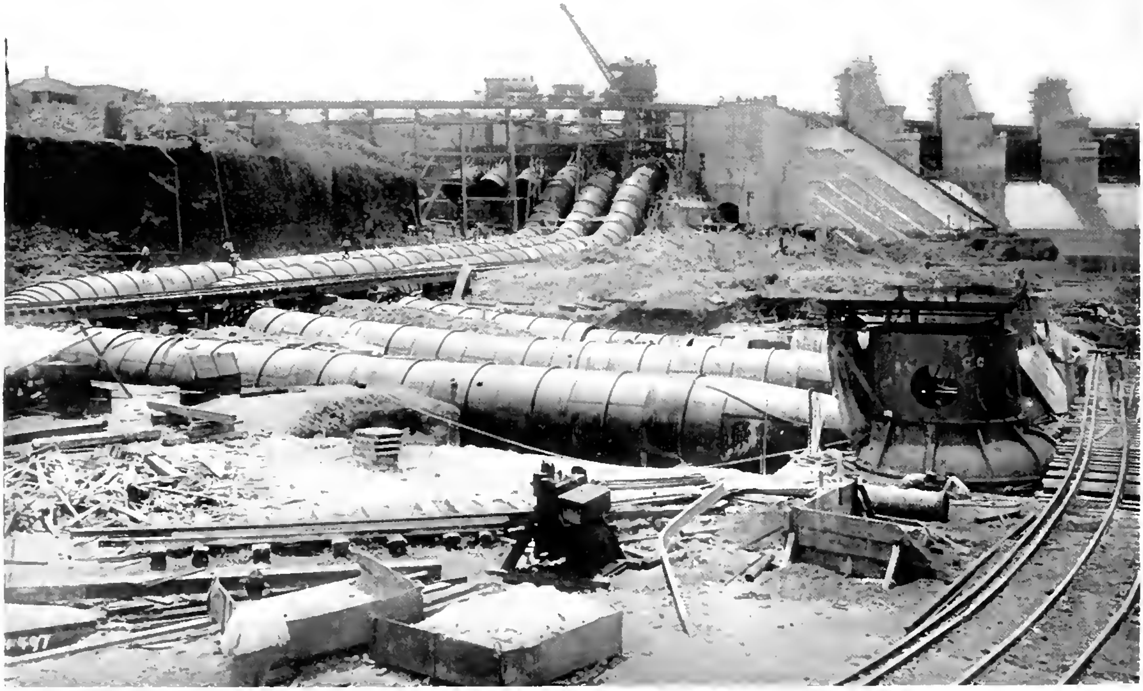

Fig. 2. Left-hand Side of Panoramic View of Gatun Hydro-Electric Installation under Construction, showing Pipelines and Turbines Erected

This form of Pitot tube is very simple and reliable, as it does not require compressed air to keep the head within readable limits and, at the same time, the difference between the static and velocity heads is read off directly.

In order to measure the flow in any pipeline, it is only necessary to bolt the Pitot tube base plates to the valve flanges and open the gates, when the tubes can be pushed into the pipes and readings taken. When the test is completed, the Pitot tubes are withdrawn until they clear the gates; then the valves are closed and the apparatus can be removed.

There are three 2200-kw. main generating units, each of which is driven by a special 50-in. vertical single-runner Pelton-Francis turbine having a maximum capacity of 3600 h.p. when operating under an effective head of 75 ft. and at a normal speed of 250

Fig. 3. Gatun Spillway Dam, looking South from Bridge, showing 14 Crest Gates. Ogee Dam and Baffle Piers. Hydro-Electric Station at Left

Fig. 4. Right-hand side of Panoramic View of Gatun Hydro-Electric Installation under Construction, showing Ogee Spillway Dam

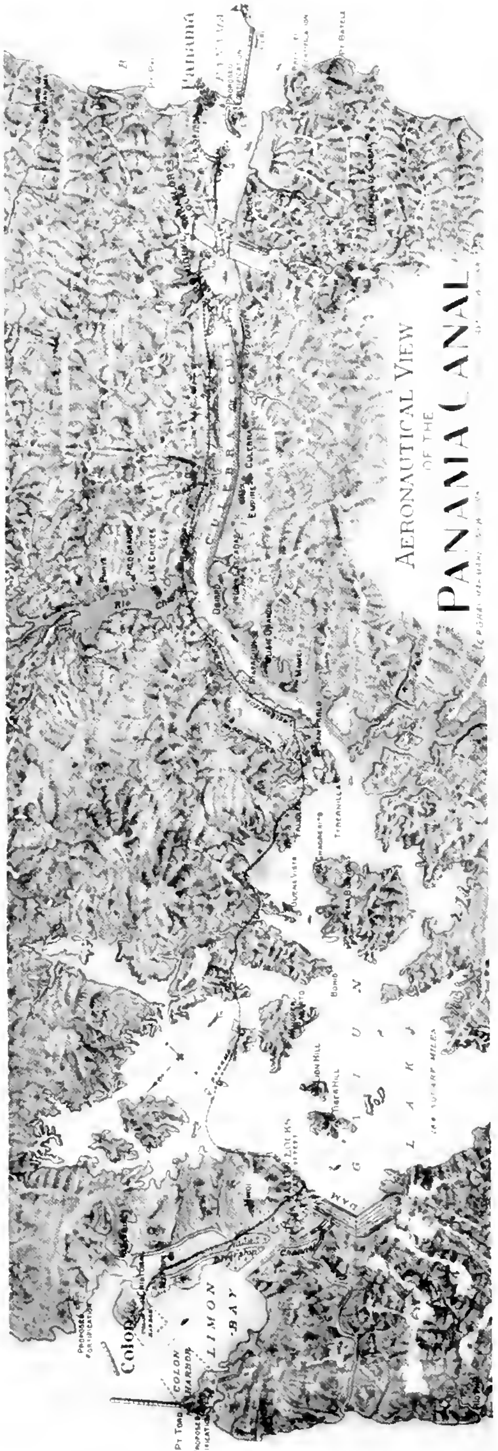

Fig. 5

revolutions per minute. The turbines are located at such a height that the center of the runners is 20 ft. above tail water.

The water is discharged through steel-lined concrete draft tubes, which are 71 in. in diameter at the discharge from the runners and increase to an elliptical section of 9 ft. by 17 ft. at the outlets, which are horizontal, there being a 90-degree bend in the tubes. The linings are made of ¼-in. steel plates, which were fitted together in the shop and shipped knocked down.

The turbines are of the spiral-case type and are fitted with heavy cast iron distance rings which carry the generators. The weight of the revolving parts of each generator and turbine is carried on a roller thrust bearing mounted on top of the generator. The turbine is so designed that the runner exerts an upward thrust of 20,000 lb. when working at full capacity, thereby relieving the thrust bearing of that amount of load.

Oil for the thrust bearing is supplied by a small pump geared to the main turbine shaft, and a tank is provided below the pump to receive the overflow from the bearing. In this way a constant circulation of oil is maintained. As this oil returns to the suction tank, it passes through the lower guide bearing on the main shaft and lubricates it.

The runners of the turbines are made of a special bronze and weigh approximately 7000 lb. each. They are bored taper and held in place on the lower end of the shaft by means of bronze nuts. The surfaces of runner vanes are all hand finished to reduce hydraulic losses.

The speed of the turbines is controlled by Pelton oil-pressure governors, which are mounted on the distance rings and are driven by bevel gearing from the main shaft. Tachometers are mounted above the governors on supports bolted to the distance rings. The tachometers are directly connected to the governor heads.

The governors are fitted with small electric motors for varying the speed of the main units for synchronizing purposes, and a device is provided on each governor for varying the permanent drop in speed from no load to full load. This can be adjusted for any variation from 5 per cent drop to absolutely constant speed from friction load to maximum load. The governors are also fitted with hand-control mechanism for adjusting the gates independently of the oil pressure.

The wicket gates for controlling the supply of water to the runner of the turbine are steel castings with hand-finished surfaces. Each gate has its pivot stem extended upward through a packing gland and is fitted with an operating lever. All the gate levers are connected to the gate ring by means of bronze links, and the gate ring is connected to the governor rockshaft. All of the regulating mechanism is therefore outside the turbine case except the gates themselves. The water passages on each side of the gates are provided with renewable rolled steel wearing plates.

The pressure oil for actuating the governors is supplied by two Pelton rotary pumping units, driven by 10 h.p. alternating-current motors at a speed of 375 r.p.m., each pump being capable of supplying the governors on all three units. The governors work on an open system, there being no vacuum chambers used. The discharge oil from the governors is led into oil sump tanks, from which it passes into the suction of the pumps. Each oil pump is connected to a steel pressure-oil receiver with an air space above the oil. The oil sump tanks and pipe connections are installed in duplicate and valves are provided to enable one set to be cleaned while the other is in service.

The complete hydraulic equipment for this installation, including racks, headgates, pipelines, Pitot tube testing apparatus, turbines, governors and oil pumping units, was designed and built by the Pelton Water Wheel Company; and all electrical apparatus, including headgate motors, limit switches, float switches and motors for driving the oil pumps, was supplied by the General Electric Company.

The shipping weight of the material furnished by the Pelton Water Wheel Company, including the electrical apparatus purchased by them from the General Electric Company, was approximately one thousand tons.

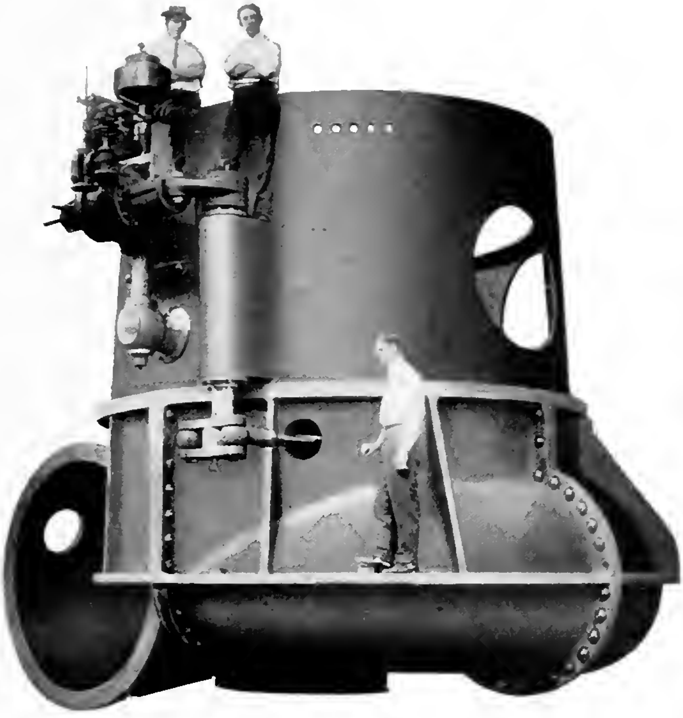

Fig. 6. 3600 H.P. Pelton-Francis Turbine

# ELECTRICAL EQUIPMENT OF THE GATUN HYDRO-ELECTRIC DEVELOPMENT, PANAMA CANAL

By T. S. Eden

Alternating Current Engineering Department, General Electric Company

This article is confined to a description of the electrical generating machinery of the Gatun stations. The number, rating, and location, of the generating units, exciters and motor-generator sets are given; and a brief description of the current-limiting reactance coils that are used in the station is included.—Editor.

The tremendous water storage in Gatun Lake has afforded the U. S. Government a excellent means of providing electric energy for lighting and power purposes on the Panama Canal. This has been accomplished by the development of a hydro-electric station at Gatun dam with a capacity of 6000 kw., provision being made to increase this to an ultimate capacity of 12,000 kw.

For three or four months of every year there is absolutely no rainfall on the Isthmus. During this period it is desirable to conserve the water to as great an extent as possible; consequently, maximum efficiency was demanded for the apparatus from both the waterwheel and generator manufacturers making bids on the installation. The complete electrical equipment was manufactured by the General Electric Company.

### Generators and Direct-Connected Exciters

There are three main generating units of the revolving field type, each being provided with a direct-connected exciter. The generators are three-phase, 25-cycle, with a guaranteed continuous capacity of 2000 kw. at 0.8 power-factor at 2200 volts and 250 revolutions per minute, and with an overload rating of 2500 kw. at 0.8 power-factor for two hours.

The exciters are of 50 kw. capacity at 125 volts, each being capable of furnishing exciting current for two generators under the maximum guaranteed load.

The units are of the vertical type and are similar in arrangement, with the exception of the exciters, to the installation of the Schenectady Power Company at Schaghticoke, N. Y., described in the General Electric Review, April, 1909.

The generators are carried on heavy cast iron distance rings furnished by the Pelton Water Wheel Company, the stationary armatures being bolted to these rings. The thrust and upper guide bearing support consists of a very rigid iron casting, bolted to the top of the stationary armature.

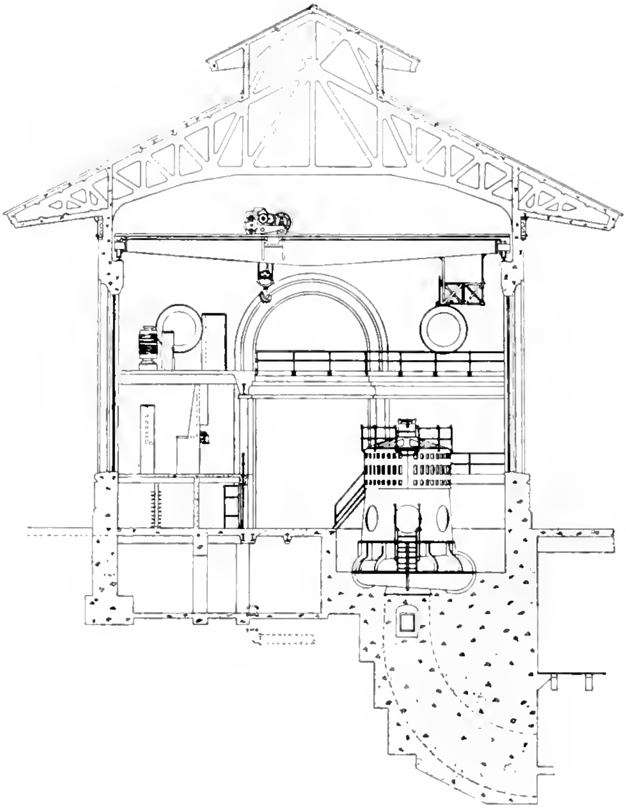

Fig. 1. Cross Section of Gatun Power House

The thrust bearings are of the roller type, manufactured by the Standard Roller Bearing Company, Philadelphia, Pa. These bearings carry the weight of the complete revolving element, consisting of the generator field, No. 1

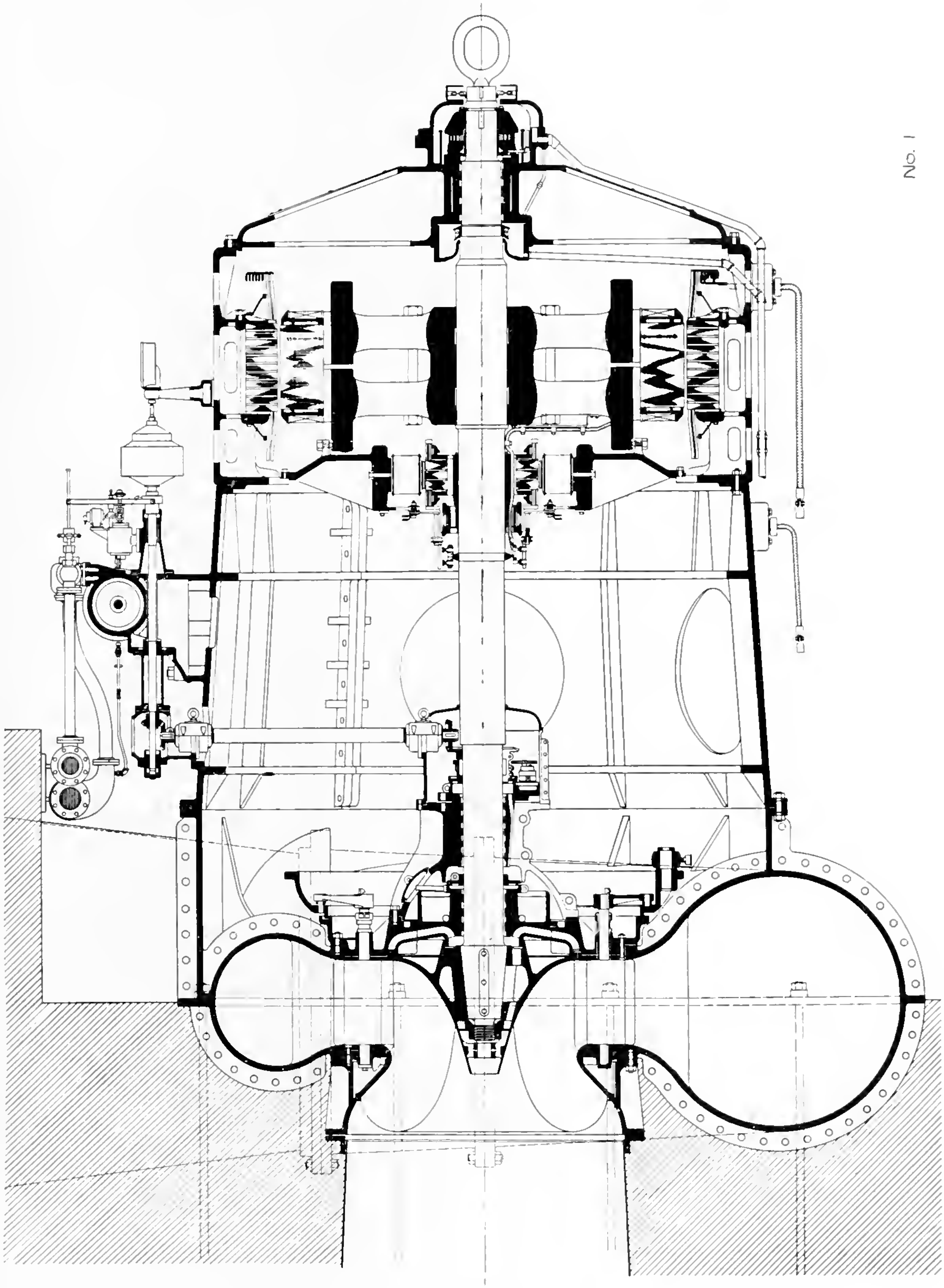

Fig. 2. Cross Section Through Waterwheel, Generator and Exciter

exciter armature and turbine runner, which are mounted in this order on a one-piece shaft. The weight thus suspended is 32 tons. The exciter magnet frame is supported by lugs cast on the stationary armature of the main generator.

Fig. 3. Interior View of Gatun Hydro-Electric Station

The exciter is readily accessible through large holes in the distance ring, a platform being provided inside the ring from which the exciter commutator and generator collector rings may be reached.

Provision is made for securing the magnet frame of the exciter to the revolving element of the generator, so that the complete rotating element, together with the exciter frame, is raised at once in unassembling.

For inspection of the roller bearing, it is necessary simply to remove a speed limiting switch from the top of the shaft and the upper half of the bearing housing. There are two guide bearings, one immediately below the thrust bearing, furnished with the generator, and the other above the waterwheel, furnished by the waterwheel builder. The arrangement of the complete unit is shown clearly in the cross sectional view given in Fig. 2.

The generators, under factory tests, showed an efficiency of 95.1 per cent at 2000 kw., 0.8 power-factor; 94.3 per cent at 1500 kw., 0.8 power-factor; and 92.5 per cent at 1000 kw., 0.8 power-factor. The guaranteed temperature rises of 40 deg. C. above room temperature, of 25 deg. C. under continuous operation at full load, and of 55 deg. C. rise after two hours run at 25 per cent overload, were met with an ample margin. The revolving field was given a running test at twice the normal speed in the testing pit which is provided for this special purpose.

All of the apparatus was subjected to the most rigid and minute inspection during manufacture by representatives of the Isthmian Canal Commission. The insulation of all windings was made moisture-proof on account of the extreme climatic conditions on the Isthmus.

### Reactances

Current limiting reactances were provided to give 5 per cent reactive drop, at 2500 kv-a., 2200 volts, three-phase, 25 cycles. While the generator windings are sufficiently rigid to stand the strain of a short circuit under full load, these reactances will reduce the shock on the windings and will also serve to render the operation of synchronizing the machines easier and safe. Fig. 4 shows the construction of these reactances.

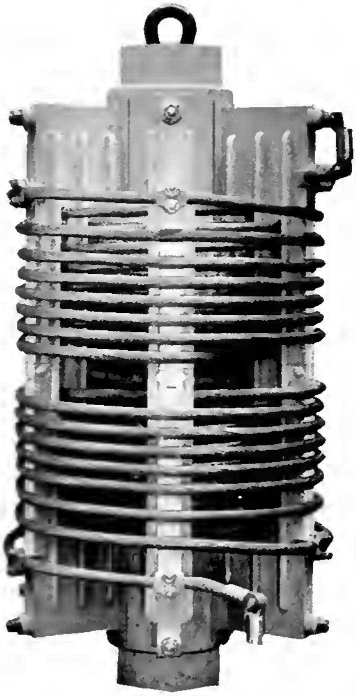

Fig. 4. Current-Limiting Reactance with Concrete Core

**Motor-Generator Sets**

In addition to the direct-connected exciters, two motor-driven exciters are supplied. These consist of a 100-kw., 125-volt, 500-r.p.m. generator, direct connected to a 150-h.p., 2200-volt, 25-cycle squirrel-cage type, induction motor. These are mounted on a common base plate and provided with three bearings.

# SWITCHBOARD EQUIPMENT FOR GATUN HYDRO-ELECTRIC STATION, PANAMA CANAL

By Emil Bern

Switchboard Engineering Department, General Electric Company

The general scheme of controlling and distributing the electrical energy in the Gatun power station forms the subject matter of this article. The fundamental features of the station wiring, instrument and control board, exciter board, and the bus and switch compartments, are described and discussed.—Editor.

The Gatun hydro-electric station is located at the dam of the artificial Gatun Lake.

This body of water, fed by the Chagres River, not only carries the ships the greater part of the way across the Isthmus on a level about 85 feet above the oceans, and supplies the water for passing them through the locks from sea to sea, but it also turns the wheels that generate the electric current for lighting the canal, for operating the gigantic gates and other locking machinery, and for the locomotives which tow the ships through the locks. Electric current will also be used for coal handling plants at both ends of the canal, for machine shops, water works, dry docks, and possibly in the future for hauling trains on the Panama Railroad. To insure continuity of service a steam-electric station at Miraflores, erected a few years ago to supply electric power for construction work, will be held ready to pick up the load when necessary.

On account of the great distance, the current is transmitted at a voltage of 44,000 from the power stations to both ends of the canal. The step-up transformers are, however, not located in the power plants, but in

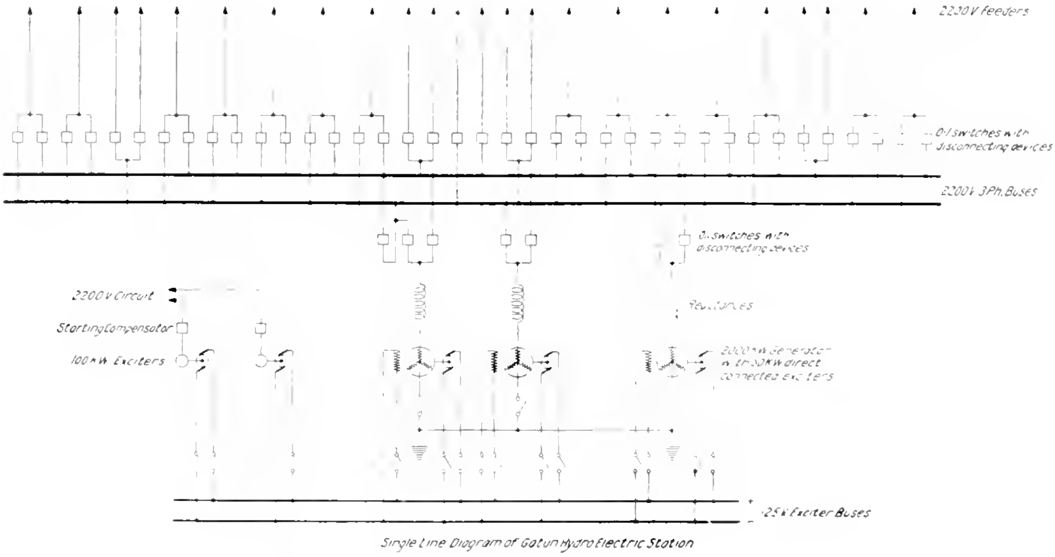

Fig. 1 Single Line Diagram of Gatun Hydro-Electric Station

substations in their vicinities; therefore, the power plants generate and distribute only 2200-volt current.

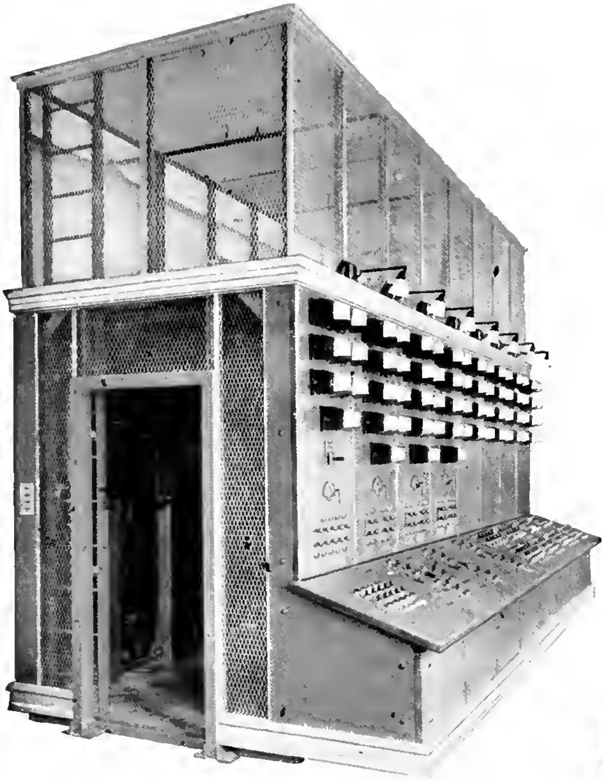

Fig. 2. Instrument and Control Benchboard in Gatun Hydro-Electric Station

### Station Equipment

The Gatun hydro-electric station has at present a capacity of 6000 kw. divided among three generators; and the station plans anticipate the possibility of doubling this equipment, should that amount of power be required for the Panama Railroad. Fig. 1 shows a single line diagram of the principal circuits and apparatus in this station, from which it will be seen that each of the three 2200-volt, 25-cycle, 2000-kw. generators is provided with a 50-kw., 125-volt, direct-connected exciter. In addition to these, there are two 100-kw. exciters driven by 2200-volt induction motors. These exciters can also be used for charging the control battery.

The double bus, double switch system was naturally selected for this station as being the most flexible for the requirement of uninterrupted service, which the engineers of the Isthmian Canal Commission have so carefully considered, though without superfluous complications.

### Instrument and Control Board

The main switchboard is of the benchboard type, as shown in Fig. 2, with vertical rear board for relays, watthour meters, graphic instruments and control battery equipment. The space between the front and the rear boards is enclosed by grille work with doors at both ends, and a metal moulding extending along the floor and the top of the board gives a finished appearance to the whole. On the top of the switchboard is a second story, for the electrically controlled generator and exciter rheostats, accessible by means of a ladder inside the structure. The first panel from the left in the benchboard controls the exciters, the next three the generators, and the remaining four the twenty-four feeder circuits. The system of connections is represented by dummy busses of polished copper on top of the bench. Fig. 3 shows the arrangement of operating busses and fuses, potential busses, instrument resistances, and the channel iron risers with distributing tubes, which carry the instrument and control leads to their points of connection on the board.

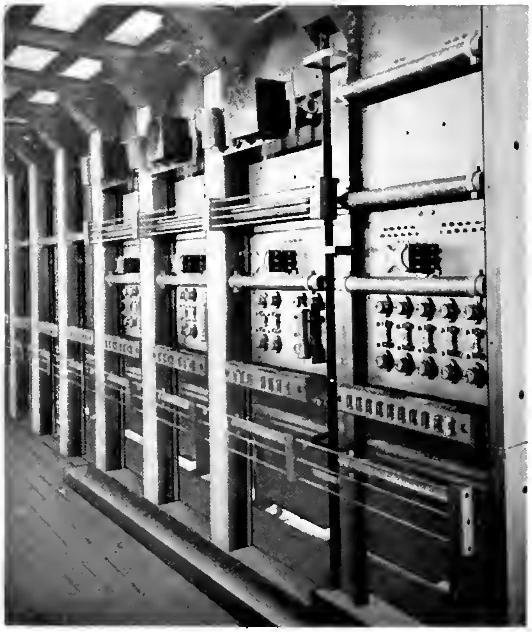

Fig. 3. Interior of Benchboard

A generator voltage regulator, transferable to either of the two sets of busses, is installed on a separate pedestal which also carries the synchronism indicators and clock.

### Exciter Board

As mentioned above, the exciters are controlled from the benchboard, but the electrically-operated exciter switches and field switches are mounted on a separate board located so as to make the exciter connections as short as possible. This arrangement eliminates the exciter busses and the main connections from the control board, but leaves the control of the whole equipment in the hands of the operator.

### Bus and Switch Compartments

The bus and switch compartments are located on two galleries as shown in Fig. 4. On the upper are located the control board near the end of the station (that may be extended) the generator reactances, the compartment for generator current and potential transformers, and the generator oil switches. From the oil switches, connections are made through the floor to the busses on the gallery below, on which gallery are also the feeder oil switches, and the compartment for the instrument transformers and cable bells. On the main floor just below this gallery is the cable vault with racks for the feeder cables.

All compartments are built of concrete with flame-proof doors. The busses and connections are made of solid copper rods of sufficient size to give a rigid construction even where the current is very small. After installation the busses and connections and all joints are heavily insulated with varnished cambric to make them safe.

The oil switches are solenoid-operated and provided with mechanisms for disconnecting them easily for cleaning and adjustment. This feature was described in detail in the January, 1914, issue of the GENERAL ELECTRIC REVIEW.

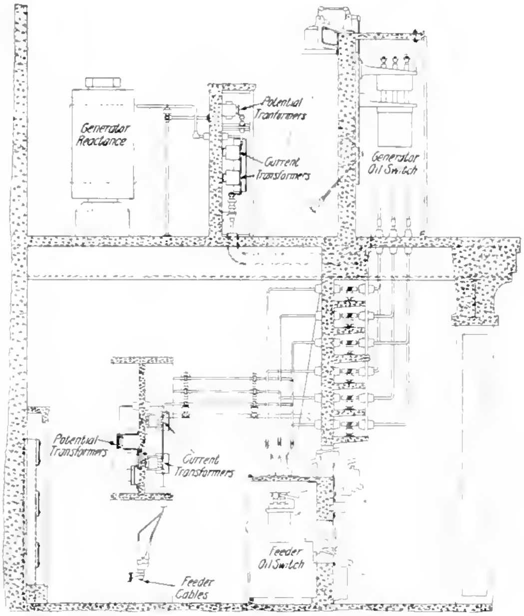

Fig. 4. Arrangement of Switching Apparatus

# PATENTS

## PART II

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Part I of this article, which appeared in the May number of the REVIEW, dealt with the laws relating to patents, the legal meaning of the terms "discovery" and "laws of nature" or "principles," and the things that form proper subjects of patents. The consideration of the rules of law on invention in this issue points to the uncertainties involved in an effort to forecast what the decision of the court may be, when this question arises in patent suits. Guesses as to the result may be made; and the larger the experience, and the better the judgment, the greater is the probability of arriving at a correct guess; but one of the litigants is certainly bound to be disappointed. The question of invention is one of special interest to the engineer engaged in designing new machines or developing new methods of manufacture.

## INVENTION VERSUS MECHANICAL SKILL

### General Characteristics

It will be noted that in the quotations from the Constitution and statutes hereinbefore given, no explanation of the meaning of the word "invented," or of the term "invention," is found; nor has any definition of them ever been incorporated in the statutes relating to patents. The determination of what constitutes invention has, therefore, been left to the courts.

Although the Patent Office may decide that a person has made an invention, and grant a patent therefor, nevertheless, should the owner of the patent bring suit against another for alleged infringement thereof, and the latter attempt to prove that the thing patented was not an invention, and the court agree with him, the patent becomes invalid, as if never granted. Such a result, however, is not derogatory to the efficiency of the Patent Office, or the ability of its staff. The Office in case of application for a patent considers whether the thing sought to be patented required invention; but the prosecution of the application is in secret, as far as the public is concerned, and thus the Office cannot have the benefit of such a full presentation of evidence and argument, on the question of invention, as may be brought to the attention of the court by contestants in a suit after the patent has been granted.

Moreover, it should be borne in mind that the question of invention is, after all, a matter of opinion, as to which even the courts have frequently differed in the same case upon the same presentation of facts. For no definite rule on the subject has been formulated further than the dictum that to entitle improvement to patent protection:

> * * * it must be the product of some exercise of the inventive faculties. (Pearce v. Mulford, 102 U.S. 112, 1880.)

which, as a definition, is merely going around in a circle; we are still in the dark as to the circumstances under which exercise of the inventive faculties is required.

Those faculties employed in making an improvement in a thing that does not amount to invention, are spoken of as *mechanical skill*, scientific skill, and the constructive ability or faculty; such improvement is the work of the *skilled mechanic*, or person skilled in the art or science to which the improvement appertains, or is a matter of engineering, and is not the product of invention.*

We may deduce an indefinite, but somewhat useful, conception of the nature of invention from the decision of Justice Matthews, as to what amounted in a certain case to nothing more than the exercise of mechanical skill:

> It [a patented identifying revenue mark or label] is but the display of the expected skill of the calling, and involves only the exercise of the ordinary faculties of reasoning upon materials supplied by a special knowledge, and the facility of manipulation which results from its habitual and intelligent practice; and is in no sense a creative work of that inventive faculty which it is the purpose of the Constitution and the patent laws to encourage and reward.
>
> It * * * seems to us not to spring from that intuitive faculty of the mind put forth in the search for new results, or new methods, creating what had not before existed, or bringing to light what lay hidden from vision; but, on the other hand, to be the suggestion of that common experience, which arose spontaneously and by a necessity of human reasoning, in the minds of those who had become acquainted with the circumstances with which they had to deal. (Hollister v. Benedict Manufacturing Co., 113 U. S. 72, 73, 1884.)

From the foregoing opinion, mere mechanical skill may be said to reside in the production of a thing, when it proceeds from application of the reasoning faculties naturally to be

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* For *Mechanical Equivalent*, see Section 9, under "Rules of Law on Invention.

expected of those skilled in the art to which the thing belongs; and is substantially the thing in all essential features, that intelligent mechanics or scientists in that calling may be expected to produce, if made acquainted with the problem to be solved, or result desired. The skilled mechanic is not one whose ability confines him, however, to mere imitation, but a mechanic, who may at least vary from the ordinary in minor particulars without departing from the real substance of the thing.

On the other hand, if the production of the thing does not appear to be suggested by and result merely from skilled knowledge combined with good reasoning, but to require an additional mental something of a so-called creative nature, it may be said to amount to invention. It is the additional mentally created something that the courts search for, and form an opinion as to its presence or absence, in suits where the question of invention is contested.

In line with the foregoing, we quote from an opinion by Justice Bradley:

> It may be laid down as a general rule, though perhaps not an invariable one, that if a new combination and arrangement of known elements produce a new and beneficial result, never attained before, it is evidence of invention. (Loom Co. v. Higgins, 105 U.S. 591, 1881,)

which with its suggestion of exceptions, still leaves us far short of knowing precisely in what invention consists.

Justice Brown, in a case before the Supreme Court, said:

> The truth is the word [invention] cannot be defined in such manner as to afford any substantial aid in determining whether a particular device involves an exercise of the inventive faculty or not. In a given case we may be able to say that there is present invention of a very high order. In another we can see that there is lacking that impalpable something which distinguishes invention from simple mechanical skill. Courts, adopting fixed principles as a guide, have by a process of exclusion determined that certain variations in old devices do or do not involve invention; but whether the variation relied upon in a particular case is anything more than ordinary mechanical skill is a question which cannot be answered by applying the test of any general definition. (McClain v. Ortmayer, 141 U. S. 427, 1891.)

The "fixed principles" referred to above, constitute *rules of law* which have been adopted by the courts as a guide to aid in deciding the question of invention. They are themselves based upon formulated opinions of the courts, and are subject to exceptions, which are also matters of opinion. Thus the whole foundation upon which the determination of the question of invention rests is a veritable honeycomb of opinion, and liable to those uncertainties that are dependable upon the necessarily human disposition and bent of mind of the court. We say this with no intention of belittling in the least the dealing of the courts with the subject, the difficulty of which is well attested by the fact that a decision as to invention is sometimes pronounced wrong, and reversed on appeal to a higher court.

### RULES OF LAW ON INVENTION

We will now consider the rules of law, which mainly by exclusion, that is to say, by designating those *operations that do not constitute invention*, enable the courts, with reasonable uniformity of result, to pass upon the question of invention in the cases brought before them in all their varying aspects. Our dealing with the subject must necessarily be limited, and substantially confined to a general presentation, and illustration in some instances, of such salient features of the rules as may be of peculiar interest to the engineer.

**1.** *It is not invention to produce a process, machine, manufacture, composition of matter or design which any skillful mechanic, electrician, chemist, or other expert would produce whenever required.* (*Walker.*)

No better insight into the reasons for this just rule can be given than by taking space here to quote from the opinion of Justice Bradley in a case in which the Supreme Court declared a patent invalid. It deserves careful reading:

> The process of development in manufactures creates a constant demand for new appliances, which the skill of ordinary head workmen and engineers is generally adequate to devise, and which, indeed, are the natural and proper outgrowth of such development. Each step forward prepares the way for the next, and each is usually taken by spontaneous trials and attempts in a hundred different places. To grant to a single party a monopoly of every slight advance made, except where the exercise of invention somewhat above ordinary mechanical or engineering skill is distinctly shown, is unjust in principle and injurious in its consequences. The design of the patent laws is to reward those who make some substantial discovery or invention which adds to our knowledge and makes a step in advance in the useful arts. Such inventors are worthy of all favor. It is never the object of those laws to grant a monopoly for every trifling device, every shadow of a shade of an idea which would naturally and spontaneously occur to any skilled mechanic or operator in the ordinary progress of manufactures. Such an indiscriminate creation of exclusive privileges tends rather to obstruct than to stimulate

invention. It creates a class of speculative schemers who make it their business to watch the advancing wave of improvement, and gather its foam in the form of patented monopolies, which enable them to lay a heavy tax upon the industry of the country without contributing anything to the real advancement of the arts. It embarasses the honest pursuit of business with fears and apprehensions of concealed liens and unknown liabilities to lawsuits and vexatious accountings for profits made in good faith. (Atlantic Works v. Brady, 107 U. S. 199, 1882.)

**2.** *It is not invention to produce an article which differs from some older thing only in excellence of workmanship.* (*Walker.*)

The incentive for excelling in workmanship proceeds from the better commercial advantage thereby gained in outselling competitors, or in a larger profit. Nickel plate, attractive finish, fine fit and high polish may be of marketable, but not patentable value.

**3.** *It is not invention to substitute superior for inferior materials, in making one or more or all of the parts of a machine or manufacture.* (*Walker.*) *Or merely to change the material.* (*Renwick.*)

It is obvious that substitution of steel or wrought iron for cast iron, or brass for either, where the purpose sought naturally turns attention to choice of the most suitable metal, is within the judgment of the skilled mechanic. And the same may be said respecting many other materials.

*Exceptions:* (*a*) The substitution of rubber-covered rolls for felt in wringing machines was pronounced invention. The rubber rolls were not only elastic, but had the additional quality of impermeability to water, whereby a new property or mode of operation of the machine, and a better result were obtained. (*b*) The advantage of using silver in the commutators and brushes of electrical motor meters in place of other metals is now obvious to the electrician acquainted with that art; along with high conductivity, good electrical contact is maintained in comparison with the use of such materials as brass, copper and platinum under long-continued service. The change to silver would no doubt have resulted in a good patent had not a description of the similar use of silver in electrical whirligigs been published in an almost forgotten little book years before. (*c*) The discovery that safranine-azo-naphthol, long thought to be insoluble and valueless, was soluble by prolonged washing, so as to produce a cheap and valuable substitute for vegetable indigo, was held a patentable invention. (*d*) *It may or may not be invention to substitute one material for another in a process, or in a composition of matter, and other rules than mere substitution must be applied to decide the question.* (*Walker.*) For instance, in a chemical process the reactions must be taken account of, and may be entirely different, and produce radically different results by substituting one element or agent for another.

**4.** *It is not invention to enlarge or strengthen a machine so that it will operate on larger materials than before.* (*Walker.*)

A circular sawmill, adapted to sawing boards from logs, was held not to be invention in view of small circular saws having been used for sawing lath from small wood blocks.

**5.** *It is not invention to change the size or degree of a thing, or of any feature or function of a machine or manufacture.* (*Walker.*) *Or merely to change size or degree.* (*Renwick.*)

(*a*) Invention was found absent in pulverized glue, ground from flake glue. (b) Paving stones made of an old shape, but with sides made rougher than before, to obtain a better bond, were held to be only a change in degree, and not patentable.

*Exceptions:* (*a*) In the early miner's lamp, the flame was protected from draughts by a coarsely perforated metal casing, which permitted passage of light; but the enlarged flame resulting within the casing from an explosive mixture of gas, readily passed through the perforations, and was communicated to the body of gas in the mine. Davy designed a safety lamp in which the casing was also perforated, preferably of wire gauze, with the perforations much smaller than in the old lamp, thereby preventing passage of the flame from the inside to the outside of the casing. Preventing passage of the flame was a new function or result of using the smaller perforations, and the manner of prevention was a new mode of operation. Although not patented by Davy, undoubtedly his lamp was an invention. (*b*) *It may or may not be invention to change the degree of heat, or other agent, used in a process, or to change the amount of ingredient used in a composition of matter, or to change the size of a feature of a design. The question of invention is to be decided by other rules than those of mere size or degree* (*Walker*). For example, old newspapers had been macerated to a pulp, which was treated with alkalies to remove, as far as possible, the oil of the printer's ink; the pulp was then made into paper board. Later on, paper board was made from old newspapers without removing the oil, with an improvement in toughness and elasticity before unknown in the finished product. Although it was demonstrated that a small amount of oil remained in the earlier product, which it was impracticable wholly to remove, nevertheless, the paper board in which all the oil of the ink was allowed to remain, and resulted in a superior product, was held to be invention. It could perform new functions with a new mode of operation by virtue of its toughness and elasticity.

**6.** *It is not invention to devise an aggregation of operations in a process, or of parts in a machine or manufacture* (*Walker*).

Non-patentable aggregation, as distinguished from patentable combination, has been considered hereinbefore in Part I, under the head of *Combination and Aggregation of Parts in a Machine.*

**7.** *It is not invention to duplicate one or more of the parts of a machine or a manufacture; unless the duplication causes a new mode of operation, or produces a new unitary result.* (*Walker.*) *Or merely to duplicate old devices.* (*Renwick.*)

(*a*) To place a pane of glass in the fare-box of a street car, so that the passengers could see into the box, was held not to be invention, when a glass had previously been provided for the benefit of the driver. (*b*) The furnaces of tobacco-curing houses had been provided with a single fire-place on each side of the chimney; it was held no invention to have two or more fire-places of different sizes in place of one.

*Exceptions:* (*a*) Single hydraulic turbines had been so installed on vertical shafts, that in operation the water exerted a considerable downward pressure on the step-bearing, additional to the weight of the shaft and wheel. Placing two turbines, face to face, on the shaft, so that the upward pressure of one counter-balanced the downward pressure of the other, was invention. The duplication of the turbines caused a new mode of operation and produced a new result. (*b*) A patent was sustained for an ice-cutting machine, which consisted of a plough-stock or beam with the usual guiding handles, provided with a number of cutters arranged one behind the other, each projecting downward more than the one in front of it; a deep groove was thereby cut in the ice by a single passage over it, each cutter preparing the way for the following one. The carpenter's plough with a single cutter for cutting grooves in wood by passing the tool back and forth until the groove was of the requisite depth was old; and it was contended that the several cutters in the ice plough were but duplication of the single cutter in the carpenter's plough, and not invention. But the court held that cutting the groove by a successive series of cuts simultaneously produced by a single passage of the ice-cutting machine was a different mode of operation from cutting the groove by successive cuts produced by a number of passages of the carpenter's tool.

**8.** *It is not invention to omit one or more of the parts of a machine or manufacture, unless that omission causes a new mode of operation of the parts retained.* (*Walker.*)

In the Nicholson wood pavement, the blocks were laid on a board foundation, with board strips between the rows of blocks. It was held that omission of the board foundation and strips, so that the pavement wholly consisted of blocks, did not constitute invention, because the parts omitted took their functions away with them, and the retained blocks did no more than they did before the omission, that is to say, they obtained no new mode of operation, and to make the change with this result was merely a matter of choice.

*Exception:* Before the advent of the meat-mincing machine, now in common domestic use, in which a wide, screw-shaped rib on the hand arbor receives the pieces of meat direct from the hopper of the casing, and feeds them forward with pressure against the mincing end-plate and revolving cutters, a similar machine had been made, in which the feed-screw did not extend back to the hopper; instead thereof, a set of radially-placed cutting blades was fixed opposite the hopper on the arbor, and another set engaging therewith on the inside of the casing, to give the meat a slicing, which was thought necessary before it passed to the screw. The cutting blades were not efficient in passing the meat to the screw, and in fact did more harm than good in causing the machine to choke. The discovery that by omitting the cutting blades and extending the screw back opposite the hopper, the screw would receive the meat without preliminary slicing, and feed it forward to the mincing devices without choking, as rapidly as it could be fed through the hopper, thus greatly increasing the efficiency and capacity of the machine, was pronounced invention.

**9.** *It is not invention to change a process, machine, manufacture or composition of matter, by substituting an equivalent for either of its parts; unless the new part, not only performs the function of the part for which it was substituted, but also performs another function, by another mode of operation.* (*Walker.*) *Or merely* *to substitute one old device for another.* (*Renwick*).

This section relates to so-called *equivalents* of parts in a machine or manufacture, of operations in a process, or of substances in a composition of matter—also termed *mechanical equivalents* in machines, and in manufactures and processes of a mechanical nature. Old equivalents are assumed to be ready at the hand of the skilled mechanic, or person skilled in the art to which the thing appertains, to be used by him, one in place of the other, as he may elect, without exercise of invention.

*It is safe to define an equivalent of one thing as a second thing that performs the same function, and performs that function in substantially the same manner (has substantially the same mode of operation) as the first thing.* (*Walker.*)

(*a*) Nitro-glycerine compounded with absorbent matter, as infusorial earth, forms dynamite. A compound formed of nitro-glycerine mixed with mica scales, called mica powder, was held to be the substantial equivalent of dynamite, although in mica powder the nitro-glycerine was not absorbed in the minute capillary tubes of infusorial earth, as in dynamite, but held upon the surfaces of mica scales. The compositions operated in practically the same way with the same result. (*b*) A bulb-syringe in which the inflow tube was connected with the bulb near the connection for the outflow tube was held equivalent to a syringe in which the tubes were oppositely connected with the bulb. No practically different function, operation or result pertained in one syringe over the other. (*c*) It was decided in respect to the operation of lamps in multiple-arc supplied from a compound-wound dynamo-electric machine, whereby the voltage at the lamps was automatically maintained substantially constant as the lamp load varied, that the lamps, as a load upon the machine, were the equivalent of a load of electro-plating cells connected in multiple with a machine of the same character. (*d*) Screws, levers, springs and weights are often equivalents of one another in mechanisms, the skilled mechanic being at liberty to substitute one for the other. But in some instances one of them, say, a spring, may operate successfully in the environments in which it is placed, and perform a desired function, where another, say, a weight, would fail, in which case they would not be equivalents.

**10.** *It is not invention to combine old devices into a new machine or manufacture, without producing any new mode of operation.* (*Walker.*) *Or merely to apply an old thing to perform its usual function with its usual mode of operation, or movement, or merely to change location, arrangement or direction of motion.* (*Renwick.*)

(*a*) There was no invention in substituting a figured hand-operated roller for pebbling leather in place of a smooth roller in a machine previously used for compressing leather. (*b*) Nor in giving paper collars the same surface that had been embossed upon other paper articles. (*c*) Nor in covering hard base-balls with a double cover, after such balls had been made with a single cover, and soft balls with a double cover.

*But while a new combination with an old mode of operation is not invention, an old combination with a new mode of operation may be invention.* (*Walker.*)

(*a*) The relative re-location of old parts of a reaping machine, so as to deliver the grain with the stalks lying cross-wise, instead of parallel, to the line of travel of the machine, with a decided advantage from so doing, was held invention. (*b*) In a seed-sower the centrifugal discharging wheel had been set on a vertical shaft, and spread the seed umbrella-fashion over a limited breadth of ground as the machine traveled along. Turning the shaft in the horizontal position, so that the wheel discharged the seed vertically many feet into the air and distributed them over a very much larger space, was held to constitute invention. (*c*) In a corn-shelling machine consisting of a rotating toothed cylinder and a stationary toothed casing for separating the corn from the cob, a traveling apron for feeding the ears to the sheller, and a winged beater, the latter revolved so as to knock back the ears that might ride upon the others and tend to choke the sheller. The operation was unsuccessful, as the choking was not prevented. It was discovered that by reversing the rotation of the beater so as to drive the riding ears forward, the choking was prevented. This was a new mode of operation, and the patent for the old machine as rearranged was sustained.

*A new combination with a new mode of operation, may be invention; even if all the parts thereof are old, and even if the function of the combination, is also old.* (*Walker.*)

Such is the opinion of the writer from whom this rule is taken, although he adds that several cases contain dicta contrary to the rule, but, nevertheless, believes, as he expresses it, that they must have resulted from incomplete thinking. He cites only one case, that of

Deere & Co. v. Rock Island Plow Co., 84 F. R. 176, 1898, which relates to Waterman patent 480,304, for an improvement in corn planters. The Circuit Court dismissed the bill for want of novelty, thus for non-patentable invention; this decision was reversed by the Circuit Court of Appeals, and the patent sustained by Judges Jenkins and Showalter, Judge Woods dissenting. We have in this case a good practical illustration of the uncertainty attending the determination of the question of invention.

**11.** *It is not invention to use an old process, machine, manufacture, composition of matter, or design, for a new and analogous purpose.* (*Walker.*) *Or merely to apply an old thing to a new purpose, or "double use" of an old thing, as sometimes termed.* (*Renwick.*)

This rule relates to what is called "double use" of an old thing, and applies to its use for a purpose, which, although it may be new, is, nevertheless, so suggestive of the use of the thing for the old purpose, that the new application may not amount to invention.

(*a*) A chamber with two walls having a space between them for a freezing mixture to preserve fish, was decided not to be invention in view of the older ice-cream freezer. The chamber constructed as described was a double use of the freezer. (*b*) A circular saw with removable teeth was not invention because of the earlier use of a circular disk with removable cutters for making tongues and grooves. The saw was put to a use analogous to that for which the disk was employed. (*c*) It was held not invention to use a compound-wound electric generator in a lighting system after the use of such a machine for supplying a system of electro-plating cells had been published, the purpose of the compound-winding in each case being to preserve a practically constant voltage at the lamps or cells (which were connected in multiple) when the number of them was varied. See reference to the same matter under Section 9, relating to equivalents. (*d*) Making changes in the method of communicating power from the armature of an electric motor to a street car axle by means of such well-known devices as friction clutches, cog-gearing and pulleys was held to be only a double use of old things.

*It may be invention to use an old process, machine, manufacture, composition of matter, or design for a new and non-analogous purpose.*

Although torsional springs had been used in clocks, and for closing doors, etc., it was held that the use of a torsional spring in a telegraph signalling key, to serve as the support for the key-lever in place of the old pivoted shaft, thus doing away with bearings, which were subject to wear, besides resulting in omission of the retractile spring for elevating the lever except when depressed by the finger, was for a new and non-analogous purpose, and invention.

*Where a new use of an old thing consists in combining it with other things in a new organization, invention may be present in the combination, though absent from the separate parts.* (*Walker.*)

Although a permanent magnet with a wire coil upon its polar end or ends was old, the combining of such device with other old devices to constitute a telephone, and thereby a new use of the magnet, was pronounced invention.

**12.** *It is not invention to change the form of a machine or manufacture, if in the domain of mere construction.* (*Walker.*) *Or merely to change the form.* (*Renwick.*)

(*a*) A luggage carrier for bicycles was held not invention, as involving merely a change in the form of an ordinary hand bag to fit the available space within the frame of the machine. (*b*) It was held that after a patent had been granted for a storage-battery plate containing rows of holes, there was no invention in making uniform rows of holes, or in merely making the holes round, square or triangular.

*But where change of form involves a change of mode of operation, or of function, or of result, it is invention, unless it is held to be otherwise in pursuance of some rule other than any that relates to form.* (*Walker.*)

(*a*) A coal-car body of conoidal form, instead of the old rectangular form, was held to be invention. The former was subjected only to tensile stresses, in place of the transverse stresses present in a rectangular car body, which introduced a new mode of operation, whereby the new design could be made of thinner and lighter material, and thus have less dead weight to be hauled. (*b*) The pole faces of an alternating current generator are sometimes shaped so that the length of the air gap varies from a minimum under the center of the pole to a maximum at the pole tip, in such way as to obtain approximately a sine curve distribution of magnetic flux over the pole faces, and therefrom the generation of a sine wave of electromotive force in the armature windings. Constructing the pole faces in this form, as contrasted with the older way of making them concentric with the armature face, and thus with an air gap of constant length over the entire pole face, would be invention, if new.

**13.** *It is not invention to change the proportions of a machine or manufacture.* (*Walker.*) *Or merely to change proportions.* (*Renwick.*) *But it may be invention to change the proportions of the ingredients of a chemical combination, or other composition of matter.* (*Walker.*)

Charles Goodyear discovered that by combining crude india rubber with from 6 to 20 per cent of sulphur, and heating the mixture, it became the well-known soft vulcanized rubber, possessing the characteristic of extreme elasticity with additional useful properties over the crude article. A patent was granted in 1844, and was reissued. Subsequently, Nelson Goodyear discovered that if the proportion of sulphur was increased to 25 per cent and more, then upon heating, the mixture assumed the hard properties of horn, was non-extensible, could be moulded, and would take a high polish; it became known as hard rubber or vulcanite. The product was patented in 1851; the patent was later corrected by reissue. The court decided that the product discovered by Nelson Goodyear, resulting from change in the proportions of sulphur and rubber, was invention. The change was accompanied by a change in the properties of the product, and thus a change in mode of operation.

**14.** *It is not invention merely to discover a new property of matter.* (*Renwick.*)

To discover a new property of matter must amount substantially to discovery of a law of nature, which is not invention. Renwick says:

> There does not appear to be any condition of facts in which the *simple* discovery of a new property of matter amounts to an invention; but there are undoubtedly cases in which such a discovery accompanied with a practical application of it, by which the newly discovered property is made available for a useful purpose, amounts to invention.

which is in line with our consideration of laws of nature, in Part I.

*(To be continued)*

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# TRANSMISSION LINES AND OUTDOOR SUBSTATIONS OF THE GEORGIA RAILWAY AND POWER COMPANY'S TALLULAH FALLS DEVELOPMENT

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The June number of the Review contained a descriptive article of the hydraulic features and generating station of the Georgia Railway and Power Company's new 100,000-h.p. development at Tallulah Falls. The present article deals with the 110,000-volt transmission lines and the outdoor substations. Of the latter, the Boulevard substation at Atlanta will be described in detail. It is the largest station of its kind, and the design involves many very interesting features.—Editor.

## Transmission Lines

The general layout of the transmission system is shown in the map, Fig. 1, and in the diagram, Fig. 2. As seen from these, there is a 110,000-volt double-circuit line from the generating station at Tallulah Falls to the Boulevard substation at Atlanta, a distance of 90 miles. About midway between these two points a tap is taken off for the Gainsville substation. From the Atlanta substation there are two 110,000-volt, double-circuit outgoing lines, one to Lindale, a distance of 80 miles, and the other to Newnan, a distance of 40 miles. The former is tapped at the Cartersville and Marietta substations. In addition to these main transmission lines, there is a 100,000-volt double-circuit line from the Tallulah Falls Station to Easley, S. C., for tying in with the Southern Power Company. The system is furthermore tied in with the Eastern Tennessee Power Company at Lindale, with the Columbus Power Company at Newnan, and with the Central Georgia Power Company at Atlanta.

## Tallulah Falls—Atlanta Line

This consists of six No. 4 0 copper conductors carried on a single steel tower line. Three wires are suspended in a vertical plane on each side of the tower, the vertical spacing being 9 ft. while the horizontal distance between the two circuits is 16 ft., giving a clearance between conductor and the tower members of 5 ft. 6 in.

The towers are of the American Bridge Company's rigid four-legged construction, Fig. 3, spaced between six and seven hundred feet apart on the average. They are provided with four crossarms, the upper for supporting the ground wires and the three lower for the line conductors. Their height is 66 ft., and they measure 5 ft. square at the top, 20 ft. at the base, and have a weight of 5554 lb. The design was based on the following load condition:

(1) A longitudinal pull of 4300 lb. at right angles to the end of any crossarm, which represents the stress due to the dead-ending of one conductor.

(2) A vertical load of 1,500 lb. at the ends of any or all crossarms, this being the weight of the wire and insulators in adjacent spans.

(3) A load of 1500 lb. in any direction at the top of tower, which corresponds to the wind pressure on the projected area of the tower.

(4) A load of 10,000 lb. at right angles to the line or parallel to the crossarms; that is, 2500 lb. at each crossarm. At the same time,

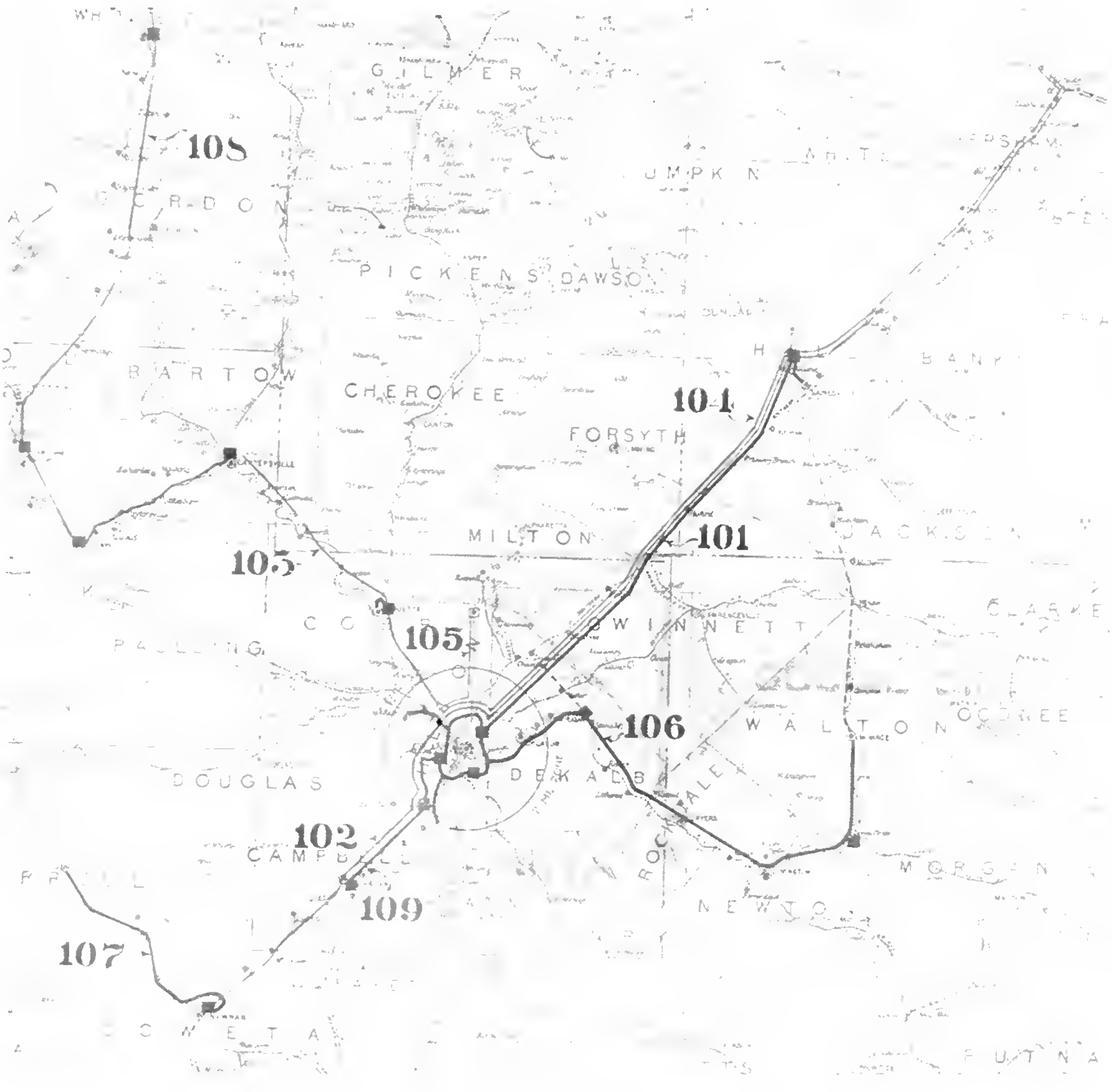


Fig. 1. Map of Section of Country Served by the Georgia Railway and Power Company

a pull parallel to the line or at right angles to the crossarms of 8000 lb.; that is, 4000 lb. in the same or opposite directions at each end of any single crossarm or at any one end of any two crossarms. The first condition represents the wind pressure on the projected area of the arms and wires themselves, and the second condition that two wires may be broken, one on each side of the crossarm at different ends, resulting in a couple which sets up torsional strains in the tower structure.

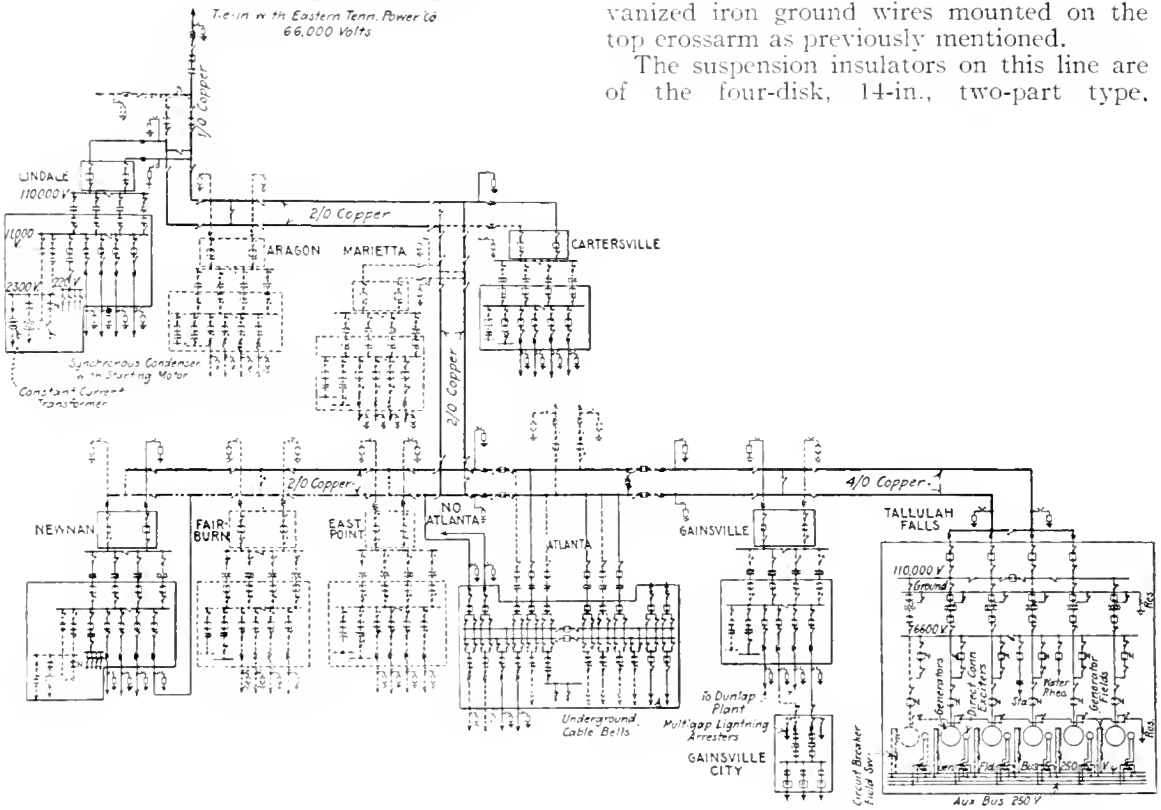


Fig. 2. Wiring Diagram of System

The crossarms are proportioned for a combining of the loads of Case 1 and Case 2, and 1250 pounds horizontal thrust at end of arm. The tower is proportioned for maximum combination of Cases 2 and 3 or 2 and 4. Unit stresses used are 25,000 pounds per square inch net for tension and $\dfrac{25{,}000}{1+\dfrac{l^2}{18{,}000r^2}}$ for compression.

The tower footings are made by extending the corner angles into the ground for a depth of 7 feet, cross angles being bolted to the bottom end.

For the line through the territory around Atlanta special towers are used, which have a height of 80 feet and weigh 8000 pounds. Besides these and the standard towers, angle towers are provided where the direction of the line changes over 10 degrees. These towers, Fig. 4, are of a heavier construction than the standard type and weigh 6880 pounds.

There are two 7/16-in. seven-strand galvanized iron ground wires mounted on the top crossarm as previously mentioned.

The suspension insulators on this line are of the four-disk, 14-in., two-part type, manufactured by the R. Thomas & Sons Company. The strain insulators, on the other hand, consist of five disks.

### Atlanta-Newnan and Lindale Lines

The construction of these two lines is identical, and the design resembles in general that embodied in the Tallulah Falls line. While both lines are of the double-circuit type, only one circuit is erected for each at the present time. The conductors are of No. 2/0 copper, spaced and mounted in a manner similar to the Tallulah Falls line. The towers have a height of 70 ft., measure 4 ft. at the top and 16 ft., at the bottom and have a weight of 4721 lb.

The design of these towers is based on the following load conditions:

(1) A longitudinal pull of 3000 lb. at right angles to the end of any one crossarm.

(2) A vertical load of 1200 lb. at the ends of any or all crossarms.

(3) A load of 1200 lb. pulling in any direction at the top of the tower.

(4) A load of 8000 lb. pulling at right angles to the line or parallel to the crossarms; that is, 2000 lb. at each crossarm. At the same time a pull parallel to the line or at right angles to the crossarms of 5000 lb.; that is, 2500 lb. in the same or opposite directions at each end of any single crossarm or at one end of any two crossarms.

The combination of loading and unit stresses is the same as for the towers with 4/0 wires.

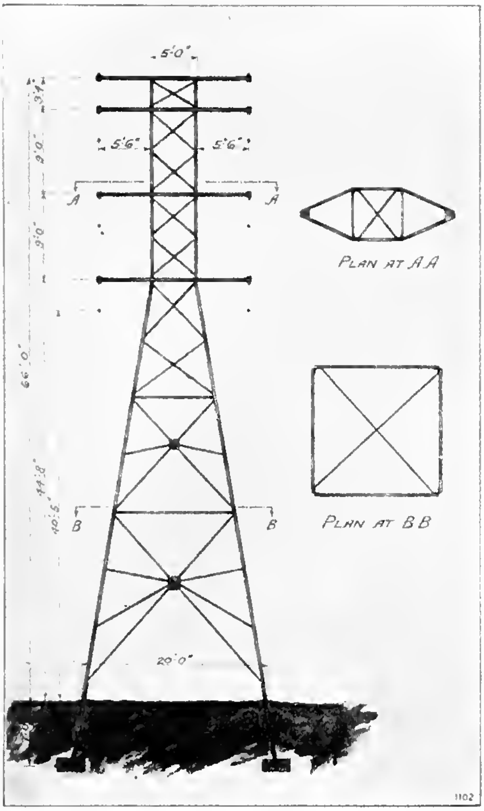


Fig. 3. Standard Suspension Tower, Tallulah Falls-Atlanta Line

The angle towers for these lines are also heavier than the standard type, weighing 6680 pounds each.

There will ultimately be two ground wires for these lines, although at present only one is in place. This consists of a 3/8-in. galvanized stranded steel cable.

The insulators for these two lines are of the Ohio Brass Company's manufacture. They have a diameter of 10 in., the suspension insulators consisting of 5 disks and the strain insulators of 6 disks.

Fig 4. Standard Strain Tower

Provisions are made on all transmission lines for sectionalizing in order to readily locate troubles, and in case of repairs this sectionalizing can be done at all the present substations as well as at the contemplated ones, where switching towers have been erected. In addition to this, means have been provided for sectionalizing every ten to fifteen miles. This being accomplished by connectors inserted in the loops on the strain towers. These connectors are made in the form of ordinary unions, and the lines can readily be opened up, cross-connected, and any sections cut out by the repair crew. After the trouble has been located and the repair made, the connections can be restored just as easily.

### Telephone Circuits

A telephone circuit follows all the transmission lines. It consists of two No. 4 copper-clad wires supported on the towers below the line conductors by 40,000-volt suspension insulators. Transpositions are made at every tower, and the circuit is protected by horn gaps arresters.

Fig. 5. Telephone Booth

Telephone booths, Fig. 5, are erected under the towers at intervals of four miles. These are provided with horn gap disconnecting switches, manipulated from the inside of the booths, for isolating the apparatus from the circuit when not in use. The equipments are furthermore protected with the usual 1:1 insulating transformer, lighting arrester and fuses.

### Substations

All the substations on this system are of the outdoor type, the high-tension apparatus being installed outdoors and the low-tension apparatus indoors. Nine stations are contemplated, as shown by the diagram, Fig. 2. Of these, six have been completed, while only part of the high-tension structure for the others was erected at the same time as the transmission lines. In this manner they serve as switching stations for sectionalizing the lines.

All the substations are of the same general design with the exception of the Boulevard station at Atlanta. This is the largest of them all, being at present time the largest of its kind in existence.

### Atlanta Substation

This station is located on Boulevard Avenue, adjacent to the north side of the city limits of Atlanta. It is laid out for an ultimate capacity of 60,000 kv-a., but at the present time apparatus is installed for only 30,000 kv-a. In order to make a description of this station clearer, it will be divided into two distinct parts; first, that dealing with the high-tension equipment, which is installed outdoors; and, second, that covering the low-tension equipment, which is indoors.

As seen from the diagrams, Figs. 2 and 16, there are at present two 110,000-volt incoming lines from Tallulah Falls and two 110,000-volt outgoing lines, one to Newnan and the other to Lindale. Ultimately, however, there will be two more outgoing 110,000-volt lines, one to each of the last named two places. The incoming lines enter the station through oil switches and connect directly with the two 110,000-volt buses, which can be paralleled by a tie-switch. Similarly, the two outgoing lines are connected to these buses through oil-switches.

There are three 10,000-kv-a. step-down transformer banks installed at the present time, space being provided for three future banks. These are connected to the buses through oil-switches, as shown in the diagram.

The arrangement of the apparatus and the general design of the station is shown by the foundation plan, Fig. 6, and the photographs, Figs. 7, 8 and 9. The transformer banks are located in the center of the station in two rows, and outside of these are the structures supporting the busbars and the high-tension wiring with the connections to the oil switches, which are located on the ground below. These busbar structures are of latticed steel work similar to the steel towers. They rest on concrete foundations, as do all the transformers, oil switches and lightning arresters. The structure and transformer tanks are thoroughly connected to a ground bus.

The busbars consist of copper tubing, which is suspended from catenary copper-clad steel cables. Turnbuckles are provided for taking up any slack or equalizing the stresses, and the messenger cables as well as the buses and other connections are insulated from the structure by 7-disk strain insulators of the Ohio Brass Company's make.

The secondary leads of the transformers are connected to a delta bus, which is mounted on a pipe frame-work back of the transformer banks. From there the connections are lead through bushings down into a tunnel which runs parallel to the transformers and into the basement of the low-tension switch house.

Each of the transformer banks consists of three 3333-kv-a. 110,000/11,000-volt shell-type, water-cooled, single-phase units, connected in delta on both the primary and secondary sides. Both windings are provided with four $2\frac{1}{2}$ per cent taps, so that a constant secondary voltage of 11,000 volts may be obtained with a variation in the primary voltage of 10 per cent above or below 110,000 volts. At the rated continuous full load of 3333-kv-a. the transformers have a guaranteed temperature rise not to exceed 40 deg. C.,

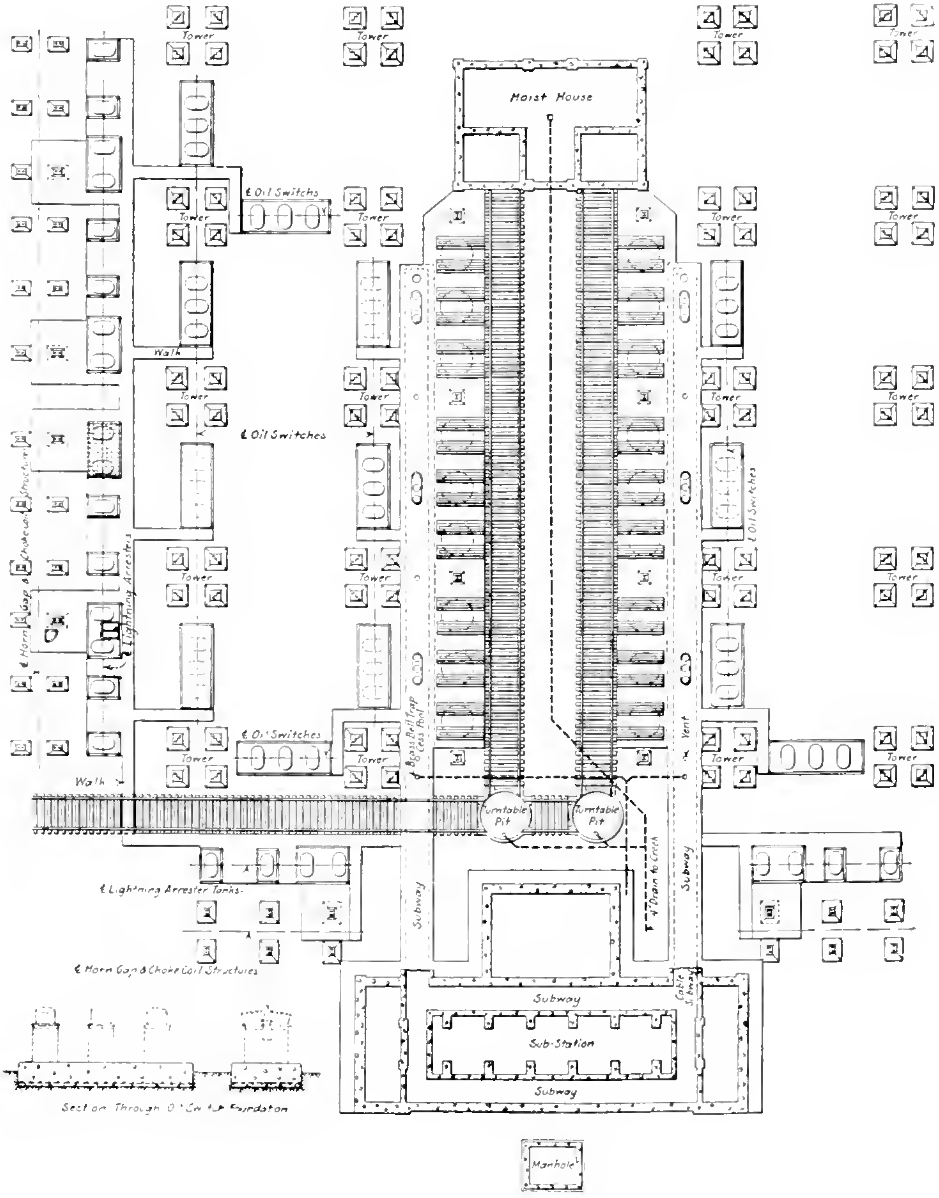
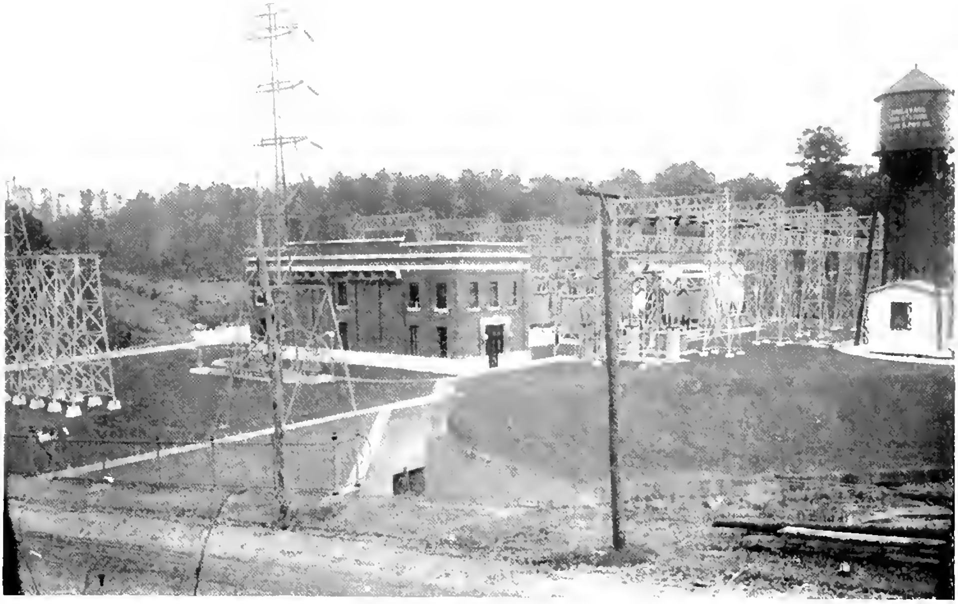
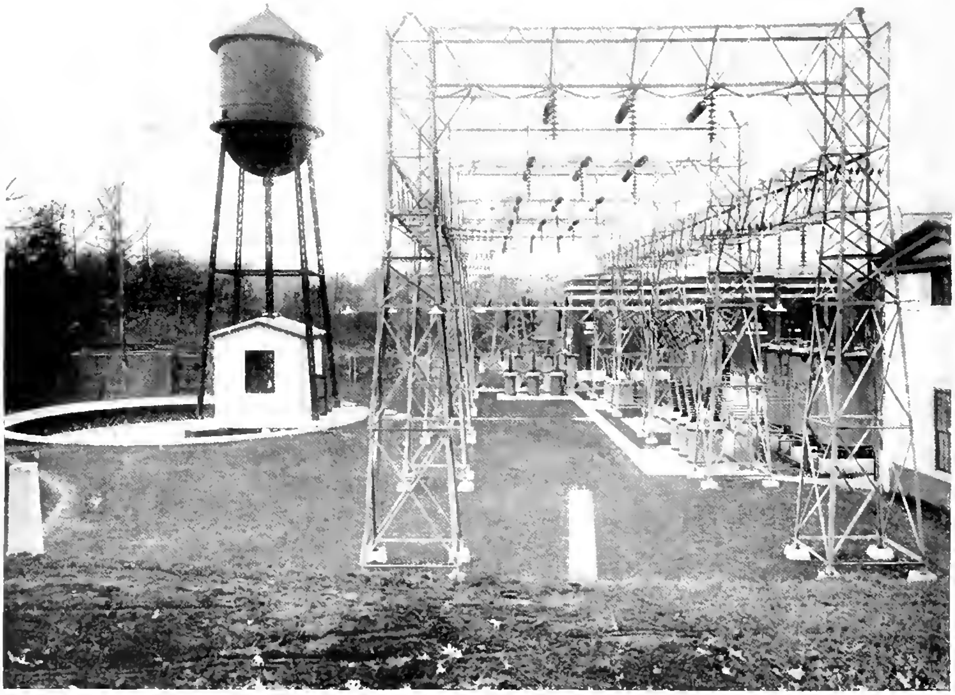


Fig. 6. Plan of Atlanta Substation





Figs. 7 and 8. Views of Atlanta Substation based on 16 gallons of cooling water per minute at 15 deg. C. For a 25 per cent continuous overload the rise is guaranteed not to exceed 55 deg. C. with 20 gallons of cooling water per minute.

The guaranteed efficiencies are:

| | $1\frac{1}{4}$ Load | Full Load | $\frac{3}{4}$ Load | $\frac{1}{2}$ Load | $\frac{1}{4}$ Load |
|---|---|---|---|---|---|
| 100 per cent power-factor . . | 98.5 | 98.6 | 98.5 | 98.2 | 97.0 |
| 80 per cent power-factor . . | 98.1 | 98.2 | 98.1 | 97.5 | 96.2 |

The regulation:

| | |
|---|---|
| 100 per cent power-factor . | 0.9 per cent |
| 80 per cent power-factor . | 4.4 per cent |

The transformers have been subjected to a one-minute high-potential test of 220,000 volts from primary to secondary and core, and 22,000 volts from secondary to core. Besides this, a potential of 220,000 at suitable frequency was applied across the full primary winding for a period of five minutes.

The transformer tanks are of round construction and are made of heavy boiler iron, with cast iron covers. The height to the top of the high tension leads is 16 ft. and to the top of the cover 13 ft. 6 in., while the diameter is 8 ft. The weight of the complete unit, including oil, is approximately 25 tons.

Pipe lines are installed below the transformers for both the oil and cooling water. By means of these any transformer may be connected with the oil filter presses or storage tanks, which are located in the repair house. For the cooling system it was necessary to drill four wells to a depth of about 450 feet, and the water is forced from these into a reservoir by compressed air. From the reservoir it is pumped by a submerged centrifugal pump into a 50,000-gallon storage tank, which is about 75 feet above the water level in the reservoir, whence it is fed by gravity into the cooling system. Provision is made so that the water in the tank can be emptied into either the waste or the reservoir if desired, for during the summer months the water in the tank may become too warm, when it will have to be let out and cooler water pumped in.

All of the high-tension oil switches are of the remote controlled, solenoid-operated type.

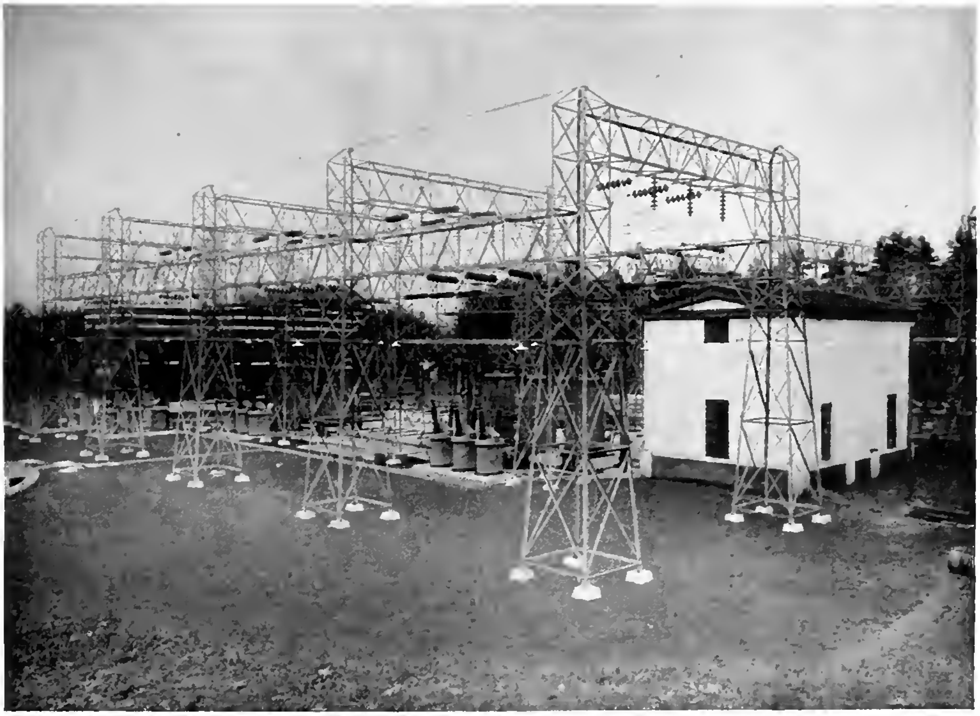


Fig. 9. Another View of Atlanta Substation

With the exception of the bus tie-switch, they are all automatic, being tripped by inverse time-limit relays actuated from current transformers in the switch bushings.

Disconnecting switches are installed, as shown in Fig. 16. They are mounted on post insulators in a slanting position so that they can be readily operated from the ground. To prevent them from accidentally opening, they are provided with safety catches, and the jaws are covered by specially designed hoods to protect them from sleet.

Each of the incoming and outgoing lines is equipped with a three-phase, four-tank, aluminum cell lightning arrester with choke coils and horn gap disconnecting switches. The transmission line ground wires are also continued over the station structure to give additional protection against atmospheric lightning disturbances.

A repair house is located at the further end of the two transfer tracks, which run parallel with and in front of the transformer banks (Fig. 13). Each transformer rests on a wheelbase and can readily be pulled out onto the transfer truck and moved into the repair house, where it is let down into a pit, by a crane so that it can easily be taken apart and repaired. By means of the transfer trucks it is, of course, also possible to interchange transformer units between the different banks, should this become necessary. As seen from the plan of the station, Fig. 6, two turntables are also provided near the low tension switch house and a single track extended clear out to the roadway, so that material can readily be unloaded from trucks or wagons and hauled into the repair shop.

The whole structure, as well as the apparatus, is painted a light gray color and all apparatus is distinctly marked. Besides giving a very pleasing appearance, this gray color causes the apparatus to absorb less heat in the summer, which is of the utmost importance in outdoor installations of this kind. Cement walks are provided where the operators are most likely to pass, and the whole property has been neatly graded and sodded.

Illumination is provided by incandescent lamps spaced around the station. They are provided with large reflectors which prevent any light from being thrown upwards so as to illuminate the bus structure. By keeping this dark, it is possible to detect any defective insulators.

The low-tension equipment is all installed in the switch house, which is a two-story building of red-faced brick with white marble trimmings and parapet. The system of connections is clearly shown in Fig. 16. There are four independent sets of 11,000-volt busbars which, however, are normally tied together so as to form only two sets, resembling a double U. The leads from the transformer secondaries are connected to either of these two sets by means of oil switches and double sets of disconnecting switches. A similar method of connection is used for all the outgoing feeders, of which there will ultimately be nine underground and six overhead.

Figs. 10, 11 and 12 represent plan views of the first and second floors, as well as a cross-section of the switch house, and show the general arrangement of the apparatus. As previously mentioned, the connections from the transformer secondary deltas run through bushings down to a concrete lined 7-ft.-tunnel below the transformers (Fig. 15), and through this tunnel to the basement of the switch house. These leads consist of 1-in. copper tubing supported on insulators, the phases being separated by barriers, as shown in the illustration.

The bus and switch structures are of enclosed construction made of pressed brick and alberene stone; the buses and disconnect-

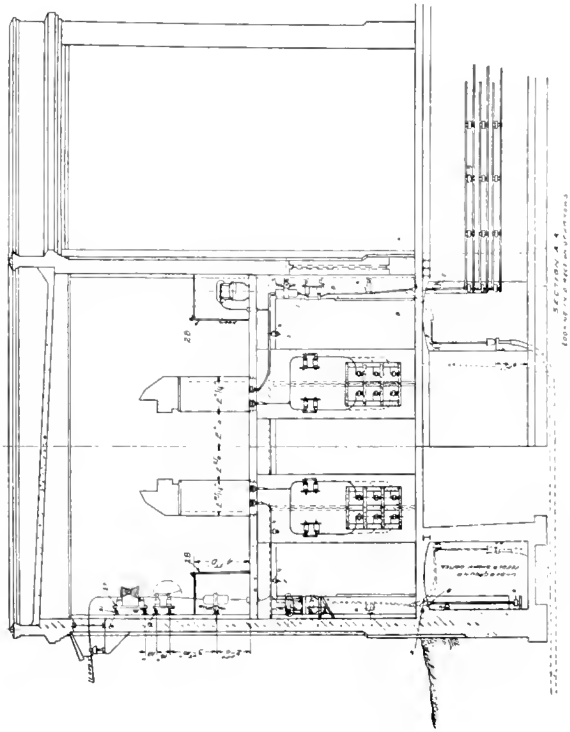


Fig. 10. Sectional Elevation of Building, Atlanta Substation

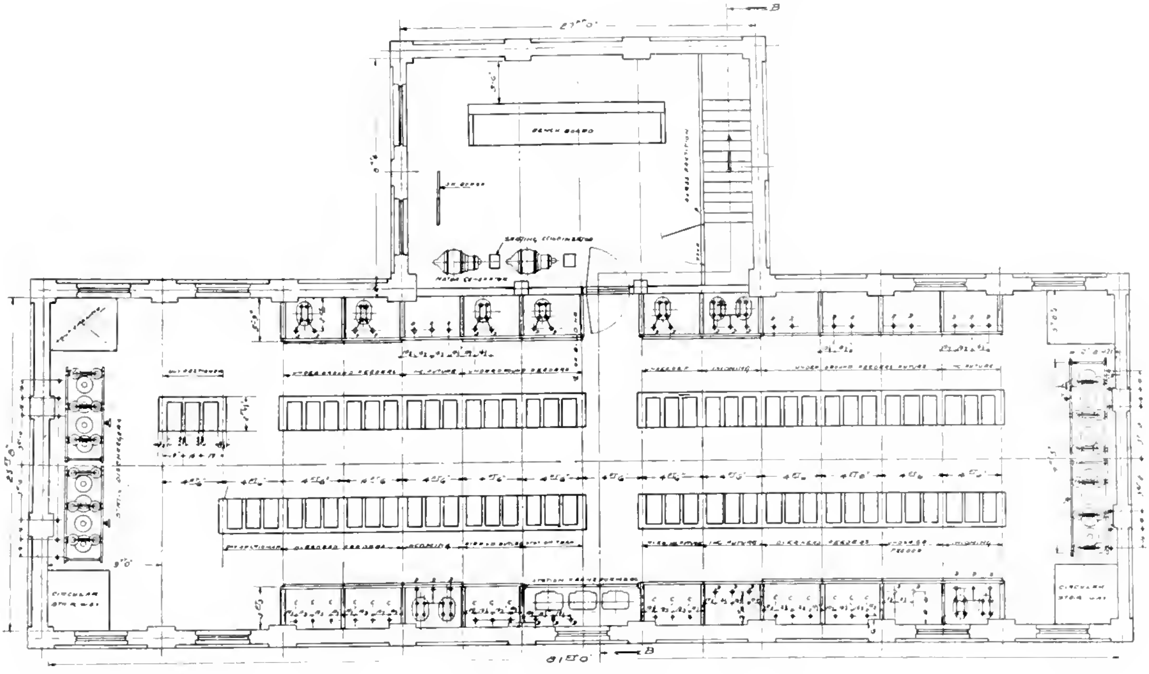


Fig. 11. Plan of Second Floor

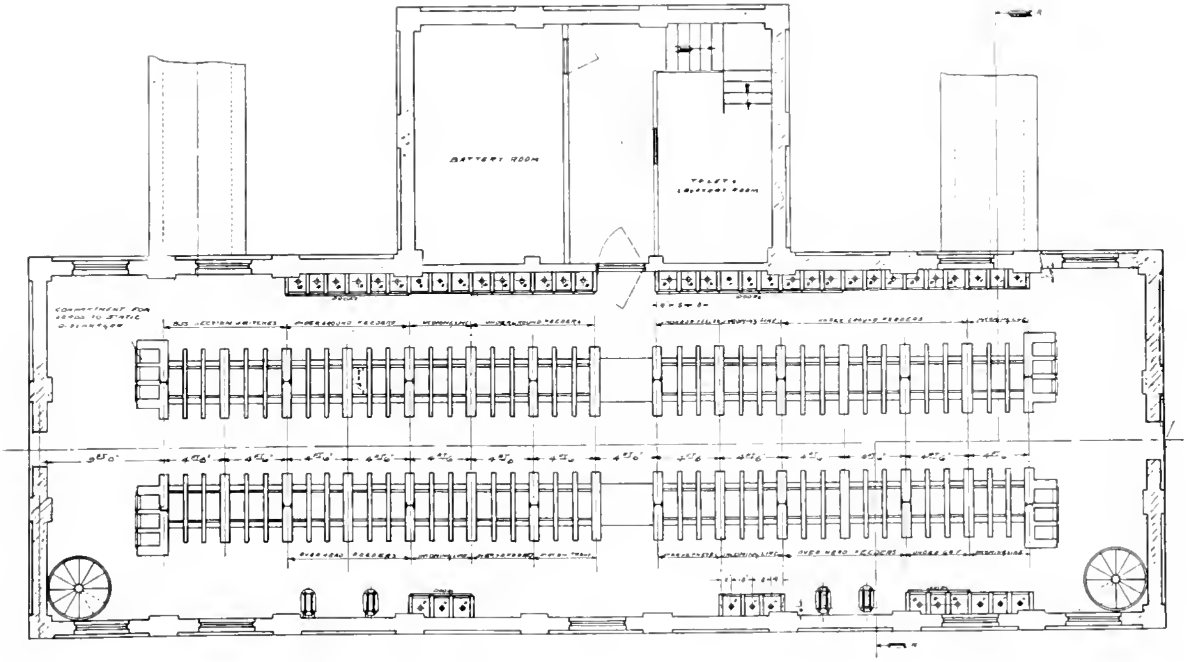


Fig. 12. Plan of First Floor

Fig. 13. Atlanta Substation. Repair House in Middle Distance

ing switches being located on the first floor and the oil switches on the second floor. The first floor in the wing of the building contains a battery room, toilet and lavatory, while the central room occupies the second floor of the wing. This contains the switchboard, telephones and the battery, and as it faces the outdoor portion of the station affords a good view of the apparatus.

The oil switches for the low-tension transformer connections are of the 15,000-volt, 500-ampere, automatic motor-operated type, provided with definite time-limit relays (Fig. 14). The switches for the outgoing feeders are of the same type, and differ only from the low tension switches in that they have a current carrying capacity of 300 amperes and are provided with inverse time-limit relays.

All the apparatus in the station is manipulated from a central board in the operator's room. This is of the usual bench-board construction, made of dull black slate. The vertical panels contain the instruments and relays, while the control switches, indicating, lamp, receptacles, mimic buses, etc., are mounted on the top of the bench.

Electrolytic aluminum cell lightning arresters with choke coils and horn-gap disconnecting switches are provided for each of the outgoing overhead feeders, and each of the four sets of busbars is equipped with a set of static dischargers of the same type. The former are installed outdoors between the station and the dead-end tower structure of the 11,000-volt lines, while the latter are installed on the second floor of the building, two at each end.

For furnishing energy for lighting and miscellaneous power purposes around the station there is provided one transformer bank, consisting of three 10-kv-a., 11,000/220-110-volt transformers, while a 20-ampere-hour, 250-volt storage battery with two 10-kw. charging sets furnish current for the operation

Fig. 14. Low Tension Oil Switch in Atlanta Substation

of all the switches. The switches and instruments for the battery equipment and the station circuits are mounted on a separate vertical switchboard, which is also located in the control room.

### Other Substations

Besides the Atlanta station, there are substations at Gainesville, Newnan, Marietta, Cartersville and Lindale. These are all identical in design and of the outdoor type; the high-tension equipment being installed outdoors and the low-tension equipment indoors in a switch house. Each station is laid out for an ultimate capacity of 12,000 kv-a., and is divided into four transformer banks with four outgoing 11,000-volt feeders. Besides this, provisions are made so that a synchronous condenser can be installed in each station, and space is provided for a bank of local service transformers and an arc lighting circuit.

At the present time the capacity of the installed transformer equipments at the various stations is as given below.

All of these transformers are of the oil-insulated self-cooled single-phase type. Both the primary and secondary windings are connected in delta, and they are provided with the following taps:

110,000 volt windings four 2½ per cent taps.
55,000 volt windings two 5 per cent taps.
22,000 volt windings eight 1¼ per cent taps.
11,000 volt windings four 2½ per cent taps.

When operated at continuous normal load the temperature rise is guaranteed not to exceed 40 deg. C., and when operating continuously at 25 per cent overload 55 deg. C.

The system of connections for the stations is shown by Fig. 15. The transformer bus will be connected to the transmission lines by means of two oil switches, one of which is installed at the present time. These switches are of the hand-operated automatic type, tripped by inverse time element relays, and are protected against rain by a simple corrugated sheet steel house.

Three-pole disconnecting switches are provided for sectionalizing and cross-over purposes, and also for connecting the transformer banks to the high-tension bus. These switches are of the horn gap bolt-type construction, mounted on the top of the steel structure and operated from the ground by a single hand lever for each three-pole unit. While these switches are not intended to be opened under load, they may be relied upon for breaking the capacity currents of the lines and the magnetizing currents of the transformers, although such switching should be avoided, as the arc formed may set up high voltage surges which may be destructive to

Fig. 15. Low Tension Bus Bar Compartments in Tunnel

TRANSFORMER EQUIPMENTS

| Substation | Number of Units | Normal Kv-a. of Each Unit | Total Capacity in Kv-a. | VOLTAGES | |
|---|---|---|---|---|---|
| | | | | Primary | Secondary |
| Gainesville | 3 | 500 | 1500 | 110,000 | 11,000 |
| Marietta | 3 | 1000 | 3000 | 110,000 55,000 | 22,000 11,000 |
| Newnan | 3 | 1000 | 3000 | 110,000 55,000 | 22,000 11,000 |
| Cartersville | 3 | 1000 | 3000 | 110,000 55,000 | 22,000 11,000 |
| Lindale | 6 | 1000 | 6000 | 110,000 55,000 | 22,000 11,000 |

the insulation of the lines and apparatus connected thereto.

Outdoor 110,000-volt electrolytic aluminum cell lightning arresters with choke coils and horn gap disconnecting switches are provided at each substation, and, as at the Atlanta station, the transmission line ground wires pass over the structure and afford additional protection.

The low-tension equipments in all the stations are, as stated, installed indoors. These equipments comprise the 15,000-volt automatic oil switches on the low tension side of

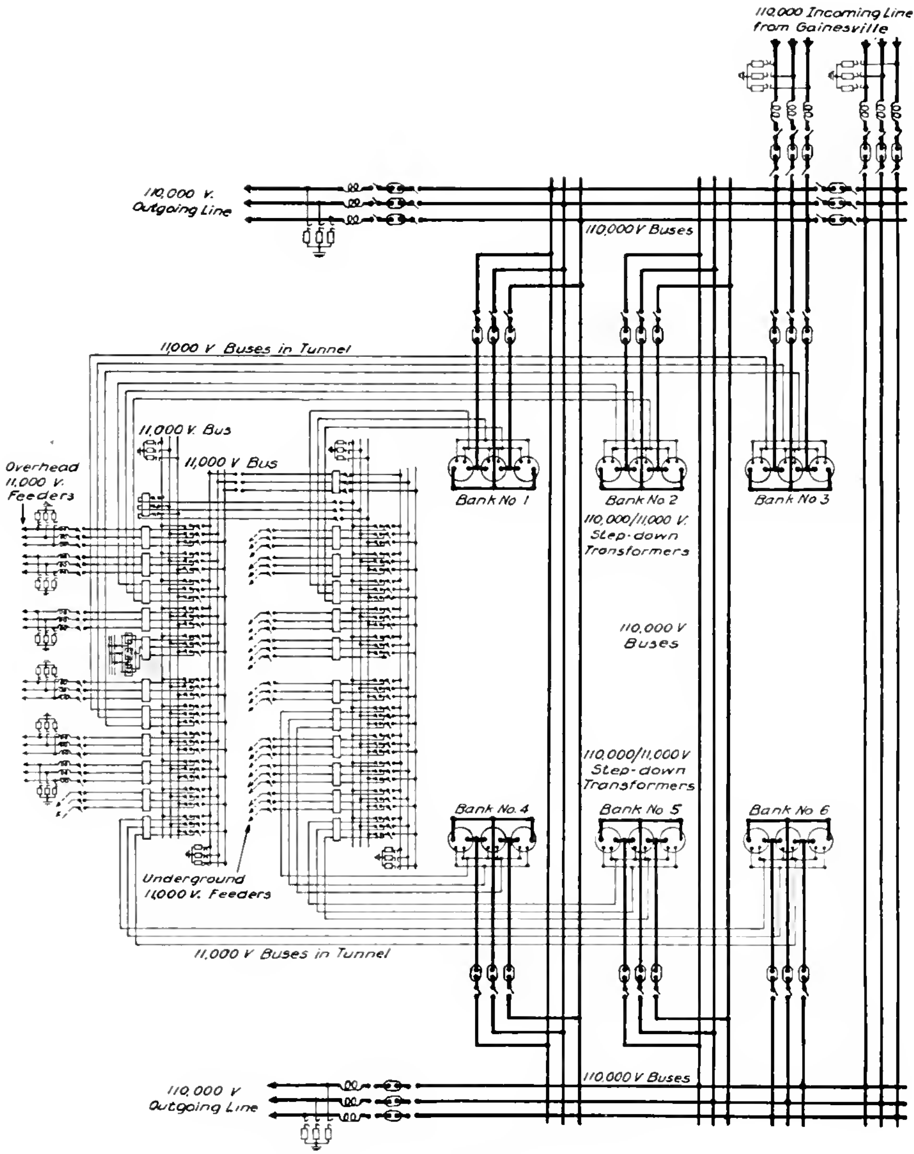


Fig. 16. Wiring Diagram of Atlanta Substation

the transformer banks and those for the outgoing feeder circuits, a 15-kw., 11,000-220/110 volt transformer bank for the station service, and the switchboard containing the instruments, meters, etc. Each of the outgoing 11,000-volt feeders are protected by aluminum cell lightning arresters, which are installed outside the building.

The construction work on the transmission lines and substations as was that on the generating station at Tallulah Falls, was done by the Northern Contracting Company under the supervision of Mr. C. O. Lenz, Chief Consulting Engineer, 71 Broadway, New York City, and Mr. C. E. Bennet, Electrical Engineer.

Fig. 17. Newnan Outdoor Substation

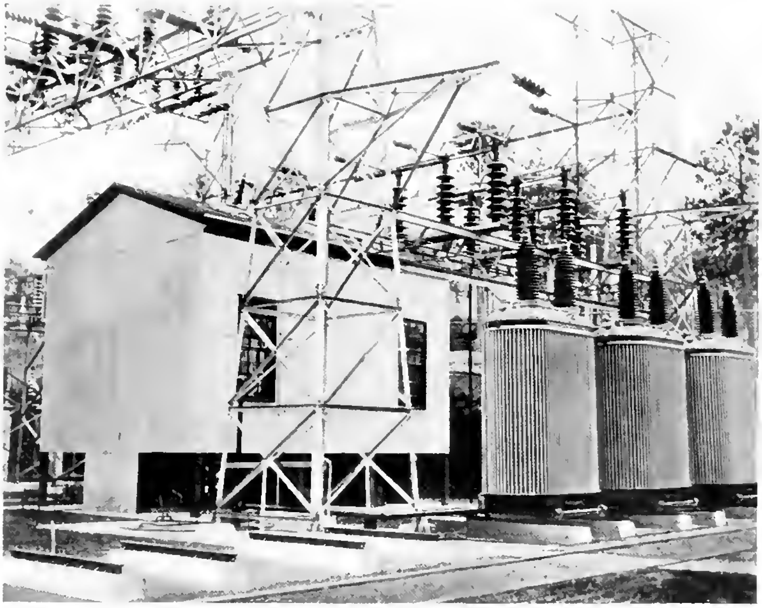


Fig 18. Gainesville Outdoor Substation

# RECTANGULAR WAVES

By G. Faccioli

Electrical Engineer, Pittsfield Works, General Electric Company

The present article explains in an extremely simple and clear manner some of the so-called "mysterious troubles" that are of frequent occurrence and annoyance to the operating and designing engineer, and that must be understood before this class of trouble can be eliminated. That is, the engineer must consider them in the design and protection of apparatus, and the operating engineer must assist him by methods of system operation which minimize the probability and frequency of occurrence of such disturbances; for example, by obviating high tension switching, and the like.—Editor.

A sudden variation of voltage, be it positive or negative, that is to say a sudden rise or a sudden drop of voltage, constitutes one of the most common sources of trouble in the operation of high tension lines.

These sudden variations of voltage, of which a rectangular traveling wave (a traveling wave with a straight front) is a common example, may be due to causes internal or external to the circuit. While the external causes are beyond our control, it is possible to control the internal causes by the proper design and proper operation of the system.

However, the stresses brought upon the apparatus by steep wave fronts are so high that the coefficients of safety, which must be used in building the apparatus so that they will withstand these stresses, are abnormally large; and the problem arises as to whether it is more advisable and cheaper to build apparatus with such coefficients of safety or to build them with lower and more reasonable coefficients of safety, at the same time giving them efficient protection by auxiliary devices. It follows that in recent times considerable work has been devoted to the study of protection of apparatus and lines against steep wave fronts.

Inductance, capacity, and resistance are the three elements at the immediate disposal of the electrical engineer, and we wish to study in this article their influence on waves with steep fronts, and especially on rectangular waves.

The phenomena reviewed hereafter are well known, but an elementary summary of them will perhaps prove useful.

If we consider a rectangular wave arriving at a certain point of a circuit, we see at once that the part of the circuit upon which the rectangular wave impinges is suddenly subjected to the action of the steady potential of the wave. We may conclude, therefore, that the phenomena due to rectangular waves are similar to those obtained in switching circuits onto electromotive forces of constant value.

We will, therefore, approach the problem by reviewing what happens when a continuous e.m.f. is suddenly applied or withdrawn from circuits containing inductance, capacity and resistance; and the results obtained will give a qualitative idea of the phenomena produced by the propagation of rectangular waves.

### I. Effect of Inductance on Rectangular Waves

We will study first what happens when an inductance, $L$, in series with the resistance, $R$, is switched onto an electromotive force, $E$, of constant value. See Fig. 1.

After the switch $S$, is closed, the current has a value of

$$i = I\left(1-e^{-\frac{R}{L}t}\right) \qquad (1)$$

where $I=\frac{E}{R}$, the final value reached by the current, $e$ is the base of natural logarithms, and $t$ is the time.

The voltage, $v$, across the resistance is

$$v = E\left(1-e^{-\frac{R}{L}t}\right) \qquad (2)$$

The electromotive force which is active across the inductance, $L$, and annuls the counter e.m.f., $-p$, generated across $L$ by the growth of the current, $i$, is

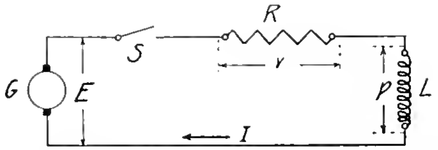


Fig. 1. Circuit Consisting of Inductance, L, in series with resistance, R, connected to source of constant e.m.f., E.

$$p = Ee^{-\frac{R}{L}t} \qquad (3)$$

If the electromotive force, $E$, is suddenly removed from the circuit, by for instance short-circuiting the d-c. generator, then the current assumes the value

$$i = Ie^{-\frac{R}{L}t} \tag{4}$$

The voltage across the resistance is

$$v = Ee^{-\frac{R}{L}t} \tag{5}$$

The voltage generated by the dying of the current across the inductance, $L$, (the impressed e.m.f., $E$, is now zero) is

$$p = -L\frac{di}{dt} = Ee^{-\frac{R}{L}t} \tag{6}$$

and this voltage is consumed by the drop across the resistance.

Fig. 2 shows the gradual increase of $i$ to a maximum, $I$, when the constant potential, $E$, is suddenly applied to the circuit of Fig. 1. In this case, $R = 500$ ohms, $L = 0.01$ henry, $I = 10$ amperes, and $E = 5000$ volts.

Since the drop across the resistance is $Ri$, $v$ is proportional to $i$. Fig. 2, therefore, represents also the growth of $v$ to a maximum, $E$, when the proper scale is taken.

After the current, $i$, has gradually increased in value until it has reached the final value, $I$ (theoretically $i$ will reach the final value, $I$, in an infinitely long time, but practically the final value, $I$, is reached after a short interval of time, as shown in Fig. 2), the electromotive force, $E$, is suddenly removed and the current, $i$, and voltage, $v$, gradually go to zero, as shown in Fig. 3.

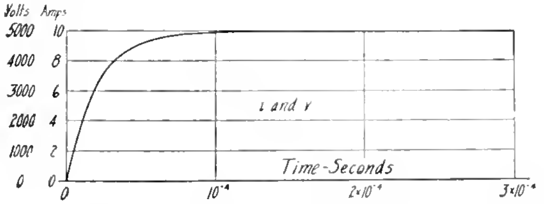


Fig. 2. Growth of Current, i, and voltage, v, when constant potential, E, is suddenly applied to circuit of Fig. 1.

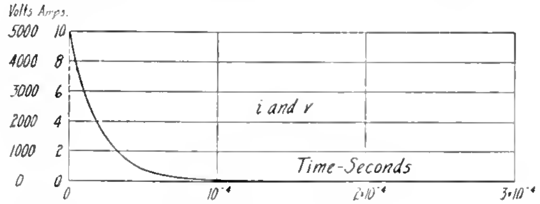


Fig. 3. Decay of Current, i, and voltage, v, when constant potential, E, is suddenly removed from circuit of Fig. 1.

Figs. 4 and 5 give the voltage, $p$, generated across $L$ by the growth and the dying away of the current, $i$, when $R = 500$ ohms, $L = 0.01$ henry, $I = 10$ amperes, and $E = 5000$ volts, as before.

When the circuit is closed and the potential, $E$, is suddenly applied, the counter e.m.f., $-p$, generated across the inductance by the growing current, is $-E$. After this first instant the counter e.m.f., $-p$, gradually goes to zero. This counter e.m.f. is at all times equal and opposite to the impressed e.m.f. The zero value is practically reached after a short time, and then the growth of the current, $i$, is complete to its full value, $I$, and the inductance, $L$, offers no further impedance to the flow of this current, $I$. (See Fig. 4.)

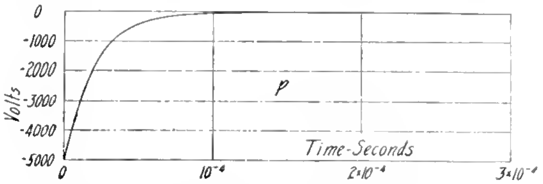


Fig. 4. Voltage, p, generated across inductance, L, by growth of current, i, when constant potential, E, is suddenly applied to circuit of Fig. 1.

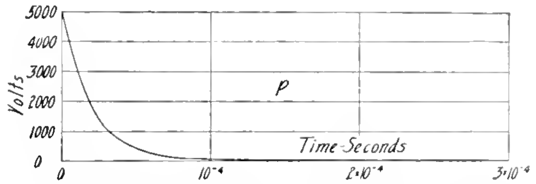


Fig. 5. Voltage, p, generated by inductance, L, when constant potential, E, is suddenly removed from circuit of Fig. 1.

The electromotive force, $p$, generated by the dying out of the current in the reactance, begins with the maximum, $E$, and gradually goes to zero as the current, $i$, dies out. This electromotive force is active and is totally consumed in sending current through the resistance, $R$. (See Fig. 5.)

When the circuit is closed, energy is stored up in the choke coil, as electro-magnetic energy, to a maximum value of $\frac{LI^2}{2}$. When the potential, $E$, is suddenly removed, this energy is given back to the circuit by the inductance and is absorbed by the resistance.

It is to be noted that when the circuit is closed the equivalent impedance of the choke coil is

$$Z = \frac{p}{i} = \frac{Ee^{-\frac{R}{L}t}}{I\left(1 - e^{-\frac{R}{L}t}\right)} = R\frac{1}{e^{\frac{R}{L}t} - 1} \tag{7}$$

This equivalent impedance is plotted in Fig. 6, where $R = 500$ ohms and $L = 0.01$

henry. This curve shows that at the first instant in which the switch is closed the impedance of the choke coil is equal to infinity and that this impedance gradually decreases until, after a theoretically infinite—but practically short—time, this impedance is equal to zero. Thus the choke coil acts at the first instant as an open circuit and gradually becomes a short circuit.

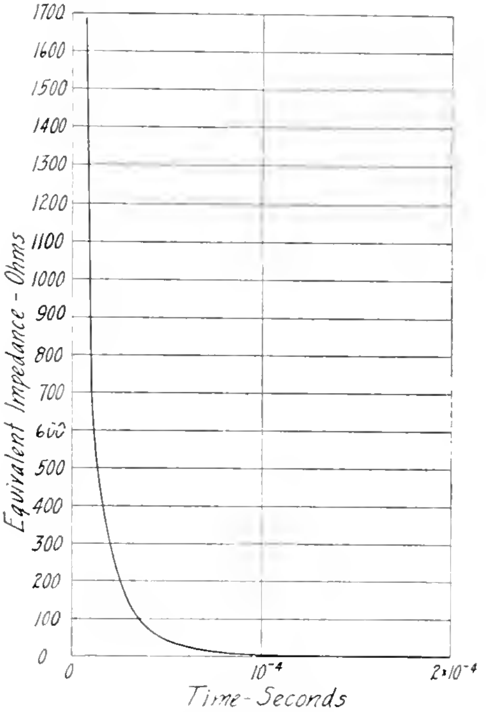


Fig. 6. Equivalent Impedance of Inductance, L, in circuit of Fig. 1, when R = 500 ohms and L = 0.01 henry

When the electromotive force, $E$, is removed, the choke coil acts as a generator of zero resistance, and the circuit has a constant resistance, $R$.

Fig. 7 shows, for comparison, the growth of current, $i$, when $L = 0.01$ henry and when $L = 0.0001$ henry, $R$ being 500 ohms in each case. The inductance in the second case is 1/100 the inductance in the first case and the growth of current requires only 1/100 of the time, that is the change is more abrupt with the smaller inductance. Likewise, if we should have an inductance of 1 henry, the time of growth would be 100 times as long as the time required when $L = 0.01$ henry.

In summarizing the above, we see that the presence of the inductance produces a single energy transient with the following results:

(1) Abrupt changes in potential and current are prevented.

(2) The inductance stores electromagnetic energy and then returns it to the circuit.

(3) The inductance acts at the first instant as an open circuit and gradually becomes a short-circuit.

If the resistance, $R$, is divided in two parts, $R_1$ and $R_2$, in series, all the phenomena above described are naturally the same and the drops across $R_1$ and $R_2$ are obviously proportional to $R_1$ and $R_2$, and, therefore, the energy returned by $L$ and absorbed respectively by $R_1$ and $R_2$ is also proportional to the values of $R_1$ and $R_2$.

### Waves passing from Circuit of Impedance, $Z_1$, to Circuit of Impedance, $Z_2$

Generally, in determining the value of the refracted and reflected waves as a function of the value of the incident wave, the procedure is as follows:

In the case of Fig. 9, for instance, where there is no additional device, Circuits 1 and 2 are directly connected in series and we have $p_1 + p_r = p_2$, that is to say, the voltage of the refracted wave is equal to the voltage of the incident wave plus the voltage of the reflected wave.

We have also $i_1 = i_r + i_2$, that is to say, the current of the incident wave divides into two parts, the reflected part, $i_r$, and the refracted part, $i_2$.

Finally: We know that the ratio between the voltage and current of the incident wave is equal to $Z_1$, the natural impedance of Circuit 1; that the ratio between the voltage and current of the reflected wave is also equal to $Z_1$; and that the ratio between the voltage and current of the refracted wave is equal to $Z_2$, the natural impedance of Circuit 2.

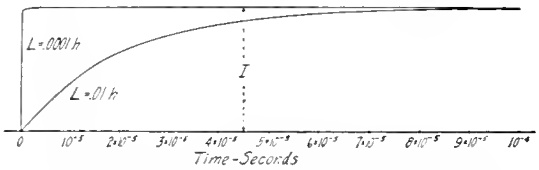


Fig. 7. Showing, for comparison the growth of current, i, in circuit of Fig. 1 when L = 0.01 henry and L = 0.0001 henry, R being 500 ohms in each case

The above fundamental equations are sufficient to determine the values of $p_2$, $i_2$, $p_r$, and $i_r$.

If a resistance, an inductance, or some other device is connected in series between Circuit 1 and Circuit 2, as in Fig. 10 for instance, then the equation of voltage must be modified to show that the voltage of the incident wave, plus the voltage of the reflected wave, is equal to the voltage of the refracted wave, plus the drop across the additional device. The current of the incident wave divides again into two parts—the reflected current and the refracted current.

If, at the junction between Circuits 1 and 2, a device is connected in shunt (as in Fig. 20), the equations must be written to show that the voltage of the incident wave, plus the voltage of the reflected wave, is equal to the voltage of the refracted wave.

The current of the incident wave divides into three parts:

One reflected back into Circuit 1.

The second passing on into Circuit 2.

And the third going through the device connected in shunt at the junction.

It is evident also that the voltage across Circuit 2 must be equal to the voltage across the shunted device.

If the wave is of finite length, we can consider it as the resultant of two infinitely long waves of opposite sign, *A* and *B*, as shown in Fig. 8. The wave *B* lags behind the wave *A* by a time, *T*, which represents the duration of the finite wave.

Then the phenomena occurring at the front of the finite wave are the same as the phenomena occurring at the front of the infinite wave, *A*. The phenomena occurring at the back of the finite wave are obtained by superimposing the condition due to the wave *A*, at the time, *T*, upon the phenomena due to the front of the negative wave, *B*.

Naturally, the phenomena due to the front of the wave, *B*, are equal and opposite in sign to the phenomena occurring at the front of the wave, *A*.

If the wave is of infinite length, then the reflected wave is super-imposed on the infinite wave; whereas if the wave is of finite length, the reflected wave will travel alone back into Circuit 1, as mentioned later in the case of choke coil connected between circuits 1 and 2.

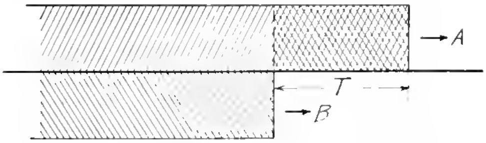


**Fig. 8.** Showing the formation of a wave of finite length by the superposition of infinite waves, A and B, of opposite sign

**Waves of Infinite Length**

Let us apply the results discussed above to a rectangular wave, $p_1$, of infinite length, passing from a circuit of natural impedance, $Z_1$, into a circuit of natural impedance, $Z_2$. (See Fig. 9.) The rectangular wave, $p_1$, is partially reflected at the junction between Circuit 2 and Circuit 1, and it enters the circuit of natural impedance, $Z_2$, with a voltage:

$$p_2 = 2p_1 \frac{Z_2}{Z_1 + Z_2} \qquad (8)$$

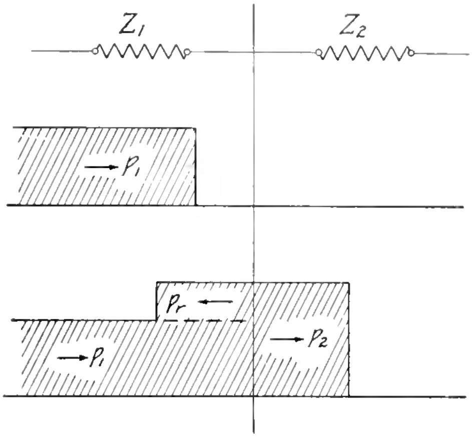


**Fig. 9.** Rectangular wave, $p_1$, of infinite length, passing from circuit of natural impedance, $Z_1$, to circuit of natural impedance, $Z_2$

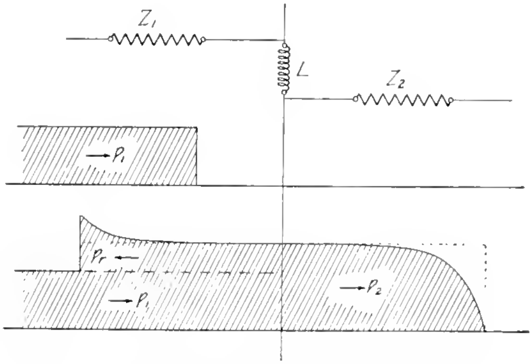


**Fig. 10.** Rectangular wave, $p_1$, of infinite length passing from circuit $Z_1$ to circuit of $Z_2$, an inductance, L, being connected between circuits 1 and 2

The reflected wave which travels back into Circuit 1 has a value of

$$p^r = p_1 \frac{Z_2 - Z_1}{Z_1 + Z_2} \qquad (9)$$

Fig. 9 shows the progress of the refracted and reflected voltage waves, assuming $Z_2 = 3Z_1$. We see that Circuit 2 is subjected to a rectangular wave of voltage $p_2 = \frac{3}{2}\,p_1$, and that a voltage $\frac{3}{2}\,p_1$ is imposed upon Circuit 1, due to the super-imposition of the reflected wave, $p_r = \frac{1}{2}\,p_1$, upon the incoming wave, $p_1$.

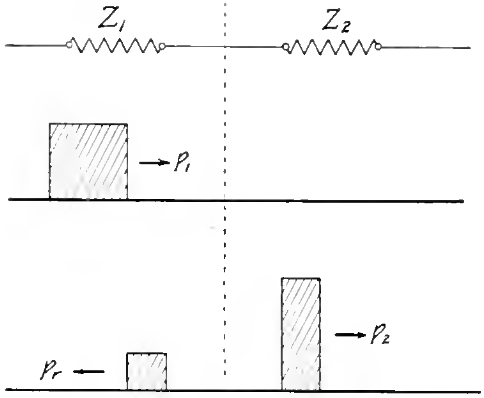


**Fig. 11.** Rectangular wave, $p_1$, of finite length, passing from circuit of natural impedance, $Z_1$, to circuit of natural impedance, $Z_2$

Similar reflections and refractions take place in the current waves, but for brevity, these will be omitted.

Let us now connect an inductance, $L$, between circuits 1 and 2, as shown in Fig. 10.

When the rectangular wave, $p_1$, arrives at $L$, the choke coil acts as an open circuit. Therefore, the voltage of the arriving wave will be totally reflected back into Circuit 1 with positive sign, and the current of the arriving wave will be totally reflected back into Circuit 1 with negative sign.

As the equivalent impedance of the choke coil gradually decreases, the voltage and current of the wave will gradually pass into Circuit 2, until, after a theoretically infinite—but practically short—time, the choke coil acts as a short-circuit. Then the wave passes from Circuit 1 into Circuit 2 in the same manner as if the inductance, $L$, were not present, but the circuits arranged as in Fig. 9.

The energy of the incident wave is divided into three parts:

One part passes from Circuit 1 into Circuit 2.

The second part is reflected back into Circuit 1.

The third part is stored in the choke coil.

Without going into mathematics, and remembering the conditions shown in Figs. 1 to 5, we may say that the voltage, $p_2$, which enters the Circuit 2, grows gradually from zero to a final value:

$$2\,p_1\,\frac{Z_2}{Z_1+Z_2}$$

and we may write

$$p_2 = 2\,p_1\,\frac{Z_2}{Z_1+Z_2}\left(1-\epsilon^{-at}\right)^{*} \qquad (10)$$

The reflected wave has a final value of

$$p_1\,\frac{Z_2-Z_1}{Z_1+Z_2}$$

and its equation may be written

$$p_r = p_1\left(\frac{Z_2-Z_1}{Z_1+Z_2} + \frac{2\,Z_1}{Z_1+Z_2}\,\epsilon^{-at}\right) \qquad (11)$$

Fig. 10 shows the reflected and refracted waves, assuming $Z_1 = 300$ ohms, $Z_2 = 3Z_1$ and $L = 0.01$ henry.

In this case $p_2$ assumes a final value of $\frac{3}{2}\,p_1$.

The reflected voltage, $p_r$, at the first instant equals $p_1$, but assumes a final value $\frac{1}{2}\,p_1$.

Circuit 1, therefore, has imposed on it at the first instant a voltage of $2\,p_1$, which quickly reduces to $3/2\ p_1$. The time required for $p_2$ and $p_r$ to change from the initial to the final value is about 0.5 second.

### Waves of Finite Length

Figs. 9 and 10 refer to the case in which the incident wave has an infinite length.

Let us now consider the case in which the wave has a finite length.

Fig. 11 represents the case in which there is no inductance connected between circuits 1 and 2. The wave has a rectangular front and a rectangular back. It is assumed that $Z_2 = 3Z_1$. Then the ongoing wave has a value

$$p_2 = 2\,p_1\,\frac{Z_2}{Z_1+Z_2} = \frac{3}{2}\,p_1$$

and the reflected wave a value

$$p_r = p_1\,\frac{Z_2-Z_1}{Z_1+Z_2} = \frac{1}{2}\,p_1.$$

In this case the reflected wave travels alone back into Circuit 1, as the short incident wave has passed on.

If a choke coil, $L$, is placed between Circuits 1 and 2, the front of the wave produces obviously the same phenomena as in the

---

*The coefficient $a = \frac{Z_1+Z_2}{L}$

similar case with the wave of infinite length. When the voltage of the wave suddenly drops to zero, the energy stored in the choke coil is returned to $Z_1$ and $Z_2$, at a voltage starting from the value of

$$2\ p_1 \frac{Z_2}{Z_1+Z_2}$$

and gradually decreasing to zero by the formula

$$p_2 = 2\ p_1 \frac{Z_2}{Z_1+Z_2} e^{-at} \qquad (12)$$

This is the equation of the rear of the ongoing wave.

The equation of the rear of the reflected voltage wave is

$$p_r = -2\ p_1 \frac{Z_1}{Z_1+Z_2} e^{-at} \qquad (13)$$

During the discharge of the choke coil into the line the current through $Z_1$, $L$, and $Z_2$ is the same, and, therefore, the portions of energy discharged into $Z_1$ and $Z_2$ are respectively proportional to the values of the impedances, $Z_1$ and $Z_2$; that is to say, if $Z_1 = Z_2$, the energy discharged by the choke coil is equally divided between the Circuits 1 and 2, whereas, if $Z_2 = 9Z_1$, 9/10 of the energy will go into Circuit 2.

Fig. 12 shows the refraction and reflection of a rectangular wave of finite length, assuming an inductance $L = 0.01$ henry connected between Circuits 1 and 2, $Z_1 = 300$ ohms and $Z_2 = 3Z_1$. About 0.4 second is required in this case for the waves to change from their initial to their final values.

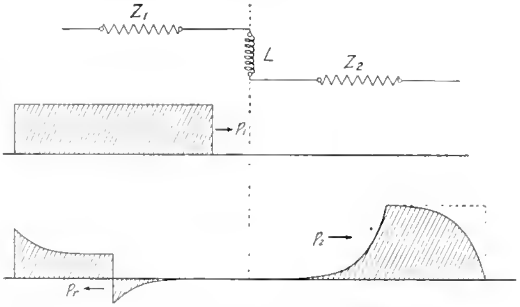


Fig. 12. Rectangular wave, $p_1$, of finite length, passing from circuit $Z_1$ to circuit of $Z_2$, an inductance L being connected between circuits 1 and 2

It will be noted that the reflected portion of the wave consists of positive and negative parts and that there is an abrupt change of voltage where these two portions of the wave join. From this it may be seen that abrupt changes in voltage are not confined to the fronts of waves.

In conclusion: The presence of the choke coil, $L$, connected in series between Circuit 1 and Circuit 2, produces the following effects:

(1) Smooths wave fronts.

(2) Gives the same final value of the wave passing into Circuit 2 as if the inductance were not present.

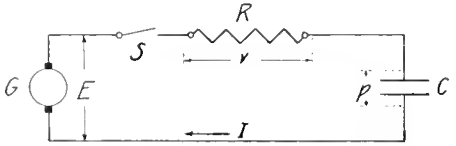


Fig. 13. Circuit consisting of condenser, C, in series with resistance, R, connected to source of constant e.m.f., E.

(3) Increases the value of the front of the reflected wave, because it produces a total reflection at the first instant the abrupt variation of voltage is applied.

It follows that a choke coil connected in series between a line and a transformer will protect the transformer from abrupt variation of voltages originating in the line, but will be an obstacle preventing disturbances originating in the transformer from passing into the line; and, therefore, in this latter respect it will increase the possible dangers to the transformer.

### II. Effect of Condenser on Rectangular Waves

We will now review the phenomena which occur when a condenser, $C$, in series with a resistance, $R$, is suddenly connected to a source of continuous electromotive force, $E$. (See Fig. 13.) In this case, when the switch is closed, the current is

$$i = Ie^{-\frac{t}{RC}} \qquad (14)$$

where $I$ is the maximum value of the current and is equal to $\frac{E}{R}$.

The voltage across the resistance is

$$v = Ee^{-\frac{t}{RC}} \qquad (15)$$

and the voltage spent in overcoming the counter-electromotive force, $-p$, produced by the charging of the condenser—caused by the current—is

$$p = E\left(1 - e^{-\frac{t}{RC}}\right) \qquad (16)$$

If the source of electromotive force is suddenly removed, by for instance short-circuiting the generator, the current, $i$, the voltage, $v$, and the electromotive force, $p$, across the condenser are respectively:

$$i = -Ie^{-\frac{t}{RC}} \qquad (17)$$

$$v = -Ee^{-\frac{t}{RC}} \qquad (18)$$

$$p = Ee^{-\frac{t}{RC}} \qquad (19)$$

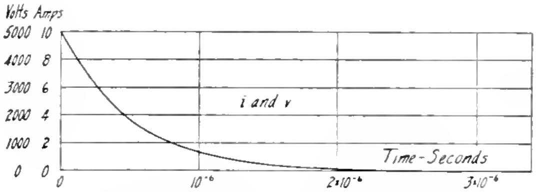


Fig. 14. Current, i, and voltage, v, when constant potential, E, is suddenly applied to circuit of Fig. 12.

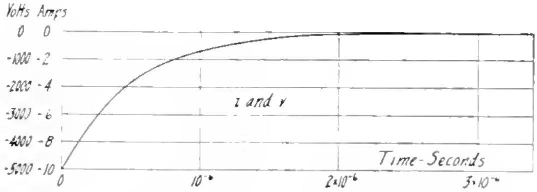


Fig. 15. Current, i, and voltage, v, when constant potential, E, is suddenly removed from circuit of Fig. 12

Fig. 14 shows $i$ and $v$ when the switch is closed, assuming $C = 0.001$ m.f. and $R = 500$ ohms.

Fig. 15 shows $i$ and $v$ when the generator is short-circuited.

Fig. 16 shows the electromotive force, $p$, active across the condenser. This electromotive force is applied by the generator and is opposite in sign to the counter-electromotive force caused by the current charging the condenser.

When the applied electromotive force suddenly stops, the condenser is charged to the full potential, $E$. (Theoretically this would only happen after an infinitely long time.)

Fig. 17 shows how the electromotive force of the condenser gradually dies out, while the condenser is discharging and its energy is being absorbed by the resistance, $R$.

It is evident that at the first instant the circuit is closed the condenser does not modify the conditions, because the maximum current, $I$, flows without producing any drop across the condenser, and this current is only limited in value by the resistance, $R$. This means that at this first instant the condenser acts as a short-circuit.

Then the voltage across the condenser grows gradually, and, therefore, less and less current flows in the circuit, until, after a theoretically infinite time—but practically after a very short time—the full voltage, $E$, is spent across the charged condenser, and both $i$ and $v$ are zero. At this instant the condenser acts as an open circuit.

Fig. 18 shows the equivalent impedance of the condenser, which is also given by following:

$$Z = \frac{p}{i} = R\left(e^{\frac{t}{RC}} - 1\right) \qquad (20)$$

When the electromotive force is removed, the condenser discharges, the current is reversed, and its value is controlled by the resistance, $R$.

While the electromotive force, $E$, is active, energy is stored up in the condenser to a maximum equal to $\frac{CE^2}{2}$ and when the electromotive force, $E$, suddenly stops this stored energy is given back by the condenser and is absorbed by the resistance, $R$.

In Fig. 18, are given for comparison, the equivalent impedance of the condenser when $C = 0.001$ m.f. and when $C = 0.0001$ m.f. It may be seen that with the smaller capacity the equivalent impedance increases 10 times as fast as with the larger capacity; therefore, the current, $i$, and voltage, $v$, die and the voltage, $p$, grows 10 times as fast.

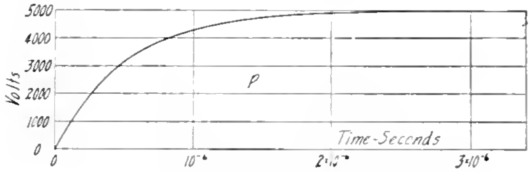


Fig. 16. Voltage, p, when constant potential, E, is suddenly applied to circuit of Fig. 12

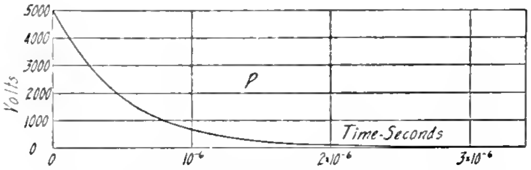


Fig. 17. Voltage, p, when constant potential, E, is suddenly removed from circuit of Fig. 12

The phenomena just discussed are further examples of single energy transients.

We may conclude that the condenser:

(1) Acts at the first instant the circuit is closed as a short-circuit, and gradually increases its equivalent impedance until it becomes an open circuit.

(2) Absorbs energy and returns it when the applied electromotive force stops.

(3) Allows the electromotive force across its plates to grow gradually, so that if the condenser is shunted by a circuit which does not substantially change the nature of the phenomena summarized above, the presence of the condenser prevents an abrupt change of voltage across the shunted circuit.

Fig. 19 shows a resistance, $R_1$, shunted by a condenser, $C$. The voltage across $R_1$ is the same as the voltage across $C$, and, therefore, the voltage across $R_1$ will grow and die gradually, following an exponential law.

*Waves passing from Circuit of Impedance, $Z_1$, to Circuit of Impedance $Z_2$:*

### Waves of Infinite Length

Let us apply the results just obtained to the case of a traveling rectangular wave which passes from a circuit of impedance, $Z_1$, to a circuit of impedance, $Z_2$.

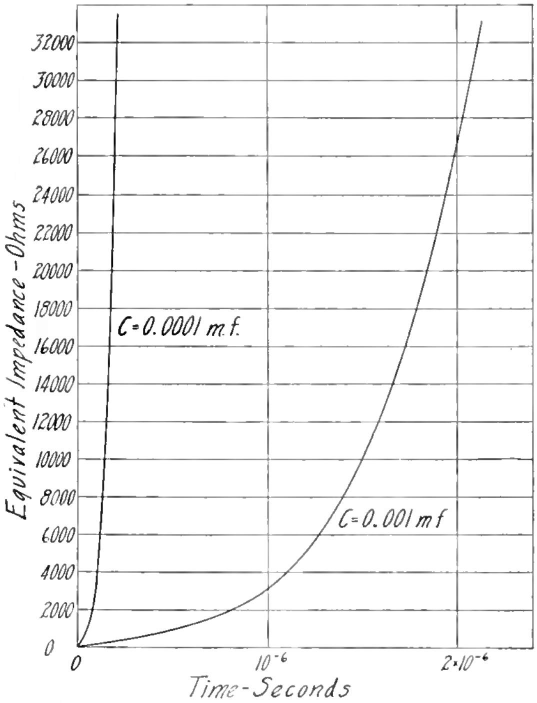


**Fig 18.** Equivalent impedance of condenser, C, in Fig. 12 when C = 0.001 m.f. and C = 0.0001 m.f., R being 500 ohms in each case

At the instant when the wave arrives at the junction between Circuit 1 and Circuit 2, the condenser which is there connected acts as a short-circuit; and, therefore, the voltage of the rectangular arriving wave is totally reflected into Circuit 1 with negative sign, and the current of the arriving wave is totally reflected into Circuit 1 with positive sign. At this instant no voltage and no current enter Circuit 2.

Then the impedance of the condenser gradually rises to infinity, that is to say, the condenser gradually becomes an open circuit. This last condition is reached after a practically short time, and then voltage and current enter Circuit 2, just the same as if no condenser were connected.

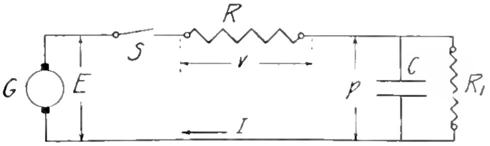


**Fig. 19.** Circuit consisting of resistance, R, in series with resistance, $R_1$, (the latter shunted by condenser, C,) connected to source of constant e.m.f., E

Then the voltage, $p_2$, of the wave passing into Circuit 2 grows from zero to

$$2\,p_1\frac{Z_2}{Z_1+Z_2}$$

where $p_1$ is the voltage of the incoming wave.

Remembering the phenomena connected with the circuit of Fig. 13, we may write the following equations of ongoing and reflected voltage, for a wave of infinite length:

$$p_2=2\,p_1\frac{Z_2}{Z_1+Z_2}\left(1-e^{-at}\right)^* \qquad (21)$$

$$p_r=p_1\left[\frac{Z_2-Z_1}{Z_1+Z_2}-\frac{2Z_2}{Z_1+Z_2}e^{-at}\right] \qquad (22)$$

Fig. 20 represents the refracted and reflected voltage waves. In this case it is assumed that $Z_1=300$ ohms, $Z_2=3Z_1$ and $C=0.001$ m.f.

The final value assumed by $p_2$ is $\frac{3}{2}\,p_1$ and the final value assumed by $p_r$ is $\frac{1}{2}\,p_1$. This, by super-imposition on the incoming wave, gives a total height of $\frac{3}{2}\,p_1$.

The total change from the initial to the final value takes place in about $1\times10^{-6}$ second.

### Waves of Finite Length

For a wave of finite length, the equations of the rear of the ongoing and reflected waves are as follows:

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* The coefficient $a=\frac{1}{C}\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right)$

$$p_2 = p_r = 2\, p_1 \frac{Z_2}{Z_1+Z_2} \epsilon^{-at} \qquad (23)$$

It will be apparent that $p_2$ and $p_r$ are the same when it is considered that the original wave has disappeared and the discharging condenser impresses its voltage upon Circuits 1 and 2, which are in multiple with the condenser.

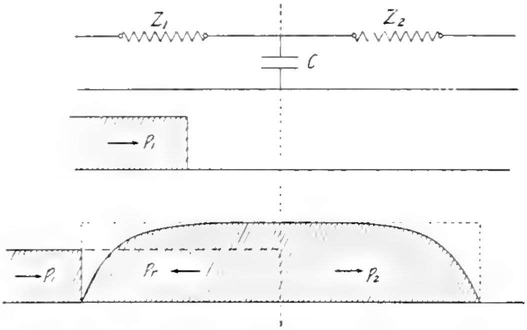

Fig. 20. Rectangular wave, $p_1$, of infinite length passing from circuit of natural impedance, $Z_1$, to circuit of impedance, $Z_2$; condenser, C, shunted across circuit at junction between circuits 1 and 2

Fig. 21 shows the reflected and refracted voltage waves. As in the case of the infinite wave, the total change from the initial to the final value requires about $1 \times 10^{-6}$ second.

The energy of the arriving wave is divided into three parts:

One part passes into Circuit 2.

Another part is reflected back into Circuit 1.

And the third part is stored in the condenser, and then is given back to Circuit 1 and Circuit 2 as soon as the wave $p_1$ stops.

The voltage wave passing into Circuit 2 has a smooth front, but its final value is the same as if the condenser were not connected.

The voltage wave reflected into Circuit 1 has a higher front than if $C$ were not connected, because the condenser totally reflects the voltage wave when an abrupt change of voltage strikes it.

In conclusion: The phenomena are very similar to those obtained by connecting an inductance between Circuit 1 and Circuit 2, and again we see that the condenser connected for instance between a line and transformer protects the transformer from abrupt wave fronts originating in the line and constitutes an obstacle preventing disturbances originating in the transformer from easily passing into the line.

The difference between the inductance and the capacity is that the inductance delays the growth of current because it stores energy under electromagnetic form, and, therefore, it delays the growth of the electromotive force across a resistance connected in series with the inductance; whereas the condenser delays the growth of the e.m.f. across its plates, because it stores energy under electrostatic form, and therefore delays the growth of the electromotive force across a resistance connected in shunt with the condenser.

### III. Effect of Series Resistance

Fig. 22 shows a resistance, $R$, which is supposed to be a pure ohmic resistance and concentrated at one point, connected between Circuit 1 and Circuit 2.

The sudden application of a direct current voltage to a resistance results in a sudden rise of the current to its final value. The resistance does not, as we have seen the inductance and the condenser do, smooth over abrupt wave fronts.

If $p_1$ is the voltage of a rectangular wave, which tries to pass from Circuit 1 into Circuit 2, the voltage, $p_2$, which enters Circuit 2 is

$$p_2 = 2\, p_1 \frac{Z_2}{R+Z_1+Z_2} \qquad (24)$$

and the voltage, $p_r$, which is reflected into line $Z_1$ is

$$p_r = p_1 \frac{R+Z_2-Z_1}{R+Z_1+Z_2} \qquad (25)$$

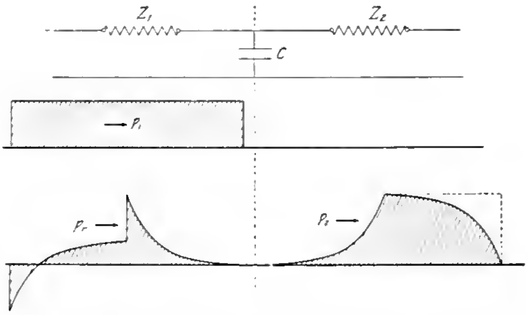

Fig. 21. Rectangular wave, $p_1$, of finite length passing from circuit of natural impedance, $Z_1$, to circuit of natural impedance, $Z_2$; condenser, C, shunted across circuit at junction between circuits 1 and 2

The energy of the wave $p_1$ is divided again in three parts:

One part passes into Circuit 2.

A second part is reflected back into Circuit 1.

A third part is absorbed by $R$.

In the two preceding cases we have discussed, i.e., inductance in series and capacity in shunt, the third part of the energy stored in the inductance or capacity prevented abrupt wave fronts, but was later given back by the inductance or capacity to the circuit. In the case of resistance, the third part of the energy is absorbed and destroyed by the resistance and the wave fronts are not made smoother, but remain rectangular at lower value.

An examination of the formulae giving the values of $p_2$ and $p_r$ shows that the voltage wave passing into Circuit 2 is the same as if the impedance of Circuit 1 were $Z_1+R$; whereas the wave reflected into Circuit 1 is the same as if the impedance of Circuit 2 were $Z_2+R$.

If $Z_2$ is larger than $Z_1$ (for instance if a rectangular wave passes from a line into a transformer), there is always a positive reflected wave. The wave entering Circuit 2 decreases in value with increasing $R$, and is equal to the incident wave when $R=Z_2-Z_1$. Under this condition, however, a reflected wave in Circuit 1 still exists, but the resistance, $R$, absorbs enough voltage to make the voltage wave passing into Circuit 2 equal to the original wave $p_1$.

When R is larger than $Z_2-Z_1$, the wave entering Circuit 2 is smaller than the original wave $p_1$, although a positive reflected voltage wave always exists in Circuit 1 and raises its voltage from $p_1$ to $p_1+p_r$.

If $Z_2$ is smaller than $Z_1$, which is the case when a wave passes from a transformer into a line, there is a negative reflected voltage wave if $R$ is smaller than $Z_1-Z_2$. When $R$ is equal to $Z_1-Z_2$, then there is no reflection.

Fig. 22. Resistance, R, connected between circuits of impedance, $Z_1$, and circuit of impedance, $Z_2$

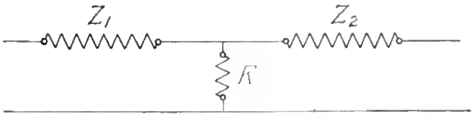

Fig. 23. Circuit of impedance, $Z_1$, connected to circuit of impedance, $Z_2$; resistance, R, shunted across circuit at junction between circuits 1 and 2

When $R$ is larger than $Z_1-Z_2$, then the reflected voltage wave is positive.

The wave entering Circuit 2 has always a lower value than incident wave $p_1$.

It follows that if we connect between a transformer and the line, for instance a resistance $R=Z_2-Z_1$, then voltage waves coming from the line enter the transformer at a voltage equal to the voltage of the line waves, and the voltage waves coming from the transformer enter the line with reflection.

If $R$ is smaller than $Z_2-Z_1$, then the waves coming from the line enter the transformer with increased voltage, and the waves coming from a transformer and entering the line are partially reflected back with negative sign.

Fig. 24. Series resistance shunted by choke coil to afford low impedance to currents of low frequency, and high impedance to currents of high frequency

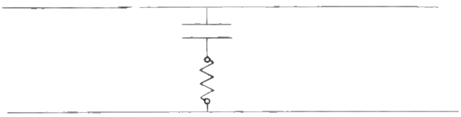

Fig. 25. Shunt resistance in series with condenser to afford high impedance to currents of low frequency, and low impedance to currents of high frequency

If $R$ is larger than $Z_2-Z_1$, then waves coming from the line enter the transformer at lower voltage, and waves coming from the transformer and entering the line are partially reflected back with positive sign.

The value of $R=Z_2-Z_1$ is, therefore, the most favorable.

### IV. Effect of Resistance in Shunt

Referring to Fig. 23, the voltage of the wave entering Circuit 2 is

$$p_2 = 2\, p_1 \frac{Z_2\, R}{Z_2R+Z_1R+Z_1Z_2} \qquad (26)$$

where $p_1$ is the voltage of the incident rectangular wave.

It is evident from Fig. 23 that the voltage entering Circuit 2 must be equal to the voltage existing across the resistance, $R$, because Circuit 2 and $R$ are connected in multiple. Now the voltage existing across $R$ is naturally proportional to the current flowing through $R$ and it will, therefore, be useful in this case to consider currents as well as voltages of the different waves.

The current passing into Circuit 2 is

$$i_2 = 2\, i_1 \frac{Z_1 R}{Z_2R+Z_1R+Z_1Z_2} \qquad (27)$$

where $i_1$ is the current of the incident current wave.

The voltage of the reflected wave is:

$$p_r = p_1 \frac{Z_2R - Z_1R - Z_1Z_2}{Z_2R + Z_1R + Z_1Z_2} \qquad (28)$$

The case of the resistance in shunt is similar to the case of the resistance in series, if in the former case we consider currents and in the latter case we consider voltages. In other words, the reflected waves of currents entering Circuit 2 are the same as if the impedance of Circuit 1 were the combined impedance of Circuit 1 and $R$ in parallel, and the waves of current reflected back into Circuit 1 are the same as if the impedance of Circuit 2 were the combined impedance of Circuit 2 and $R$ in parallel.

If $Z_2$ is larger than $Z_1$, as for instance when $Z_2$ represents a transformer and $Z_1$ a line, then if

$$R = \frac{Z_1Z_2}{Z_2 - Z_1}$$

there is no reflection of the voltage wave and the incident wave, $p_1$, enters the Circuit 2 with unchanged voltage. If $R$ is larger than this limit value, then there will be a partially reflected wave with positive sign, and the voltage wave will enter Circuit 2 with increased voltage. If $R$ is smaller than this limit value, then there will be a partial reflection of the voltage wave with negative sign, and the wave entering Circuit 2 will have less voltage than the original wave. In other words, if the combined impedance of Circuit 2 and $R$ in parallel is equal to the impedance of Circuit 1, there will be no reflection. If the combined impedance is larger than $Z_1$, there will be positive reflection, and if this combined impedance is smaller than $Z_1$, there will be negative reflection of the voltage wave.

However, the current $i_1$, of the incident wave, will divide itself into two currents; one current, $i_2$, entering Circuit 2, and one current, $i_R$, entering the resistance. This current, $i_R$, and the drop across the resistance (which is equal to voltage $p_2$) constitute the amount of energy which is absorbed by the resistance.

The energy is again divided into three parts:

One part is reflected back into Circuit 1.

A second part passes into Circuit 2.

A third part is absorbed by $R$.

We see that if we connect a resistance, $R$, as shown in Fig. 23, between a transformer and a line, the waves coming from the line will enter transformer with higher voltages as long as

$$R > \frac{Z_1Z_2}{Z_2 - Z_1}$$

If

$$R = \frac{Z_1Z_2}{Z_2 - Z_1}$$

then the voltage waves coming from the line will enter the transformer at the same voltage, but with less energy, because part of the current of the original wave is shunted away by $R$.

Finally:

If

$$R < \frac{Z_1Z_2}{Z_2 - Z_1}$$

then waves coming from the line will enter a transformer with less voltage. In any case of course the waves entering the transformer have less energy than the incident waves.

The voltage waves coming from a transformer will enter the line always at less voltage and will be partially reflected back into the transformer with negative sign.

It is obvious that connecting resistances in series or in shunt in lines is impractical, because of the losses which these resistances would produce under normal operating conditions. Therefore, when a series resistance is necessary, it must be by-passed by a choke coil, as shown in Fig. 24. This coil will offer small impedance to currents of normal operating frequency, but very high impedance to currents of high frequency or to abrupt changes of currents.

Likewise, if a shunt resistance is necessary, it must be connected in series with a condenser, as shown in Fig. 25. This condenser will offer a very high impedance to currents of normal frequency, but will offer very low impedance to currents of high frequency or to abrupt changes of currents.

Furthermore, as we have seen, inductance and capacity modify and smooth over the abruptness of rectangular traveling waves, but do not decrease the amount of energy involved; whereas ohmic resistances do not change the abruptness of the waves, but efficiently decrease the amount of energy involved.

It is evident that no one of the devices examined above is sufficient alone to give protection against rectangular waves or similar abrupt phenomena, but it may be foreseen that the combination of these devices may prove very efficient for this purpose.

Considerable study and investigation have been given to the combination of inductance, capacity and resistance to protect against abrupt changes in voltages and current, and this may form the subject of another article in continuation of the present one.

# TELEPHONES FOR POWER TRANSMISSION SYSTEMS

By John B. Taylor

Consulting Engineer, New York

The author first discusses the relative merits of private, leased wire, and exchange service for electric power transmission systems. He then describes the advantages and disadvantages of running the telephone wires on the same towers or poles as the power cables, and also on a separate line paralleling the main transmission line. The conclusion of the article is devoted to brief statements regarding the safety provided by the telephone transformer and the convenience gained by the use of the loud-speaking telephone in this class of service.—Editor.

In the operation of any power transmission system some means of communication between the various divisions, such as generating, receiving, switching and distributing, has come to be an essential part of the undertaking. The telephone rather than the telegraph is, almost without exception, used for this service; and the need for establishing the communication without delay under normal conditions of operation and, as near as may be instantaneous under abnormal and emergency conditions, has resulted generally in the assumption of the construction, equipment and maintenance of the telephone plant by the power companies themselves. In some cases the service is obtained from local or long distance telephone companies, either by the usual exchange connection or by leased circuits. Where the importance of the service warrants it, both private lines and exchange or leased wire service are provided, the independent pole lines and usually different routes giving a certain assurance of continued service through the various hazards that wires must face in the open air.

The route selected for the power transmission lines is generally the logical route for the telephone line and the poles or structures erected for the power wires have naturally been considered for reasons of economy and frequently used for telephone wires also.

There are advantages in having power and telephone wires along the same right of way. Patrol and inspection of the power lines may include the telephone lines at the same time. Portable or more permanent instruments connected at any point along the line reduce delays in reporting and repairing trouble and in the resumption of service after a shut-down to make repairs or for new construction work.

There are disadvantages in placing the telephone wires on the same structures that carry the power wires and also disadvantages in following the same right of way. The fire and life risk from accidental contact between telephone and power wires need only be mentioned. A more frequent and sometimes continual source of trouble is from "induction." Very briefly, conductors which are charged (or alive) and carrying currents exert an "influence" on and through the surrounding space. These influences are usually called "electrostatic field" and "electromagnetic field." Conversely the changing fields "induce" changes and currents on conductors such as telephone wires. The telephone receiver gives sound which may be heard with extremely small currents; and in case of trouble when the conditions such as length of line, operating voltage, short-circuit current, etc., are considerable then induced voltages and currents may become sufficient to ring the bells, give unpleasant shocks, burn out the windings of telephone instruments or even start fires or kill if proper protective devices are omitted or neglected.

While the fields of force extend to an indefinite distance and probably travel to the planets and even to the stars with the velocity of light, practically they become vanishingly small at distances that may be used to separate power and telephone lines. Also of practical importance is the fact that the fields have a "sign" or direction so that the resultant field at any point is only what is left after subtracting all the forces of one sign from those of opposite sign. Thus a telephone wire may be close to two wires transmitting much power at high voltage and yet be free from induced current through being at the same distance from each wire, as the direction of the current in the two power wires is opposite. Similarly a telephone receiver on two wires equally distant from a single power wire may be silent through balanced forces.

For the best telephone service we must make what at first thought may seem almost a fetish of the word "balance." Power generators and transformers should be so designed and connected, as well as the lines themselves, as to insure at all times the same current flow in opposite direction in the two, three or more wires of the transmission lines; the voltage to earth should at all instants of time add up to zero (making allowance for opposite polaritier); current may not be returned by the earth; it may or it may not be permissible to ground the neutral as this may be done in many ways, as the terms "grounded neutral" and "third harmonic" have been made to cover a multitude of sins and their virtues often overlooked.

The telephone circuit must be metallic. Grounded lines inherently call for electrical isolation and even when away from other wires are more susceptible to atmospheric disturbing noises. The final refinement lies in the transpositions. Since the two wires of the telephone circuit must be separated for mechanical and electrical reasons, transposition, ro interchanging the positions of the wires at intervals, makes the neutralization closer. Transpositions are frequently desirable, though not always needed, on the power wires also.

In most cases a transposition of the two telephone wires every 1000 feet is sufficient. Sometimes more are cut in while endeavoring to eliminate undesirable noises, but often such work is worse than time and money wasted if the noise chances to be due to a high resistance ground at some point or to high resistance joints, etc.

Some power lines are transposed every mile or two but in the absence of any specific case to be considered it may be proper to suggest the use of two transposition points—giving, for a three-phase system, three equal sections—between generating and receiving stations or between switching points.

Conditions and requirements of a power company's private telephone differ from exchange service. In exchange service all protective devices aim to save the instruments, cables and switchboards from damage at the expense of the service. The line is opened or grounded on what, for a power line, would be regarded as slight provocation. In many of the early power telephone lines service was bad and frequently interrupted when most needed through following exchange practice in equipping the telephone stations. The gap to ground adjusted to strike at 300 to 500 volts is too sensitive for a power telephone line. Some station operators merely discarded these with attending risks to users and equipment.

In the endeavor to give safe and continuous service in spite of trouble on the power lines, the writer developed the now well known telephone transformer.

This is essentially a "repeating coil" with sufficient insulation between the line and instrument windings to withstand a production test of 25,000 volts for one minute. Some over-zealous advocates of its use have claimed that it will quiet a noisy line. It *may* do this by improving the line insulation, but it is properly regarded as a device to protect instrument and user and enable lines paralleling power lines to be safely connected into exchange systems.

Although, by balancing and transposing, a telephone may give excellent service with the wires on the same towers with high voltage lines, a separate pole line is preferable; and on most of the lines recently built and under construction for use at 60,000 volts and higher a separate line of poles from 50 ft. to 200 ft. removed from the main tower line is set to carry the telephone wires. At these distances the induced voltage with accidental grounds or short circuits is much reduced and the risk of actual contact is practically eliminated.

Unless power transmission conditions alter materially, the telephone will continue an indispensable part of the whole system. Proper provision should be made for lines and equipment in planning new work and tests and inspections to ensure continued high efficiency should be regularly applied. Rapidity and reliability in establishing communication between distant points must exist at all times where there is any pretense of giving first class service. As indicating a possible direction in which there may be some innovations, attention is directed to the increasing use of loud speaking telephones. When an operator is continually in attendance some time may be saved, as there are occasions when seconds are precious, and the operation of ringing and waiting for an answer can be eliminated. A loud speaking telephone has been found to give good service in train dispatching at busy terminals. A loud speaking receiver with amplifying horn is mounted on wall or ceiling close to the tower-man's position and instructions given and questions asked without the customary ringing and answering. With such a loud speaking telephone near the controlling board of a generating station the operator could be spoken to with no delay and without requiring him to lose sight of instruments or use of hands to control switches.

# CENTRAL STATION SERVICE FOR ARTIFICIAL ICE PLANTS

By W. J. Moore

Small Motor Department, General Electric Company, New York Office

Artificial ice is superior to the natural product in every respect; it is purer and more transparent, and the quantity is not dependent upon weather conditions. It is fast supplanting natural ice, even in those localities where the winter weather insures an abundance of the latter. This article describes the principal features involved in the latest method of ice manufacture by the raw-water system, and shows by means of a carefully compiled table and a discussion of its significance that the central station can profitably supply power to ice manufacturing plants at a price that compares favorably, per ton of ice produced, with the costs of steam and gas producer plants.—Editor.

Until recent years the artificial ice plants in this country were driven by steam engines, and the ice was manufactured from the distilled water obtained by condensing the steam exhausted from the engines. In order to entirely remove the cylinder oil from the water supplied in this manner, and thus prevent it from becoming frozen into the ice, a complicated filtration system was necessary.

A marked improvement in the process of ice making was later introduced, namely, the adoption of the multiple-effect evaporator. This machine operates on the principle that less heat is required to evaporate water under vacuum than under atmospheric pressure. By the use of this type of evaporator, it is sometimes possible to obtain an evaporation as high as 50 lb. of water per lb. of coal. With the adoption of the evaporator, distilled water could be secured at low cost and free from oil. It therefore became possible to drive the main compressors by a compound condensing engine, an oil engine, a gas engine, or any other type of prime mover which could be operated economically and which would give continuity of service.

Due to the general realization by central stations that the ice plant was desirable from the standpoint of constant load and high load-factor and in keeping with the practice of making reductions in rates for the class of users taking current at off-peak periods, power companies have been in a position to make attractive inducements to artificial ice plants.

Various methods have been devised for making ice without the use of distilled water, where local conditions are favorable for obtaining satisfactory well, spring, or city water. The original "raw-water system," adopted for the manufacture of ice direct from well, spring, or city water, was known as the plate system; and consisted of freezing water into large cakes sometimes 9 ft. by 16 ft. by 12 in. in size and weighing five tons. In this system cold brine is made to circulate through hollow plates immersed vertically in tanks filled with water. The water is agitated and the ice forming on both sides of the plates rids itself of any air or impurities. The large cake thus formed is removed by a crane to a sawing table and there cut into cakes of the desired size.

Within the last two years considerable progress has been made in perfecting the raw-water can system. This system necessitates a modification of the can, as used in the manufacture of distilled-water ice, because the water must be constantly agitated during the process of freezing. An air pipe is connected at the bottom of the can, through which air is supplied at about 3 lb. pressure. Water in freezing liberates its entrained air and carbon dioxide, which are carried off by agitating the water. If for any reason the agitation ceases, the bubbles of air and carbon dioxide are frozen into the block, which causes the ice to be opaque. The quantity of air required for agitation depends upon the rate of freezing and varies with different waters.

In the process of freezing, small crystals of pure ice are formed. As the crystals form, the soluble mineral salts, being more capable of solution in water than of being frozen into ice, are removed by the water which has not as yet become frozen. If the proper agitation takes place, solids and matter in solution or in suspension are "pushed ahead" of the freezing ice until they arrive at the center of the can.

When about 12 to 40 lb. of water are left still uncongealed in the center of a 300-lb. cake (the amount depending upon the type of freezing system used) this water, which contains practically all of the impurities originally in the 300 lb. of water, is then removed. Various methods have been adopted for removing this core. One method provides for its removal by opening a master valve controlling a drain pipe, which drains out the impure water from 60 or more cans by one operation. Another method is to withdraw the water from the top of each individual can by means of a suction pump. The hole through the center of the cake is then filled with distilled water, or additional raw water, and the cake frozen solid. Ice manufactured by the raw-water system is more sanitary, palatable, and more nearly free from odor than that made by any other system. The cake is transparent and has a slight feathery appearance at the center.

Recent tests have shown that while the impure core-water may contain 200,000 bacteria per cubic centimeter, the entire cake will contain on the average less than 20 bacteria per cubic centimeter after the core-water has been withdrawn, fresh water added, and the cake completely frozen.

Previous to the adoption of the raw-water system, central stations did not consider the artificial ice business as within their field of operations. They regarded the production of the necessary amount of the engine exhaust a serious handicap to economical manufacture by electricity. However, with the advent of this system, central stations could compete in power costs with the gas producer, oil engine, and high-economy compound condensing engine; and their attention was therefore directed to the large possibilities presented by this class of business. Much has been accomplished within a short time in this new field. The city of Chicago has fifteen central-station-driven ice plants (the daily tonnage ranging from 60 to 140 tons each, totaling 1355 tons with an aggregate installation of 5344 h.p.); Buffalo, N. Y., has five, operated by Niagara Falls power; and there has recently been built in Brooklyn, N. Y., two of the largest electrically-driven raw-water ice plants in the world, which are operated entirely by central-station power.

The first cost of a central-station-operated plant is considerably less than that of an engine-operated plant with a consequent reduction in fixed charges, such as interest, depreciation, insurance and taxes. The space required for an electrically-driven plant is less than for a steam plant. The plant operated by electricity may be located in residential sections, where, due to the nuisance of smoke, noise, etc., steam plants would not be allowed. Hence, with this central location with respect to customers, delivery charges and shrinkage are reduced to a minimum and prompt deliveries are assured.

The use of the electric motor meets with favor by the ice manufacturer, since it eliminates engine and boiler troubles: the necessity for making boiler repairs recently shut down a large plant in Brooklyn for five days during the hottest weather.

The artificial ice plant makes the ice man independent of weather and furnishes a grade of ice that is superior to natural ice, for it is purer, cleaner, more transparent, and more uniform in size, purity, and density. The use of natural ice is rapidly decreasing. A number of the Great Lake cities no longer use it, because the streams from which it was taken have become impure due to the increase in population, sewage, and polluting refuse from manufacturing plants, etc. No more natural ice is being shipped up the Potomac River, and a large electrically-driven raw-water plant has been installed at Winnipeg, Canada, where the temperature in the winter is often 40 deg. below zero, and in Minneapolis, Minn., where from zero to 20 deg. below is often prevalent. The city of Buffalo, N. Y., will soon be entirely supplied by artificial ice.

Natural ice can be cut for about 15 cents per ton, but added to this is the cost of shrinkage, storage, loading on cars or boats, transportation, dock rentals, etc. These factors, together with the long hauls from the railroad terminals or docks in the cities, make the final price only slightly less than that of the artificial product. The quality of the artificial product enables the manufacturer to over-balance any difference in price and compete with the natural ice dealer.

In the manufacture of the average article the power cost may be between 2 and 5 per cent, while in ice making it ranges between 30 and 50 per cent of the total cost of production. It is apparent, therefore, that the cost of power largely affects the cost at which ice may be manufactured. The power required to manufacture one ton of ice would of course depend upon the system used, and the type and efficiency of the machinery. Data are available which show that in a raw-water plant of about 100 tons capacity, it may take as low as 45 kw-hr. or as high as 60 kw.-hr. per ton of ice. The average throughout the country is about 52 kw-hr. per ton of ice produced, based on cooling water at 65 to 70 deg. F., the exact figures depending upon the conditions existing at the plant.

An examination of the chart, which has been compiled by the Arctic Ice Machine Company, Canton, Ohio, and which covers the Arctic Pownall system of raw-water ice manufacture, shows the cost from the standpoint of power, labor, and sundries, which include oil, waste, ammonia, and calcium; and also the investment necessary to build a power plant for operating an ice plant employing a simple steam engine using bituminous coal, a compound condensing engine using bituminous coal, a producer-gas engine using bituminous, anthracite, or lignite coal, a gas engine using natural gas, an oil engine using fuel oil, or a plant using motors operated by central station service.

The figures given in this chart are maximum. This is necessarily due to the fact that the figures are compiled for use in all parts of the world. That is, if a chart of this kind was made based on 50 kw.-hr. per ton of ice produced when electrically-driven, and a plant installed where exceedingly warm condensing water was used, or where it might be necessary to go to great expense in pumping condensing water, such figures would come within the data given herewith. The chart in question should also only be used to make *comparison* between the operation and installation cost of different prime movers, data based on local conditions being substituted for those given in the table.

It will be seen that by the use of a simple steam engine about six tons of ice per ton of coal may be manufactured, while with the use of the compound condensing engine this is increased to 11 tons.

It will also be noticed that the lowest operating cost is secured by the use of a producer-gas engine using bituminous coal, while the highest operating cost results with central station service using electric motors at 1 cent per kw.-hr. However, although the cost of operating per day by a producer-gas engine using a $3.00-a-ton bituminous coal is $46.70, and the cost of electrically operating per day with current at $^1{}_2$ cent per kw.-hr. is $47.51, it should be observed that the investment for the power plant using a producer-gas engine is $65.00 per h.p. as compared with $16.00 per h.p. where electric motors are used.

To obtain the total cost per ton of ice, the cost of the water from which the ice is made, and the interest on investment, insurance, taxes, depreciation, maintenance, and management charges on the plant must be added to this cost of operation. It will be noted that the labor in the electrically-driven plant is less than in most other types in that the firemen may be dispensed with.

Although there is a difference in the cost per unit of power, in favor of the gas or oil engine as compared with the electric motor, the final cost of the ice manufactured by the use of such engines may exceed that manufactured by motors operated from central station power, because of repairs, losses due to shut-downs to make such repairs, additional depreciation, etc.

From the central station standpoint the ice plant is a very desirable load. Current is used 24 hours a day, and the peak of the ice plant does not overlap the peak of the central station. The maximum peak of the average central station occurs during the months of November, December, January and February, and between the hours of 4 and 8 p.m. During this time the main compressor motors of the ice plant may, without any inconvenience, be shut down and the small auxiliaries operated without interfering with the production of ice. As a result the central station can consistently offer a low rate for current.

In order to insure continuity of operation and to be in a position to offer a low rate, the central stations may furnish current from their primary system, that is, direct from the main generators, and thus eliminate transformer losses. At Buffalo, high-tension power at 2200 volts is delivered to the compressor motors; in Brooklyn, the primary current direct from the main generating station is delivered at 25 cycles and 6600 volts to the ice plant, where it is transformed to 440 volts for use at the motors.

From an engineering standpoint the ice plant presents a serious problem to the central station as regards reliability of service, for considerable trouble in the ice plant might develop due to momentary shut-downs; more so than ordinarily results from the shutting down of the usual industrial plant. Great care must be taken to prevent momentary interruptions to the service, for when the large compressor motors are shut down it interferes with the ammonia distribution, and, as the ammonia compressors must start under full load, a return of current on the line is very apt to blow the fuses and otherwise interfere with the operation of the plant. It has been found necessary to devise a system of no-voltage relays in order to eliminate possible fuse trouble with its attendant delays.

The question of transformers for use in connection with ice plants is a very important one. Manufacturers of transformers frequently design them bearing in mind that in ordinary use they will have a chance to cool due to variations in load. The ice-plant load is practically constant, and this should be kept in mind in selecting the size of transform-

## COST OF MANUFACTURING RAW-WATER ICE—100 TONS CAPACITY—VARIOUS SOURCES OF POWER

*(Courtesy of the Arctic Ice Machine Co., Canton, O.)*

| | Motive Power | Using | H.P. | Total H.P.-Hrs. Per Day | Fuel per H.P. | Fuel or Power Per Day | Unit Cost of Fuel | Fuel Cost per Day | Tons of Ice per Unit of Fuel | Sundry Costs | | | Labor Cost | | | | | Total Cost per Day | Cost per H.P. of Power Plant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Oil Waste Etc. | Ammonia | Calcium | 1 Day Engineer | 1 Night Engineer | 4 Ice Pullers | 1 Extra Man | 2 Firemen | | |
| 1 | Simple Steam Engine | Bituminous Coal | 367 I.H.P. | 8808 | 3½ lb. | 15.4 tons | 2.00 tons | $30.80 | 6.38 Tons Ice per Ton of Coal | 2.00 | 2.50 | 0.50 | 5.00 | 3.25 | 8.00 | 2.00 | 5.00 | $59.05 | $32.00 |
| | | | | | | | 2.50 tons | 38.50 | | | | | | | | | | 66.75 | |
| | | | | | | | 3.00 tons | 46.20 | | | | | | | | | | 74.45 | |
| 2 | Compound Condensing Engine | Bituminous Coal | 375 I.H.P. | 8952 | 2 lb. | 8.95 tons | 2.00 tons | 17.90 | 11.15 | 3.50 | 2.50 | 0.50 | 5.00 | 3.25 | 8.00 | 2.00 | 5.00 | 46.15 | 40.00 |
| | | | | | | | 2.50 tons | 22.38 | | | | | | | | | | 50.63 | |
| | | | | | | | 3.00 tons | 26.85 | | | | | | | | | | 55.10 | |
| 3 | Producer Gas Engine | Bituminous Coal | 360 B.H.P. | 8640 | 1¼ lb. | 5.4 tons | 2.00 tons | 10.80 | 18.5 | 3.50 | 2.50 | 0.50 | 6.00 | 4.00 | 8.00 | 2.00 | 4.00 | *41.30 | 65.00 |
| | | | | | | | 2.50 tons | 13.50 | | | | | | | | | | 44.00 | |
| | | | | | | | 3.00 tons | 16.20 | | | | | | | | | | 46.70 | |
| 4 | Producer Gas Engine | Anthracite Coal | 360 B.H.P. | 8640 | 1 lb. | 4.31 tons | 3.00 tons | 12.93 | 23.2 | 3.50 | 2.50 | 0.50 | 6.00 | 4.00 | 8.00 | 2.00 | 4.00 | 43.43 | 65.00 |
| | | | | | | | 3.50 tons | 15.09 | | | | | | | | | | 45.59 | |
| | | | | | | | 4.00 tons | 17.24 | | | | | | | | | | 47.74 | |
| | | | | | | | 4.50 tons | 19.40 | | | | | | | | | | 49.90 | |
| | | | | | | | 5.00 tons | 21.55 | | | | | | | | | | 52.05 | |
| | | | | | | | 5.50 tons | 23.71 | | | | | | | | | | 54.21 | |
| | | | | | | | 6.00 tons | 25.86 | | | | | | | | | | 56.36 | |
| 5 | Producer Gas Engine | Lignite | 360 B.H.P. | 8640 | 1¾ lb. | 7.56 tons | 2.00 tons | 15.12 | 13.2 | 3.50 | 2.50 | 0.50 | 6.00 | 4.00 | 8.00 | 2.00 | 4.00 | 45.62 | 65.00 |
| | | | | | | | 2.50 tons | 18.90 | | | | | | | | | | 49.20 | |
| | | | | | | | 3.00 tons | 22.68 | | | | | | | | | | 53.18 | |
| 6 | Gas Engine | Natural Gas 1050 B.T.U. Value | 360 B.H.P. | 8640 | 10 cu. ft. | 86400 cu. ft. | 0.20 per M | 17.28 | 864 cu. ft. gas req'd per ton of ice produced | 3.50 | 2.50 | 0.50 | 6.00 | 4.00 | 8.00 | 2.00 | | 43.78 | 35.00 |
| | | | | | | | 0.25 per M | 21.60 | | | | | | | | | | 48.10 | |
| | | | | | | | 0.30 per M | 25.92 | | | | | | | | | | 52.42 | |
| | | | | | | | 0.35 per M | 30.24 | | | | | | | | | | 56.74 | |
| 7 | Oil Engine | Fuel Oil | 360 B.H.P. | 8640 | 0.075 gal. | 648 gal. | 0.02½ gal. | 16.20 | .155 Tons Ice per Gal. of Oil | 3.50 | 2.50 | 0.50 | 6.00 | 4.00 | 8.00 | 2.00 | 4.00 | 46.70 | 40.00 to 60.00 |
| | | | | | | | 0.03 gal. | 19.44 | | | | | | | | | | 49.94 | |
| | | | | | | | 0.03½ gal. | 22.68 | | | | | | | | | | 53.18 | |
| | | | | | | | 0.04 gal. | 25.92 | | | | | | | | | | 56.42 | |
| 8 | Motor | Electricity | 327 on wire | 7848 | 0.746 kw. | 5854 kw. | 0.00½ kw. | 29.27 | 58.54 kw-hrs req'd per ton of ice produced | 2.00 | 2.50 | 0.50 | 5.00 | 3.25 | 8.00 | 2.00 | | 47.51 | 16.00 |
| | | | | | | | 0.00⅝ kw. | 36.48 | | | | | | | | | | 59.63 | |
| | | | | | | | 0.00¾ kw. | 43.90 | | | | | | | | | | 67.15 | |
| | | | | | | | 0.00⅞ kw. | 51.23 | | | | | | | | | | 71.18 | |
| | | | | | | | 0.01 kw. | 58.54 | | | | | | | | | | †81.79 | |

Water estimated at 70 deg. F.
Condenser pressure 185 lb.

Suction pressure 15 lb.
Ammonia used as refrigerant.

Power included for pumping water with 60 foot head.

* Minimum.
† Maximum.

Above costs do not include interest on investment, depreciation, taxes, insurance, management or any other fixed charges.

Power is based on summer conditions. Less power will be required if yearly average is figured on.

Oil engine fuel requirements based on engines of Diesel type.

ers to be used. Where different makes of transformers would operate in parallel in an ordinary industrial installation, such operation in ice plants often results in the burning out of either one or the other make. This is due, of course, to unequal distribution of the load caused by the difference in impedance of the transformers.

It is advisable that the lighting system of the ice plant should have available a source of power other than that furnished by the power circuit from which the motors are operated so that, in case of an interruption to the power supply, the lights can be supplied from this separate source. It is considered good practice, also, to independently connect the motors operating the compressors that furnish the agitating air so that they, too, may have a separate power circuit available. Interruption of the flow of agitating air causes white streaks in the ice.

With reference to the type of motor to be used in driving the main compressors, where alternating current is supplied, it is advisable to use the wound-rotor type. The resistance should be designed for starting duty only, as it is the general practice in ice making to use constant speed.

It is also desirable to use that type which provides for the lifting of the brushes from the collector rings and also for short circuiting them. This device increases the efficiency of the motor, inasmuch as it eliminates from the secondary circuit the resistance of the brushes and the leads to the controller. When it is considered that the ice plant operates 24 hours a day for months at a time, it will be realized that a difference in efficiency of 3 to 5 per cent in the main compressor motors is a matter of importance. Up to 150 h.p. it is well to use induction motors having the internal-resistance type of phase-wound rotor. These motors have met with marked success in this field of application.

# ELECTRICAL EQUIPMENT FOR MOTOR-DRIVEN MACHINE TOOLS

By C. Fair

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This article presents in a detailed manner the marked improvements that can be made in production by the application of electricity for driving machine tools. The selection of the proper motor and control equipment for such work is carefully considered from various standpoints. Illustrations of a number of typical motor drive installations are included, and also reproductions of oscillograph and recording-ammeter curves, which show the characteristic electrical demands upon the motors used.—Editor.

Originally, lighting was the principal, if not the only, advantage claimed for electricity. Little was known of shop equipments as we now see them. It is doubtful if there were any electrically operated cranes or if there was any electrical transportation in shops. The first few motor drives were scattered and confined practically to line shaft drives and to portable drills with flexible shafts. The individually driven machine tool was about as much of a curiosity then as an individually steam engine driven machine tool is today. When motors were installed to replace the numerous engines scattered about the shops or to break up the long mechanical transmission lines, a great saving in power and improvement in continuity of service were noticed. It was during this period that many of the claims of saving in power were made that now appear rather extravagant. It will be seen how enormous were the power losses when one considers that steam was often transmitted to numerous engines for long distances, from one or more power stations, through small pipes which were often uncovered or else the power was distributed by long shafts transmitting power from one building to another or from one shaft to another, around corners, by quarter turned belts and to various floors, etc. When the long shaft or any part of the long transmission system was broken, it often tied up a large part of the plant until key-ways could be cut and the shafts re-coupled or a section of the shaft replaced, or the belts repaired, as the case might be. Within the past two years an investigation was made of a plant that spread over a considerable area, employing less than four hundred men and the machinery of which was driven by 26 engines, the largest being about 50 h.p.

Today the two important questions continually before the manufacturer are how to increase production and how to decrease cost. In the majority of cases labor is the

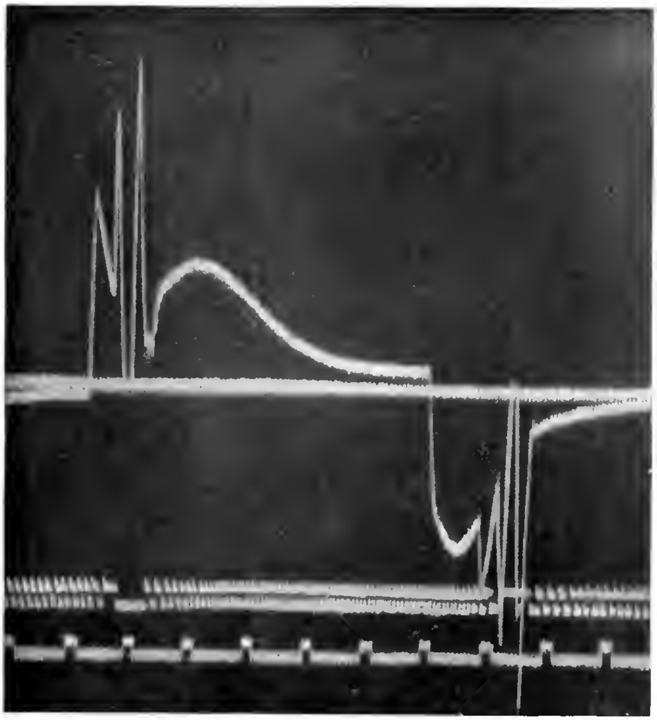

Fig. 1-a

greatest cost of production. Thus, where machine tools are a considerable factor in the production, the importance of obtaining a maximum output from the tool is evident. Tools that are limited in their productiveness because of the lack of power at the tool are a source of expense to the manufacturer, not only on this account but on account of the excessive labor due to the additional time required. The power cost of production is comparatively small, roughly, varying from one to three per cent, while the labor cost is usually a very large item of the production cost, often amounting to fifty per cent and upward. If, therefore, by increasing the power on a given tool its output can be increased, the conclusion is obvious.

The importance of motor drive for the machine shop is every day becoming more evident. Recent tariff legislation is causing American manufacturers to see, as never before, the necessity of using the most modern methods in order to compete with manufacturers of other countries where labor is cheaper; hence the continuous growth in the installation of electrically driven machinery. In practically all new industrial plants where power is required, electrically driven machinery has been installed. Due to the great improvement in motors, accessories, and methods of application, and owing to the large number and variety of motor-driven tools in service today, the relationship of motors and control to machine tools is much better understood by the machine builder and the user than heretofore. Consequently, comparatively little trouble is experienced with either motors or control for the ordinary type of machine tool. Misapplications of both motor and control occur occasionally due largely to insufficient or unreliable information regarding the characteristics of the machine, but the number of these misapplications is relatively small.

The tendency for both over and under-motoring machines is constantly growing less, owing to the

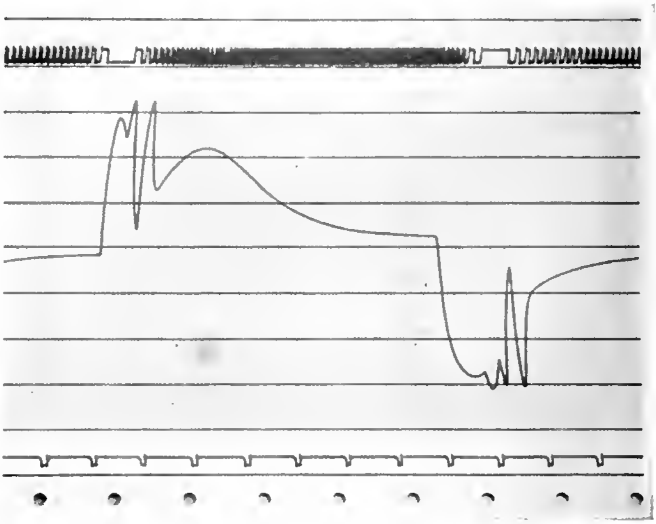

Fig 1-b. Figs. 1-a and 1-b show a comparison of curves made simultaneously on a reversing motor planer drive between the oscillograph with its period of 5000 per second and the graphic recording ammeter with its period of six per second. This comparison made approximately to the same scale of time affords better understanding of the actual value of the curves in the following Figures.

large number of tests which have been made, to the accurate information available, and to the great number of motor driven machines now in service. There is still, however, a slight tendency on the part of some machine builders to over-motor their machines either with the mistaken idea of the strength of the machine or with the idea that possibly prospective customers will be impressed with the enormous power required by their "heavy type" machines. Conversely, other manufacturers want to show how little power it takes to operate their "very efficient" machines and consequently get into overloaded motor troubles. These extremes are gradually disappearing and a more normal condition is taking its place. In a comparatively short time the greatly over-motored and under-motored machine will be a thing of the past, at least insofar as the general type of machine is concerned.

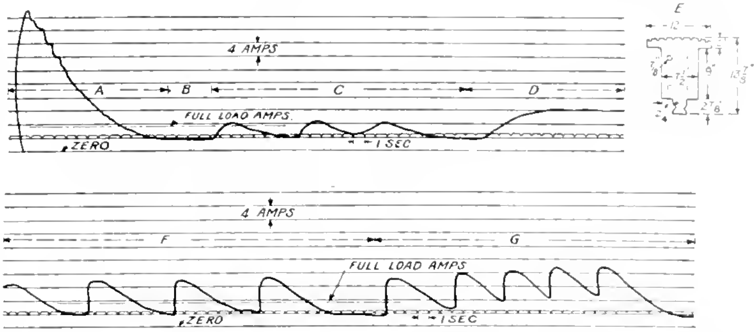

Fig. 2. Curves from a Ferracute Punch Press S. G. 52. A, accelerating the flywheel, clutch not engaged; B, load of flywheel only; C, stroking without punching at the rate of nine strokes per minute, flywheel recovers its energy; D, stroking without punching at the rate of 16 strokes per minute, flywheel recovers very little energy; F, punching piece "E" at the rate of 8 per minute, flywheel nearly recovers its energy; G, punching piece "E" at the rate of nearly 14 per minute, flywheel only partly recovers its energy

A number of manufacturers have already recognized three ratings of motor drive on certain of their machines; namely, heavy, medium, and light. Much of the existing trouble in motor applications to special machines, or to machines rigged for special operations, could easily be avoided if only preliminary tests were made with a temporary motor before making the permanent installation. A not uncommon source of trouble with motor-driven tools, and one that could easily be avoided, is that of attempting to increase the productiveness of the tool considerably by speeding up the machine, increasing the cuts, or attaching automatic feeding devices, etc. Although any one of these changes will increase the productiveness of the tool, the motor must not be overlooked for, if the tool were originally under-motored and the capacity of the motor is not increased when the change is made, trouble is very apt to result. Increasing the productiveness of the tool calls for an increase in power, although there are some cases where this is not true.

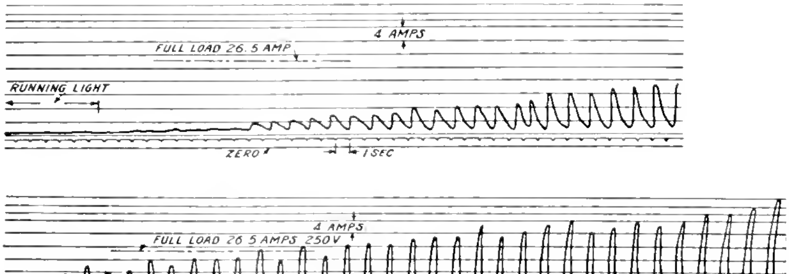

Fig. 3. Shows graphically the effect of automatically rough-shaping gear teeth with a V-shaped tool. Each peak represents a cutting stroke

Although the advantages of the motor drive have been dwelt upon at length numerous times, a brief statement of the advantages derived from electrical installations will perhaps be worth repeating:

1. Maximum output of the direct connected tool due: to greater power and overload capacity, absence of slipping belts, closer speed regulation which allows a maximum cutting speed for metals of varying degrees of hardness, rapid speed changes, quick starts, stops, reversals, independent operation of auxiliaries

and ease of manipulation through convenient control stations. Too much stress cannot be laid on maximum output of tools.

2. Power distribution not only for tools, stationary or portable, but for lights, cranes, elevators, furnaces, welders, transportation, etc. This means that power and light can be had quickly and cheaply in any part of the buildings or yard, permanently or temporarily without regard to structural conditions.

Fig. 4. Group of Nine Drop Hammers consisting of one 2500, two 1600, two 800, two 600 and two 400-lb. hammers, driven from 80 ft. of shafting carrying 18, 30 in. by 8 in. flywheel pulleys and driven by a direct connected 40 h.p. motor. In the middle foreground will be seen a motor-driven air hammer

3. Elasticity in the arrangement of tools. Tools can be arranged to the greatest advantage for sequence of operation in routing work, and also for good lighting as well as for compactness when necessary.

4. Ease of adding new tools and of moving and rearranging tools. Ease of adding new tools means a great deal in growing plants. Rearrangement becomes necessary after reasonable growth or because improvements in methods of manufacture call for a better routing of work.

5. Head room for cranes, hoists, etc. For example, note the expensive manner in which work is often handled because belts or shafting interfere with the installation of cranes or hoists.

6. Facility for running only such tools as are required for overtime work.

7. To a large extent the elimination of belts and belt troubles.

8. Unobstructed light and sanitation. Numerous belts obstruct light, whether natural or artificial. Under the modern structural conditions, avoidance of the well understood difficulties of line shaft installation in concrete buildings.

9. Safety to operators. The individual motor drive offers absolute protection to the operator from accidental starting up of the machine by merely opening a switch. Machines so protected cannot be started unexpectedly by the starting up of line shaft, the creeping of belts from loose to tight pulley, the sticking of clutches, etc., or by the accidental tripping of clutches by the operator. This additional safety is of particular advantage on machines requiring certain setting up operations, as on punch presses, etc., also by the fact that machines can be quickly stopped from any one of a number of motor control stations.

10. Competition today necessarily means the monotonous duplicate system of manufacturing wherein the individual makes only one part of the finished product. It is now recognized as not only desirable but as economical that some form of interest be restored to help break this monotonous routine of duplicate manufacturing. This can and is being accomplished in a manner by making the surroundings attractive. Electric drive not only increases production, but reduces to a minimum many of the unattractive features of the shop, such as overhead revolving pulleys, masses of moving belts, noisy transmission, stirring up of oil and dust, and bad lighting conditions. Electric drive also reduces many heavy manual operations to a minimum by the use of auxiliaries. It pays to capitalize cheerfull surroundings.

The general use of high speed steel has made it not only possible, but necessary for economical production, that the cutting speed be increased in order to meet competition. Increasing the cutting speed naturally means more power; and while much has been said from time to time regarding the increased production and saving in power due to applying the power direct to the tool, yet the writer has very serious doubts if anything like the real importance

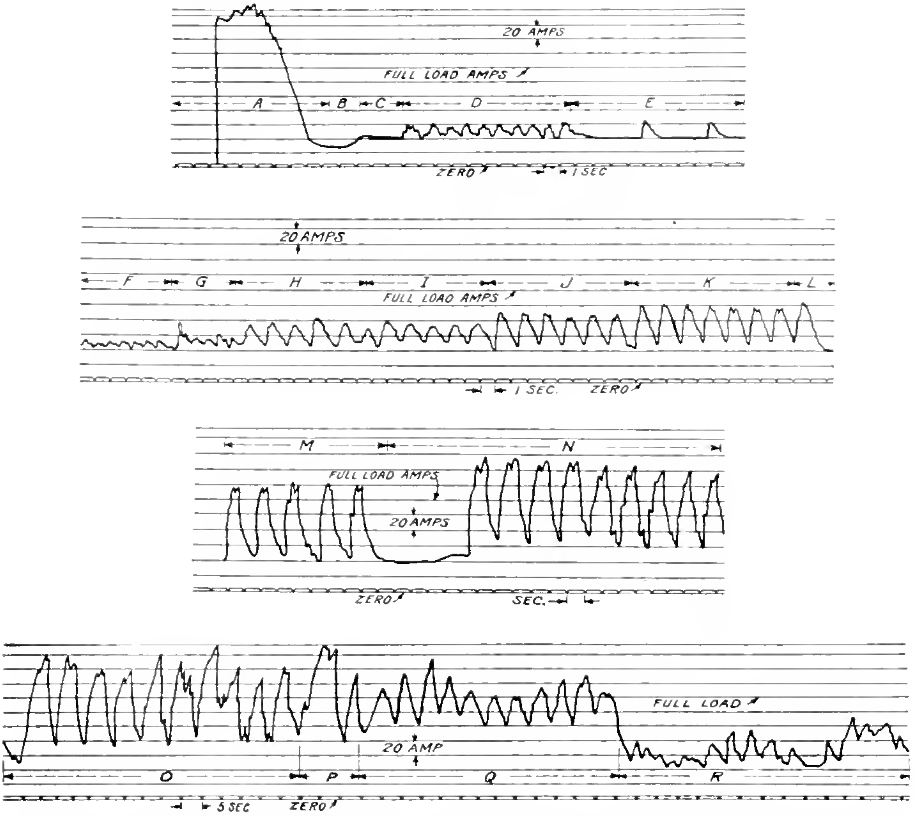

Fig. 5. Results of Tests on Hammers in Fig. 4. A, starting shaft; B, running light; C, hammers up; D, one 400-lb. hammer stroking light; E, forging; F, one 600-lb. hammer stroking (shorter stroke than previous 400-lb.); G, forging; H, one 800-lb. stroking; I, forging; J, one 1600-lb. stroking; K, forging steel commutating poles; L, final lift of hammer; M, one 2500-lb. hammer stroking; N, working steel gear blanks for air compressors; O, P, Q and R, hammers in regular production; O, 2500, 800, 600 and 400-lb. working; P, 2500 and 1600-lb. working; Q, 1600, 800, 600, and 400-lb. working; R, 800, 600 and 400-lb. working

of this direct application of power is realized in many cases, even by those who are advocating it. For instance, the saving of power is looked upon generally as a matter of how much of the transmission friction load can be saved, and, though this saving may amount to 50 per cent, it is in many cases only a part of the real saving, as has been proved by numerous tests made by the writer.

The slipping, due to a belt not being able to pull its cut, means waste power and loss of production. If the cut be heavy enough the maximum slip will be reached when the machine is stalled, the power input remaining approximately the same. The load is now entirely one of friction due to slip in the belt. A familiar illustration of this fact is that of an operator decreasing the depth of his cut on account of the slow down, because the belt will not carry the load. The solution of this would seem to be to increase the size of the belts. This will suffice in some cases, but there are numerous instances where either there is not room to increase the width of the belt or where step cones are used the number of steps will have to be decreased; such means as multiple countershafts or additional gearing must be included to complete the speed range. Furthermore, it is difficult to shift large belts, and this method generally results in much loss of productive time.

As previously mentioned, up to a few years ago in the majority of shops where motors were used they were usually belted to the line shaft or counter-shaft of the tool. Adjustable speed motors were not so commonly used then as now, nor were they made in the great variety of sizes and speeds now obtainable. Today, especially in the case of new tools with their requirements of high power and close speed regulation, it becomes not only more convenient, but in many cases almost a necessity, to apply the motor directly to the tool.

In driving tools with individual motors it will be noted that the motor not only supplies the power and speeds best adapted to the tool, but that in the case of variable speed tools the speed range of the adjustable speed motor alone in many cases will cover the entire speed range of the tool. The motor and its controlling apparatus should whenever possible be connected directly to the tool, thus making a compact unit, which has also the additional advantage of allowing the entire machine to be moved by simply disconnecting the leads and connecting them in the new position. In the case of portable tools this, of course, is an absolute necessity.

Fig. 6. Shows a section of a small shop equipped more than fifteen years ago, nearly all of the machines being driven by individual motors. A number of these machines are the first of their kind to be driven by individual motors, and although fifteen years have elapsed since the original installation, it compares favorably with an up-to-date equipment of today

Many tests have been, and are being made, to determine the kind and the horse power of the motor that should be used for different types and sizes of tools; but up to the present time the motor is generally considered only as a means of driving the tool and not as one of the main elements of the tool construction. Recent motor improvements will produce many new designs in tools with corresponding higher efficiencies.

While there are numerous motor applications to machine tools which are a decided credit to the machine designers and for which due credit should be given, there are still many motor applications where it is only too plainly to be seen that the motor is an after-thought and thus much of the advantage of the application is lost. In order to derive the greatest advantage from motor drive, the motor should as far as possible be direct-connected to the machine. There are today many cases where motors are driving machines through unnecessary auxiliary apparatus. This additional apparatus not only takes up valuable floor space and wastes power, but fails to give the maximum output available when the motor could be connected directly to better advantage and in some cases at actually less cost. From the foregoing it will be seen that the advantages derived from an up-to-date direct method of applying the motor not only increases the productiveness of the tool, but also decreases the actual power required, by the extent of the friction load loss, and also decreases the first cost of the motor on account of the less horse power required. The writer knows of cases where improved drives have cut the power required to half and even less. A cheap first cost is sometimes an expensive investment.

The advantages of individual motor drive for large tools and for certain of the smaller tools have been conceded for years, but there are many tools where either the cost of the motor or the cost of applying the motor to the tool on account of the construction of the machine is prohibitive. This cost could be modified by making the motor a part of the tool rather than a mere addition to it.

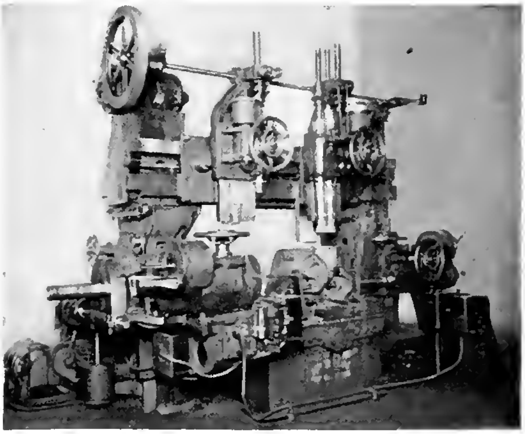

Fig. 7. A Special Five-Spindle Boring Mill. Three-motor drive

Better drives are possible now than they were formerly owing to the greater motor speed range obtainable, to the decrease in size of motor per horse power, to motor characteristics which specially adapt them to the work which they are to do, to more perfect balance of the rotating parts at high speed; and, to a certain degree, to improvements in gears which allow higher speeds without excessive vibration and noise, and to the many recent improvements in control.

Much more exacting requirements of both motor and control are now demanded. Motors driving machines reversing ten times per minute, and operating twenty-four hours per day are now not unusual. Duty cycles that were impossible to meet only a short time ago are now not only practicable but common. With the great variety of motors and controllers now on the market, and the large quantity sold sometimes without the motor manufacturer even knowing for what service they will be used, it would be surprising if trouble did not occasionally occur.

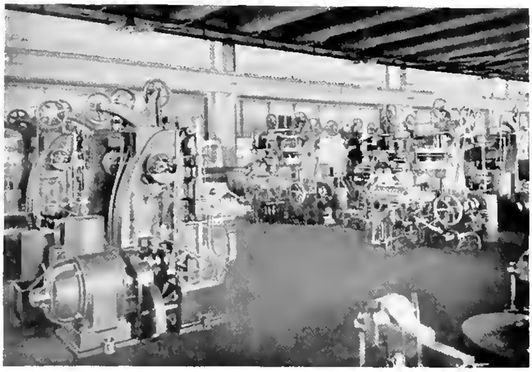

Fig. 9. Group of Individual Motor-Driven Milling Machines each driven by a 10 h.p. motor. Note head-room clearance for cranes

Much of the success of a motor-driven machine depends on its control. Magnetic control, which is coming into more general use somewhat complicates the control situation. While the possibilities of magnetic control are infinitely greater than the older types of control, likewise the chances for misapplication are greater. However, as the characteristics of the different types of control become better known these complications will disappear.

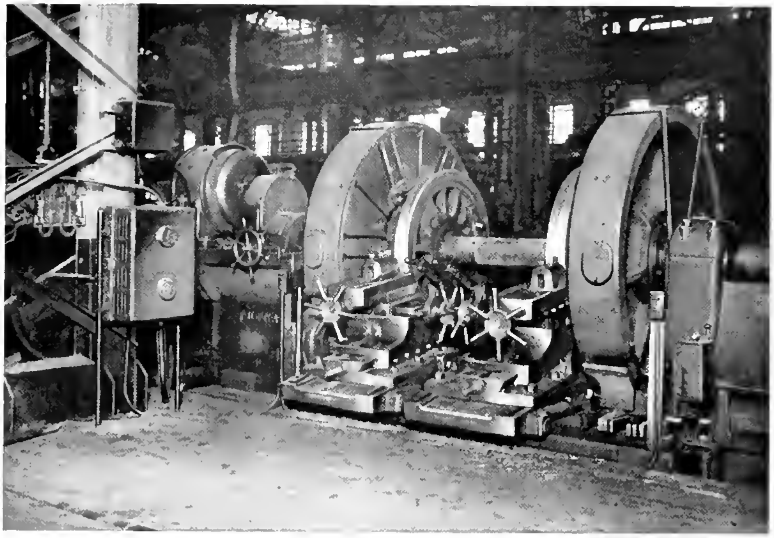

Fig. 8. Motor-Driven Wheel Lathe. Push button control; start, stop and slow down

The increase of the number of individual motor-driven tools is due fundamentally to the facts, as has been shown, that the tool can do more work, do it better, and do it cheaper.

Increasing discrimination is being exercised in applying motor drives. When the work of actually equipping a factory with motor drive is undertaken, it is necessary to study the conditions of operation, which vary greatly with the product manufactured. The arrangement of a factory may be entirely different if many motors are used instead of a few groups. Simply the difference in the position of a number of the tools may greatly facilitate the handling of material.

In general, the most satisfactory electrical equipment for machine shops, using a large number of motors, would be one having available both a-c. and d-c. distribution; a-c. for all constant speed machines and d-c. for adjustable speed machines.

In the smaller shops, with rare exceptions, the choice of motors would depend upon the current available, which in the majority of cases would be alternating current. The very size and product of the small factory makes a proper layout a comparatively simple matter, while in larger factories skill and ingenuity are essential to obtain the most advantageous equipment. The standard motor of today will answer for the majority of the machine tools, although special motors are in some cases necessary.

When equipping tools with individual drives, the controlling apparatus as well as the motor should be attached directly to the tool whenever possible. In the case of portable tools this, of course, is a necessity.

A graphic recording wattmeter in circuit with a tool is of value in efficient management as it not only tells the actual power consumed by the machine, showing whether or not the tool is properly motored, but it also shows whether the tool is operating at its maximum rate, by registering the time of unproductive cycles or the length of time the tool is idle. By analysis, the cause of the lost time may be discovered and a change of operating conditions can be made with a corresponding increase in production.

Table I will, in a general way, aid in the choice of motors. The great variety and the size of tools of the same name make it necessary in a general list, such as this, to double-check a number of tools. It must be kept in mind, however, that various circumstances, such as size and roughness of work, and flywheel capacity, etc., may call for radical departures in the choice of motors, this list being compiled to meet average conditions.

Shunt motors, for instance, are used in the following cases: When work is of a fairly steady nature, when considerable range of adjustment of speed is required as on lathes and boring mills, and on group and lineshaft drives, etc.

Compound-wound motors are used where there are sudden calls for excessive power of short duration, as on planers (not reversing motor drives), punch presses, bending rolls, etc.

Series motors should be used where speed regulation is not essential, and where excessive starting torque is required, as, for instance, in moving carriages of large lathes, in raising and lowering the cross rails of planers and boring mills, and for operating cranes, etc., but not where the motor can be run without load as through a clutch, or belt that might leave its pulley, as the motor would run away if the operator failed to shut off the power.

When in doubt as to the choice of compound or series motors of small horse power, the choice might be determined by the sim-

### TABLE I

### MOTORS FOR MACHINE TOOLS

| Tool | D.C. | | | A.C. | | |
|---|---|---|---|---|---|---|
| | Shunt | Comp. | Series | * | † | ‡ |
| Bolt cutter | ✓ | | | * | | |
| Bolt and rivet header | | 20%<br>40% | | * | † | |
| Bulldozers | | 20%<br>40% | | | † | |
| Boring machines | ✓ | | | * | | |
| Boring mills | ✓ | | | * | | |
| Raising and lowering cross rails on boring mills and planers | | 20% | ✓ | | † | |
| Boring bars | ✓ | | | * | | |
| Bending machines | | 20%<br>40% | | * | † | |
| Bending rolls | | 20%<br>50% | ✓ | | | ‡ |
| Corrugating rolls | | 20%<br>50% | | * | † | |
| Centering machines | ✓ | | | * | | |
| Chucking machines | ✓ | | | * | | |
| Boring, milling and drilling machines | ✓ | | | * | | |
| Drill, radial | ✓ | | | * | | |
| Drill press | ✓ | | | * | | |
| Grinder—tool, etc. | ✓ | | | * | | |
| Grinder—castings | ✓ | 20% | | * | | |
| Gear cutters | ✓ | 20% | | * | | |
| Hammers—drop | | 20%<br>40% | | | † | |
| Keyseater—milling—broach | ✓ | | | * | | |
| Keyseater—reciprocating | | 20% | | * | | |
| Lathes | ✓ | | | * | | |
| Lathe carriages | | 50% | ✓ | | † | |
| Milling machines | ✓ | | | * | | |
| Heavy slab milling | ✓ | 20% | | * | | |
| Pipe cutters | ✓ | | | * | | |
| Punch presses | | 20%<br>40% | | * | † | |
| Planers | | §20% | | * | † | |
| Planers—rotary | ✓ | 10% | | * | | |
| Saw—small circular | ✓ | | | * | | |
| Saw—cold bar and I beam | | 20% | | * | | |
| Saw—hot | | 20% | | * | | |
| Screw machine | ✓ | | | * | | |
| Shapers | ✓ | 10% | | * | | |
| Shears | | 20%<br>40% | | * | † | |
| Slotters | ✓ | 20% | | * | | |
| Swaging | | 20%<br>40% | | * | † | |
| Tappers | ✓ | | | * | | |
| Tumbling barrels or mills | | 20% | | * | | |

* Squirrel cage rotor.
† Squirrel cage rotor—high starting torque.
‡ Slip ring induction motor with external rotor resistance.
§ Does not apply to reversing motors.

plicity of control in favor of the series motor.

The alternating-current motor of the squirrel cage rotor type corresponds to the constant-speed, shunt, direct-current motor; but with a high-resistance rotor it approaches more closely the characteristics of a compound, direct-current motor. It is understood that the variable-speed machines checked in Table I under the alternating-current squirrel cage rotor column have the necessary mechanical speed changes.

The slip-ring induction motor with external rotor resistance would be used for variable speed, but this must not be construed to mean that it corresponds to a direct-current, adjustable-speed motor, as it has the characteristics of a direct-current shunt motor with armature control.

The self-contained, rotor resistance type could be used for lineshaft drives, and for groups when of sufficient size.

Multi-speed, alternating-current motors are those giving a number of definite speeds, usually 600 and 1200, or 600, 900, 1200 and 1800 r.p.m., and are made for both constant power and constant torque. These motors would be used where alternating current only was available, and where the speed ranges of the motor, together with one or two change gears, would give the required speeds. These motors should, however, be used with discretion, especially on sizes above six horse power.

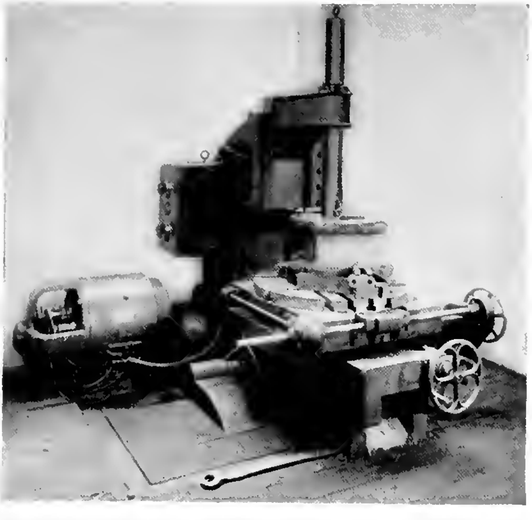

Fig. 11. A Direct-Connected Reversing Motor-Driven Slotter for slotting locomotive driving wheel boxes. Besides the regular control equipment the motor can be started and stopped from a push button station

The adjustable speed, a-c., commutator brush-shifting type of motor with shunt characteristics would, on account of high cost, be used mostly where an adjustable speed motor was highly desirable and where a-c. only was available and where there were not enough machines calling for adjustable speed drive to warrant putting in a motor-generator set.

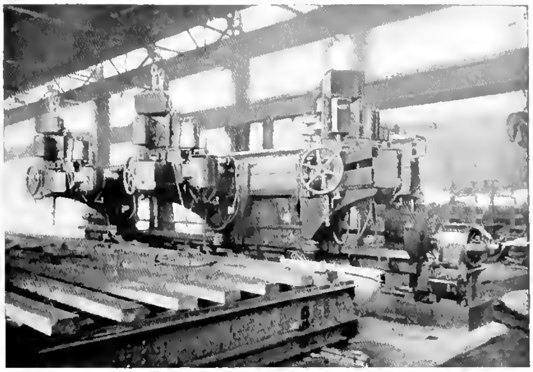

Fig. 10. Is an illustration of a recent direct-geared motor application to radial drills. The 7 1/2 h.p. vertical, adjustable speed motor is mounted on the saddle and geared direct to the drill spindle. Although radial drills have been motor-driven for years, this drive was the means of omitting much of the usual mechanical transmission. The weight heretofore objected to in this type of drive has been overcome by mounting the saddle on large rollers plainly seen in the cut. The drive is in every way satisfactory and part of an original order of forty-two

An important feature in the selection of motors, and one that is often overlooked, is the adherence to the use of standard motors, and by standard motors is meant standard armature shafts as well. The importance of maintaining standard armature shafts will be recognized when it is pointed out that by such an arrangement spare armatures are reduced to a minimum. In emergencies it is often possible, where spares are not carried in stock, to replace the armature or even a whole motor by one from an idle tool, or from a tool of relatively less importance at the time. Also, of course, stock motors can be supplied promptly by the manufacturer and shipments materially improved if special shaft extensions are not called for. That special features in a motor are sometimes desirable, is true; it may so happen that the advantages from some special feature in the motor may more than offset the disadvantages referred to, but in cases where these features are thought necessary they should be carefully considered before final decision.

In the early days of motor drive before the present great variety of sizes and speeds of standard motors were obtainable, many special features were thought necessary in the motor to make it adaptable to the tool; special frames, shafts, and speeds were required, and little thought was given to the interchangeability of parts. In fact, tools which only a few years ago it was thought necessary to drive with special motors are today driven by standard motors, and as a result are easily and quickly repaired. It is therefore easy to recognize in these early equipments the responsibility for part of the existing idea that special features in the motor are still necessary for tool equipments. Many of these special features required for the early drives are now recognized as unnecessary, and today the tool builder in the majority of cases builds his tools ready for attaching standard motors.

The old prejudice existing against the electric motor, which was mostly a mistrust due to a lack of familiarity with its operation, is rapidly dying out, and today motors are found driving machines in shops of every description.

Equally important with the choice of motors is that of control. In selecting the control its adaptability, its accessibility to the operator, the method of attaching it to the tool and in some cases its relative position to other tools should be considered. As an illustration of this last point, an open-type starting rheostat, if used, or unprotected magnetic control, should not be mounted on a machine in such a manner as to be exposed to danger of short-circuit by flying chips. It is now, however, only a matter of time before all live parts of both motor and control will be enclosed. In the majority of cases, a shunt motor of ½ h.p. and less would be started by a switch. Exceptions to this would be motors on tools that must be gotten under way slowly. With adjustable-speed motors, care should be taken to first throw the switch on full field. Series motors up to 8 h.p. or even larger can be started by a switch without resistance. Exceptions to this would be cranes and tools requiring a certain amount of armature speed regulation. Larger motors for tools where starting service is infrequent or not severe, and for lineshafts, and for group drives, would be satisfactorily operated with a dial-type controller, which is cheaper than the drum controller, provided, however, that the controller is placed in a protected position.

When making the installation, accessibility to the controller in case of accident should be kept in mind, even though but of little importance so far as starting up is concerned. The starting apparatus should be placed where the motor or some of the moving parts can be seen by the operator. On individually motor-driven tools, where the motor is started and stopped many times a day, or where the starting conditions are of a severe nature, or where tools are edged along, drum type controllers or magnetic control with extra heavy starting resistance should be used. For adjustable-speed motors using the drum type control, the field control should be connected through fingers making contact on segments of the controller drum and not by sliding contacts on a dial as with the latter trouble will develop sooner or later. With magnetic control, provision should be made in the control either to start the motor on full field or to provide necessary points for starting on weakened field in order to protect the motor. Motors of moderate size and larger, operating under severe duty cycles, are best controlled by magnetic switches. This class of starting apparatus will stand almost any amount of abuse and, by the addition of a simple current limit relay device, becomes practically a fool-proof protection for the motor. There are cases where it might be advantageous to use magnetic control even with smaller motors.

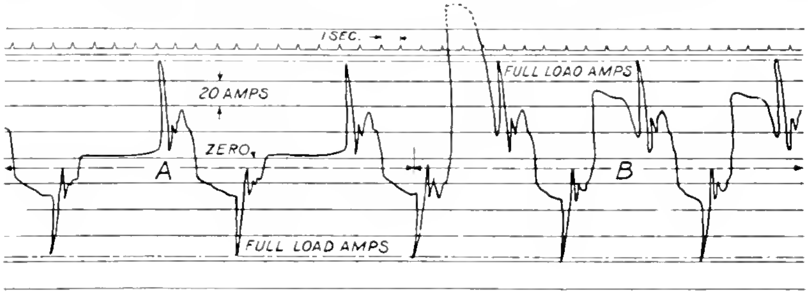

Fig. 12. Curve made from Machine shown in Fig. 11. A, running light; B, cutting

Squirrel cage rotor type motors, two-phase and three-phase, up to 5 or 8 h.p., generally speaking, can be thrown directly on the line, depending largely upon the power conditions. Above 5 or 8 h.p. this type should be operated by a compensator or sliding resistance in the rotor, while for the slip-ring type a controller with external resistance should be used.

Upon the convenient arrangement of the control depends, to a considerable degree, the output of the tool; and the importance of the arrangement from the standpoint of the operator should not be ignored, since the output of a tool will be materially increased when an operator can start and stop the tool and obtain at all times maximum cutting speeds by simply turning a handle. The controller must be placed in a safe position and should be accessible for repairs, which very often mean that some arrangement is necessary to bring the operating handle within easy access of the operator. A familiar illustration of the convenience of control is the arrangement so commonly seen on lathes, whereby the operating handle travels with the tool carriage and allows the operator at all times a complete control of his tool. Strange as it may seem, this most important feature, the convenience of control which bears directly on production, is ignored in many tool equipments.

Exhaustive tests have been and are being made to determine the amount of power required to drive tools. Hasty conclusions should not be drawn from incomplete data since they are apt to be misleading; for instance, where tests are made with motors which are considerably underloaded or over loaded, where efficiencies are not taken into consideration, where the material used and duration of test are not stated, or where there has been failure to state whether the test was a practical one or merely a breakdown test. The conclusions drawn from breakdown tests are often deceptive and should not be used for determining the power required to drive tools, for it does not follow that a tool which stands up longer than another under breakdown conditions will do the same under practical conditions. To develop a general formula that would be of practical value in determining the horse power required to drive tools would be difficult, as the power required varies with the metal worked, the cutting speed, the kind of tools used, the efficiency of the machine, and many other conditions.

The construction of the tool is seldom taken into consideration when estimating horse power, thus some of the worm-driven tools are notoriously inefficient. Other machines are so constucted that the greatest part of the power delivered to the tool is consumed in friction losses and not in useful work; again, the tool may be constructed upon approved lines but may not be stiff enough to stand the strains to which it is subjected thereby causing a considerable loss of power, all of which, as well as the difference in power due simply to the shape of a cutting tool, have been repeatedly proved by tests. Again the duty required of a tool in one shop may be more severe than that in another, from which it will be seen that it cannot be accurately stated that a definite size of motor is required for a given tool. In the majority of cases, however, the horse power for small tools is very well fixed. With the larger tools the variation in horse power required for such tools, of course, is more pronounced, and demand more consideration on account of the size of the motors involved.

Little trouble is experienced in obtaining new tools already arranged for attaching motors, since many of the tool manufacturers are alive to the superiority of the motor drive and have for years built tools especially adapted for motor drives. Unfortunately, others have seen fit to merely arrange a make-shift for attaching the motor, while still others leave the purchaser to attach the motor as best he can, and consequently the best results are not always obtained.

When the driving of old tools by individual motors is under consideration, the speed range, the number of similar tools to be equipped, and the condition of the tool should be considered. It sometimes happens that when a tool in itself would not call for an individual drive, certain circumstances might make such a drive advisable. As an illustration, when the majority of tools in a shop have become individually driven, there might still remain a number of scattered tools, which, unless they were driven by individual motors, would necessitate the running of long lines of shafting; or, in the event of moving into new quarters, a cement building perhaps, it is decided not to use line shafting.

Since production is the ultimate aim of progressive shop management, and since the electric motor is generally conceded to be the greatest factor in increasing production, it is only a matter of time before the motor will be universally used in machine shops.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## ENERGY DENSITY

One of the most valuable features of electrical energy is the high energy concentration which it permits, allowing the production of higher energy densities than have been reached heretofore.

Usually, when considering high electric energy concentration, we think of the electric arc furnace, where thermal energy densities (temperatures) about twice as high as can be reached by combustion or any other means are obtained. It is interesting to note, however, that still very much higher energy densities can be reached by electrostatic fields in vacuum tubes.

Investigations by the Consulting Engineering Department of the General Electric Company and others have shown that air has a definite dielectric strength, (30 kilovolts per centimeter) at atmospheric pressure, but that much higher voltage gradients are reached close to the terminals of the spark gap, especially if the terminals are brought together to a distance within the dielectric energy distance (the space around the terminals in which the dielectric strength must be exceeded before rupture can occur). The dielectric strength decreases with the air pressure down to a minimum; but with still lower pressure, it increases again, since the energy distance, which increases with decreasing air pressure, becoming larger than the distance between the terminals. At a very high vacua the dielectric strength thus becomes very high, approaching values apparently of the magnitude of a million volts per centimeter. If then we calculate the energy stored in a cubic centimeter of space at a voltage gradient of a million volts per centimeter and the weight of the matter still existing in one cubic centimeter space at the highest vacua which have been reached, we find values per gram of matter of many millions of joules or calories, that is, energy densities thousands of times higher than those of the highest explosive. These energy densities are possibly the highest which can be reached. They are of the magnitude of the internal energy of radio-active atoms, and the phenomena of high electrostatic fields in high vacua thus would be the most promising starting point for an experimental study of the transformation of chemical elements into each other. C. P. STEINMETZ

## PERMITTIVITY OF ORGANIC LEAD SALTS

It has often been claimed that the permittivity of the organic salts of lead, such as the stearate, palmitate, oleate, etc., would be found to be very high—in the range between 10 and 20. Samples of these salts have recently been obtained and subjected to permittivity measurements at 24 deg. C. with these results:

| | PERMITTIVITY |
|---|---|
| Lead stearate | 5.2 |
| Lead palmitate | 5.2 |
| Lead oleate | 5. (Approx.) |

The permittivity of the stearate and palmitate was measured also at 40 deg. C. and found to be much higher; viz., 9½ for each.

The stearate has a similar consistency to that of rosin, the palmitate resembles paraffine, while the oleate is almost as soft as lard. The first two salts are very good dielectrics at atmospheric temperatures. Disks of the stearate and of the palmitate, ⅜ in. in thickness, successfully withstood 60,000 volts applied between 2 in. spheres. S.T.

## ALLOYS OF MAGNESIUM METAL

In the January, 1914 issue, mention was made of aluminum magnesium alloys, and a number of inquiries have since been received as to their conductivity.

A few samples containing about 6 per cent magnesium, 92 per cent aluminum, about 5 per cent iron, 5 per cent silicon, and a small amount of copper have been examined and found to give a conductivity of 52 per cent at 20 deg. C. and a temperature coefficient of 0.0038 from 20 deg. to 52 deg. C., and 0.0033 from 52 deg. to 100 deg. C.

The conductivity of pure aluminum is 57.5 per cent and of pure magnesium 37.7 at 20 deg. C. Therefore a small amount of magnesium does not seriously affect the conductivity.

In some of the recent English magazines we note that English designers are finding considerable use for a new aluminum alloy that goes under the trade name of "Ivanium." This metal is claimed to be 2½ per cent heavier than aluminum, and is non-magnetic. The castings are equal in finish to the finest gun metal, and they may be easily machined and soldered. The melting point is very low, 300 deg. C., whereas both aluminum and magnesium melt at approximately 550 deg. C. This metal is also a good dioxident. J.D.B.

## QUESTION AND ANSWER SECTION

The purpose of this department of the Review is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the Review.

Second, it publishes for the benefit of all Review readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting subject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

### ALTERNATOR: FULL-LOAD AND NO-LOAD FLUX

**(106) In an alternator delivering constant voltage from its terminals, is the flux entering the armature windings per pole much greater at full load than at no load?**

There has always been a great deal of misconception on this question due to the indefiniteness attached to the term "reactance voltage." If, with the rotor in place, full-load current of the periodicity of the machine is sent from some external source through the stator windings, the voltage across the terminals will have a value which (after correcting for the IR component) is sometimes termed the "reactance voltage." If a similar test is made on the stator when the rotor has been removed, a lower value will be obtained, which has also sometimes been considered as representing the "reactance voltage." Combining vectorially the terminal voltage, the IR drop, and the "reactance voltage" (measured with or without the rotor), a resultant considerably in excess of the terminal voltage will be obtained. This resultant cannot, however, be taken as an index to the amount of flux per pole.

Actually, the flux per pole at full load is only very slightly greater than that corresponding to the terminal voltage plus the IR drop. This has been shown to be the case by fitting an exploring coil in the machine and noting, by readings on a voltmeter connected to its terminals, the fluxes present at no load and at full load. By working backward from such results, proof has been obtained to show that the "reactance voltage" to be employed in a vector diagram, constructed with the true value of the internal voltage as obtained by the exploring coil, is of a very small amount. But since the result, as thus deduced, depends upon the difference between nearly identical quantities, the reactance voltage could not be obtained in this way with any degree of accuracy. We can only arrive at the conclusion that it is very low. The reactance of the end connections is about sufficient to account for it. Consequently, in estimating the internal voltage in an alternator this should be taken as the resultant of the terminal voltage, the IR drop, and the "reactance voltage" of the end connections. No serious error will result from the absence of any exact data for the estimation of the "reactance voltage" of the end connections, since the value employed will, in any case, only slightly affect the estimated internal voltage and the corresponding flux.

From the reasoning given in the preceding, it will be seen that the flux entering the windings at full load is only slightly greater than that at no load.

The subject is inherently complex and, in order to deal with it in as simple a manner as possible, no allusion has been made to the power-factor of the external load. The conclusions stated are more nearly true the higher the power-factor of the load. At low power-factors the end-connection reactance voltage, small as it is, is more nearly in phase with the terminal voltage and consequently occasions a greater difference between the flux at full load and the flux at no load. H.M.H.

### AUTOMATIC VOLTAGE REGULATORS: PARALLEL OPERATION

**(107) It is desired to operate in parallel two alternating current generators which are each equipped with an automatic voltage regulator, the machines being located in separate power houses. Is this possible?**

Yes, this can be accomplished by connecting a current transformer on one regulator 90 degrees out of phase with the potential transformer. With this arrangement, the current winding of the regulator is only energized by the leading or lagging current. Under such an action, the voltage will be automatically changed to correspond to the voltage being maintained by the other regulator. O.C.R.

### INDUCTION MOTORS: LOW SPEED

**(108) What are the objections to the employment of low-speed induction motors?**

Induction motors for operation from a circuit of a given periodicity are of lower power-factor and efficiency the lower the speed. A 300-horse-power, 60-cycle motor for a synchronous speed of 120 r.p.m. would require 60 poles and its power-factor would be less than 0.8 whereas a 300-horse-power, 1200-r.p.m., 60-cycle motor (with 6 poles) would have a power-factor well above 0.9. Low speeds are more practicable the lower the periodicity of the supply. A 24-pole, 25-cycle, 300-horse-power motor for a synchronous speed of 125 r.p.m. would have a power-factor a little above 0.8. In addition to the low power-factors of low-speed, high-periodicity induction motors, the efficiency is low and the cost is excessive as compared for the same output and speed with continuous-electricity motors whereas very-high-speed, squirrel-cage induction motors have higher efficiency and are much cheaper than continuous-electricity motors for the same output and speed.

Recently, phase advancers have been developed and their use in connection with low-speed induction motors removes from them all objections associated with low power-factor, since, when of appropriate design, the phase advancer may bring the power-factor up to unity even at fractional loads, or it can be so designed that the induction motor shall consume a leading current. The phase advancers may be of either the rotating or the vibrating type and will add but slightly to the cost of the combined set. Phase advancers may also greatly increase the stalling load, which is otherwise very low in the case of induction motors for low speeds.

A good description of rotating phase advancers is given at p. 33 of *The Electrical Times* for January 8, 1914, and a description of an installation of a vibrating phase advancer employed with a 330-horse-power, 12-pole, 50-cycle induction motor is given at p. 214 of *Electrical Engineering* for April 15, 1914. The curves published in this latter article show that at half load the power-factor was 0.99 leading and that at full load it was 0.96 leading. The corresponding power-factors without the vibrator were 0.76 lagging at half load and 0.87 lagging at full load. (See article on "Phase Advancers," June, 1914, REVIEW.) H.M.H.

### SYNCHRONOUS CONVERTER: LINE DROP

**(109) What are the reasons for the commonly published statement that synchronous converters will not operate satisfactorily if the alternating-current line drop is 10 or 15 per cent or more, regardless of the use which is made of the direct current taken off? What are some of the other conditions that prevent the successful operation of synchronous converters?**

The feature limiting the satisfactory operation of a synchronous converter under the conditions mentioned is pulsation. This is an alternate acceleration and retardation of the machine with respect to the supply frequency. Pulsations may be set up by changes in frequency, voltage, load, etc., and the amount by which the converter swings out of phase will depend upon the synchronizing current available. As the synchroning current is limited by the resistance of the line, it follows that the higher the line drop the farther will the machine swing out of phase before the required synchronizing current is obtained. The farther the converter swings out of phase, the greater the possibility of its dropping out of step and the greater its tendency to flash over, due to the out-of-phase armature reaction which produces a voltage between the commutator segments under the brushes.

Another effect of increased line drop is that of causing a slower period of pulsation. It so happens that in most machines the natural period, that is, that which takes place when there is no line drop, is usually somewhat higher than the periods of disturbance such as variable impulses per revolution in a steam engine. Owing to the added resistance in the line, the period of swing of the converter is reduced to a value which more nearly corresponds with that of the disturbance, so that the effects are accumulative and the pulsations become more violent. At the same time, the resistance reduces the synchronizing current so that the machine has less current available for bringing it back into phase.

A given machine may operate satisfactorily with line drop in excess of 10 per cent, provided other conditions of operation are favorable. The other principal conditions enabling satisfactory operation are good voltage regulation and uniform frequency, especially with absence of regular periodic variations.

J.L.B.

### TURBINE-GENERATORS: INTEGRAL FAN *vs.* EXTERNAL FAN VENTILATION

**(110) Is it better to circulate the cooling air for a steam-turbine-driven generator by means of an independently-driven fan or by fans incorporated in the design of the rotor?**

Since the conditions involved in machine ventilation vary to a considerable extent in different stations, it would not be practicable to make the assertion that either particular method is the better in all cases. Both arrangements have their advantages and disadvantages, and a statement of these will be given from which conclusions may be drawn to apply to specific instances.

The usual plan is to build the fan as an integral part of the rotor of the turbine generator; and the fan is usually so designed as to *force* the air through the generator, as distinguished from drawing it through by suction. Fans are inherently of low efficiency under the best of conditions and when the design has to be adapted to the space or dimensions available in the rotor, and to the speed of the rotor, the efficiency is lower than would be the case for a design not limited by such considerations. A certain amount of space in the generator is also sacrificed for the purpose of providing for the fan. The cooling air is slightly heated in passing through the fan, owing to the latter's inefficiency. On the other hand, by incorporating the fan in the design of the rotor, the machinery is self-contained and little or no thought or attention need be given to it.

By adopting the alternative plan of employing an independently-driven fan, it becomes entirely feasible to let the fan *draw* the air through the rotor instead of *forcing* it through. Consequently, there is avoided the slight heating of the air, by a fan, prior to passing it through the parts of the generator requiring to be cooled. An independently-driven fan may be of more appropriate proportions and of slightly higher efficiency. Furthermore, in the case of the independently-driven fan, arrangements may be made to operate it at lower speed at times of light load for then less cooling air is required than at heavy load. This will have the effect of increasing the light load efficiency of the plant, which consideration is not by any means of negligible importance. That this is the case will be seen when it is pointed out that the friction of the cooling air is an important component of the total losses in a turbine-driven generator. With the self-contained fan, this loss is a constant at all loads and is consequently a still more considerable proportion of the total losses at fractional loads than at full load. The plan of using independently-driven fans also works in well with the practice, adopted in modern installations, of "conditioning" the air.

Unless air is cleaned, either by passing it through spray washers or suitable dry filters, the passages in the turbine generator may, in the course of time, become clogged by deposits. With self-contained fans, the quantity of air passing through the generator will in time become gradually less, owing to the obstruction in the ventilating passages; and the machine will run warmer. When an independently-driven fan is employed, steps may be taken to increase the pressure impelling the air, and there may be passed through the machine the required quantity, notwithstanding the partial obstruction of the ventilating passages.

E.C.S.

# GENERAL ELECTRIC REVIEW

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Assistant Editor, E. C. SANDERS

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DR. WILLIAM D. COOLIDGE

Dr. Coolidge has recently been honored with the Rumford Medal for his invention of Ductile Tungsten and its Applications in the Production of Radiation

GENERAL ELECTRIC REVIEW

### THE PATHS OF PROGRESS

We publish in this issue of the REVIEW, a photograph of Dr. William D. Coolidge, Assistant Director of the Research Laboratory of the General Electric Company, who has recently been honored by the American Academy of Arts and Sciences with the Rumford Medal. This medal was awarded Dr. Coolidge for his invention of ductile tungsten and its application in the production of radiation.

We believe that there have been few inventions that have had such a spontaneous and far-reaching effect upon the electrical industry as has the invention of ductile tungsten. Like most other great accomplishments in the scientific world, ductile tungsten was only finally arrived at after a long and carefully thought-out series of investigations had been made, and many blind alleys were followed before a consistent and persistent research led to the results sought. The results accomplished in this particular case are especially illuminating as showing the excellent work that is being done, and the valuable contributions that are being made to our scientific knowledge, through the medium of our Industrial Research Laboratories. Many great accomplishments have recently been brought about through this medium which it is hard to believe would have been achieved in any other way.

In talking of the particular development under consideration the inventor is emphatic in emphasizing the all important part played by three factors, namely: the corps of scientifically trained men who were constantly co-operating with him, the wonderful facilities at his disposal, and the constant help and encouragement rendered by a large factory organization versed in innumerable processes of manufacture. He further calls attention to the fact that the large organization in presenting to the inventor a definite problem for solution is thereby going a long way towards insuring the attainment of the desired end. Incidentally, the achievement of such results by an industrial research laboratory emphasizes the fact that the world at large very quickly reaps the benefits of the development work carried out by a large modern manufacturing concern.

The outcome of this work has been a revolution in the electrical incandescent lamp. In America alone approximately one hundred million incandescent lamps were made last year and it is surely one of the romances of modern science when we consider that this work has led to so great an increase in the efficiency of the incandescent lamp that it has been estimated to save the public in the neighborhood of $1,000,000 a day. It is on account of the wonderful economy secured by the modern incandescent lamp that the work of producing ductile tungsten will for many years to come, be looked upon as one of the mile-stones of progress in the electrical industry.

The production of ductile tungsten with its valuable physical properties led to a search for new applications. One of the first of these was the substitution of tungsten for platinum as the target or anti-cathode in X-ray tubes. The advantages of tungsten for this purpose have been so marked that it is now practically universally used in all high power tubes. Its superiority is due to its higher melting point, lower vapor pressure, and greater heat conductivity and its use has led to a marked increase in the intensity of the X-rays which can be produced.

The experimental work necessary in producing this new form of target led further to the development of an entirely new X-ray tube with characteristics radically different from those of the older form of tube.

In the older form the operation depended upon the maintenance of a perfectly definite gas pressure within the bulb, while in the Coolidge tube the gas is removed just as thoroughly as possible, so thoroughly in fact that without a special form of cathode no discharge current can be passed through the space between the electrodes. In the new tube current conduction is made possible by heating a portion of the cathode to a temperature at which it emits electrons, the remainder of the cathode serving as a focusing device to so direct the movement of the electrons across the space that they will all bombard the target on a small area called the focal spot, which is the source of the X-rays.

The use of a higher vacuum and of a hot cathode greatly change the characteristics of the tube, doing away entirely with puncturing troubles, with movement of the focal spot, local heating and fluorescence of the active hemisphere, and with the emission of troublesome X-rays from the glass. The discharge current carried by the tube when a definite potential is impressed upon the terminals, and hence the intensity of the X-rays produced, may be either increased or decreased at will, as it depends only on the temperature of the heated portion of the cathode. The penetration of the X-rays produced may be instantly increased or decreased at will by raising or lowering the potential difference impressed upon the tube.

Among the many practical advantages which the new tube offers may be cited the fact that it renders it possible for an operator to do all classes of work ranging from that calling for the lowest to that calling for the highest penetration with a single tube. Further, it becomes possible for him to reproduce exactly what he or some other operator has done before. It also makes it possible for him to produce X-rays of higher penetrating power than have heretofore been available. For the future it holds out the possibility of the production of X-rays of any penetration between that of the present X-rays and of the most penetrating gamma rays of radium.

Another interesting and important application of wrought tungsten is as a metal for the contact points in electric make-and-break devices such as are used in automobile ignition systems and in voltage regulators. Tungsten has already very largely supplanted the platinum metals for this purpose.

It may be of interest to all our readers to note that the founder of the Rumford fund was Benjamin Thompson, one of the many illustrious men who have made the name of Thompson so famous in scientific spheres. Benjamin Thompson, who was created a count by Prince Maximilian, was born in Woburn, Massachusetts, March 26, 1753, and died at Auteuil, France, in 1814. He left America for England at the time of the Revolutionary War and soon afterwards entered the service of Prince Maximilian of Bavaria, whose army be reorganized. He also instituted important social reforms, at the same time that he carried on much valuable research work. The most noteworthy of his investigations conclusively disproved the fluid theory of heat which was then commonly held. In 1799 Count Rumford returned to England and founded the Royal Institution of Great Britain.

Among the illustrious men who have been honored with the Rumford Medal may be noted: Robert Hare, for the invention of the compound blowpipe; John Ericsson, for his caloric engine; Alvan Clark, for his refracting telescopes; George Henry Corliss, for his improvement in steam engines; Joseph Harrison, Jr., for his steam boilers; Lewis M. Rutherford, for his work in astronomical photography; Henry A. Rowland, for his researches in heat and light; S. P. Langley for his researches in radiant energy; Charles F. Brush, for his electric arc-lighting; Elihu Thomson, for his inventions in electric welding, Charles Gordon Curtiss, for his improvements in steam turbines and Frederick Eugene Ives for his color photography.

# THE NATURE OF ELECTRICAL DISTURBANCES IN POWER TRANSMISSION WORK

## Part I

By David B. Rushmore and Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The authors deal at some considerable length with the nature and the means of controlling or eliminating the disturbances which occur in the operation of transmission lines. The disturbances are divided into two classes, i.e., those caused by high currents and those caused by high voltages. In the present article the authors treat of the abnormal conditions resulting from excessive current and in a following number they will deal with the abnormal conditions due to excessive voltage. The disturbances due to high currents may be caused by overloads or short circuits resulting in excessive heating or undue mechanical strains which often damages the apparatus in circuit. The effects of excessive currents can be minimized or prevented by the provision of reactance in the circuit or the introduction of external power-limiting reactance. Careful attention should be given in designing systems to so locate the switches as to sectionalize the network in such a way that the trouble can be confined to a small area. This article is an amplification of a paper recently presented by the same authors before the N.E.L.A. convention.—Editor.

For the sake of analytical study and comparison, all forms of commercial occupation may be considered as manufacturing enterprises. In each case there is a raw material on which is performed certain work or operation, which thereby becomes a finished product to be sold to a consumer. The public service company manufactures and sells electrical energy, although people sometimes think it is selling power. Scientifically speaking, energy cannot be manufactured as the amount in the universe is absolutely unchangeable, but its form can be altered. The raw material of the public service company represents the potential mechanical energy of water-power, or the stored chemical energy of coal or other fuel, the energy of which has previously been received in radiant form from the sun.

All energy, whether it be in the form of mechanical, chemical, electrical, heat or radiant energy, consists of two parts: a quantity factor and an intensity factor.

The transmission of energy, usually erroneously called the transmission of power, may be accomplished in many different forms—electrical energy may be transmitted over wires; water or air under pressure may be conveyed through pipes; gas or oil wherein the energy is in a chemical form may be transported either through pipes or in tank cars, and the most usual form of chemical energy, coal, is usually transported in cars over railroads. Mechanical energy is transmitted through friction drives, gears, belts, ropes, chains, etc., which methods for the purpose of our discussion fall into a different class.

Commercial enterprises having for their object the production of wealth, and therefore necessitating a limitation on the investment, render the attainment of perfection impossible and necessitate the use of a factor of safety, the magnitude of which depends upon the number of failures permissible under the conditions of operation. This is really the reason for the existence of the engineering profession, for there is very little in the way of attainment which cannot be accomplished if the cost be not an element which enters into consideration.

In all instances where energy is being transmitted from one place to another, or changed from one form to another, we have normal operating conditions, and we also unfortunately have what might be termed abnormal conditions. This general statement holds true over practically the entire field of human endeavor. Apparatus is designed generally with due consideration of the conditions of normal operation, but the features involved under emergency conditions must have some consideration, and frequently are the factors necessitating a compromise in designs.

It is always of interest to look at specific cases in the light of broad, general laws. Throughout our civic and social order we have large numbers of individuals who devote themselves to the class of phenomena which comes under emergency or abnormal operating conditions. The medical profession, the police department, and the fire department are all for such business. A large number of machines and appliances are devoted entirely for use when the conditions of operation become abnormal.

In the transmission of intelligence, in the transportation of men, in the transportation of commodities, and in the transmission of energy this statement is generally applicable. This fact is due primarily to the variation in the factors which enter these different situations and the possibility of pre-determining them with accuracy. Also to the fact that materials in general undergo wear and depreciation, that human capacity has its limitations, and that developments are always active on the frontier of knowledge, where facts are first brought to light through experience.

In the specific field of the transmission of energy under pressure, which we may take to include the mediums of electricity, air and water, we have some more or less close analogies between the three divisions with regard to the factors concerned when abnormal conditions obtain and the operation of a system of transmission is disturbed.

The investigation and study of the nature of many electrical disturbances have been accomplished with very great difficulty, due to the character of the disturbances themselves and of the instruments available for their detection and measurement. In the absence of definite experimental knowledge a great deal of theory has been elaborated based upon assumptions, the justification for which in some cases may be open to question. Due to the rapid advance of electrical development there is much that has not as yet become a matter of exact knowledge, but there is also a considerable part of the field that has been explored with some degree of thoroughness, and a better knowledge of the nature of these disturbances is rapidly being attained, as well as a more exact measurement of their magnitude.

The electrical disturbances which generally occur in the operation of power transmission systems can be divided into two broad classes: first, those which are due to excessive currents and, second, those which are due to excessive voltages.

### Excessive Currents

Excessive currents are caused either by overloads or short circuits and may result in overheating and burn-outs of the apparatus, with a subsequent interruption of the service, unless protective measures are provided to prevent the same. It is the maximum temperature at which the insulating material of a machine may be operated for a certain period which determines the load that the machine can carry, and if these safe limits are exceeded, the insulation will rapidly deteriorate. The result of operating at temperatures in excess of the safe limit is to shorten the life of the insulating material, and the damage will increase with the length of time that the excessive temperature is maintained and with the amount of excess temperature, until finally the insulation breaks down entirely.

There is a large variety of insulating material used in the construction of electrical machinery, and it has been found by actual experience that the safe temperature limit does not only depends on the particular material used but also on the method of its application. Based on actual observations of the operations of different classes of machinery for a number of years, the new A.I.E.E. standardizing rules recommend the following safe temperature limits.

Class A1—Cotton, silk, paper and other fibrous materials, not so treated as to increase the thermal limit, 95 degrees C.

Class A2—Same as A1 but treated or impregnated, 105 degrees C.

Class B—Mica, asbestos, or other suitably high heat resisting material, in which any Class A material or binder, if used, is for structural purposes only, and may be destroyed without impairing the insulating or mechanical qualities, 125 degrees C.

Oil in which apparatus is immersed shall in no part be subjected to a temperature in excess of 90 degrees C., and in water-cooled transformers, the maximum temperature shall not exceed 85 degrees C.

The above temperature limits should therefore not be exceeded by any machine when operating at its rated output, and the temperature should refer to the hottest spot where damage to the insulation may occur, which is usually in the interior of the embedded portions of the winding.

As it is usually impossible to determine exactly the maximum temperature attained in insulated windings, it has been found convenient to apply a correction factor to the measured temperature, to allow for the possible difference between the actual maximum temperature and the measured temperature by the method used. This correction or margin of security is provided to cover the errors due to the fallibility in the location of the measuring devices, as well as inherent inaccuracies in the measurement and methods.

In determining the temperature of different parts of a machine, three different methods are recommended in the new standardization rules. These methods are outlined in Table I and give the suggested margin between the observable temperatures and the hottest spot, as well as the temperature rise.

It is also recommended that the standard rating of a machine shall be its capacity when operating with a cooling medium of standard ambient temperature (40 degrees for air and 25 degrees for water), assuming no abnormal barometric conditions. Unless otherwise specified, the rating of any machine shall also be understood as its rating for continuous service.

With large generating units the question of ventilation becomes of great importance and is now given very careful consideration both in connection with the design and the location of the machines. Instead of allowing the paths of the air to be determined by chance, the air is, wherever possible, drawn from the outside and, in some cases, passed through filters. The air is drawn up into the generators, either by forced ventilation or by natural ventilation created by the generator itself. By designing the generator so as to properly direct the paths of flow of the air, a very marked improvement is made in large generators, and by taking this air from the cool space over the tail-race it has, in some cases, been possible to reduce the temperature of the machines very considerably.

### TABLE I

Method of measuring temperatures to determine approximate hottest spot temperatures

| | | METHOD I THERMOMETER ONLY | | | METHOD II RESISTANCE (With Thermometer check when practicable) | | | METHOD III IMBEDDED THERMO-COUPLES OR RESISTANCE COILS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | DOUBLE-LAYER WINDINGS FOR ALL VOLTAGES | | | SINGLE-LAYER WINDINGS 5000 VOLTS OR LESS | | | SINGLE-LAYER WINDINGS ABOVE 5000 VOLTS | | |
| Class | Permissible Hottest Spot Temp. | Hot-test Spot Correction | Limiting Observable Temp. | Limiting Temp. Rise above 40° | Hot-test Spot Correction | Limiting Observable Temp. | Limiting Temp. Rise above 40° | Hot-test Spot Correction | Limiting Observable Temp. | Limiting Temp. Rise above 40° | Hot-test Spot Correction | Limiting Observable Temp. | Limiting Temp. Rise above 40° | Hot-test Spot Correction | Limiting Observable Temp. | Limiting Temp. Rise above 40° |
| $A_1$ | 95° | 15 | 80 | 40 | 10 | 85 | 45 | 5 | 90 | 50 | 10 | 85 | 45 | 10 + (E − 5)* | 85 − (E − 5) | 45 − (E − 5) |
| $A_2$ | 105° | 15 | 90 | 50 | 10 | 95 | 55 | 5 | 100 | 60 | 10 | 95 | 55 | 10 + (E − 5) | 95 − (E − 5) | 55 − (E − 5) |
| B | 125° | 15 | 110 | 70 | 10 | 115 | 75 | 5 | 120 | 80 | 10 | 115 | 75 | 10 + (E − 5) | 115 − (E − 5) | 75 − (E − 5) |

* In this formula *E* represents the rated pressure between terminals in kilovolts. Thus for a three-phase machine of 11 kilovolts between terminals the hottest spot correction to be added to the maximum observable temperature will be 16° C.

In the line of operating generators and transformers within safe limits it has now also become general practice to place temperature coils in the hottest part of the armature from which leads are taken to an indicating device on the switchboard, so that the operator can tell at any moment the maximum temperature to which the armature winding is being subjected.

For cables, the temperature at the surface of the conductor should not be permitted to exceed the following values:

| | |
|---|---|
| For impregnated paper insulation | (85-E) |
| For varnished cambric | (75-E) |
| For rubber insulation | (60-0.25 E) |

where *E* represents the r.m.s. operating electromotive force in kilovolts between conductors.

Thus at a working pressure of 3.3 kilovolts the maximum safe limiting temperature at the surface of the conductor or conductors in a cable would be:

| | |
|---|---|
| For impregnated paper | 81.7 deg. C. |
| For varnished cambric | 71.7 deg. C. |
| For rubber | 59.2 deg. C. |

Excessive currents are, as previously mentioned, also caused by short circuits, and the very high mometary values of these currents may result in severe mechanical strains being imposed on the apparatus of the system. Experience has proved that the magnetic stresses set up under these conditions may be so powerful as to entirely wreck the apparatus, or they may result in a displacement of the windings, which in turn may cause the insulation to break down at different points and put the whole system out of commission.

The short circuit current of an alternator is limited by the resistance and self-inductive reactance, and besides this by the reaction of the armature current on the field.

It is equal to

$$I = \frac{E}{Z}$$

where $E$ is the generated e.m.f. corresponding to the field excitation and $Z$ the synchronous impedance.

The above value of $I$ represents the permanent short circuit current, while the instantaneous value will be very much higher. This is due to the fact that in the first instant, when the generator is short circuited, the current is only limited by the resistance and self-induction of the armature circuit, while a time lag of sometimes a few seconds takes place before the armature reaction becomes effective. The armature resistance and reactance are thus the only two quantities that limit the instantaneous short circuit current. This limiting effect is, however, not constant but decreases slightly with high short circuit currents due to their saturation of the magnetic circuit.

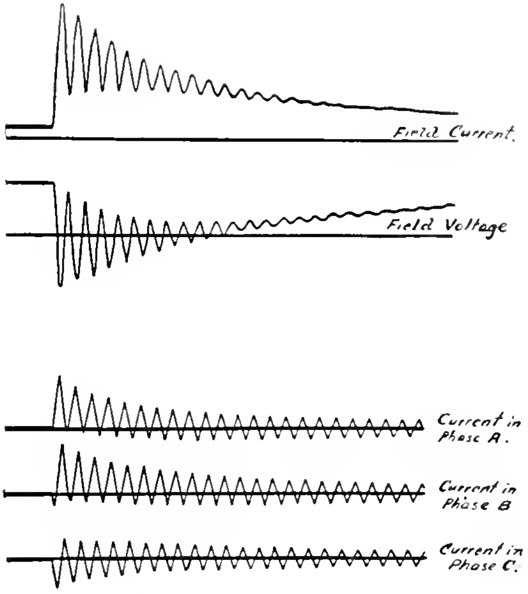


Fig. 1. Oscillogram of Three-Phase Alternator Short Circuit

Considering a waterwheel-driven generator having a resistance of approximately 1 per cent and a reactance of 10 per cent, then the impedance of the circuit will be

$$Z = \sqrt{0.01^2 + 0.1^2} = 0.1 \text{ approximately}$$

If the full load current is 1, the instantaneous short-circuit current would then be equal to

$$\frac{1}{0.1} = 10 \text{ times full load current.}$$

As soon as the armature reaction becomes effective, the short circuit current will be reduced to its permanent value which is only a few times the full load value.

When a short circuit takes place the current becomes lagging, and its effect will be to demagnetize the field poles. In the above example for instance the power-factor is equal to 9 per cent.

$$\tan.\ \theta = \frac{0.1}{0.01} = 10 \text{ and } \theta = 84.5$$

$$\text{thus } \cos.\ \theta = 0.09$$

It, however, requires an appreciable time to reduce the magnetic flux to its low short circuit value, since it is surrounded by the field coils, which act as a short-circuited secondary opposing a rapid change in the field flux, that is, in the moment when the short circuit starts, it begins to demagnetize the field, and the magnetic field flux, therefore, begins to decrease. In decreasing, however, it generates an e.m.f. in the field coils, which opposes the change of field flux, that is, increases the field current so as to momentarily maintain the full field flux against the armature reaction. The field flux, however, gradually decreases, and also the field current which increased considerably the first moment. This is clearly illustrated in the oscillograms shown in Fig. 1.

With the present tendency toward very large generating stations and units, and the concentration of large amounts of power at one place, it is evident that short circuits may give rise to very destructive effects. It therefore becomes imperative that the flow of energy into such faults be limited to a safe value and the damaged part isolated as quickly as possible, so that the trouble does not spread to other parts of the system. The current rush is reduced by providing a sufficient amount of reactance in the circuits. In some cases the inherent reactance of the apparatus may be increased to a value sufficiently high to limit the current to the desired value, while in others it may be necessary to resort to external reactance coils. For high tension transmission systems these may be placed in the generator leads, between the low tension busbar sections or in the low tension transformer leads. In the substations they may, of course, also be placed in the outgoing low tension feeders. Which one of the above locations, or combinations thereof, is preferable depends on a number of conditions, and either has its advantages and disadvantages.

The following example is therefore given in order to show what the value of the short circuit current will be when external reactance coils are provided as shown in Fig. 2. It is assumed that four 12,000-kv-a., three-phase, 11,000-volt generators, having a 12 per cent inherent reactance, are operating in parallel on a low-tension bus. There are two outgoing high-tension lines, each fed through a transformer bank having a capacity of 24,000 kv-a. and an inherent reactance of 4 per cent. It is also assumed that the fault takes place in one line near the station so that the intervening line reactance is negligible. What is then the value of the short circuit current passing through the transformer bank of the damaged line with external reactance coils inserted as shown in the figure? Each coil has a reactance of 6 per cent, based on the full load current of one generator.

The single-phase reactance of a generator, transformer bank or set of reactance coils is obtained from the formula

$$x = \frac{10 \times p \times E^2}{\text{kv-a.}}$$

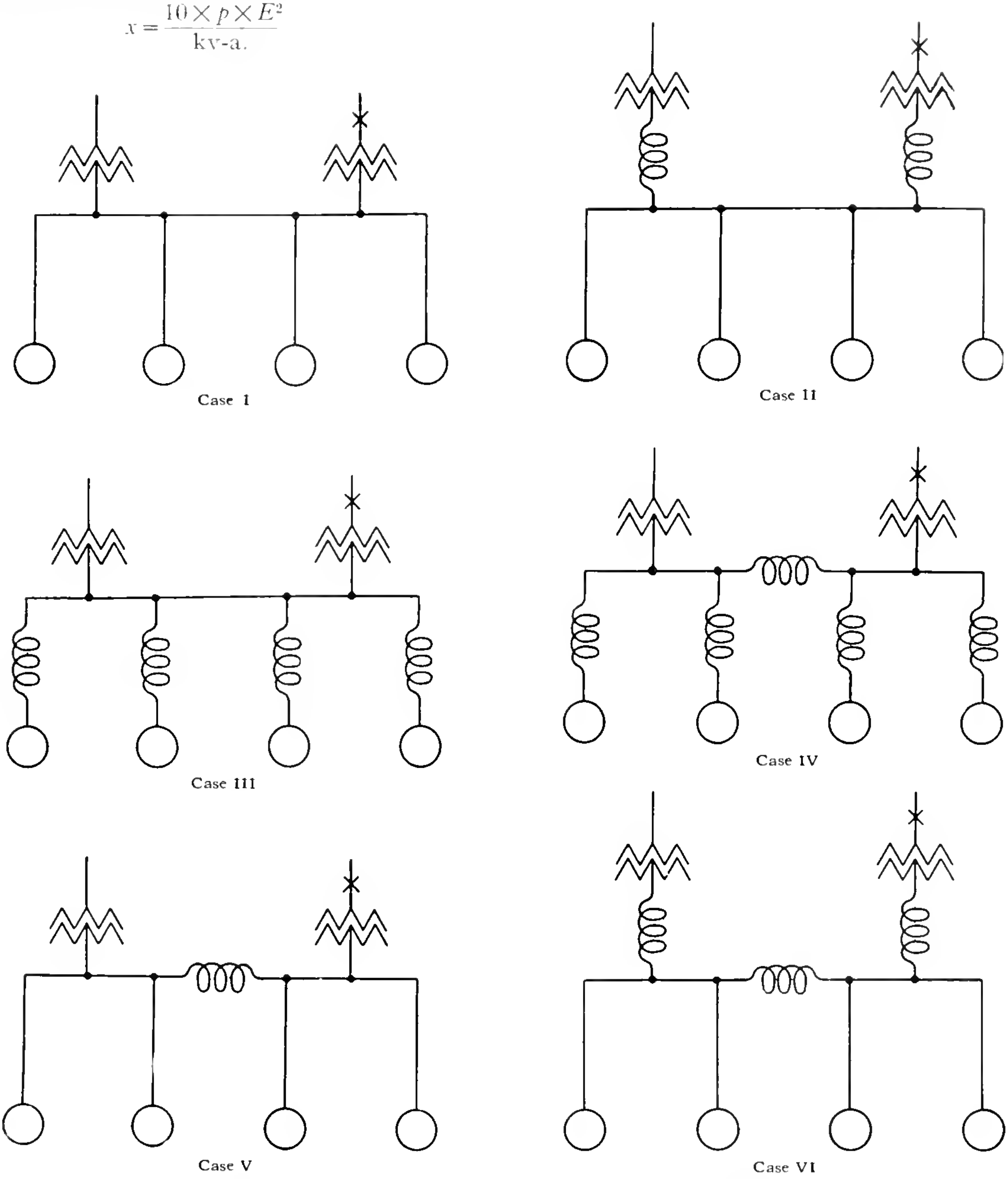
where

$x$ = single-phase reactance in ohms.
$p$ = reactance in per cent.
$E$ = voltage between phases in kilovolts.

Thus:

Reactance of generator

$$= \frac{10 \times 12 \times 11^2}{12{,}000} = 1.2 \text{ ohms.}$$



Case I

Case II

Case III

Case IV

Case V

Case VI

Fig. 2. Various Methods of Installing Power Limiting Reactances

Reactance of transformer bank

$$=\frac{10\times 4\times 11^2}{24{,}000}=0.2 \text{ ohms.}$$

Reactance of set of coils

$$=\frac{10\times 6\times 11^2}{12{,}000}=0.6 \text{ ohms.}$$

*Case 1.* No external reactances.

Reactance of four generators in parallel

$$=\frac{1}{4\div 1.2}=0.3 \text{ ohms.}$$

Total reactance of generators in series with one transformer bank $=0.3+0.2=0.5$ ohms.

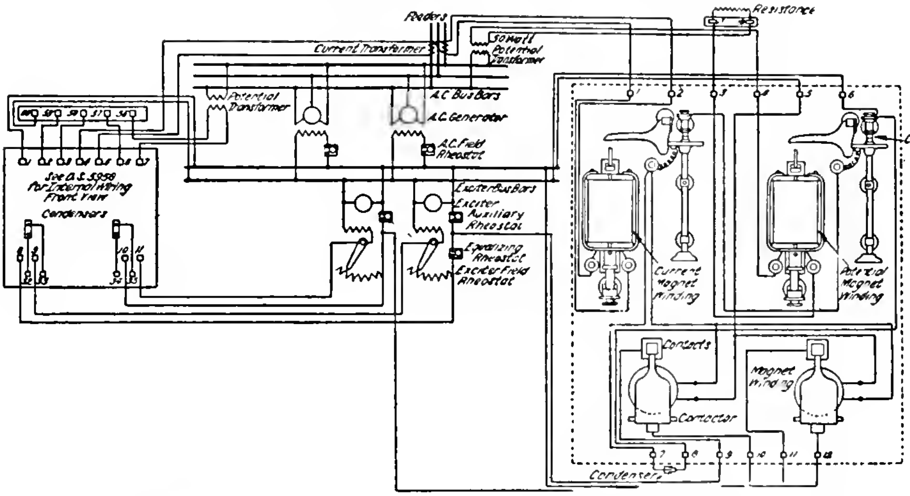


**Fig. 3. Connections of High Voltage, High Current Cutout Relay with Voltage Regulator and Two Exciters in Parallel**

$$\text{S.C.C.}=\frac{11{,}000^2}{0.5\times 1000}=242{,}000 \text{ kv-a.}$$ or approximately 20 times the full load of one generator.

*Case 2.* A 6 per cent reactance is inserted in all the generator leads.

Reactance of the parallel combinations of generators and coils

$=\frac{1}{4\div 1.8}=0.45$ ohms. Total reactance of this in series with one transformer bank $=0.45+0.2=0.65$ ohms.

$$\text{S.C.C.}=\frac{11{,}000^2}{0.65\times 1000}=186{,}000 \text{ kv-a.}$$

or approximately 15½ times one generator.

*Case 3.* The low-tension bus is sectionalized in two groups with a 6 per cent reactance.

Reactance of generators No. 1 and No. 2 in parallel $=\frac{1}{2\div 1.2}=0.6$ ohms.

This in series with the reactance coils

$$=0.6+0.6=1.2 \text{ ohms}$$

and this in multiple with the two parallel generators No. 3 and No. 4

$$=\frac{1}{\frac{1}{1.2}+\frac{2}{1.2}}=0.4 \text{ ohms.}$$

and finally this in series with the transformer bank $=0.4+0.2=0.6$ ohms.

$$\text{S.C.C.}=\frac{11{,}000^2}{0.6\times 1000}=200{,}000 \text{ kv-a.}$$

or approximately 17 times one generator.

*Case 4.* Six per cent reactances inserted in low-tension transformer leads.

Reactance of generators in parallel

$$=\frac{1}{4\div 1.2}=0.3 \text{ ohms.}$$

Total reactance of generators, coils and transformer bank (all in series)

$$=0.3+0.6+0.2=1.1$$

$$\text{S.C.C.}=\frac{11{,}000^2}{1.1\times 1000}=110{,}000 \text{ kv-a.}$$

or approximately 9 times one generator.

*Case 5.* Six per cent reactances in all generator leads and one bus sectionalizing reactance.

Reactance of generators No. 1 and No. 2 with coils $=\frac{1}{2\div 1.8}=0.9$ ohms.

In series with sectionalizing reactance

$$=0.9+0.6=1.5 \text{ ohms.}$$

In multiple with generators No. 3 and No. 4 and their coils

$$=\frac{1}{\frac{1}{1.5}+\frac{2}{1.8}}=0.56$$

and in series with the transformer bank

$$=0.56+0.2=0.76$$

$$\text{S.C.C.}=\frac{11{,}000^2}{0.76\times 1000}=160{,}000\text{ kv-a.}$$

or approximately 13 times one generator.

*Case 6.* Six per cent transformer and bus-section reactances.

Reactance of generators No. 1 and No. 2 in

$$\text{parallel}=\frac{1}{2\div 1.2}=0.6\text{ ohms.}$$

In series with bus-section reactance

$$=0.6+0.6=1.2$$

In parallel with generators No. 3 and No. 4

$$=\frac{1}{\frac{1}{1.2}+\frac{2}{1.2}}=0.4\text{ ohms.}$$

In series with transformer coils and transformer bank $=0.4+0.6+0.2=1.2$

$$\text{S.C.C.}=\frac{11{,}000^2}{1.2\times 1000}=100{,}000\text{ kv-a.}$$

or approximately 8½ times one generator.

## SUMMARY

Case 1—20 times full load of one generator.
Case 2—15½ times full load of one generator.
Case 3—17 times full load of one generator.
Case 4— 9 times full load of one generator.
Case 5—13 times full load of one generator.
Case 6— 8½ times full load of one generator.

The above illustrates clearly that reactance coils inserted in the transformer leads are very effective in reducing the short circuit currents when the fault occurs in the transformers or in the lines. Different values of reactances may be tried and the best combination found. The cost must, of course, be considered and it may be found that a less number of bus reactances may serve the purpose and be more economical. No rule can be laid down and each case must be solved for itself.*

With reactances in the generator leads, the current flowing in the armature winding is limited, and this method, therefore, affords an excellent protection for the generator itself. It necessarily also limits the current that can flow into any short circuit beyond the reactances, inasmuch as the amount of current which can flow is limited to that which the generators can supply. An objection to generator reactances is the fact that a short circuit on or near the busbars will cause a voltage drop on all the feeder circuits connected thereto.

With reactances inserted between the busbar sections, trouble is confined to the particular section on which the short circuit takes place. These reactances will permit a free exchange of current between the sections under normal operation, while under short circuit conditions they will limit the amount of current which would otherwise flow from the adjacent sections. If properly selected, a fault in one section may, therefore, be confined thereto without seriously affecting the nearby sections. Bus-section reactances afford, of course, no protection to the generators connected to the bus to which the faulty line is connected, but they give added protection to the generators on the other sections. As a rule, however, waterwheel-driven generators have a sufficiently high inherent reactance to withstand short circuits for short durations. Under normal operation the losses in bus sectionalizing reactances are negligible.

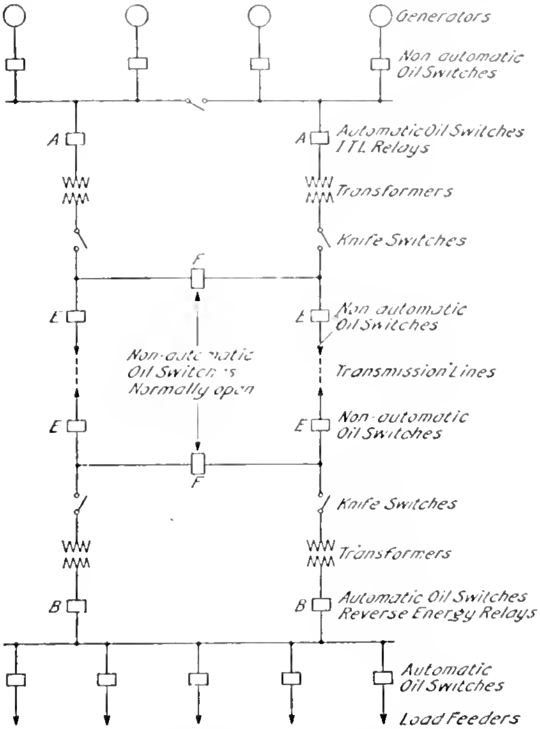


Fig. 4. An Arrangement for Paralleling High Tension Transformers on Low Tension Side. The Banks of Transformers are Equal in Capacity to that of the Line and may be Considered as Part of the Line

Reactance in the low-tension leads of the transformer banks is of considerable value for protecting against short circuits in the lines,

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* For selection of Power Limiting Reactances, see GENERAL ELECTRIC REVIEW, June, 1914.

where they of course mostly take place. They are, however, not of value if the short-circuits should occur on the low-tension bus, or in the generators or their leads. There is also a constant loss of power in the reactance coils when they are inserted in the transformer leads, as is also the case when they are installed in the generator leads. For large systems, this may reach a considerable value, and must not be ignored when the selection of reactances is made.

Various schemes have been devised for limiting the disastrous effects of short circuits by automatically reducing the generator voltage at such instances and by preventing its rise when the short circuits are cleared. One such method employs a cutout relay in connection with an automatic voltage regulator. If a short circuit should occur somewhere on the system: for example, in the transmission lines, the action of the automatic regulator would naturally be to deliver the maximum excitation to the fields of the exciters and generators, so as to keep up the voltage of the system. This in turn necessitates that the waterwheel governors be wide open, and if the short circuit should be suddenly relieved, the voltage often rises considerably, owing to the time element involved in closing the governors and in demagnetizing the fields. If the voltage rises above a predetermined value, the relay will operate and open one or more contactors, which ordinarily short-circuits auxiliary resistances connected in series with the exciter field circuits. The insertion of these resistances will then result in a lowering of the voltage of the system.

Such cut-out relays may be used to protect a system against either ordinarily high currents or high voltages, and are, therefore, either provided with current or potential coils, Fig. 3. Sometimes two relays are used, one for high and the other for low voltage, the advantage of the low voltage feature being that it reduces the possibility of a sudden rise in voltage after the release of a short circuit. When a short circuit occurs, the voltage, of course, drops to a very low value, and by inserting resistance in the exciter field circuits, as before mentioned, it prevents the voltage from rising when the short circuit is released.

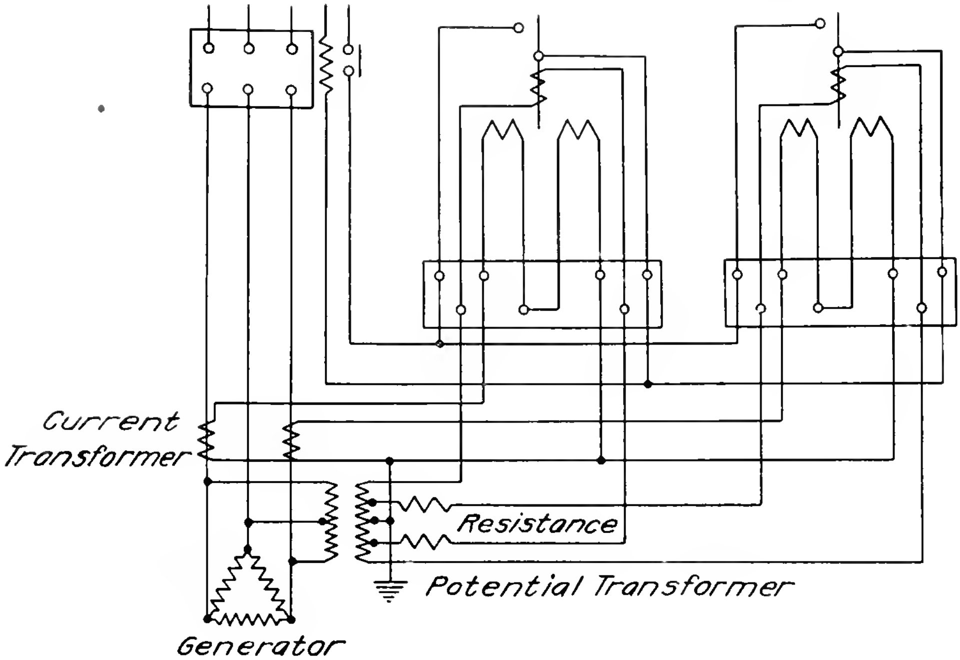

Fig. 5. Reverse Energy Relay

In one of the most recent hydro-electric systems such a relay is adjusted to operate on a 15 per cent rise in voltage and on a 50 per cent drop. Another large system, on the other hand, has an arrangement whereby on short circuits the automatic opening of the bus sectionalizing switches will cause resistance to be inserted in the field circuits of the exciters for the short circuited section, and reduce the voltage of this section to less than half of its normal value. In this manner a certain class of troubles, such as arcing ground, etc., may also be cleared due to lack of potential without even causing the synchronous machinery on the system to fall out of step.

The system of connections and the switching equipment has necessarily a most important bearing on the successful operation of a water-power system, and great care must be exercised in laying out the same. Switches with a safe rupturing capacity should be selected, and the connections and selective switch actions should be such that troubles may be confined to the smallest area possible.

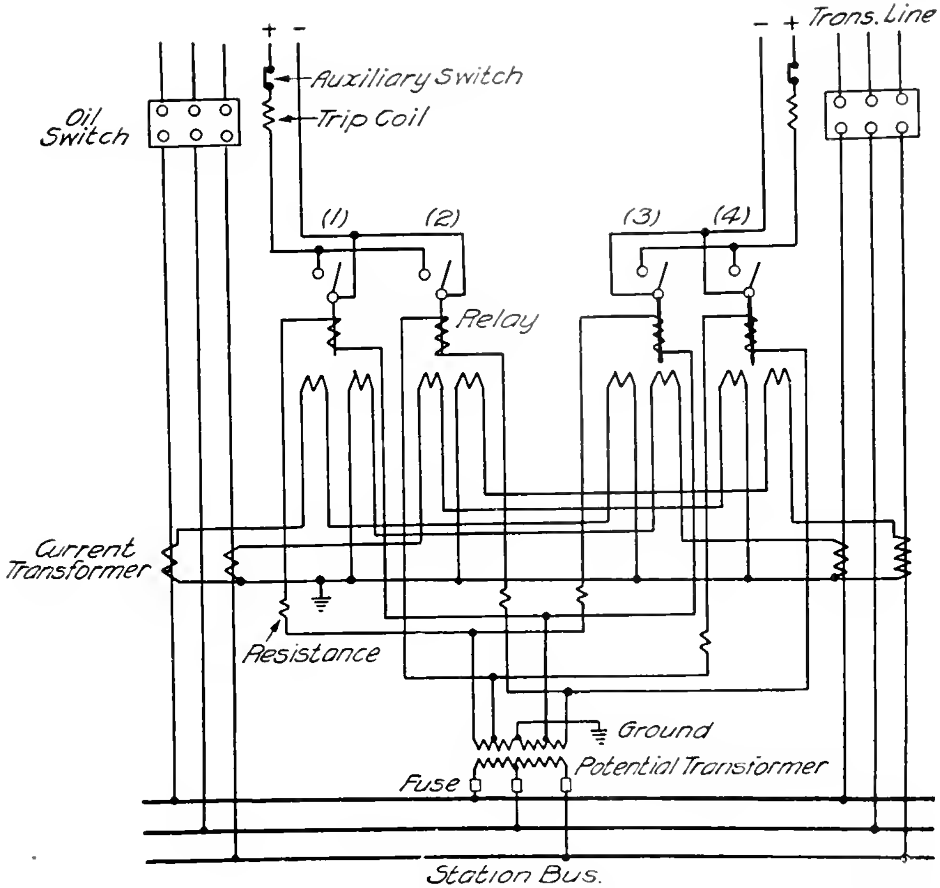

Fig. 6. Reserve Energy Relays, Double Pole, for Parallel Transmission Lines, with Power Flowing in Either Direction under Normal Conditions

Actual experience has demonstrated that high tension switching should be avoided as much as possible, and all disconnecting or sectionalizing under load should be done on the low tension side of the step-up or step-down transformers, so as to prevent any disastrous effects, such as transformer breakdowns, which may be caused by the surges set up by switching in the high tension circuit.

The diagram shown in Fig. 4 represents an up-to-date method of connections for a high tension transmission system.* The generators in each station are paralleled on a low tension bus, and where the total generator capacity is large, the bus should be sectionalized and reactances installed as previously mentioned.

It is preferable to make the generator switches non-automatic as it is of the utmost importance to keep the generators in service, and the possibility of trouble between the generators and the paralleling bus is rather remote. If it is desirable to provide automatic overload protection for the generator switches, they may be equipped with definite time limit relays with a high setting. Reverse energy relays are sometimes provided, Fig. 5, so that a damaged generator may be cut out on a

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* For Circuit Connections in High-Voltage Systems, see General Electric Review, June, 1913.

reversal of the power in its leads, or the relay may simply be connected to an alarm bell.

It is the general practice to provide double transmission lines and if possible to so arrange the transformer banks that they form a unit with the lines, i.e., one bank or group of banks is provided for each line. These are not connected together on the high tension side, all paralleling and switching being done on the low tension side, both in the generating stations as well as in the substations. The high tension line switches are, therefore, of the non-automatic type and are only intended for sectionalizing purposes, the other sectionalizing switches being kept normally open.

The low tension transformer switches are made automatic, the switches in the generating stations being equipped with inverse or definite time limit relays and the substation switches with reverse energy relays, see Fig. 6, which will only operate on a reversal of power and not on overload. With this arrangement a perfectly selective protection is obtained. Should, for example, a short circuit take place in one of the transmission lines, this would cause a reversal of power in that section of the line nearest the substation, and its low tension transformer switch would immediately open and shortly thereafter the transformer switch in the generating station, thus cutting out the faulty line without affecting the other, which, of course, then would have to carry all the load. By means of the high tension line switches and the sectionalizing switches, the transformer banks can readily be disconnected from the damaged line and paralleled with the other transformer, so as to prevent these from being overloaded.

All the feeder switches should, of course, be provided with automatic switches, equipped with either inverse time limit or instantaneous overload relays with a setting such that any trouble in these circuits will be confined thereto.

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# SYNCHRONOUS BOOSTERS IN TRANSMISSION LINES

By Lee Hagood

Lighting Department, General Electric Company

The author wrote a series of articles for the Review on the subject of voltage and power-factor control for moderate voltage systems which were published in our issues of October, November and December, 1912. He later wrote an extensive analysis of this subject for high-voltage systems which was published in the proceedings of the A.I.E.E., 1913. In the present article, he makes an analysis of the application of synchronous boosters to transmission lines. He has pointed out in particular that, when a synchronous booster is driven by a synchronous condenser, an ideal method is secured for deriving flexible voltage for a distribution point on a transmission system. Such voltage is independent of the system's voltage and yet does not involve the local synchronous machines in operating at undesirable power-factors, since the insertion of the booster effects a means of securing only such power-factors in the transmission line itself as is desired to meet the operating conditions.—Editor.

A synchronous booster is simply a synchronous generator in design, and is employed on electric power circuits for controlling voltage. It is intended for series operation in a circuit and hence must be driven synchronously. Synchronous motors offer a convenient method of drive, the booster being arranged on the same shaft so as to secure proper phase relation for the booster voltage. By controlling the field of the booster, any desired degree of bucking or boosting of the circuit voltage may be obtained.

In action, a synchronous booster is quite similar to a feeder voltage regulator. Feeder voltage regulators are designed essentially for feeder circuits; but in some instances are used in small transmission line circuits and in tie-line circuits. In very large sizes, however, feeder voltage regulators become expensive relatively, especially for the higher voltages, such as 11,000 and 13,200.

It is for use in tie-line circuits and in transmission line circuits that the synchronous booster has been developed. It can be built in any size and for any voltage standard for generators. The actual cost per kilovolt-ampere is substantially the same as that of synchronous generators. Quite an advantage accrues from the use of synchronous boosters in that they can be operated in parallel with the same facility as is afforded by two synchronous generators. Another advantage that arises from the use of boosters for large power circuits is that they may be driven by synchronous condensers and thus combine the advantages of the booster for voltage compensation and of the synchronous condenser for power-factor correction.

In view of the fact that a booster must be driven by a synchronous motor, the inherent losses are considerably greater than that of a feeder regulator. For a given amount of power transmitted, the feeder regulator would have losses in the magnitude of two-tenths of one per cent of this power, whereas the synchronous booster with its synchronous motor would have inherent losses between 10 and 15 times this amount. When the booster is driven by a synchronous condenser, however, the improved power-factor will frequently effect a reduction in generator, line and transformer losses more than sufficient to offset the losses of the booster set.

The excitation of a booster may be either automatic or non-automatic. When driven by a large synchronous condenser it is better, in general, to control the excitation of the synchronous booster non-automatically, and that of the synchronous condenser automatically. This arrangement offers a very flexible method of voltage and power-factor control under very adverse line and load conditions.

Fig. 1 illustrates a general case of a synchronous booster driven by a synchronous condenser. It will be assumed that the synchronous condenser is controlled by a voltage regulator, that the booster field is hand-controlled by means of a double-dial rheostat, and that the excitation of the main generator is also controlled by a voltage regulator.

Fig. 2 illustrates the phase relations between the receiver voltage and the current in the line, synchronous condenser and load. For the sake of simplicity, the assumption will be made that the voltage difference between the receiving and generating stations is constant. Let $E_G$ be the generator voltage, $E_R$ the receiver voltage, and $E_B$ the booster voltage. The load current, $I_L$, and its power-factor ($\cos \theta_L$), are fixed by the load conditions. Evidently the line drop for any given load condition will depend upon the power-factor ($\cos \theta$) of the line. Since the voltages $E_G$ and $E_R$ are maintained constant by means of the voltage regulators in each station, the line drop can be varied at will by changing the value of $E_B$. This must involve changes in the line power-factor ($\cos \theta$), since to change the line drop for a given kilowatt load, the line power-factor must be changed. Whatever is done to the line power-factor by means of the synchronous condenser whenever $E_B$ is changed is done automatically due to the voltage regulator. Thus, within the limits of its automatic excitation the kilovolt-ampere load on a synchronous condenser may be changed at will by changing the excitation of the booster.

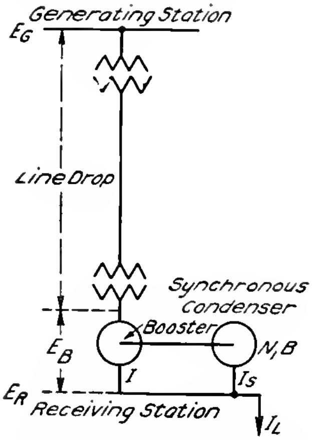

Fig. 1. One-line Diagram illustrating an application of a synchronous booster driven by a synchronous condenser

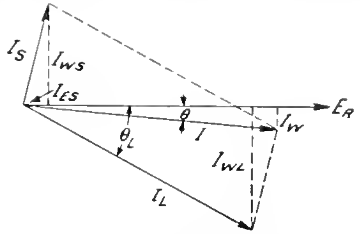

Fig. 2. Vector Relations of the load, synchronous condenser and line currents for the arrangement shown in Fig. 1

The wattless kilovolt-amperes available for power-factor correction from a synchronous condenser driving a booster is slightly reduced below the kilovolt-ampere rating of the synchronous condenser, since a "pump-back" occurs between it and the booster, the booster effecting the equivalent of a mechanical load. The exact value of this load depends upon the booster voltage $E_B$. Since the booster is arranged on the shaft of the synchronous motor so that its generated e.m.f. at full load will be approximately in phase with that of the receiver voltage, the incoming and outgoing currents of the booster may be considered approximately equal and in phase. The leakage reactance of the booster itself is relatively small as compared with the circuit reactance, and for the requirements of this problem may be neglected. In Fig. 2, $I_{ES}$ and $I_{WS}$ are respectively the energy and wattless components of the condenser current, $I_S$; the energy component depending upon the condenser and booster losses and the booster voltage, $E_B$. The line current, $I$, is necessarily the vector sum of $I_S$ and $I_L$. Since the kilovolt-ampere capacity of the booster is usually below one-half that of the synchronous condenser, its effect on the corrective kilovolt-ampere available from the synchronous condenser is quite small.

To illustrate the importance of the advantages which may accrue from the application to a transmission system of a synchronous booster driven by a synchronous condenser, a definite set of operating conditions will be taken. Although the booster set is essentially applicable to systems of moderate sizes, a case will be chosen which involves a large system interconnected with other systems. It will be seen that the principles illustrated are general ones.

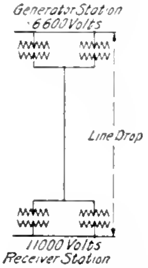

Fig. 3. One-line Diagram of a 110,000-volt, 90-mile transmission line with 4 0 conductors spaced 10 feet vertically

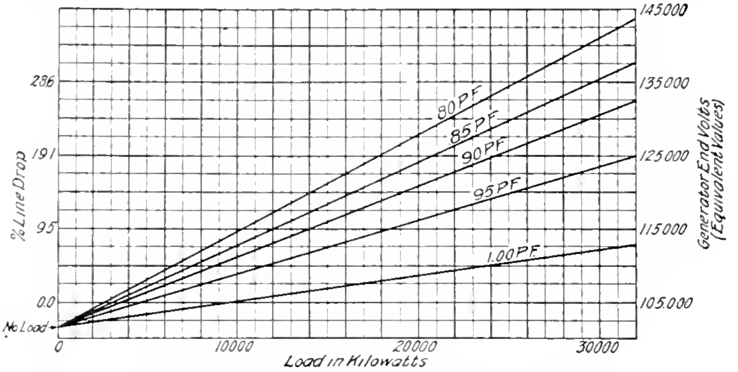

Fig. 4. Relation of Generator Voltage to Receiver Voltage for the line illustrated in Fig. 3. Equivalent values of voltage are used and it is assumed that the receiver voltage is 105,000 and that the power-factors given occur at the receiver end of the line

Fig. 3 illustrates a 110,000-volt, three-phase, 60-cycle transmission line. The generating station is a 60,000 kw. hydro-electric plant, and the receiving station supplies a large city. The transmission line is 90 miles long and consists of two circuits of 4 0 copper spaced 10 ft. in a vertical plane. The transformer banks, in both the receiving and generating stations are 10,000 kilovolt-amperes each. For the sake of simplicity, only one transmission line circuit is shown and the calculations are worked out with the transformer constants included with those of the line. Including the transformer constants with those of the line introduces a slight error, but this, after all, is below the precision required by practical requirements.

Fig. 4 shows a set of curves giving the voltage drops between the receiving and generating stations for different loads and power-factors, under the assumption that the equivalent receiver voltage is maintained constant at 105,000 volts.

When designing a new transmission line or transmission system, or in the operation thereof, the question of suitable line voltage regulation must be carefully considered. This regulation must be within such limits that both proper service and safety to the connected apparatus is secured.

From Fig. 4 the regulation of the transmission line in question may be obtained under various conditions of power-factor and load. For example, if 20,000 kw. were delivered to the receiving station at 0.80 power-factor and at an equivalent voltage of 105,000, the voltage drop would be about 22 per cent; and at no load, to establish the same receiver voltage, the generator voltage must be operated at a value of 4 per cent lower than that of the receiver voltage, thus making a total variation in voltage of the generating station of 26 per cent (in terms of the receiver voltage); in other words, the generating station must operate at a regulation of about 27 per cent. Such a regulation is, of course, out of the question for either satisfactory service or safety to the connected apparatus.

Lightning arresters are designed to relieve a system of transient voltages, such as those set up by lightning, arcing grounds, switching, etc. They offer protection to a system only when the dynamic voltage has a value near that at which the lightning arrester has been charged. If a lightning arrester is called upon to relieve a system of a transient, and the dynamic voltage is much above normal, the arrester is in danger of destruction. Just what margin is allowable is uncertain; however, a safe basis on which to operate would be to figure that the dynamic voltage should never exceed say 15 per cent above that at which it is necessary to charge the arrester. Another important reason for good voltage regulation on a transmission line is the question of the proper exciting voltage for the transformers. If the voltage impressed on the transformer is carried above normal, the core losses and exciting currents begin to increase rapidly and thus excessive heating may be experienced due to the over-voltage, although the kilovolt-ampere load is normal.

Taking all things into consideration, a transmission line should be operated at a voltage regulation less than 15 per cent at the points at which transformers and lightning arresters are located.

Figs. 5, 6, 7 and 8 illustrate the application of synchronous boosters driven by synchronous condensers. The transmission line is the same as that considered in Figs. 3 and 4.

Fig. 5 shows the arrangement of the booster sets. Fig. 6 illustrates the effect of wattless lagging kilovolt-ampere on the line drop, when applied at the receiver end of the line, on the assumption that the receiver voltage is maintained constant and the energy load is zero. Fig. 7 is *derived from Figs. 4 and 6.

The curves of Fig. 7 are based on the following assumptions, viz : the load at the receiving station is supplied at 0.85 power-factor and at an equivalent voltage of 105,000; a voltage regulator is used at both the generating and receiving stations; the relative voltage settings are such as to give a total voltage drop of 6.2 per cent; the excitation of the synchronous booster is hand-controlled by means of a double-dial rheostat; and the transformers are connected approximately for 6600 to 110,000 volts in the generating station, and 103,000 to 11,000 volts in the receiving station. Since the booster can add or subtract voltage and thus change the voltage drop of the transmission line, and since the total drop is assumed constant (being controlled in the two stations by voltage regulators), the booster offers a means of controlling the relative amounts of wattless kilovolt-amperes supplied by them.

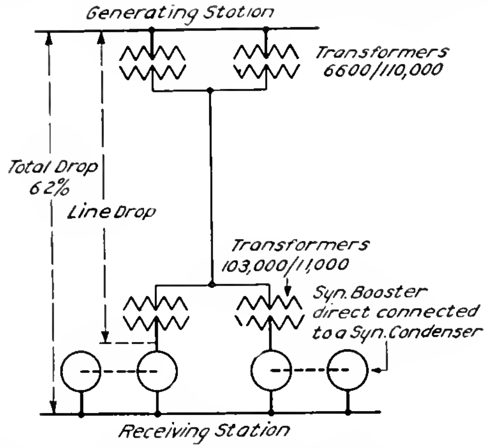

Fig. 5. Illustration of the Application of synchronous booster driven by synchronous condensers for the line given in Fig. 3

The different curves in Fig. 7 show the wattless kilovolt-amperes required from the receiving station for different field settings of the synchronous booster. For convenience, these wattless kilovolt-amperes, which are assumed under automatic control, will be referred to as synchronous condenser kilovolt-amperes. It can, of course, be supplied from any synchronous machine. When an exciter for a synchronous condenser is directly controlled by a voltage regulator, the limits of automatic excitation allow a supply of wattless kilovolt-amperes from about 25 per cent of full kilovolt-ampere lagging to about full kilovolt-ampere leading. By using an auxiliary exciter controlled by a voltage regulator to excite the synchronous condenser exciter, the synchronous condenser excitation may be controlled automatically for a range from full lagging wattless kilovolt-amperes to full leading wattless kilovolt-amperes. If the synchronous booster is set for a buck of 6.2 per cent, then the curve *abc* indicates the synchronous condenser kilovolt-amperes necessary for different amounts of power. Under this condition the line drop is maintained constant at 0 per cent, since it has been assumed that the total drop between the low tension busses of the two stations will be 6.2 per cent. If the booster is set for 1.6 per cent buck, the line drop will be 4.6 per cent, and the synchronous condenser curve

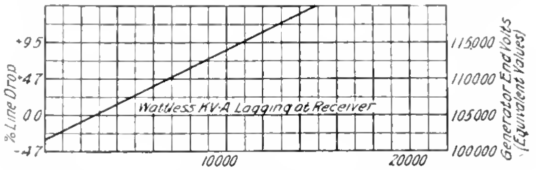

Fig. 6. Relation of Generator to Receiver Voltage for different amounts of wattless lagging kilovolt-amperes at the receiver. It is assumed that the equivalent receiver voltage is 105,000 and the kilowatts zero

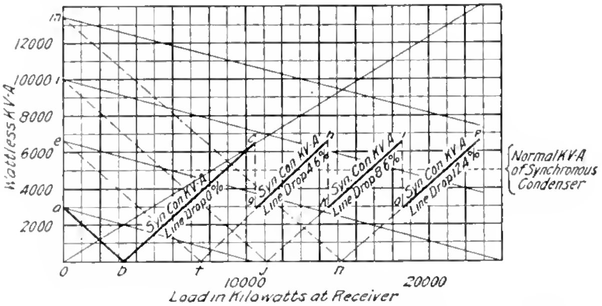

Fig. 7. Wattless Kv-a. Required from the Synchronous Condenser in Fig. 5 for different kilowatt loads at different line drops. It is assumed that the synchronous condenser is controlled by a voltage regulator and that the load is supplied at 0.85 p-f. and at an equivalent voltage of 105,000

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* The method for determining these curves, etc., is given in the author's article in the Proceedings of the American Institute of Electrical Engineers for 1913, pages 2163 to 2189, entitled "Operation of Transmission Lines."

will be *efgh*; if the booster is set for 2.4 per cent boost, the line drop will be 8.6 per cent, and the synchronous condenser curve will be *ijkl*; and finally, if the booster is set for 6.2 per cent boost, the line drop will be 12.4 per cent, and the synchronous condenser curve will be *mnop*. By using these five settings of the booster, the synchronous condenser kilovolt-ampere can be made to follow the curve *abcghklop* for a load at 0.85 power-factor between 0 and 23,000 kw. In actual practice, the station operator would adjust the boosters in such a manner from time to time as to load the synchronous machines under automatic voltage control in accordance with the most favorable conditions to them, and yet secure the desired power-factor correction for the transmission line itself. The synchronous machines under automatic voltage control may be either the synchronous condensers driving the boosters, or other synchronous machines such as generators or motors, or both. If the synchronous condensers driving the boosters are large enough, it will often work out satisfactorily to have them under automatic control and to excite all the other nearby synchronous machines non-automatically.

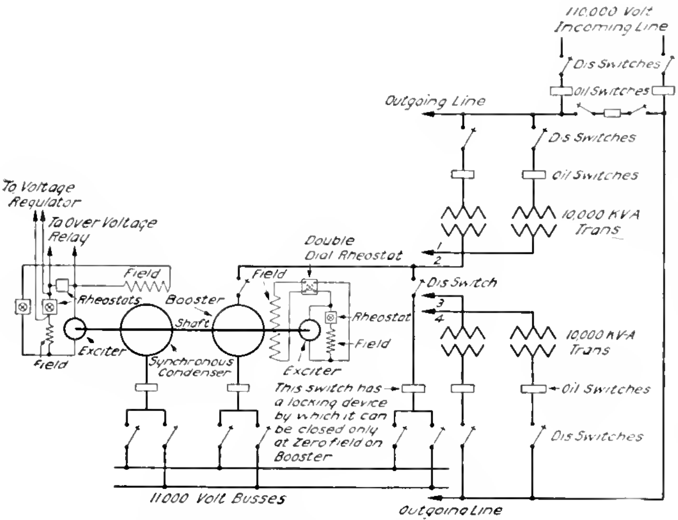

Fig. 8. One line Diagram of an installation where a synchronous booster driven by a synchronous condenser is located in each transformer circuit

In the case illustrated, it has been assumed for simplicity, that the total voltage drop is maintained constant. In actual operation the low tension bus voltages at either generating or receiving station may be maintained at such values as is consistent with the best results. In general, it seems desirable when supplying a lot of feeders from a given bus that means be provided for raising the bus voltage as the load increases, and thus meet the general voltage requirements of the distribution system. This can be done by devices used in connection with the voltage regulator, the simplest being a rheostat located in the circuit of the regulator's potential transformer. The addition of the booster in the circuit allows these voltage changes, since the necessary compensation can be made with it, so as to secure at all times such power-factor conditions as meet the requirements. As has already been stated, the booster makes it possible to control at all times the wattless kilovolt-amperes from the synchronous machines under automatic control. The amount of wattless kilovolt-amperes supplied, however, should always be sufficient to keep the regulation of the transmission line within about 15 per cent.

Fig. 8 illustrates in detail the electrical equipment involved. The two incoming lines are from the 60,000 kw. hydro-electric station, and the two outgoing lines supply a large territory, and at the same time form an interconnection with two or three other large systems. The receiving station itself distributes electric power to a large city. This power is distributed at 11,000 volts to several stations scattered through the city, some of these being generating stations and some substations. The various feeders supplying them may be sectionalized or paralleled, either on the main busses or at the various stations and substations, depending upon the operating requirements.

Only one booster set is shown. A duplicate of this equipment is necessary for each transformer circuit. In the drawing it will be noted that a switch is shown for taking the booster out of circuit. Such an arrangement is considered necessary because of the possibility of accident to the booster set. Although such a thing is very remote, at the same time, continuity of service is of great importance and the extra expense seems warranted. The synchronous condenser field, in addition to being controlled by a voltage regulator, is equipped with a resistance controlled by an over-voltage relay. The voltage regulator will take care of all normal tendencies towards changes in voltage, the over-voltage device being for the purpose of protection from abnormal conditions, such as those which would tend to occur should the load be dropped suddenly. In such an event, the synchronous condenser would automatically be brought to a very weak field and the voltage thereby reduced to a safe value. If a synchronous generator, under say, full load and normal excitation, is supplying a transmission system and the load is suddenly dropped, leaving the machine supplying only the empty transmission line, the voltage can build up excessively. This is owing to the capacity effect of high voltage transmission lines. In a certain case with which the writer is familiar, the measured value of this voltage at the generating station was practically double that of normal. At the receiving end of the transmission line the voltage was, of course, considerable greater. The exact maximum value which might occur for a given transmission line would depend upon the normal voltage of the transmission line, the length, spacing and diameter of the conductors, and the degree of excitation of the synchronous machine at the time of the drop in load. Therefore, to protect a system, from over-voltages, due to a sudden dropping of load, all of the large synchronous machines should be equipped with over-voltage devices. It is a particular protection to have some of these synchronous machines located at the receiving end of the transmission line.

Summarizing, the advantages of the installation of a synchronous booster equipment, as described previously, are as follows:

First: The receiving station is enabled to supply power for distribution at such voltages as the distribution system demands, and yet only supply such wattless current to the transmission line as is consistent with the design of the connected synchronous machines and necessary to keep the transmission line within the limits of safe voltage regulation. An incidental advantage of having a booster in each transformer circuit is that when the transformers are paralleled the division of current can be definitely controlled by relatively exciting the boosters. Some value of this application may apply where the impedance in the circuits are unequal, due to the length of the various feeder circuits before paralleling them.

Second: The generating station is also enabled to operate at such voltages as will afford the best service, independent of the transmission line regulation.

Third: The regulation of the transmission line can be controlled within such limits that safety is secured for the connected apparatus.

Fourth: The power-factor of the transmission line may be regulated within such limits as to secure favorable voltages for other receiving stations on the system.

Fifth: The equipment involved is comparatively cheap and simple to operate, and the energy losses inherent to its operation in most instances will be more than offset by the improved power-factor conditions. The operation of the equipment is exceedingly simple in that the station instruments, etc., give the operator complete information as to the conditions established. As stated the excitation of the synchronous condenser is automatic over a large range, hence the amount of attention required by the complete equipment is comparatively small, and necessary only during periods when considerable changes in load are occurring.

# SOME INTERESTING APPLICATIONS OF THE COOLIDGE X-RAY TUBE

By Dr. Wheeler P. Davey

Research Laboratory, General Electric Company, Schenectady

This article is of particular interest when read in connection with our editorial this month. The physical properties of the Coolidge tube make it useful to the physicist, physician, botanist and biologist alike. The collection of radiographs that accompany this short article show in a striking manner the capabilities of the tube.—Editor.

There have lately been published many very interesting radiographs of flowers, leaves and insects. Typical instances are shown by Pierre Goby, Hall-Edwards and others. These men have found it desirable in such work to use tubes in which the vacuum was widely different from that employed in ordinary radiographic work. For instance, in referring to a splendid radiograph of tulip blossoms, Hall-Edwards (Archives of the Roentgen Ray, June, 1914), who is using tubes of the ordinary type (in this case a "Muller" with a Bauer regulator) notes that "it is rather dangerous to use new tubes for this purpose (although the best results can undoubtedly be obtained by them), for the reason that it is very easy to pass the boundary line and get a vacuum so low that it cannot be raised without re-exhausting the tube." Such difficulties, though they have not prevented securing beautiful radiographs have doubtless kept this method of internal and structural photography from advancing as rapidly as it might otherwise have done.

The Coolidge X-Ray Tube (see Physical Review, December, 1913, or General Electric Review, February, 1914), has proved itself to be an efficient tool in the hand of the medical profession, and it occurred to the writer that it would prove equally valuable to botanists and biologists in connection with the study of plant and animal life.

The main advantages in the use of the Coolidge tube are (1) the independence of the *quantity* and the *penetrating ability* of the rays produced, (2) the ease and rapidity with which the *quantity* and penetration of the rays may be regulated, and (3) the fact that when the tube is once adjusted to the requirements of the operator it needs no further attention. To bring the tube to any desired adjustment, the operator pulls a handle which regulates the current through the tube, thus determining definitely the quantity of X-rays produced. He then adjusts the voltage across the tube until the penetration is of the desired degree. These adjustments are rapid and require the minimum of technical skill.

To illustrate this, the writer took a tube at random (it happened to be No. 280) from the rack and took a number of radiographs of various botanical specimens. It was at once found that, when the proper penetration and exposure had been determined, the radiographs could be duplicated time after time with absolute precision. Then biological specimens were tried, and finally radiographs were taken of dense objects, such as fuse plugs and Ingersoll watches. As in the case of the botanical specimens, all of these radiographs could be accurately reproduced as often as desired.

About this time tube No. 280 was accidentally broken. Another tube (No. 297) was picked at random from the rack and much of the former work was repeated with it. There was no difference noticeable between the two sets of pictures.

It was the original intention to publish only those radiographs taken with tube No. 280, but it was later decided to add such of those taken with No. 297 as seemed to be of peculiar interest. The radiographs reproduced here were not chosen from the total number taken because of any novelty or excellence in the pictures themselves, but rather because they show what a wide range of work can be done with a *single* Coolidge tube, and because they suggest that the Coolidge tube is destined to become a precision-instrument of value to the botanist, biologist and mineralogist as well as to the physicist and the physician.

None of the pictures shown here have been re-touched or altered in any way.

Fig. 1. Fern Bud and Dandelion Bud. Tube 280

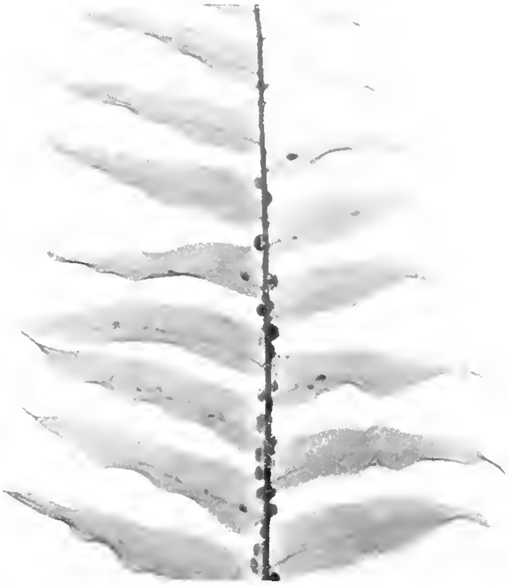

Fig. 2. Fern Leaf with Colonies of Bugs. Tube 280

Fig. 3. Cherry Twigs, with Young Leaves, Buds and Freshly Opened Flowers. Tube 280

Fig. 4. Cherry Twigs with Mature Blossoms. A Couple of the Blossoms have already lost their Petals. Tube 280

Fig. 5. Another Branch of Mature Cherry Blossoms and a Spray of Leaves. Tube 280

Fig. 7. Cherry Twig. The Cherry is starting to form around the pit. Tube 280

Fig. 6. Cherry Twig. All the Blossoms have lost Their Petals. The Cherry Pits have started to form. Tube 280

Fig. 8. Cherry Twig. The Cherries are about half developed. Tube 297

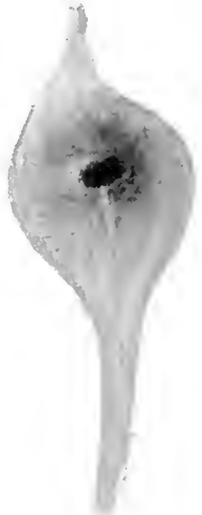

Fig. 9. Golden-Rod Gall. The worm inside is alive. After this picture was taken, the worm finished its metamorphosis and the resulting fly "Eurosta (Trypeta) solidaginis", made its way out into the laboratory. Tube 280

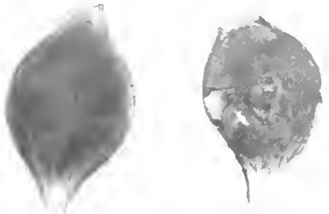

Fig. 10. Golden-Rod Galls. The Worm inside is dead. Tube 280

Fig. 11. Crayfish. This subject differs from the tadpoles, which follow, in that the bony structure is on the outside. Tube 297

Fig. 12. Young Tadpoles. Note the shape of the intestines, and the beginning of ossification of the first vertebra. The intestines show up strongly in contrast to the surrounding flesh because the natural food with which they have gorged themselves is rather opaque to the X-rays. Tube 297

Fig. 13. Still Older Tadpoles. In the oldest of the three the vertebrae show considerable ossification. Tube 297

Fig. 14. Tadpole, Size of Largest One of Fig. 13. Magnified three and one-half diameters. Note articles of food in the intestines. Tube 280

Fig. 15. Still Older Tadpoles. Note growth of the intestines, and further ossification of vertebrae. The neck is beginning to form. Tube 297

Fig. 16. A Young Frog. The intestines are taking their final shape. Ossification of bones is nearly complete. Tube 297

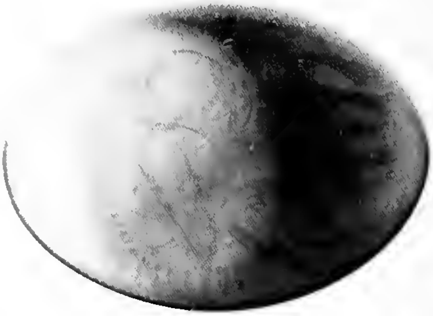

Fig. 17. Partly Hatched Egg. Tube 280

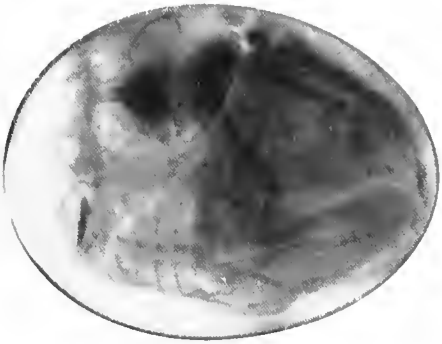

Fig. 18. Egg, Nearly Hatched. Tube 280

Fig. 19. Four-Legged Chicken. Five Hours Old. Tube 297

Fig. 20. The substances most commonly used to imitate diamonds are fused oxide of aluminum, quartz, and lead glass. The figure shows a radiograph of these three as contrasted with a diamond of the same size. In the order of transparency to X-rays they are: diamond, fused oxide of aluminum, quartz, lead glass. Tube 280

Fig. 21. Ingersoll Watch. Tube 280

Fig. 22. Cabled Copper Wire. Radiograph taken through the insulation. Tube 280

Fig. 23. Cartridge Fuse. Tube 280

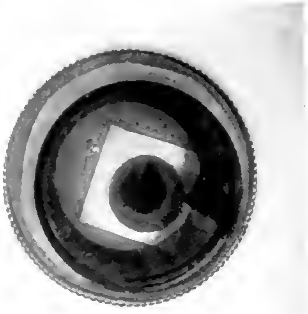

Fig. 24. Fuse Plug. Tube 280

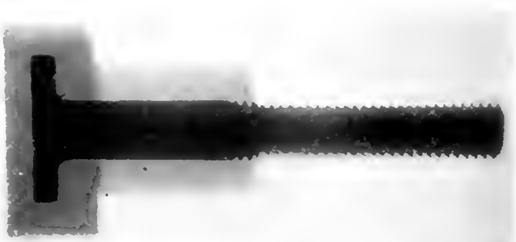

Fig. 25. "Moulded Compound" insulation around a steel bolt. Tube 280

# PATENTS

## PART III

By Chas. L. Clarke

Consulting Engineering Department, General Electric Company

Parts I and II of this article, which appeared respectively in the May and July numbers of the Review, considered the foundation of the patent monopoly in this country, the general laws on patents now in force, the legal meaning of the terms "discovery" and "laws of nature" or "principles," and the things that are proper subjects of patents; also the distinction between patentable invention and mere exercise of mechanical skill including the rules of law, as formulated through the decisions of the courts, in accordance with which a decision is made as to whether the production of a thing required invention. In this issue is presented a bird's-eye view of the salient features of the rules that must be followed in prosecuting an application for a patent, with a statement of certain precautions that must be observed to insure a valid patent, coupled with abundant caution to the inventor not to prosecute his application himself, but to entrust it to a competent attorney. The article concludes with a consideration of the subject of inventing and patenting from the practical standpoint of business common sense.—Editor.

### NOVELTY AND UTILITY

#### Inventions or Discoveries

According to Section 4886 of the Revised Statutes,* as amended March 3, 1897, in order for a thing to be patentable it must, besides requiring invention, be "new and useful." It may be intrinsically new, or a new improvement of an old thing by which the same result is more easily obtained, or a better result secured. But for a thing to be new for patentability, it need not be actually new in the dictionary sense, for it may not have such newness and still be patentable under certain circumstances. The term "novelty" is commonly used by the legal profession to designate patentable newness.

An invention, to have patentability, must also be useful, or have "utility," as termed by the legal profession, substantially in the sense that it accomplishes the purpose intended, and is not obnoxious to law and good morals.

An invention is new for patentable purposes, if not known or used by others in this country and not patented or described in any printed publication in this or any foreign country before the invention was made by the person filing an application for a patent therefor in this country, or more than two years prior to such application, and not in public use or on sale in this country for more than two years prior to the application.

An invention is also new for patentable purposes, although it may previously have been known and used by others in a foreign country, if it was not patented or described in any printed publication in this or any foreign country before the invention was made by the person filing application for a patent therefor in this country.

An invention is also new for patentable purposes, although the inventor may have first patented it in a foreign country, if application for a patent in this country is made *not later than twelve months* after the application for the foreign patent was filed.

#### Designs

According to Section 4929 of the Revised Statutes, as amended May 9, 1902,* in order for a design to be patentable it must, besides requiring invention, be "new, original, and ornamental." It must be new, or possess novelty, in the same sense that things invented or discovered have patentable newness, as previously explained. It must be original, probably in the sense that it must have originated with the only person that can in law be said to have invented it—the term original in the statute seems redundant.

A design, to have patentability, must, besides being new and original, also be "ornamental." But it does not appear from Section 4929 that patentable designs must possess utility, as is specifically required in the case of inventions or discoveries, except so far as it may perhaps be inferred that ornamentation in a design embodies a certain although rather academic utilitarian value.

A design is new for patentable purposes, if not known or used by others in this country and not patented or described in any printed publication in this or any foreign country before it was invented by the person filing application for a patent therefor in this country, or more than two years prior to such application, and not in public use or on sale in this country for more than two years prior to the application.

A design is also new for patentable purposes, although it may previously have been

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* See Part I, May number of the General Electric Review, page 445.

* See Part I, May number of the General Electric Review, page 446.

known and used by others in a foreign country, if it was not patented or described in any printed publication in this or any foreign country before it was invented by the person making application for a patent therefor in this country.

A design is also new for patentable purposes, although the inventor may have first patented it in a foreign country, if application for a patent in this country is made *not later than four months* after the application for the foreign patent was filed.

### INDEPENDENT AND JOINT INVENTORS

If an invention is made by the exercise of the inventive faculties of one man, he is an "independent inventor," but if a thing is really invented by two or more men, they are "joint inventors." They may have required the help of skilled artizans, mechanics or chemists, to assemble the apparatus, or machinery for working an invented process, or to construct an invented machine for producing a given result, or to turn out an invented article of manufacture in a desirable form, or to handle and bring together the materials forming an invented composition of matter, or perhaps an artist to whip an invented design into shape, but the skilled persons employed to do these things do not thereby participate in making the invention. *If one man does all the inventing and another does all the constructing, the first is the sole inventor.* (*Walker.*)

It sometimes happens, for example, in research work, that a physicist or chemist conceives a certain novel sequence of operations upon a material, or materials, perhaps including applications of electricity, heat, or pressure under delicate and accurately adjusted conditions, and wishes to know the result. He explains his conception to an assistant and instructs him to put the process to test. The investigation may require weeks and months of patient endeavor to bring it to a conclusion, although nothing more than carefully applied skill was called for. Under such circumstances, if the process called for invention, it would reside in the original conception of the sequence of operations by the chief, and not in the laborious work of the assistant. Generous disposition on the part of the chief to promote the welfare of a faithful and able assistant conveys no authority to resign the merit of invention to the latter; the patent must in law go to the real inventor. But should the assistant in his investigation find known apparatus, or machinery, inapplicable for working the process, and invent suitable means therefor, a patent for the apparatus, although not for the process, should be taken out on his application. It is not always easy when several persons have to do with an invention, and the putting of it into practical shape, or its reduction to practice, so-called, to determine whether one of them is the sole inventor, or some of them be joint inventors; all the facts in each case must be taken into consideration to determine the question.

Joint inventors are entitled to a joint patent issued to all of them, but no one of them may alone obtain a patent for a joint invention. And independent inventors of distinct and independent improvements in the same machine may not obtain a joint patent for their several inventions.

The fact that one man furnishes the capital and another makes the invention does not entitle them to a joint patent.

It is not invention on the part of one man to perceive the benefit of a result, if accomplished, and then employ another to devise means to produce that result; if an invention has been made in arriving at the means, it has been made by the person devising the same.

### ABANDONMENT

In general, a person may abandon an unsuccessful effort to make an invention; or, having made an invention, he may abandon it in the sense of not obtaining a patent, thereby in law giving the invention to the public, or he may openly dedicate it to the public; or having made an invention and having applied for a patent, he may under certain circumstances abandon that particular application, by not pursuing it, without abandoning the invention, the obtaining of which may be pursued by a new application. Abandonment may not only result from his own desire, but also from neglect on his part to take proper steps to make and prosecute application for a patent within the times and with the diligence prescribed by law; or by his publicly using, or selling, or permitting others so to use or sell the invention in this country for more than two years prior to his application., and in various other ways.

### LIFE OF PATENTS

Patents for inventions or discoveries in arts, machines, manufactures, or composition of matter, and improvements thereof, are granted for a term of seventeen years.

Patents for designs are granted for three and one-half, or seven, or fourteen years, at the option of the applicant; if granted for one of the shorter terms, the patent cannot afterwards be extended by the Patent Office to a longer term. The life of a patent cannot be extended beyond the term for which it was originally granted except by special act of Congress.*

## APPLICATIONS FOR PATENTS

### Preamble

The prosecuting of applications for patents is signally a business by itself, properly demanding the services of an expert attorney, if the inventor is to feel reasonably assured of obtaining a safe, and as comprehensive or broad a patent as is permissible. An inventor should unless circumstances have given him special training in that line, no more think of prosecuting applications for patents for his own inventions, than of undertaking to conduct a law suit on his own account. We have heard that "the man, who is his own lawyer, has a fool for a client," which experience has shown still holds good, even should the man happen to be a lawyer And we raise the question whether even a patent attorney may not be in the same category, if he undertakes to prosecute the application for a patent for an invention of his own; and whether he had not better eliminate such risk of inefficiency, as may come from doubts and fears over such a personal matter, by letting a brother attorney do the work for him.

The official *Rules of Practice in the United States Patent Office* contain the following pertinent suggestion: "An applicant or an assignee of the entire interest may prosecute his own case, but he is advised, unless familiar with such matters, to employ a competent attorney, as the value of patents depends largely upon the skillful preparation of the specification and claims."

### Application

The application must be made to the Commissioner of Patents.

### Signature

The application must be signed by the inventor, if alive and otherwise lawfully competent so to do.

### Filing

An application will not be placed on the files for examination until all its parts (except the model or specimen, which is seldom required) are received, which must be done within one year after the receipt of the first paper—the petition.

### Abandonment

An application will be regarded as abandoned if all its parts are not received within one year after the receipt of the petition, or upon failure of the applicant to prosecute the same within one year after any action of the Patent Office thereon, unless the delay was unavoidable.

### Petition

The petition requesting the grant of a patent must be addressed to the Commissioner of Patents, state the name, the residence, and the post office address of the petitioner, designate by title the invention sought to be patented, contain a reference to the specification for a full disclosure of such invention, and must be signed by the applicant.

### Specification

The specification is a written description of the invention or discovery, and of the manner or process of making, constructing, compounding, and using the same, and is required to be in such full, clear, concise, and exact terms as to enable any person skilled in the art to which the invention or discovery appertains, or with which it is most nearly connected, to make, construct, compound, and use the same. The principle of the invention, and the best mode of applying it known to the inventor must be given. If the invention is a mere improvement, what is new must be distinguished from what is old.

### Claims

The specification must conclude with a specific claim or claims of the part, improvement, or combination which the applicant regards as his invention or discovery. It is of vital importance that the real invention be expressed in the claims, stripped of all unessential details relating to the particular form in which the inventor may have embodied his invention, as described in the specication. It is in the drafting of proper claims that the service of an experienced attorney is especially advisable. The less a claim says, yet truly expressing the invention, the broader

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* The last patent extended by Congress was No. 55,469, June 12, 1866, to Henrietta H. Cole for a fluting machine; reissued. April 25, 1871, No. 4,349. It was extended for seven years from June 12, 1883 (the date of expiration of the original patent) by act of Congress, approved Aug. 4, 1886; and the certificate of extension was issued Aug. 9, 1887; *Official Gazette of the United States Patent Office*, Vol. XL, page 814.

is its scope, and the greater is the monopoly sought.

By rule of the Patent Office, *independent inventions* (for example, one invention in steam engines and another in electric generators, the operation of one of which is not necessarily connected with the operation of the other, and thus one of the inventions may be used independently of the other), cannot be claimed in the same application; but where there are several distinct, although *dependent inventions*, (for instance, in an electric generator, one invention for an arrangement of armature coils, and another for a core construction adapted for receiving such coils) which mutually contribute to produce a single result, they may be claimed in one application.

In fact, each claim of an application, or of a patent, must represent a separate invention to be valid.

But should a single patent be granted for two or more unrelated inventions, it might be held, for that reason, to be invalid, though *no patent has ever yet been held void for containing more than one invention.* On the other hand, two or more patents for related inventions that are embodied in one extensive machine may lawfully be granted. (Walker)

### Oath

The inventor must make oath or affirmation that he believes himself to be the original and first inventor or discoverer of the art (process), machine, manufacture, composition or improvement therein, for which he solicits a patent; that he does not know and does not believe the same was ever before known or used; and must state of what country he is a citizen and where he resides, and whether he is the sole or the joint inventor of the invention in his application, as expressed in the claims thereof. He must state under oath that the invention has not been patented to himself, or to others with his knowledge or consent, in this or any foreign country for more than two years prior to his application, or on his application for a patent filed in any foreign country by himself or his legal representatives or assigns, more than twelve months(four months in the case of application for a design patent) prior to his application in this country.

If application for a patent has been filed in any foreign country by the applicant in this country, or by his legal representatives or assigns, prior to his application in this country, he must state the country or countries in which such application has been filed giving the date of such application, and must also state that no application has been filed in any country or countries other than those mentioned, and if no application for a patent has been filed in any foreign country, he must so state; also that to the best of his knowledge and belief the invention has not been in public use or on sale in the United States, or described in any printed publication or patent in this or any foreign country, for more than two years prior to his application in this country. If the inventor is not living or is not otherwise lawfully competent to make oath, say, if insane at the time application is made, corresponding changes are to be made in the oath.

### Drawings

The applicant for a patent is required to furnish a drawing of his invention whenever the nature of the case permits it.

### Models

A model will only be required or admitted as a part of the application when, on examination of the case, the primary examiner in the Patent Office shall find it to be necessary or useful.

### Issue

The final fee for the grant of a patent must be paid not later than six months from the time notice of allowance of the application was sent to the applicant, and the patent must be issued within three months thereafter.

### Re-Issue of Patents

Whenever a patent is inoperative or invalid, by reason of a defective or insufficient specification, or by claiming more than the inventor had a right to claim, provided the error arose through inadvertance, accident, or mistake and without evil intent, the patent may be surrendered, and another patent may be issued for matter within the scope of, or as disclosed by the original patent.

### Design Patents

The proceedings in applications for patents for designs are substantially the same as in the case of patents for arts, machines, manufactures, and compositions of matter. The claim should be in the broadest form for the article, as shown in the drawing.

### Assignment of Patents

An inventor may sell his invention and assign his rights therein to another, and the assignment may be recorded in the Patent Office, whereafter the patent for the invention may be granted and issued to the assignee. In all cases of application for a patent by an assignee, the application must be made and a specification sworn to by the inventor or discoverer, if living and competent.

## INVENTING AND PATENTING

### Why Inventions are Made

Inventions are generally made through trouble experienced in the use of things, which suggests the idea of lessening or overcoming the difficulty by improving the thing, or through striving for a better result, or in perceiving that a new result of a certain kind, would, if accomplished, become a want of more or less value. Thereupon, effort is directed toward making the improvement, or in accomplishing the better, or the new result, and in so doing an invention may be forthcoming. Very few inventions are made in a flash—in the twinkle of an eye—or by accident, or seeming inspiration; in the main they come only with persistent effort, and often after discouraging failures.

### Pursuit of Invention

Conception of methods and means for embodying an idea in usefully operative form arise in the mind of the inventor; artisans, mechanics, physicists and chemists may be called upon to bring their skill to bear upon the problem and assist him. Conferences between them are had; investigation and research are undertaken; the draftsman may be required for making working drawings of models and various apparatus, which have to be built in connection with the work, for experimentation is necessary in the majority of cases; and all this is done, frequently at great expense of time and money, before the end sought is obtained, with the risk meanwhile of final failure and expense incurred without chance for reward.

### Difficulties in the Patent Office

Should success be attained, the next step is to obtain a patent to make the opportunity for reward secure; application for a patent is made and trouble begins. The Patent Office may say that the invention is not new, or that the thing did not require invention, and cite earlier patents, technical journals, and publications of scientific societies to prove it, resulting often in final rejection of the application, or in serious limitation of its scope and the value of the invention allowed. Or the Office may place the application in interference with pending applications of others for the same thing; then come months, perhaps years, of delay and expense in attempt to prove that our applicant was the first one to make the invention, which is often prolonged by interference with still other applications filed after the contest began.

### Infringement and Law Suits Come

Should our applicant prevail and succeed in having the patent awarded to him, then infringement by outside parties begins; suit is commenced against the infringer and the patent comes into court, where the questions arise, whether invention was required to make the thing, whether by reference to prior patents and publications it is old,* and whether it may have been in public use or on sale in this country for more than two years before the patent was applied for, etc.; which must be met at great cost, if the patent is of enough importance to warrant a serious effort to sustain it.

### Note-Books and Records

In a contest in the Patent Office over the granting of a patent to our applicant instead of to others, the history of the conception and development of the invention becomes of vital importance, as it must be related through the testimony of witnesses, which should be as definite and unequivocal as possible, both as to the progressive steps that were made and the times at which they were taken. Often the same sort of history is called for in suits for infringement after the patent is issued.

Dependence upon the unaided memory for good history is a very poor substitute for a written record of events made when they occur; the memory of witnesses should be refreshed and supported by documentary proof. Note-books, well kept by the inventor and by those assisting him, constitute the best of such proof. Therein should be entered daily, on consecutively numbered and dated pages, preferably in ink, a concise but lucid account of experiments made and results obtained, illustrated as far as possible by instructive sketches. The record should be signed or initialed on each page by the inventor or assistant, as the case requires, and is improved, if subscribed to by witnesses

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* The engineer, because of his technical training and experience, is often called upon to read prior publications to find out whether an invention is old. In examining prior patents he will save time and unnecessary labor by confining attention to the description in the specifications, and to the drawings; time and effort spent in considering the claims, for the purpose of determining whether an invention is old, are thrown away.

who may have seen the work carried on; we remember a worthy example to follow in the person of an eminently prolific and successful inventor in mechanical and electrical fields, who never failed to enter in his journal a full record of the experiments and results of the day, together with carefully made sketches of the apparatus used. These records, covering long years of work, call to our mind the methodical system pursued by Faraday in setting down the original notes of his Experimental Researches in Electricity, which were so well kept that they went to press practically without editing.

While the orderly entering of experiments, illustrative sketches, and suggestive ideas on the pages of note-books is, in general, the proper way to preserve a record of efforts leading to possible invention, nevertheless, circumstances almost inevitably lead to the making of fugitive notes and sketches on loose sheets, besides there may be loose drawings and blueprints; such records should be dated, signed or initialed, preferably witnessed, and pasted in scrapbooks for preservation.

### Value of Inventions

It is not often that an approximation to the just value of an invention can be estimated at the time it is made, for there are numerous uncertainties to interefere with the correctness of even a guess. Application must be made for a patent; this may result after expensive proceedings in denial of a patent for want of invention, or grant of one of limited scope, or to another.

If the patent be obtained, large expense may be necessary to develop the invention in practical form which may prove so burdensome, compared with the benefit derived, as to result in commercial failure; or some other invention may supplant, and drive it from the field.

It is, furthermore, almost certain to be infringed, if of marked utility, which may lead to great expense in effort to susta n the patent, with possible failure and thus loss of the capital put into it.

The value of inventions is, therefore, nearly always a matter which cannot be forecast; the value grows or diminishes as determined by many circumstances, and sometimes by chance.

### Inventor's Reward

A good inventor deserves encouragement at proper times, commensurate with the importance of his accomplishments. But ideas in profusion are not inventions; they must be followed up and embodied in concrete form, if invention is to result; and after that must come commercial development and application before a suggestion of value is arrived at that can be accepted with confidence.

The man ambitious to experiment and invent, spurred on by hope of money reward, should not become over-elated at the prolific appearance of his record for ideas, and for things devised by him, or be misled into imagining these things have considerable immediate value, when in fact, this almost always requires time to demonstrate, and at another's expense, unless he can furnish the requisite capital himself. The inventor is necessary to improve the conditions of civilization, but his labor would be of comparatively little avail except for the capitalist. The inventive faculties and money must go hand in hand to get the best results.

## PATENT DEPARTMENT
## GENERAL ELECTRIC COMPANY

### Relation to Inventors

At the outset we disclaimed special qualification to expound the patent situation in all its aspects from the legal point of view, which naturally must be left for patent lawyers to elucidate in respect to its many sides. We have undertaken only to give engineers a general outline of the nature of patents, and for what, and in what manner, they are granted. To such a general presentation of the subject there are bound to be a great number of exceptions, calling for modification of our broad statements to fit specific cases, which would require the writing of a large volume for their consideration, and the experience of a trained lawyer properly to present.

Therefore, although what we have said about patents may be added to our store of interesting information, and may, we hope, prove of utility, it must not cause the engineer to act for himself where supposed inventions of his own are concerned; he should not judge anything for himself in respect to patent laws in such a case, but should consult a good lawyer in every instance, if a single step taken is to be safe.

In connection with the work of the General Electric Company, any man who believes he has made an invention should, without delay, submit to its Patent Department a clear description of his achievement, and an illustration of it, if possible. This is most important as the first step toward protecting an invention in the interest of the inventor, as well as that of the Company.

He should take special pains to insure that the *real nature* of his invention is understood by the Department; this has sometimes not been done. Reference to this important matter was made, Aug. 1, 1911, by Mr. A. G. Davis, Head of the Patent Department, in a communication forming part of Circular Letter A-549, from which we quote as follows:

> "There have been a number of cases in which patents taken out by the General Electric Company have failed fully to protect the real invention, due to the imperfect communication of the invention to the Patent Department or to the imperfect understanding of the invention by the particular attorney who wrote the case. Inventors are most earnestly requested to take pains to read over drafts of the patent applications sent to them with the utmost care, to be sure that their whole invention in all its aspects is therein fully and clearly described, and in general to make any suggestions which occur to them; in other words, each engineer should try to treat the matter just as he would, if the patent in question, when issued, were to be his own personal property.

It is important that no delay occur in submitting the invention to the Patent Department, because should there be delay, another may independently invent the same thing, and when both parties submit descriptions of the invention, the question as to which invented it first must be determined, since the law permits a patent only to one. This has more than once proved a difficult matter to ascertain, particularly when there has been laxity in keeping dated records, and the memory had practically to be relied upon to supply the information.

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# ALTERNATOR SHORT CIRCUITS

By Cassius M. Davis

Railway Engineering Department, General Electric Company

It is of great importance that the operators of electrical machinery should understand the underlying fundamentals of short circuit phenomena. The author has written a most instructive article on the subject. After defining the difference between the armature reaction and armature reactance, he gives an excellent description of the "mechanism" of alternator short circuit, which is accompanied with diagrams. The phenomena attending the building up of the armature current under a short circuit are analyized in detail and the behavior of the armature voltage described. The attendant changes in both the field current and field voltage are cited and Helmholtz's law, as applied to the growth and decay of currents when a short circuit occurs, is stated. Tests of various alternators are given which show that the theoretical calculations correspond closely to the observed facts.—Editor.

## Introductory

The question of short circuit currents on generating and transmission systems has received a great deal of consideration on the part of operating companies during the last few years, owing to the fact that as their systems increased in output accidental short circuits became far more disastrous in their effects than before. When it is recalled that turbo alternators that were built up to a few years ago could *momentarily* give from 10 to 30 or 40 times their rated current when suddenly short circuited, and further, when we remember the mechanical forces exerted on an armature coil, on a busbar, or on a cable increase as the *square* of the current, we easily understand why machines were ruined, buses torn from their supports, and other serious damage was wrought to apparatus and property. Thus, if a generating system of 50,000 kv-a. connected load, which could momentarily yield twenty times normal current, was short circuited, the resulting power would amount to 1,000,000 kv-a., a formidable figure for the central station man to contemplate.

It is for this reason, then, that the subject has been one of particular interest to the operator as well as the manufacturer. In spite of all this activity, comparatively little has been written concerning the general "mechanism" of short circuits. It will, therefore, be the purpose of this article to give a very general discussion of short circuit phenomena, confining the discussion to alternator short circuits.

Questions of design are omitted here as being too important to be introduced in a general survey.

## Armature Reaction and Armature Reactance

In the discussion of alternator short circuits a very careful distinction must be drawn between armature *reaction* and armature *reactance*. Both involve magnetic flux and in this respect they are similar, but in all other respects they differ materially. Armature reactance is a constant of the armature circuit just as the reactance of a transmission line is a constant of the circuit; it is directly dependent upon the inductance and has nothing to do with the amount of current. Armature reaction, on the other hand, is not a constant of the armature circuit in the above sense, but depends on the combined magnetic circuits of the field and armature, and increases or decreases as the armature current increases or decreases. It is a *flux* and exists only when there is current in the armature conductors, while armature reactance exists whether there is current in the conductors or not. The flux of armature reactance interlinks only with the armature turns, thus passing in a large measure along the air gap at right angles to the shaft; while the flux of armature reaction interlinks both with the armature turns and the field turns, crossing the air gap perpendicularly to the pole face and traversing in general the path of the field flux. Fig. 1 is a diagram illustrating the two flux paths, when the armature is supplying a non-inductive load. The drawn lines represent the flux of armature reactance and the dotted lines the flux of armature reaction. The diagram represents the flux from only one phase of a three-phase machine. At the time of a dead short circuit, the load is almost entirely inductive and this condition is shown in Fig. 2. Here it is seen that the flux of armature reaction directly opposes the field flux. It should be noticed that the reluctance of the magnetic circuits for both fluxes depends on the position of the field poles relative to that of the armature coils.

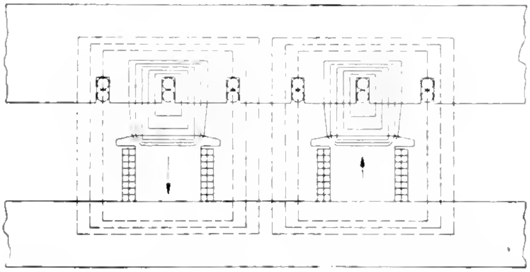

Fig. 1. Diagram Showing Paths of the Fluxes due to armature reactance and reaction where the alternator carries non-inductive load

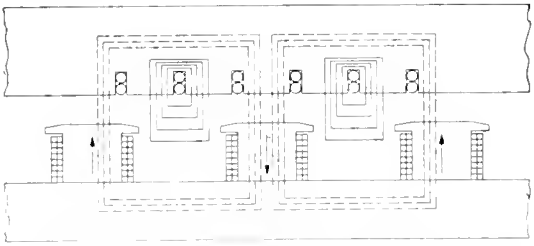

Fig. 2. Diagram Showing Paths of the Armature Reactance and Reaction Fluxes as affected by a short circuit on the alternator

### Description of an Alternator Short Circuit

Consider what takes place at the time of a short circuit:

*First*, the alternator is running (either at no load or full load near unity power-factor) with the field and armature in the relative position shown in Fig. 1.

*Second*, a short circuit takes place and the armature current rises to several times its normal full load value, its instantaneous value being determined by the "nominal generated e.m.f." and the reactance* which is effective in the circuit. At the instant before the circuit is closed the field flux predominates, but as the short circuit current comes on the flux of armature reaction builds up and the relative position of the field and armature becomes as shown in Fig. 2, the flux of armature reaction opposing the field flux.

A current cannot exist in a circuit without simultaneously producing a flux interlinking with that circuit and proportional to the current. The field flux and the flux of armature reaction are of about the same magnitude and opposed to each other. It, therefore, follows that practically all the flux which exists must pass around the armature conductors and crowd in between the armature and the pole face; thus it is the flux of armature self-induction. From this, it can be seen that the initial rush of current is limited only by the self-inductive reactance of the armature circuit.

*Third*, the condition described above cannot exist indefinitely—it is not a condition of stable equilibrium. The field flux, having a certain density before the short circuit when no flux of armature reaction exists or when it has a density corresponding to the load, is now reduced by the opposing flux of armature reaction. Ultimately the resultant flux which issues from the pole pieces, and which is the flux generating voltage in the armature conductors, is very much smaller than that which existed previous to the short circuit.

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*"Impedance" is of course the proper word to use here, but since the resistance of the circuit is usually quite small in comparison with the reactance it is customary to neglect it.

This change of field flux cannot take place instantaneously, because any flux represents stored energy, and even though the armature current rises to many times its normal in the first half cycle the flux of armature reaction which accompanies it cannot reduce the field flux until after the elapse of a relatively long time.

Fig. 3. Curve Illustrating the Building Up of Single-Phase Alternating Current from zero to a permanent value

Some idea of the amount of energy stored in the field flux may be obtained by considering the flash and its attendant heat when the field switch of an alternator is suddenly opened. If the field circuit were non-inductive, that is, if the field current produced no flux, there would be no flash.

The rapidity with which the field flux is reduced by the armature reaction depends upon how quickly the energy of the field can be changed into some other form of energy and conducted away. It is first changed into electrical energy by virtue of the interlinkage of the field conductors with the varying flux and thence into heat in the resistance of the field circuit.

When the field flux is reduced, and with it the resultant flux, the voltage generated in the armature conductors is decreased and hence the short circuit current diminishes; the decay of current taking place with the same speed as the decay of the field flux.

The final result is that the field flux and the opposing flux of armature reaction reach a condition of equilibrium, and the short circuit current reaches a permanent value which is determined by the "synchronous reactance" of the alternator. This "reactance," it will be recalled, is a combination of armature reaction and armature reactance.

This discussion indicates that the duration of a short circuit current is dependent upon the resistance in the field circuit—the greater the resistance the faster the current dies down to its permanent value. Thus it is advantageous to so design the exciter and field circuits that there is always a fair amount of the field rheostat in circuit.

To recapitulate, the mechanism of an alternator short circuit may now be stated in a few words: The instantaneous current rush is limited only by the inductive reactance of the armature circuit. The armature reaction gradually reduces the field flux and with it the generated voltage and current until a permanent condition is reached—that of the sustained short circuit current.

This general discussion applies to both polyphase and single-phase short circuits. The only difference to be noted is the well known double frequency pulsation of the armature reaction during a single-phase short circuit, which makes itself manifest in the field circuit, as will be seen later. The armature reaction under polyphase short circuit in general is not pulsating except during the first few cycles. The reason for this will be given in another paragraph.

### Armature Current

A short circuit current building up on the armature circuit follows the general laws governing the building up of an alternating current in any circuit. In order to make the discussion complete a brief description of the phenomenon is included.

Fig. 3 represents an alternating current starting from zero and building up to a permanent value. It must be remembered that when a current, either direct or alternating, starts through a circuit, or when it changes from one value to another, magnetic energy must be stored around the conductors, or its amount must be changed. This storage or change does not take place instantly. Hence during the first few moments the change from one current value to another takes place gradually while the magnetic energy approaches its new value. In the figure, the permanent or final value is $i_1^1$, but the actual value, $i_1$, gradually approaches $i_1^1$. The curve $i_1^0$ is called the "transient." This last quantity is the difference between $i_1^1$ and $i_1$, and the rate at which it approaches zero depends on the resistance and reactance of the circuit.

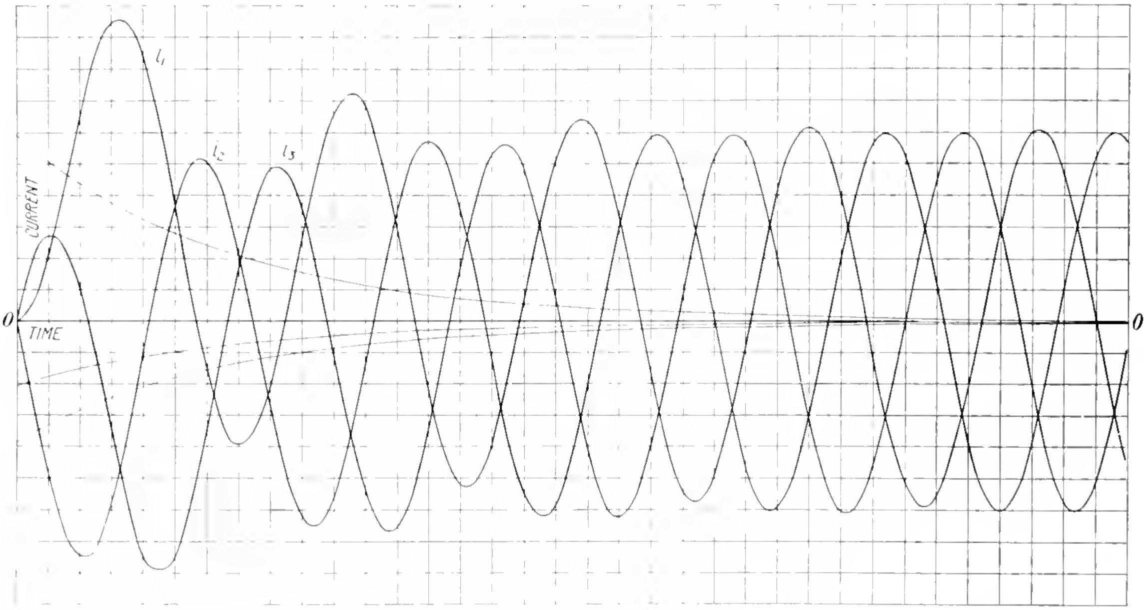

Fig. 4. Curve Illustrating the Building Up of a Three-Phase Alternating Current from zero to a permanent value

If the current starts when $i_1^1$ should be zero, $i_1^0$ disappears and the actual current and the permanent current are coincident. This constitutes the only exception to the statement made in the last paragraph. Really, however, it is no exception at all, since when the actual current and the permanent current are both zero at the same instant there is no change of current and hence no change of stored energy.

The curve $i_1$ is symmetrical with respect to $i_1^0$, so that if an oscillogram is taken of the armature current at the time of a short circuit, the transient $i_1^0$ can be drawn and from its shape (the resistance of the circuit being known) the armature reactance can be calculated.

A three-phase alternating current building up in a circuit is represented in Fig. 4. Here each of the three currents has its own transient, which may be derived in the same manner as was the transient of the single-phase current in Fig. 3.

In an alternator short circuit the armature current does not approach a constant permanent value, but instead approaches a gradually decreasing value, due to the gradual reduction of the field flux by the flux of armature reaction. The armature current during short circuit, theoretically, looks like Fig. 5, which represents the currents in the armature windings of a three-phase alternator.

A glance at Figs. 3 and 4 shows that it is difficult to state just what value a short circuit current has, due to the fact that the

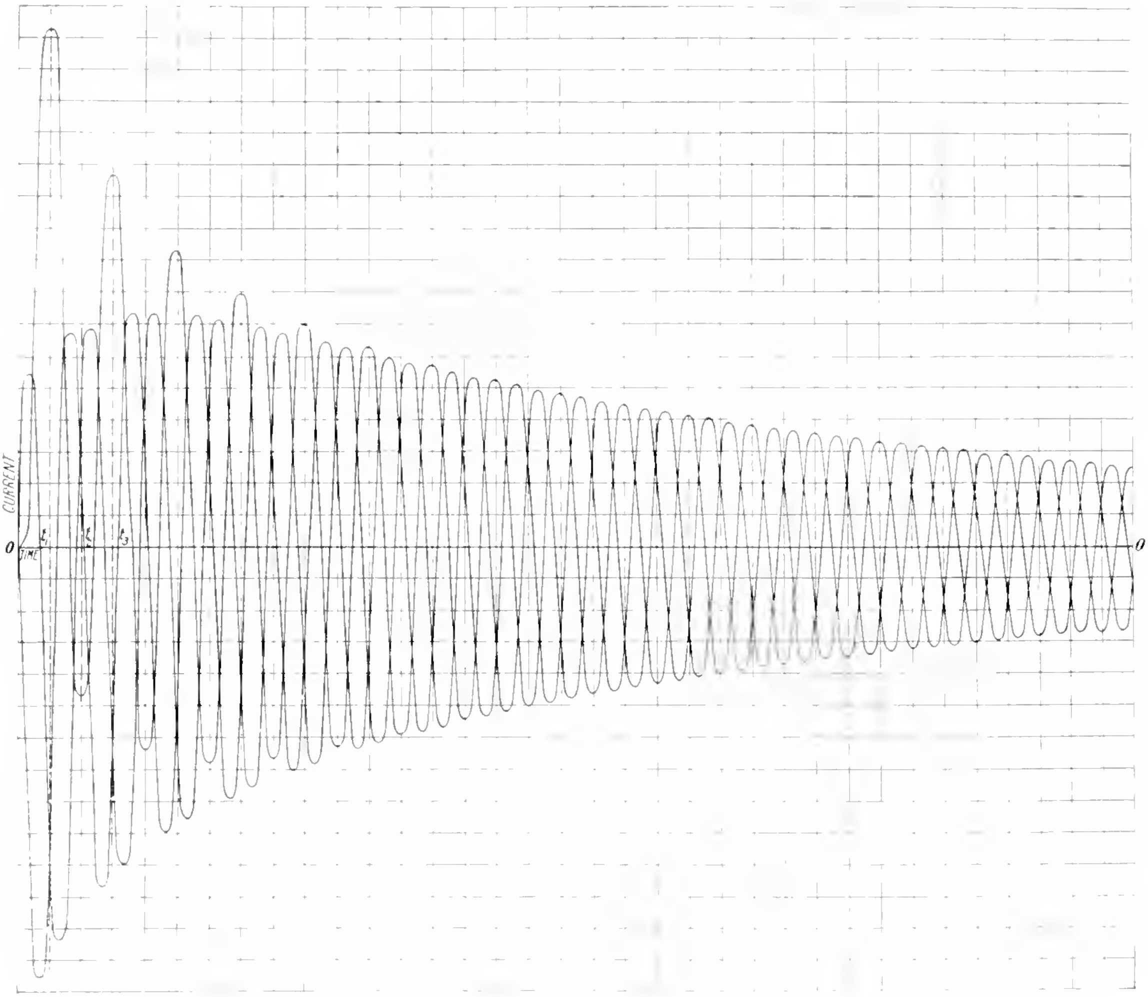

Fig. 5. Curve Illustrating the Growth and Subsequent Decrease of the short circuit current in a three-phase alternator

currents are not symmetrical. One quantity, which is definite whether the current wave is symmetrical or not, is the total amplitude. Suppose Fig. 6 represents an oscillogram of the short circuit current in one phase of an alternator; then the initial current rush may be determined as follows:

Through the positive and negative crests draw the two light lines, and at the first crest measure the total amplitude $a$. This has the value

$$a = 2\,I\sqrt{2}$$

where $I$ is the effective value of the current. Then

$$I = \frac{a}{2\sqrt{2}} \doteq 0.353\,a$$

is the effective value of the current at the first crest and is a true measure of the current. Theoretically, $a$ should be measured at the instant the short circuit begins, but since the actual current is zero at this time, the theoretical amplitude is of no value.

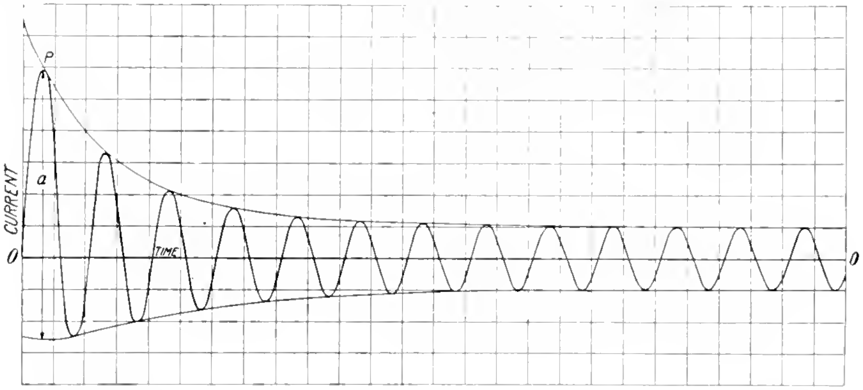

Fig. 6. Curve Representing an Oscillogram of the short circuit current in one phase of a three-phase alternator

This argument assumes a sinusoidal wave shape for the current. This usually is not the case, owing to saturation of the iron at high armature currents. A more accurate method would consist in establishing the medial line (armature transient), and with this as zero determine the root mean square value of the wave.

The actual instantaneous value of the current at the first crest, $P$, may range all the way from $I\sqrt{2}$ to twice this value, depending upon the point of the wave at which the short circuit appears. It is $I\sqrt{2}$ when the short circuit begins at the instant when the final current should be zero; it is $2\,I\sqrt{2}$ when the short circuit begins at the instant when the final current should be maximum. Since the mechanical forces which the armature conductors must withstand are proportional to the square of the *instantaneous* values of the current, the quantity $2\,I\sqrt{2}$ is the one which is the controlling feature in the design of machines to withstand short circuit currents.

The armature current during a single-phase short circuit does not differ from that of a polyphase short circuit, except perhaps as regards magnitude. Experiment shows no definite rule can be given for its magnitude. Some machines have initial single-phase current rushes of about the same magnitude as the polyphase currents, some greater, and some less.

### Armature Voltage

If a polyphase alternator is short circuited on all its phases at the terminals of the machine, the terminal voltage instantly falls to zero. The "nominal generated e.m.f." then assumes a value corresponding to the reactance of the armature circuit and follows the same shape as the armature current. If a polyphase machine is short circuited on one phase only, the voltage of the short circuited phase follows the armature current, while the voltage of the other phases becomes distorted, due to the pulsating armature reaction and to the mutual inductance between the coils of the various phases. Under any condition of short circuit the armature voltage does not rise to more than double its normal value and hence it is seldom a factor which has to be taken into account. Its accurate determination is very difficult and owing to its relatively small importance it has not been very thoroughly investigated.

**Field Current**

There are two effects noticeable upon the field current:

*First.* While the flux of armature reaction builds up it is changing (reducing) the field flux; and wherever a change of flux is impressed upon a circuit it induces an e.m.f. in that circuit which in turn forces a current through the circuit. Consequently, by Lenz's law, when the armature reaction reduces the field flux an e.m.f. is induced in such a direction as to produce a current which tends to maintain the field flux; in other words, the field current rises. The amount it rises depends on how well the armature and field magnetic circuits are interlinked.

As the armature reaction first comes into play it reduces the field flux most rapidly. As it approaches a constant value this reduction becomes less rapid. Hence the field current rises to its maximum value during the first part of the short circuit and then gradually returns again to its normal value.

*Second.* A study of Fig. 5 will show that the armature reaction during the first few cycles cannot be constant in intensity. The instantaneous currents at the time $t_1$ are all high, while at $t_2$ they are all low, and at $t_3$ they are again high. Since the armature reaction is proportional to the armature current, it follows that until the armature currents become symmetrical the armature reaction is alternately large and small. The armature reaction, then, is pulsating with a gradually decreasing amplitude. This induces in the field winding an oscillating current.

The combination of the two effects noted above results in a field current is shown in Fig. 7, the oscillating current being superimposed on the transient field current. The oscillatory part of the current lasts as long as the armature currents remain unsymmetrical; in other words, as long as does the transient due to armature reactance. The transient value of the field current, the shape of which depends on the reactance and resistance of the field circuit, is shown by the line $i^0i$. It immediately jumps up to the value $i^0$ when the short circuit takes place and then gradually dies down to its original value $i_0$ after the armature reaction has reached its full value and the condition of sustained short circuit is established.

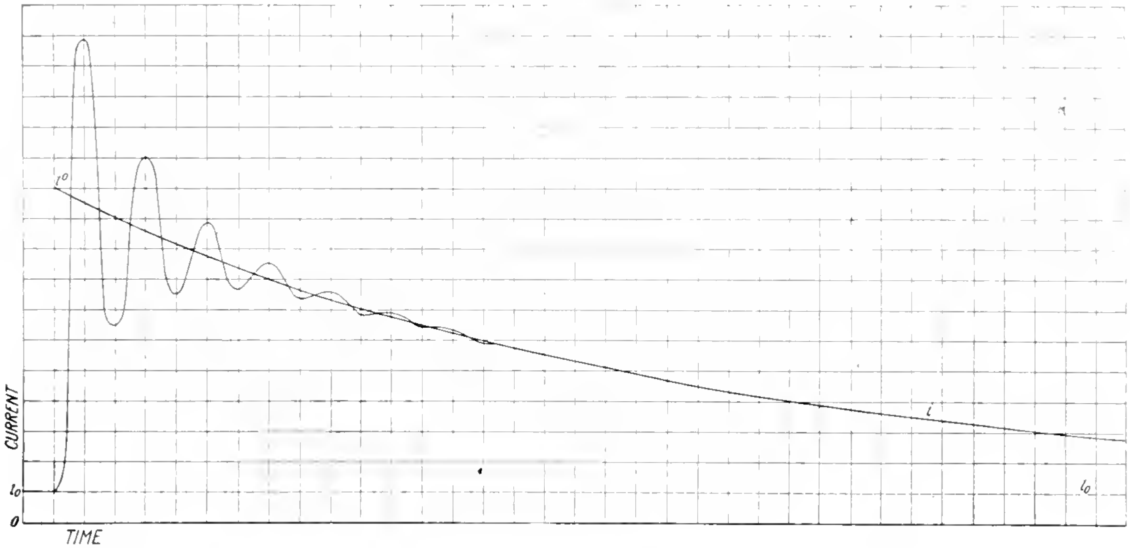

Fig. 7. Curve Illustrating the Growth and Subsequent Decrease to Normal in the value of field current of an alternator when short circuited

It is well understood that a single-phase current in the armature circuit causes a pulsating armature reaction, and furthermore this reaction is of double frequency. The effect upon the field current during a single-phase short circuit is to superimpose a second oscillatory current of double frequency which is alternately in phase with the fundamental oscillation and 180 degrees out of phase. This gives a field current with alternate high and low peaks which gradually approach each other in amplitude until in the sustained condition the field current consists of pulsations of equal amplitude at double the machine frequency.

### Field Voltage

During normal operation the exciter supplies an e.m.f. to the field circuit, but at the time of short circuit the field coils themselves become a source of e.m.f. Although the field current induced by this e.m.f. is in the same direction as that supplied by the exciter, it produces a voltage at the field terminals in the opposite direction. So the net result is a tendency to reverse the voltage at the slip rings. How completely the reversal takes place depends upon the value to which the current rises—thus on the mutual inductance between the field and armature circuits, and on the resistance and reactance in the exciter circuit.

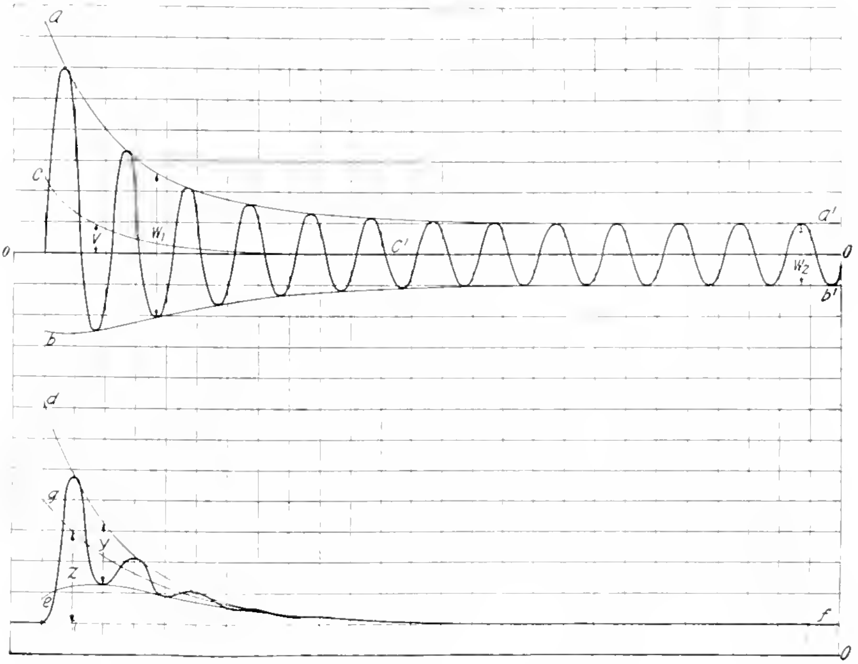

Fig. 8. Curve Illustrating Method for determining the armature and field transients from the armature and the field current

The discussion under *Field Current* relative to single-phase short circuits may be applied here to explain the variations in field voltage. In general, it may be said the voltage at the terminals of the field bears a reciprocal relation to the field current during a short circuit. Thus a single-phase short circuit produces a general depression of the field voltage, from which it slowly recovers in a series of alternate low and high peaks gradually approaching each other in amplitude until a steady double frequency pulsating sustained voltage is reached.

### Law Governing the Growth and Decay of Currents

The building up of the armature current, the decay of the oscillatory part of the field current, the decay of the average field flux (which corresponds to $i^0i$ in Fig. 7), and consequently the decay of the armature current, all follow Helmholtz's law. This law is expressed mathematically by an equation of the form:

$$x = X\epsilon^{-\frac{r}{L}t}$$

or

$$x = X(1-\epsilon^{-\frac{r}{L}t})$$

The first equation applies to an increasing quantity, while the second applies to a decreasing quantity. In these $x$ may be the current or the flux at any instant of time $t$; $X$ is the maximum value to which $x$ ultimately rises, or from which it begins to fall; and $r$ the resistance and $L$ the inductance of the circuit. The equations apply fundamentally to continuous current circuits, but they may be equally well applied to circuits in which oscillatory or transient alternating currents flow. In this latter case they represent the change in amplitude of the waves with time.

From what has already been said it is evident that the transients of both the armature and the field of an alternator may be determined from both armature current and the field current. Reference to Fig. 8 will make this clear.

*From the Armature Current.* Draw lines $aa^1$ and $bb^1$ through the positive and negative peaks respectively. Then draw $cc^1$, bisecting the vertical distance between the two first lines at every point. The ordinates $v$ determine the armature transient, and the ordinates $(w_1 - w_2)$ the field transient. Then $w_2$ is the sustained current and is the zero value for the field transient.

*From the Field Current.* Draw the lines $df$ and $ef$ through the maximum and minimum points. Then draw $gf$ bisecting these two lines. The ordinates $y$ determine the armature transient, and the ordinates $z$ the field.

The values of $v$, $w$, $y$ and $z$, measured at corresponding times $t$ may be now substituted in the formulae given above, and, knowing the resistance of the armature and field circuits, the inductance $L$ can be found, from which the reactance at once follows.

The problem usually appears as outlined above, the reactance being the quantity desired. This arises owing to the difficulty encountered in making satisfactory measurements of the reactance of either the armature or field.

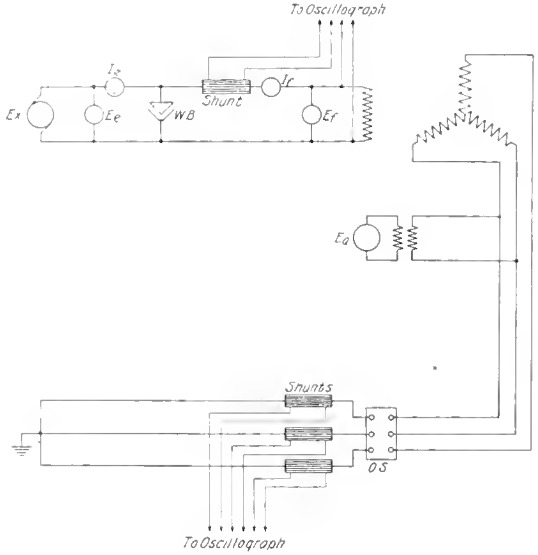

Fig. 9. Diagram of the Connections used in making the short circuit tests used on an alternator

### Tests

Some time ago a comprehensive series of tests was made to determine the characteristics of various alternators and to see how closely they corresponded to theoretical calculations. A short account of the tests may prove of interest in connection with the foregoing.

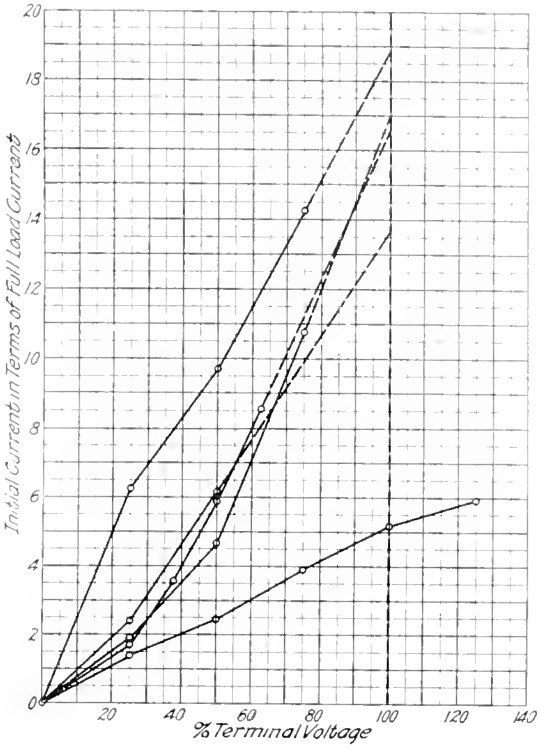

Fig. 10. Curves Showing the Relation between open circuit voltage and initial armature short circuit current of several different alternators

The general scheme of connections is shown in Fig. 9, which is self-explanatory. From previous experience current transformers were found unsuitable for the measurement of transient alternating currents due to the fact that, being inductive apparatus, they had transient characteristics of their own, the effects of which were added to the transient characteristics of the armature circuit. Therefore, direct current ammeter shunts were used as shown in the figure. The water box across the exciter armature was used to eliminate the effect of the unknown reactance of the exciter. The current through it was always several times the alternator field current. Thus, in effect, the alternator was excited by the non-inductive drop across the water box.

Two oscillographs were used, one recording the armature characteristics and the other the field. The two oscillograms taken at each test were easily correlated as to time and speed, since the instant at which the short circuit starts is very sharply defined in both the field current and voltage. In some respects it would have been better if one phase of the armature current had been recorded on the same film with the field characteristics, but for matters of convenience it was thought more desirable to proceed as outlined above.

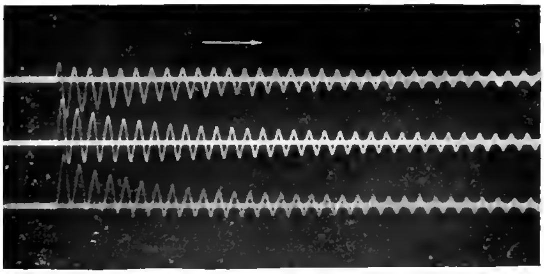

Fig. 11. Polyphase Short Circuit of a 9375-kv-a. turbine-generator at one-half voltage, showing the three armature currents

Previous to each test instrument readings were made of exciter current and voltage, alternator field current and voltage, and alternator armature voltage. Then the oil switch was closed, throwing on the short circuit.

On single-phase short circuits the voltages of the two open phases were recorded in place of the other two armature currents.

With this general arrangement tests were made on several sizes and types of machines at various voltages and under many external conditions of armature and field circuits. In all, some 360 oscillograms were taken which furnish a wealth of data on the subject.

For the purposes of this article it will be possible to give only a brief outline of some of the more interesting features resulting from these tests.

### Agreement Between Theoretical and Actual Characteristics

In general, the tests results agree very closely with their calculated values and perhaps remarkably so in face of the fact that an alternator represents about as complicated a network of interlinked electric and magnetic circuits as can be found.

One of the first assumptions made in connection with alternator short circuits is to the effect that the instantaneous short circuit current is directly proportional to the terminal voltage which exists immediately previous to the short circuit; that, for instance the current at full voltage is four times the current at one quarter voltage, or twice that at one half voltage. Roughly this is true but a glance at Fig. 10 shows the assumption cannot be relied upon. In fact experience shows a tendency toward disproportionately higher currents at full voltage than at lower voltages. A possible explanation of this variation is found when we consider that the armature reactance depends in part on a magnetic circuit which includes the field pole faces, and thus at different field excitations various parts of the pole face assume different degrees of saturation. Therefore, the magnetic constants of the armature circuit change with field excitation and hence with the terminal voltage. It also follows as a consequence that the construction and shape of the pole face, the shape of the armature teeth, the depth of the armature winding in the slots, and various other points have much to do with this particular characteristic.

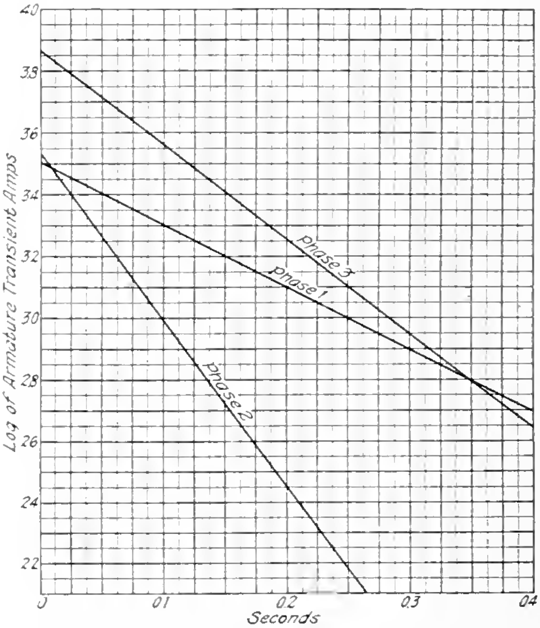

Fig. 12. Curves Showing Unequal Rates of Decay of transients in the three phases at the time of a polyphase short circuit

All the above is apart from the question of wave shape. For instance, suppose the wave at the lower voltages had a peaked crest and at the higher voltages had a flattened crest, then, measuring the total amplitude *a*, as previously described, we would obtain a proportionately lower short circuit value at full voltage.

A second assumption usually made provides an equal rate of decay for the armature transient in all phases on a polyphase short circuit. Experiment, however, shows this is not always true. It would appear from a casual glance at Fig. 11 that all three armature currents become symmetrical at the same time, but on closer inspection we see that the middle current becomes symmetrical after about 7 cycles while the lower current is not symmetrical at 10 cycles, and the upper current is still unsymmetrical at 15 cycles. This is even more strikingly shown in Fig. 12 where the logarithm of the armature transient is plotted against time. Here it is readily seen the three phases have very different transients. As a rule it appears that the wave which is least unsymmetrical has the shortest armature transient. It does not always follow, however, that the most unsymmetrical current has the longest transient.

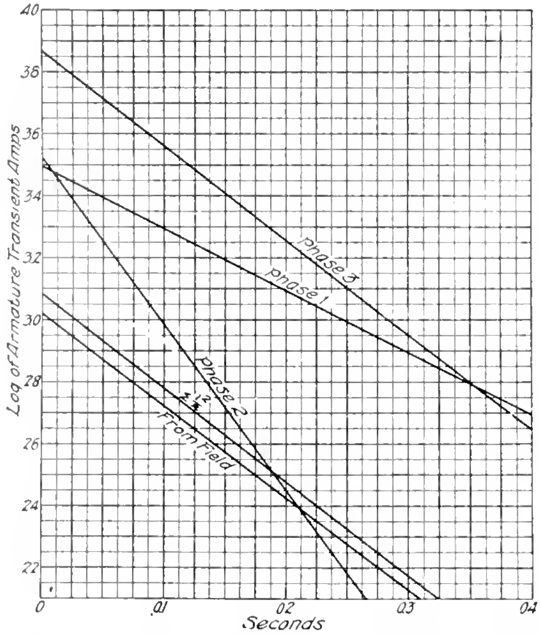

Fig. 13. Curves Showing Armature Transients plotted from each of the phases, from the quantity $\epsilon\frac{i^2}{2}$ and from the field current. Note: The curves $\epsilon\frac{i^2}{2}$ and "From Field" are plotted to scale but their location with respect to the other curves is arbitrary

No satisfactory explanation is yet forthcoming for this peculiarity. It may be due to saturation, or mutual induction between the phase windings, or a combination of these two and other factors. It seems to be taken into proper account by remembering that the magnetic energy stored in the armature circuit is proportional to the square of the current and that the total energy is dissipated in the armature circuit. Thus if $L$ is the inductance of the armature circuit, the stored energy in one phase of a three-phase machine is $w_1 = Li_1^2/2$, in the next $w_2 = Li_2^2/2$ and in the third is $w_3 = Li_3^2/2$ so that the total magnetic energy is $w = \Sigma\, Li^2/2$. It might be supposed the armature transient as determined from the field current would give the true value. But when we consider that the oscillatory portion of the field current lasts as long as the armature reaction is pulsating, which means as long as the armature currents are unsymmetrical, we see the oscillation of the field current would tend to last as long as the longest armature transient, hence is not a true measure of the average armature transient. Fig. 13 shows the five armature transients plotted to the same scale, where it is seen the curves are far from being parallel.

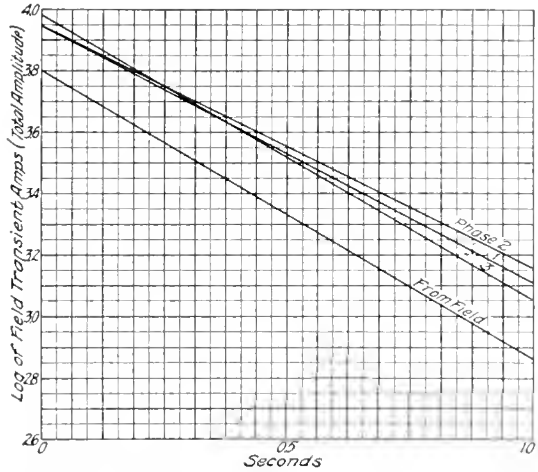

Fig. 14. Curves Showing Field Transients plotted from each of the phases and from the field current. Note: The curve "From Field" is plotted to scale but its location with respect to the other curves is arbitrary

The field transient seems to be more consistent in this respect as is shown in Fig. 14. Here it will be noticed the four curves (three from the armature currents and one from the field current) show fair parallelism.

The following tabulation gives the armature reactance of the 9375 kv-a. turbogenerator from which the oscillograms shown in Fig. 11 were taken.

### ARMATURE REACTANCE AS DERIVED FROM THE VARIOUS ARMATURE TRANSIENTS (See Fig. 11)

Armature reactance from:

| | |
|---|---|
| Upper curve | 1.2 ohms |
| Middle curve | 0.42 ohms |
| Lower curve | 0.79 ohms |
| $\Sigma Li^2/2$ | 0.81 ohms |
| Field oscillation | 0.82 ohms |
| Average current amplitude | 0.78 ohms |

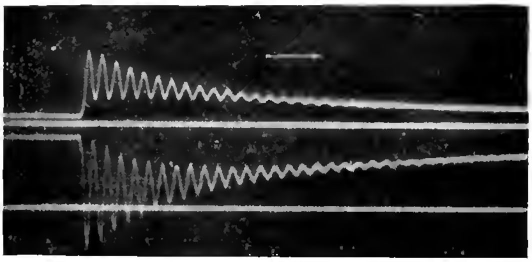

Fig. 15. Polyphase Short Circuit of a 9375-kv-a. turbine-generator at one-fourth voltage, showing the field current (upper curve) and field voltage (lower curve)

It will be noticed the reactance as determined from the measurement of the actual current rush corresponds very closely to the $\Sigma Li^2/2$ value. This fact has been found to generally hold true, which gives added weight to this method of determining the armature reactance.

The results obtained from these tests indicate a very close agreement exists between the actual armature reactance and the reactance as obtained from a measurement of the field oscillation. It is therefore only necessary to take an oscillogram of the field current during a short circuit from which all the characteristics can be calculated. If only approximate values are wanted the field characteristic could be taken at reduced voltage, say 25 per cent and, assuming a lineal armature current relation, the short circuit current at full voltage could very readily be found.

An amortisseur winding on the pole faces seems to have no appreciable effect upon the armature reactance. One small machine was tested both with and without this winding and the currents in both cases were practically identical. Neither does it seem to have any effect on the duration of the field transient as might be expected. There is perhaps a slight tendency to prolong the short circuit when the amortisseur winding is in place but the difference is so small as to be negligible.

## Conclusions

Some of the general conclusions to be derived from the tests may be summarized as follows:

1. The fundamental armature and field characteristics agree closely with those indicated by theory, the greatest deviation being found in the armature transients where the transients of the various phases decay at rates differing from each other, and where they frequently depart from an exponential curve, especially during the first one or two cycles.
2. The real armature reactance corresponds closely to the $\Sigma Li^2/2$ value.
3. The short circuit current is not necessarily proportional to the open circuit voltage just previous to closing the switch.
4. The armature and field transients can be determined from an oscillogram of either the armature or field current.
5. The entire machine characteristics may be calculated and constructed from the field characteristic alone, assuming the synchronous reactance is known. However, the reverse of this is not true. For example, the amplitude of the field oscillation cannot be determined from the armature current without knowing the mutual inductance between the armature and field coils.
6. An amortisseur winding has little or no influence on the reactance of the armature or field.

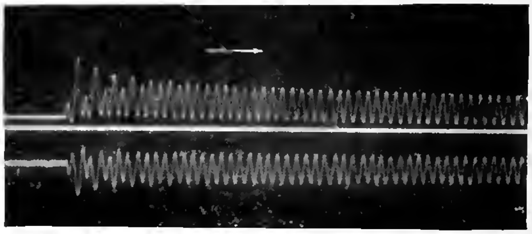

Fig. 16. Single-Phase Short Circuit of an 850-kv-a. synchronous motor at one-fourth voltage, showing the field current (upper curve) and field voltage (lower curve)

# DIAGRAMS OF THE POLYPHASE COMMUTATOR MOTOR

By Dr. H. Meyer-Delius

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This is a continuation of the author's previous article on the theory of the polyphase commutator motor. The shunt motor theory is explained, and the geometrical relations are developed clearly showing this motor to be impracticable. The compound motor is then developed along lines similar to the series and shunt motors. The method of obtaining the characteristics graphically is fully demonstrated and the influence of the variable design constants of the motor is explained. The alternating-current constant-speed motor diagram is developed and its similarity to the normal polyphase induction motor diagram is noted. The article concludes with an explanation of the various methods of speed control for this class of motor.—Editor.

In an article by the writer in the General Electric Review for February, 1914, it was shown how a voltage diagram can be developed for the polyphase commutator motor by separating the stator windings into a compensating winding and a field winding. If the compensator winding neutralizes the armature ampere turns entirely, the transformation e.m.f's. induced by the main field in armature and compensating winding must be equal and opposed, so that they don't appear at the main terminals and must not be considered at all in calculations and diagrams. As with d-c. machines, the only remaining e.m.f's. are the rotation e.m.f. $e_r$ induced in the armature by rotation in the main field and the impedance drop $iZ$ in the conductors carrying the main current. The voltage diagram so obtained is shown again in Fig. 1.

In the previous article we dealt with the series motor; we will now study the shunt motor.

### The Shunt Motor

The connections are shown in Fig. 2 for quarter-phase current; $R$ is the d-c. armature and commutator, $C_1$ and $C_2$ the compensating windings, and $F_1$ and $F_2$ the field windings. In a d-c. machine the field $F_1$ would be excited by the terminal voltage between the terminals $T_1$; but with alternating current, the current in the field winding is 90 deg. lagging behind the exciting voltage, and therefore the field $F_1$ is excited by the voltage of the terminals $T_2$. In this way the phase displacement of 90 deg. is made good and the field $F_1$ is again in phase with the terminal voltage $T_1$.

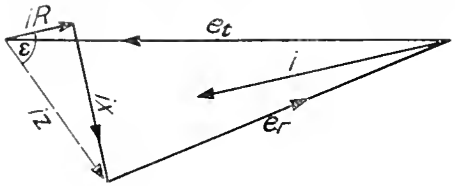


Fig. 1. Voltage Diagram of a Commutator Motor

If the frequency and voltage of the line are constant, the shunt field is also constant in intensity, and just as in a shunt d-c. machine the rotation e.m.f. is proportional only to the speed.

Draw the voltage diagram, Fig. 3.

1. $QE = e_r$ = rotation e.m.f. It is in phase with the terminal e.m.f. $e_t$; its intensity is directly proportional to the speed.

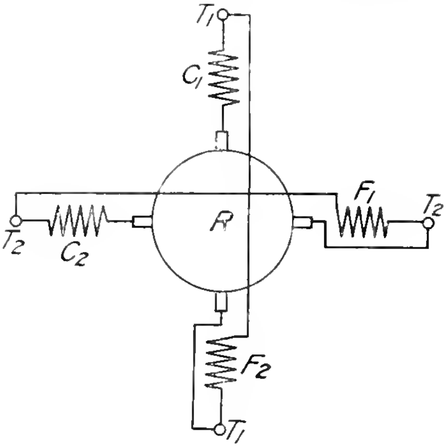


Fig. 2. Connection Diagram of a Shunt Motor

2. $OQ = iZ$ = the impedance drop in the conductors carrying the main current. It is the resultant of the ohmic drop $iR$ and the leakage reactance drop $iX$. As in the series motor, the impedance triangle is of constant shape (corrected commutation assumed); therefore the impedance drop $iZ$ is proportional only to the current and has a constant phase displacement $\epsilon°$ from the current $\left(tan\ \epsilon = \frac{X}{R}\right)$.

At running light the current is zero. Point $Q$ coincides with $O$. For increasing load $Q$ travels from $O$ to $E$. $Q$ coinciding with $E$ indicates standstill, where the rotation e.m.f. $e_r$ is zero.

The diagram is very similar to the voltage diagram of a d-c. motor, Fig. 4. For the plain ohmic drop $iR$ in the d-c. motor we have substituted $iZ$, the impedance drop, since the leakage reactance drop $iX$ must be added. In both motors, if the load increases, the speed will drop; therefore the rotation e.m.f. decreases and the current must grow until its drop is equal to the increased difference between the constant terminal e.m.f. and the decreased rotation e.m.f. But the leakage reactance drop throws the current nearly 90 deg. (really $\epsilon^\circ$) out of phase with the field and the terminal e.m.f. The motor is therefore an extremely poor one, with a constant power-factor of only about 20 per cent for all loads.

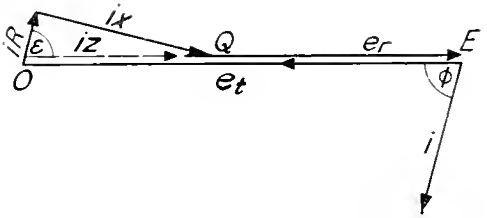


Fig. 3. Voltage Diagram of a Shunt Motor

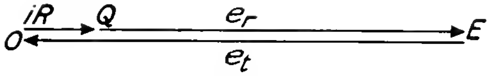


Fig. 4. Voltage Diagram of a D-C. Shunt Motor

These operating conditions may be improved slightly by the connections shown in Fig. 5. The field $F_1$ is excited not only by the terminal e.m.f. $T_2$, but also partly by the other terminal e.m.f. $T_1$. The phase of the resultant field is shifted from the phase of the terminal e.m.f., $T_1$, over an angle which is determined by the ratio of the number of turns of the two exciting windings. This angle, which we will call $\gamma$, is constant for all loads. Since the rotation e.m.f. is in phase with the field, this e.m.f. has a constant phase displacement $\gamma^\circ$ from the terminal e.m.f. Fig. 6 shows the voltage diagram.

For varying load the point, $Q$, of the impedance vector $iZ$ travels on the line $e_r$. It is possible to make the power-factor unity for a certain load; but on departing from that load to either side, the power-factor quickly becomes very low—for lower loads extremely leading, for higher loads extremely lagging. The current is thrown out of phase with the field by the reactance drop $iX$, and the torque diminishes quickly so that the motor breaks down even at slight overloads.

We see that the straight shunt motor is entirely impracticable. In order to make it work it is necessary to compensate the disturbing reactance e.m.f. $iX$ by a series rotation e.m.f. as in the series motor. This leads us to the compound motor.

### The Compound Motor

The compound motor unites the characteristics of the shunt and series motor. The rotation e.m.f. consists of two components:

1. The shunt rotation e.m.f. $= e_{sh}$ with all the properties found in the shunt motor.
2. The series rotation e.m.f. $= e_s$, with all the properties found in the series motor. The series rotation e.m.f. has a constant phase shift, $\beta^\circ$, from the main current, which angle is determined by the phase combination of the exciting winding. As in the series motor, the series rotation e.m.f., $e_s$, has also a constant phase displacement $\delta^\circ = 180 - \epsilon - \beta$ (page 127, General Electric Review, February, 1914) from the impedance drop $iZ$. The intensity is proportional to the main current as well as to the speed of the motor.

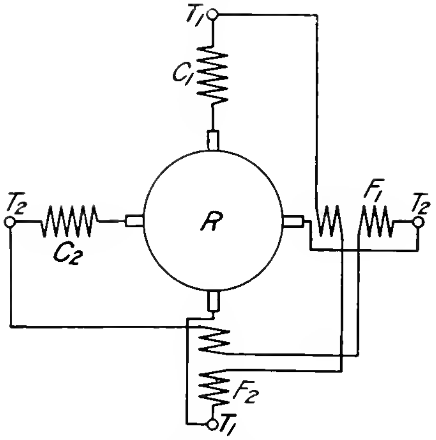


Fig. 5. Connection Diagram of a Shunt Motor with phase combination in exciting winding

We obtain the voltage diagram, Fig. 7:

For a certain load we may have:

$OQ = iZ$ the impedance drop.
$QA = e_s$ the series rotation e.m.f.
$AE = e_{sh}$ the shunt rotation e.m.f.
$EO = e_t$ the terminal e.m.f.
Angle $OQA = \delta =$ constant.
Angle $AEO = \gamma =$ constant.

$OQ^1BEO$ may indicate the voltage diagram for a large load and lower speed. Let us assume, first that the speed for this second load would have remained the same as for the first load.

$EQ = e_{sh}$, and $Q^1A^1 = e_r^1$ are the two rotation e.m.f's., still at the higher speed $n$. The speed for the larger load may be $n^1$. For the actual lower speed $n^1$, the above two rotation e.m.f's must be reduced in the ratio of the speeds $\frac{n^1}{n}$.

Therefore $\frac{Q^1B}{Q^1A^1} = \frac{BE}{AE} = \frac{n^1}{n}$.

1. Thus the lines $AA^1$ and $Q^1E$ are parallel. Further we find $\triangle\, OQA$ similar to $\triangle\, OQ^1A^1$ since (a) angle $\delta$ is the same in both.

(b) $\frac{OQ}{QA} = \frac{OQ^1}{Q^1A^1}$

Therefore angle $AOQ$ = angle $A^1OQ^1 = \alpha$.

If the end of the impedance vector $OQ$ moves on any curve from $Q$ to $Q^1$, the end of the vector $OA$ moves on a similar curve from $A$ to $A^1$. For all points the two corresponding vectors $OQ$ and $OA$ form at $O$ the constant angle $\alpha$. $QQ^1$ and $AA^1$ are also corresponding vectors, since they connect corresponding points.

2. Thus $QQ^1$ and $AA^1$ are shifted from each other over the same angle $\alpha$. Under (1) we found $Q^1E$ must be parallel to $AA^1$.

Therefore the angle $QQ^1E = 180 - \alpha$.

The load point $Q^1$ was an entirely arbitrary point. For any other load point we find the same condition, that angle $QQ^1E = 180 - \alpha$. Thus the locus on which all points $Q^1$ must lie is the circle in which $QE$ as chord subtends angle $\alpha$. This circle is the desired locus for the end point of the impedance vector.

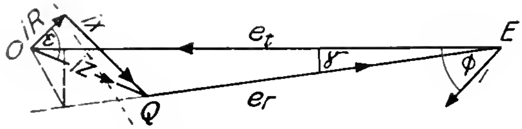


Fig. 6. Voltage Diagram of a Shunt Motor with phase combination in exciting winding

In a similar way as for the series motor, we can draw in this circle diagram lines for the power-factor, input, output, torque, speed and efficiency. These lines are drawn in Fig. 8. $L_1$ is the input line through $O$ forming angle $90 - \epsilon$ with $OE$, the standstill current. At right angles to $L_1$ is the power-factor line $L\phi$, also through $O$. The output line $L_2$ connects the running light point $Q_0$ with the standstill point $E$. The torque line $L_3$ connects the running light piont $Q_0$ with $Q_\infty$, the point for infinite speed. For both points the torque is zero. The latter point, $Q_\infty$, is of special interest.

To study it we draw the line $Q_\infty U_1 U_2$, at right angles to $OU$ (Fig. 9). The machine runs as generator, input and output being interchanged. $Q_\infty U_2$, the mechanical input, is larger than the electrical output, $Q_\infty U_1$, delivered to the line. We know that the torque is zero, and in order that at the same time the mechanical energy may be a finite amount, the speed must be infinitely large. The shunt and series rotation e.m.f's. are therefore infinitely large too. Thus they must be parallel and bucking each other. The angle between the impedance vector, $OQ_\infty$, and the series rotation e.m.f., $e_{r\infty}$, is the constant angle $\delta$. From the fact that $e_{r\infty}$ is parallel to $e_{sh}$, the angle $Q_\infty FE$ must also equal $\delta$. Point F must lie on the circle, because for the impedance vector $OF$ the series rotation e.m.f., which always forms angle $\delta$ with the impedance vector, must again be in phase with the shunt rotation e.m.f. We can find $Q_\infty$ in the following way:

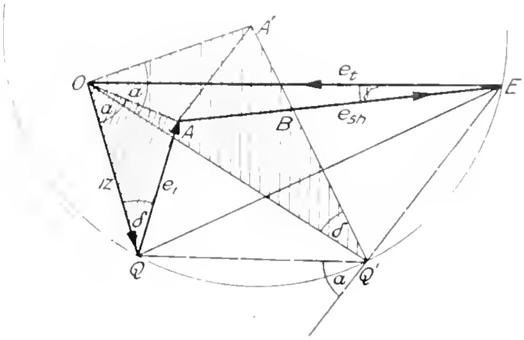


Fig. 7. Circle Diagram of a Compound Motor

Prolong the shunt rotation e.m.f. until it intersects the circle at $F$. Draw the line $FO$ until it intersects the circle at $Q_\infty$. The torque line $L_3$ is found by connecting $Q_\infty$ with $Q_0$.

For point $Q_\infty$, the shunt and series field neutralize each other in their effects. The shunt and series rotation e.m.f's. and the shunt and series fields are opposed and equal. If the fields are generated in the same iron, the total flux is zero. The current is therefore so large as to excite a series field equal to the constant shunt field. Thus we can calculate the current $OQ_\infty$ in the following way:

For normal speed and load let the current be $i$, the shunt rotation e.m.f. $e_{sh}$, and the series rotation e.m.f. $e_s$; then $OQ_\infty = i \times \frac{e_{sh}}{e_s}$.

The speed line $L_s$ is parallel to the torque line through a convenient point $P$ on the output line $L_2$ (see Fig. 8). The line $Q_eQ$ cuts off the length $PN$, which is proportional to the speed. For a load point $Q$, the current is $OQ$ with a phase displacement of angle $QOL\phi$. Draw a line through $Q$ perpendicular to $OC$ ($C$ the center of the circle). $QL_1$ represents the input, $QL_2$ the output, and $QL_3$ the torque. Draw $Q_eQN$. $NP$ indicates the speed. The efficiency may be indicated in the same way as for the series motor.

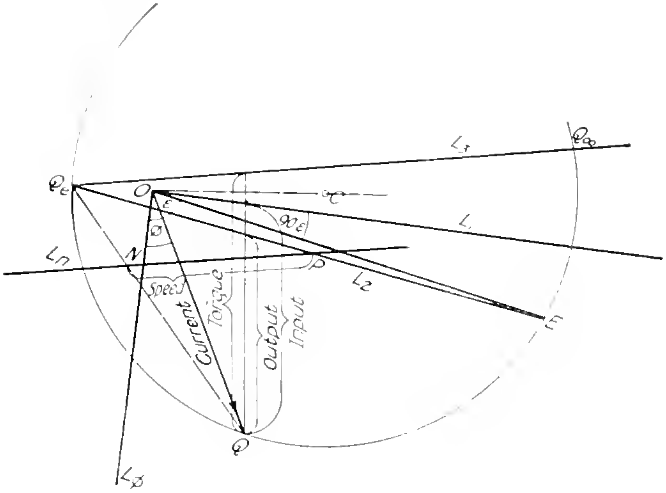


Fig. 8. Complete Diagram for a Compound Motor

To complete the diagram we must add to all currents the constant magnetizing current for the shunt field. This is not a plain wattless current, as it has a small watt component due to the $i^2R$ losses in the exciting winding and the core loss of the field. The magnetizing current may be $im = MO$, with a phase shift of $\phi m$ degrees from the terminal e.m.f. or the power-factor line $L\phi$ (see Fig. 10.) For the load point $Q$ the main current is $OQ$ and the total line current $MQ$. Power-factor line $L\phi$ and input line $L_1$ must be shifted from $O$ to $M$.

### Influence of the Different Constants of the Motor

1. *Shunt excitation.*

If the shunt field is in phase with the terminal e.m.f. ($\gamma = 0$), the running light main current is zero, just as was found for the plain shunt motor of Figs. 2 and 3. The circle therefore goes through $O$, and the strength of the field determines the running light speed exactly as in a d-c. machine. For a stronger field the speed is lower, and for a weaker field the speed is higher.

If the shunt field is given in a phase different from the phase of the terminal e.m.f. ($\gamma_0$), the main current at running light cannot be zero, since the shunt rotation e.m.f. and the terminal e.m.f. can never balance each other, as they are out of phase. A current must flow to close the voltage diagram with its impedance drop and series rotation e.m.f. Since the motor does not do any work at running light (losses neglected), the running light current is a wattless current. Depending upon the sense in which the shunt field is shifted from the terminal e.m.f., the wattless current may be lagging or leading. The latter case is the more interesting one, because it is possible in this way to compensate the magnetizing current of the shunt field, so that even at running light the power-factor can be made unity.

2. *Series excitation.*

It has the same influence on the operating conditions as in the series motor.

Fig. 11 shows the impedance drop $OQ$ and the series rotation e.m.f., $e_1 = QA$. We may again separate two components of the series excitation:

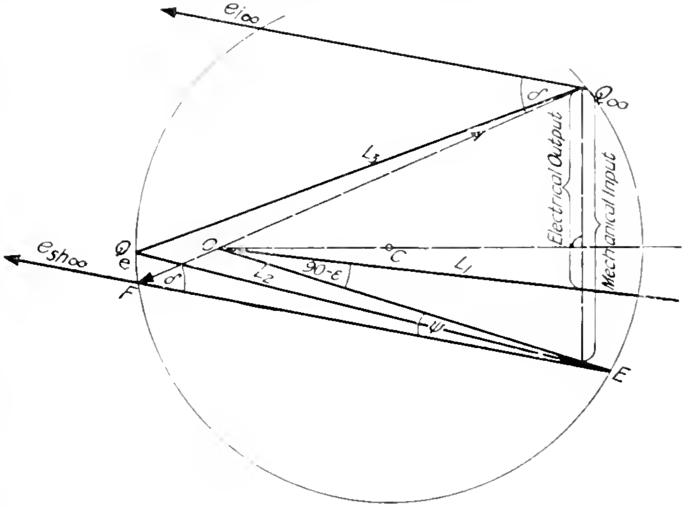


Fig. 9. The Point for the Infinite Speed

(a) $BA$ in phase with main current and its ohmic drop and

(b) $QB$ at right angles or in phase with the reactance drop $iX$.

The first, the watt component $BA$, acts exactly in the same way as the compound excitation in a d-c. motor. It causes a larger speed drop from no load to full load than the ohmic drop alone would do in a plain shunt motor.

The second, the wattless component $QB$, balances more or less the reactance drop $iX$ and checks its bad influence upon the power-factor and speed torque characteristic, found in the plain a-c. shunt motor. If this wattless component $QB$ were exactly equal to the reactance drop $iX$ for all speeds, there would be no difference between the a-c. and d-c. motor. The motor would have unity power-factor for all loads, as do all d-c. motors, and the same speed torque characteristic, efficiency, etc. Since in a shunt motor the speed variation for normal loads is only small, it would seem that these ideal conditions would take place almost exactly. But the reactance drop $iX$ is large compared with the ohmic drop, and only a slight difference between the reactance drop and the balancing series e.m.f. throws the resultant e.m.f. $OA$ rather much out of the phase with the ohmic drop. The power-factor and over-load conditions are therefore no better than those of the series motor, but are about the same.

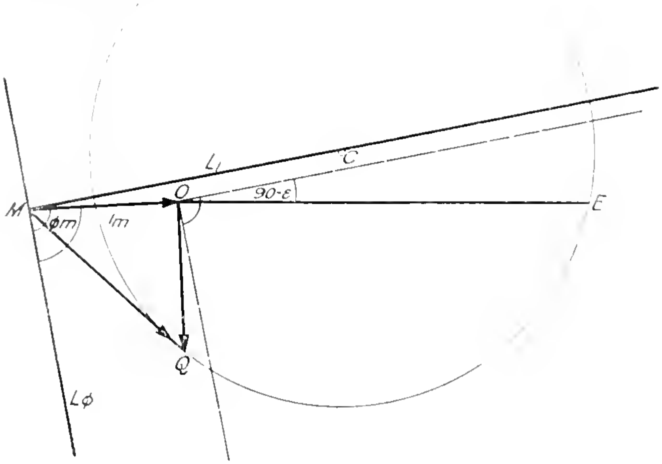


Fig. 10. The Shunt Magnetizing Current in the Diagram

We will now apply the above considerations to the problem of building an a-c. constant speed motor possessing good power-factor and overload characteristics. We have seen that we must build a compound motor in which the reactance drop is balanced by a series rotation e.m.f.

**The A-C. Constant Speed Motor**

For the sake of simplicity we will not compensate at running light the magnetizing current of the shunt excitation by means of a shift (over $\gamma°$) of the shunt field from the phase of the terminal e.m.f. We therefore take angle $\gamma = 0$, or the shunt field, in phase with the terminal e.m.f. For the same reason we will neglect the constant losses of the shunt field excitation and take the magnetizing current of the shunt field as plain wattless current.

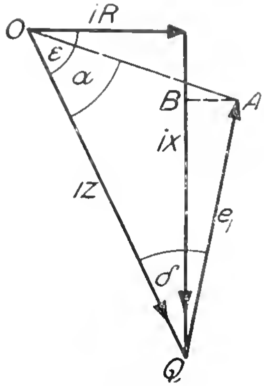


Fig. 11. The Series E.M.F. Diagram of a Compound Motor

In Fig. 12, we have $MO$, the plain wattless magnetizing current, lagging 90 deg. behind the power-factor line $L\phi$, $OE$, the standstill current; angle $EOL_1 = 90 - \epsilon\left(\tan\epsilon = \frac{X}{R}\right)$. For $\gamma = 0$, we have found that the running light main current must be zero, or that the circle must go through $O$. The friction losses neglected, the running light point $Q$ falls in $O$. $OE$ is the output line $L_2$.

In order to draw the circle over $OE$ as chord we must find the bulging angle $\alpha$ for the running light speed, which angle is given by the series e.m.f. diagram for that speed.

The series rotation e.m.f. has here no other purpose than to balance the reactance drop $iX$. It must be therefore chosen in phase with and opposed to the reactance drop. For the sake of simplicity we will assume that the balance is just right at running light.

The series e.m.f. diagram for the running light speed is shown in Fig. 13. Since we must find only angle $\alpha$, the size of the current assumed for this diagram does not matter (the current is actually zero).

$$e_1 = QA = iX$$

$$\text{Angle } \alpha = \text{angle } AOQ = \epsilon.$$

The locus for the current vector $OQ$ in Fig. 12 is therefore the circle in which $OE$ as chord subtends angle $180 - \epsilon$. The center $C$ of this circle falls on the input line $L_1$, and the circle is therefore the semi-circle over the input line.

For the torque line we must locate point $Q_\infty$ on the circle. $OQ_\infty$ forms angle $\delta$ with the shunt rotation e.m.f., which has here the same phase as the terminal e.m.f. Angle $Q_\infty OE$ must be equal to angle $\delta$. From Fig. 13 we find angle $\delta =$ angle $AQO = 90 - \epsilon$. $Q_\infty$ therefore lies on $L_1$, the input line; and $OQ_\infty$, the torque line, falls on the input line $L_1$.

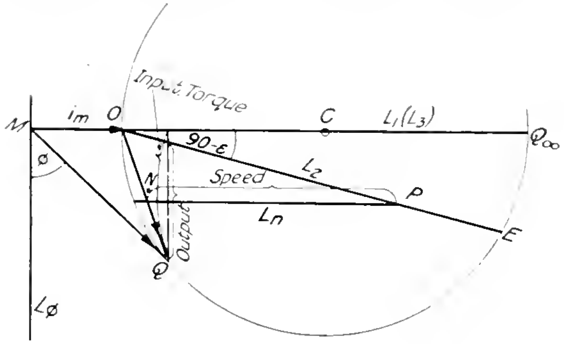


Fig. 12. Diagram of the Commutator Induction Motor (simplified

We can calculate the current $OQ_\infty$ with the formula $\left[OQ_\infty = i \times \frac{e_{sh}}{e_s}\right]$ on page 820. For running light speed the shunt rotation e.m.f. is equal to the terminal e.m.f., $e_{sh} = e$, and the series rotation e.m.f. $e_s = iX$, the reactance drop. It is therefore

$$OQ_\infty = i\frac{e_{sh}}{e_s} = iX\frac{e_s}{iX} = \frac{e_s}{X},$$ the ideal short circuit current.

This diagram is very similar to the circle diagram of the normal polyphase induction motor as first developed by Heyland in 1894. In fact it is the exact induction motor diagram neglecting, for simplicity, those factors that we have previously mentioned. It is interesting to see, in the light of our considerations of the commutator motors, that the normal induction motor appears as a compound motor. Though perhaps at first surprising, it is clear that the compound motor is the most general case of a motor imaginable, and if properly generalized must comprise all motors.

We will study this fact a little closer, since the commutator induction motor is the basis for the practical designs of the polyphase adjustable speed motors.

The connections are shown in Fig. 14. $C_1$, $C_2$, and $C_3$ are the compensating winding distributed in small slots around the whole circumference, as is the stator winding of a normal induction motor. Since the shunt field is in phase with the terminal e.m.f. $(\gamma^2 = 0)$, the field winding, $F_1$, $F_2$, $F_3$, is exactly co-axial with the compensating winding and in an exactly similar way is distributed in the same small slots. It may have the same number of turns as the compensating winding. It is then exactly the same kind of a winding as the compensating winding, and may be just as well united with it to only one stator winding, as shown in Fig. 15.

At running light the main current is zero and the motor takes only the shunt magnetizing current, $i_m = MO$, from the line. For a certain load the main current produces in the stator winding an impedance drop $iZ_1$. The air gap field, therefore, is not alone excited by the constant terminal e.m.f. but by the vectorial difference of the terminal e.m.f. and the impedance drop $iZ_1$, which latter is proportional to the current. To obtain the air gap field we have to add to the constant shunt field a series field, which is in phase with and opposed to the stator impedance drop $iZ_1$. Since at synchronism (the running light speed of the motor) all rotation e.m.f's. are equal to the transformation e.m.f's., we find that at synchronism the strength of the series rotation e.m.f. produced by this series field is equal to the impedance drop $iZ_1$ itself.

We will neglect the small magnetizing current for this series field; the fault is very small and may be easily corrected. To simplify matters we will also neglect the ohmic drop in the stator winding, because we know from the induction motor that this affects the diagram very little. There is, however, no difficulty in drawing the exact diagram. The

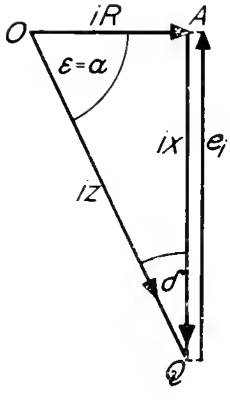


Fig. 13. Series E.M.F. Diagram for the Motor of Fig. 12.

above series rotation e.m.f. at synchronism is then equal and opposed to the primary reactance drop $e_1 = iX_1$ (see the series e.m.f. diagram of Fig. 16).

We see that the placing of the exciting winding in the same slots with the compensating winding or the uniting of it with the latter automatically sets up a series field whose rotation e.m.f. balances the primary reactance drop at synchronous speed.

If the rotor reactance would remain constant, as it does with a commutation artificially corrected by interpoles, the motor would be still rather poor, since the bulging angle $\alpha$ for the circle ($AOQ$ in Fig. 16) is still rather small and consequently the circle is very flat. But fortunately smaller motors of this type commutate without interpoles well enough for practical purposes. It has been shown in a previous article that incorrect commutation causes a decrease in the reactance of the rotor for higher speeds; how much for each type of motor can only be found by test. For the sake of simplicity we will assume that at synchronism the rotor reactance is decreasing just to zero. This is the case for the slip-ring induction motor. It can never be reached by the commutator induction motor, where at synchronism a part of the rotor reactance is always left. The above assumption therefore gives us too good values for power-factor and breakdown point.

The circle diagram is based on a constant rotor reactance. To take in account its variation from the full amount at standstill to zero at synchronism, we assume $\alpha$ series rotation e.m.f. in phase with and opposed to the rotor reactance e.m.f. For synchronous speed the strength of this series rotation e.m.f., $e_2$, is equal to the standstill reactance e.m.f. $iX_2$.

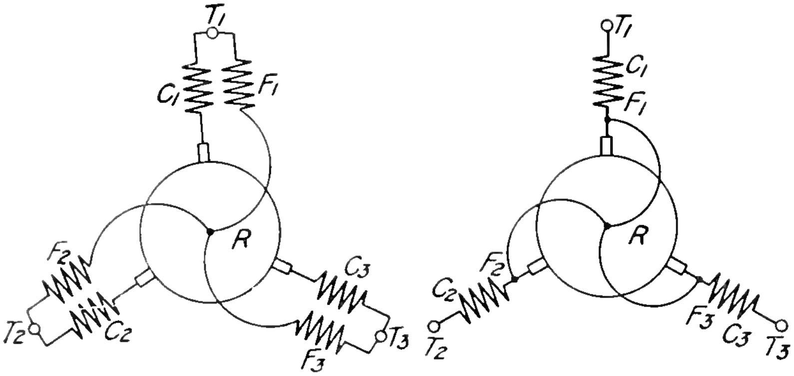


Fig. 14 Fig 15
Connection Diagrams of the Commutator Induction Motor

The total series e.m.f. diagram for synchronous speed is therefore the diagram of Fig. 17. The total reactance e.m.f. $iX = iX_1 + iX_2$ is balanced by the sum of the two series rotation e.m.f.'s $e_{i_1} \times e_{i_2}$. The bulging angle $AOQ$ is equal to $\epsilon$, and we obtain the circle diagram of Fig. 12, which is at the same time the diagram of the normal slip-ring induction motor. We must remember, however, that the circle for the actual commutator motor is somewhat flatter, due to the incorrectly assumed variation of the rotor reactance.

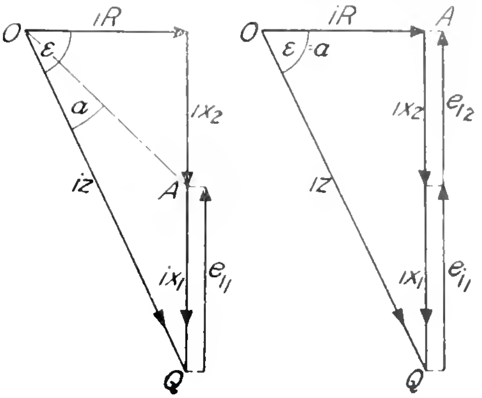


Fig. 16 Fig. 17
Series E.M.F. Diagrams for the Commutator Induction Motor

It is interesting to note by what means the commutator induction motor becomes a practical motor in which the reactance e.m.f., which spoils the plain shunt motor completely, is neutralized. It is due, first, to the fact that the exciting winding is placed in the same slots as the compensating winding or united with the latter one; and second, to the incorrected commutation, possible for small motors with hard carbon brushes.

### Speed Regulation

Just as in a d-c. shunt motor there are two means to obtain speed regulation:

1. Field variation at constant terminal e.m.f.
2. Variation of the terminal e.m.f. at constant field (Ward-Leonard control for d-c. motors).

#### 1. Field Variation

Figs. 18 to 20 show various connections to obtain field variation for three-phase current.

In Fig. 18 the motor has a separate compensating winding $C$ and field winding $F$. The exciting voltage for the field winding $F$ is regulated by a regulating transformer with taps and controller.

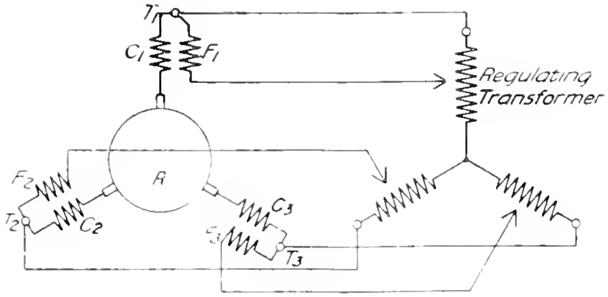


Fig. 18

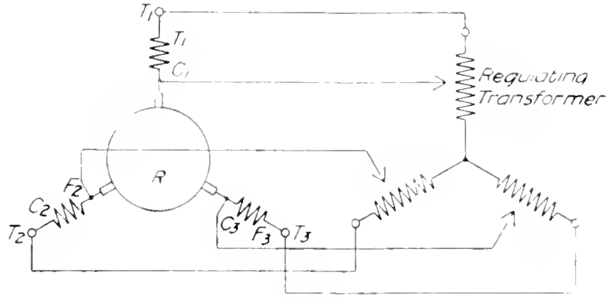


Fig. 19

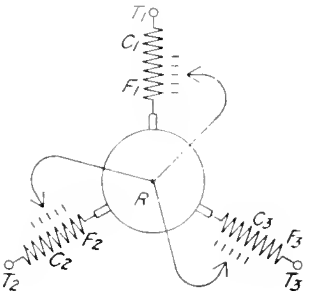


Fig. 20

Figs. 18, 19 and 20. Connection Diagrams for Field Variation

In Fig. 19 the field and compensating winding are united to one stator winding. The regulation of the field is effected in the same way as before.

In Fig. 20 the regulating transformer is united with the stator winding, which has taps connected to a controller.

The effect of all connections is the same; viz., the shunt field is varied in strength. We will develop the diagram for different running light speeds.

For synchronous running light speed we have already obtained the diagram of Fig. 12, which coincides with the diagram of a normal induction motor and is shown again in Fig. 21. Since the phase of the shunt field is kept in phase with the terminal e.m.f. during the regulation, the main current is zero for all running light speeds, and all circles must go through point $O$. Since the terminal e.m.f. is constant, the standstill current $OE$ is constant for all conditions. All circles must therefore go through the two points $O$ and $E$.

The circle for each running light speed is determined by the bulging angle $\alpha$ for that speed. We assumed that for synchronous speed the series rotation e.m.f. just balances the reactance drop $iX$. Then $\alpha$ became equal to $\epsilon$ (see Fig. 22a). Let us assume that the shunt field is increased to double the amount at synchronous speed. The running light speed will be half of the synchronous speed. The series rotation tension $\epsilon$ is therefore also only half of the value at synchronism, when it was equal to the reactance drop $iX$. We obtain the angle $\alpha =$ angle $AOQ$ in Fig. 22b. This angle is much smaller than for synchronous running light speed, the circle is much flatter, and we obtain the circle $B$ in Fig. 21. The power-factor and overload characteristic is rather poor, since only half of the reactance drop is balanced by the series rotation e.m.f.

Let us now weaken the shunt field so that the motor runs at 50 per cent above the synchronous speed. The series rotation e.m.f. increases in the same ratio to $QA$ in Fig. 22c. Angle $AOQ = \alpha$ is large and the circle $C$ in Fig. 21 bulges higher. We obtain high power-factor, even leading, since the reactance drop is considerably over balanced.

It may be noted that the currents for infinite speed $OQ_\infty$ are proportional to each shunt field. We have seen that the torque is zero for this point and that the shunt field and series field are opposed and equal, from which fact it results that the currents $OQ_\infty$ must vary proportionally with the shunt fields or inversely proportionally with the running light speeds. If the synchronous circle is known we can find the corresponding point $Q_\infty$ for another running light speed directly by this fact. The new circle is then determined by the three points, $Q$,, $E$, and $Q_\infty$.

For the complete diagram we must add the shunt field current, which varies with the shunt field. All data for each load may be obtained by the use of the input and torque line $OQ_\infty$, the output line $OE$, and the speed line.

So far we have assumed that the shunt field is in phase with the terminal e.m.f., so that the running light main current is zero. By choosing a proper phase shift for the shunt field from the terminal e.m.f., we have seen that the motor can be forced to take a leading current from the line at running light, which current will balance the magnetizing current for the shunt field. The power-factor and overload capacity may be improved in this way, especially for the flat circle $B$ at the low speeds, as indicated by the dotted circle in Fig. 21.

### 2. Variation of the Terminal E.M.F. at Constant Shunt Field

Figs. 23 to 26 show various connections.

In Fig. 23 the field winding is lying at the constant line e.m.f. The terminal voltage is regulated over a transformer with taps and controller.

Instead of regulating the terminal voltage between the line and the compensating winding, we get the same effect if we introduce the regulating voltage between the compensating winding and the rotor, as shown in Fig. 24.

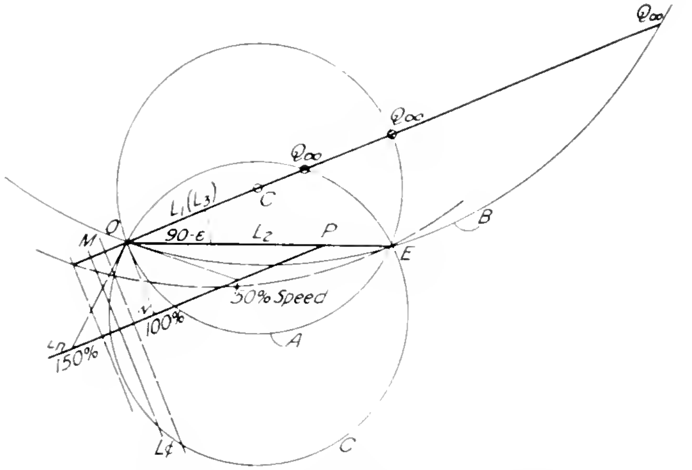
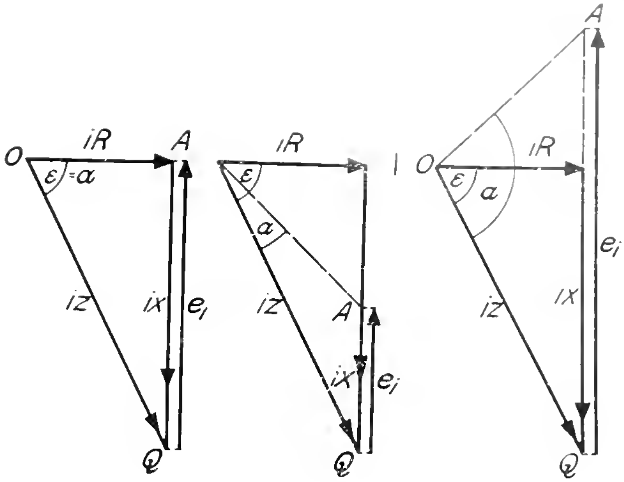


Fig. 21 Diagrams for Synchronism (A), 50 per cent below (B), and 50 per cent above (C) synchronism obtained by field variation

We may then unite the field and compensating winding again to one winding, as indicated in Fig. 25. Finally we can unite the transformer and the stator winding and bring out taps from the stator winding to a controller (Fig. 26).

In all connections the effect is the same: the shunt field is constant and the terminal



Figs. 22A, 22B, 22C. Series E.M.F. Diagrams for the Motor of Fig. 21

voltage is varied, which varies the speed in an exactly similar way as does the Ward-Leonard control for d-c. motors.

We draw the diagram not for the line voltage but for the actually applied terminal voltage. To obtain the line currents from the diagram currents we must only reduce them in the ratio of the terminal to the line voltage.

Assuming again the shunt field in phase with the terminal voltage, the running light main currents are again all zero and all circles go through point $O$. The standstill currents $OE$ vary proportionally to the terminal voltages, or to the running light speeds. The bulging angle $\alpha$ is the same as found before for each speed, obtained by field variation. The circles for synchronism, 50 per cent above and 50 per cent below synchronism are shown in Fig. 27. The overload capacity varies naturally with the applied terminal e.m.f. For the lower speeds it is therefore much reduced as compared with the former motor regulated by the field, and for higher speeds much increased.

The current $OQ_\infty$ for infinite speed is here constant, since the shunt field is constant. If the synchronous circle is known we can

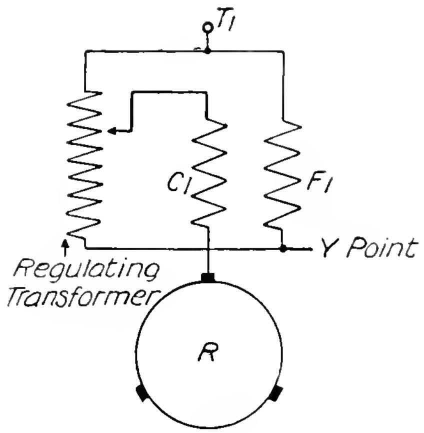


Fig. 23

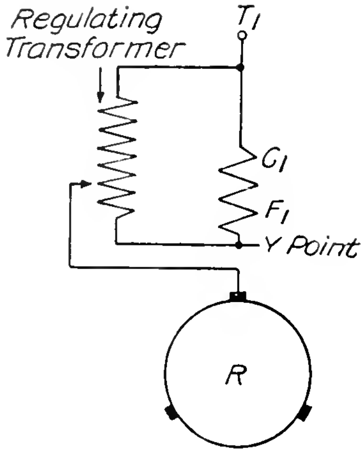


Fig. 25

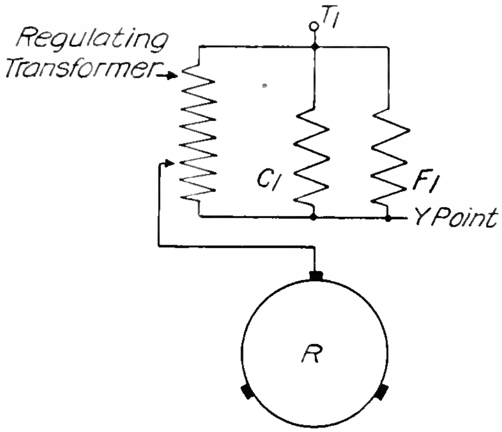


Fig. 24

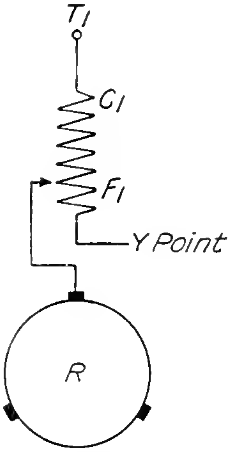


Fig. 26

Figs. 23, 24, 25, 26. Connection Diagrams for variation of the terminal voltage at constant field draw directly the circle for another speed, by reducing the standstill current $OE$ in the ratio of the new speed to the synchronous speed. The circle is then determined by the three points $O$, $E$ and $Q_\infty$.

To complete the diagram we have to add the magnetizing current for the shunt field. Although this current is constant, we must vary it indirectly proportionally with the terminal e.m.f., for the diagram is drawn not for the constant line e.m.f. but for the actual terminal e.m.f.

The diagram is similar to the above diagram for field regulation. It is evident also that here we can improve the power-factor and overload capacity at the lower speeds by shifting the phase of the shunt field from the terminal e.m.f., or what amounts to the same thing, by shifting the terminal e.m.f. from the phase of the shunt field.

The variety of connections suggested by various inventors for speed regulation is large. All, however, are based upon either field or terminal e.m.f. regulation and the diagram may be applied to all of them in a similar way.

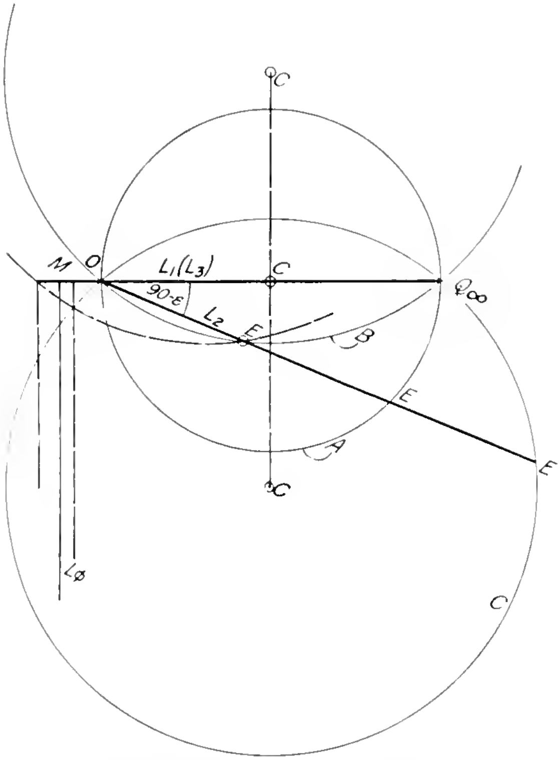


Fig. 27. Diagrams for Synchronism (**A**), 50 per cent below (**B**), and 50 per cent above (**C**) synchronism obtained by variation of the terminal E.M.F. at constant field

# THE BIG CREEK DEVELOPMENT OF THE PACIFIC LIGHT AND POWER COMPANY

By H. C. Hoyt

Power and Mining Department, General Electric Company

The author gives some interesting data concerning the general conditions on the Pacific Coast that have led to so many wonderful hydro-electric developments. In describing the Big Creek Development, he recites some of the unusual difficulties met in the construction work and the vast amount of work necessary before actual construction could begin. His general description of the construction work is full of interesting facts and figures. The electrical and mechanical equipment of the power houses, buildings, transmission line, and the incidental work are described in some detail.—Editor.

In probably no other locality in the world are conditions as ideal for the generation of hydraulic power as in that portion of the United States bordering on the Pacific Ocean. The comparatively low Coast Range mountains offer a barrier to the warm moist winds from the sea, in crossing which a part of their moisture is precipitated on both slopes of the range, while still further east are encountered the high snow-covered peaks of the Sierras, forming a rampart over which the winds can sweep eastward only after giving up practically all the moisture which they carried from the ocean. The resulting rainfall is of such proportions as to give rise to large streams and rivers from a very small drainage area, and at elevations which insure a rapid fall in their course toward the lowlands. But as the flow of these streams is variable between wide ranges, according to the season of the year, their usefulness as a source of power can only be realized by suitable storage of the flood waters. This fact has been so well demonstrated by the operation of all the earlier plants in this territory, where the capacity of the machinery installed is far in excess of the normal stream flow, that hardly a prospective development can now be found which will not include in even its preliminary plans the construction of large storage reservoirs.

A development of this character, recently completed and notable for its size, distance from a market for its power and unusual construction difficulties, is the Big Creek project in Fresno County of the Pacific Light & Power Corporation of Los Angeles.

Prior to the drawing of the plans for the Big Creek development, this company already had in operation six small hydro-electric plants with an aggregate capacity of about 15,000 kw. and three steam plants with a total capacity of nearly 50,000 kw., including 30,000 kw. in modern turbo-generating units. These stations supplied power over a transmission system of more than 400 miles of trunk power lines and nearly 300 miles of distributing lines to seventeen cities and towns of Southern California having a population of over 450,000. To meet its increasing requirements for power it was decided to install another hydro-electric plant, and the site finally selected was on a branch of the San Joaquin River, known as Big Creek, near a point where a natural basin in the hills offered a location for water storage at an elevation of 6800 ft. above sea level.

The site is located in the Sierra Nevada Forest Reserve, and the permit granted by the U. S. Government is the largest ever authorized, covering ultimately 4 power houses, 2 reservoirs, 25 miles of tunnel and the development of 350,000 h.p., the entire development to be completed in 12 years.

Above the reservoir is a drainage area of only about 88 square miles, but mountains on the north and east sides rising to an elevation of 10,000 to 11,000 ft. cause an approximate precipitation over the entire area of 80 in. a year, with a run off equivalent to fully 50 in. For the first six miles below the reservoir site there is a drop of 4000 ft. in the stream which can be utilized for power development. With this high head available a comparatively small volume of water is required and with the aid of a reservoir to equalize the annual flow a development of 140,000 kv-a. is possible within this distance. With the ultimate water storage contemplated it is estimated that this power could be developed for 150 days on the basis of 50 per cent load factor from storage water alone.

The reservoir site had only two depressions in its southern and western banks, besides the channel for Big Creek, which would have to be closed to form a lake 120 ft. deep and 4½ miles long by ½ mile wide, containing 2,310,000,000 cu. ft. of water, and by raising

Fig. 1. Excavating for Dam No. 4. Looking Down Stream

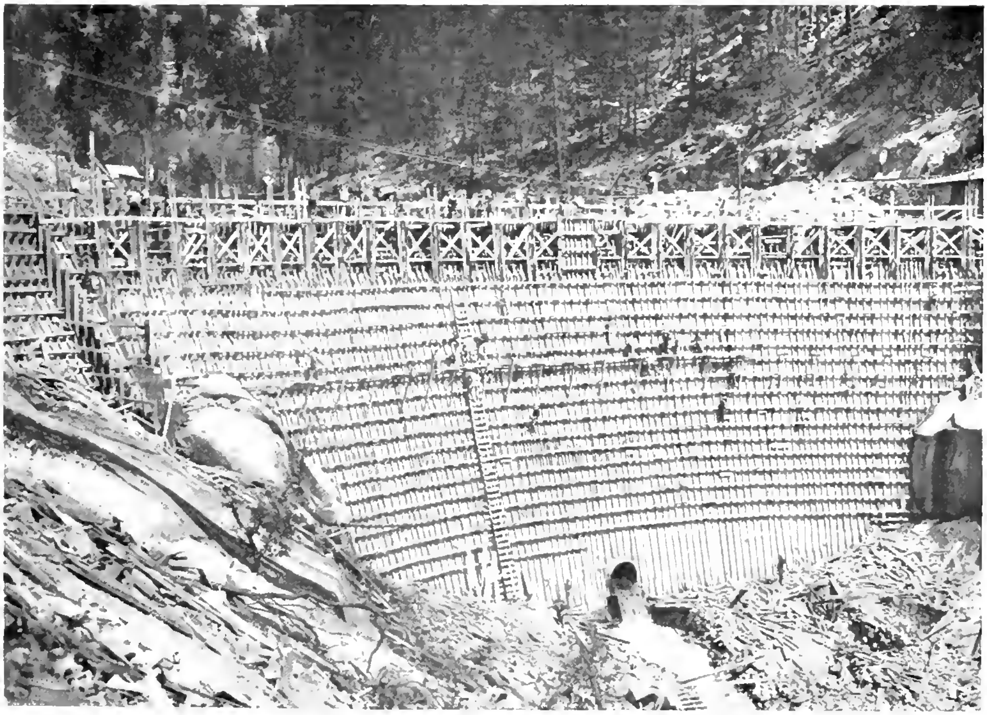


Fig 2. Dam No. 4 in Process of Construction. Down Stream Side

the dams 50 ft., 2,210,000,000 cu. ft. would be added to the storage capacity, which would carry 120,000 kw. at 50 per cent load factor for 240 days.

The final plans for the project were adopted early in 1912, and the schedule called for the completion and operation of the installation in 1913. The latter requirement necessitated the impounding of the flood waters in the spring and early summer of 1913, so that haste in the construction of the storage basin was imperative. It was the first intention to haul the necessary material and supplies from the nearest railroad to the plants in the usual manner by teams, but when estimates were actually made it was discovered that it would require the use of 10-horse teams leaving the railroad siding every five minutes for seven years to complete the entire development. One of the first requirements, therefore, was the construction of a railroad and on January 26th, 1912, orders were issued for such work. In 165 days the line was located, right-of-way purchased, government permit secured, and the last spike driven in a 56-mile standard gauge railroad, the last 30 miles of which was laid through the mountains with grades up to 5 per cent and hardly a tangent worthy of the name. The difference in elevation between the two ends of the road is 4920 ft., and over the mountain division two 60-ton Shay locomotives were required on a six-car train. The road runs along the top of the canyon above No. 2 Power House, and thence to No. 1 Power House below the storage reservoir, with inclines each over a mile in length and having a maximum grade of 85 per cent connecting the railroad sidings with the construction camps at No. 2 Power House and the reservoir basin.

The initial development called for the construction of the reservoir dams to an elevation of 6915 ft.; tunnels and flow pipes with a capacity sufficient to operate six 20,000 h.p. waterwheels under 1900 ft. head; two power houses, each to contain two 20,000 h.p. wheels, with floor space in each for a third unit and provision for extending the power houses for the ultimate development; and 245 miles of double circuit, 150,000 volt transmission line. With only one year in which to complete the storage reservoir and about 18 months to place the entire system in operation, it was necessary that work be rushed on a day and night basis and every provision made to guard against delays. To accomplish this, camps were established at the various dam and tunnel sites, as well as at the two power houses, and as many as 4200 men were employed at one time, while before the completion of the railroad and inclines 1300 horses were in use.

To care for this army of men, bunk houses were constructed having a capacity for 3800 men and dining halls capable of feeding 4250. At one camp alone 865 men could be fed at one time. A main hospital was established, with complete surgical equipment including an X-ray outfit, and "first aid" stations were located at all other camps.

To insure continuation of the work in case railroad communication with the outside world should be interrupted, especially in winter, enough food was kept in stock at times to feed 4000 men for six months; ham and bacon were ordered in carload quantities; flour by the five car loads; while 90,000 gal. of oil fuel, 33,000 bbl. of cement and other materials in proportion were held in reserve. All structural steel work was cut, drilled and fabricated at the site. A complete cement testing plant was installed to examine samples before any of the 186,000 bbl. of cement were used. Thirteen standard locomotives ranging from 25 to 42 tons, and five 60-ton Shay locomotives were used to haul material from the outside, as well as gravel, sand and rock obtained on the site. All lumber for forms, buildings, trestles and construction work was cut from the reservoir site and handled by a saw mill having a capacity of 40,000 ft. per day, in addition to which 8000 cords of wood were used for fuel.

With the exception of the oil-burning locomotives, power for construction work was secured over a 30-mile temporary transmission line from the Crane Valley power house of the San Joaquin Light & Power Company. This line delivered 2400 kw. at 33,000 volts, which was stepped down to 6600 at the main substation for distribution to the various camps, where it was again reduced to 440 volts for motors and 110 volts for lighting. A novel feature was the operation of 15 hoisting engines by compressed air furnished from eight motor-driven compressors during the periods when the air drills were not used extensively; the boilers for these engines being held in reserve for use in case of failure of power, and also to furnish steam for extra heating of the materials when concrete was placed during cold weather.

Both inclines were operated by motor-driven hoists of 300 and 200 h.p. respectively, employing 1 3/8 in. steel cables with special "bridles" for attaching to cars. The hoisting and lowering of cars was regulated from

Fig. 3. Dam No. 1 Completed

Fig. 4. Excavating for Power House No. 2. A Large Portion of this Work was done by Means of a High Pressure Stream of Water, as shown

lookout towers which gave an unobstructed view of both inclines. No passengers were allowed to ride on the inclines, and to further reduce the chance of accidents the inclines terminated at some distance from the camp sites so that the breaking loose of a car would not wreck the work.

The area of the storage reservoir as now constructed is 1544 acres, giving a storage capacity of 53,000 acre feet of water. For the ultimate development, with the dam height raised 50 ft., the storage will be nearly 120,000 acre feet, forming a lake 6½ miles long by ½ mile wide.

There are three dams closing the natural outlets of the reservoir. No. 1, which is placed at the outlet of Big Creek, is the largest and has a top length of 1000 ft. and a maximum height to the spillway of 147 ft. The width of the dam at the top is 10 ft. and at the base 80 ft., and it contains 61,000 cu. yards of cyclopean concrete, all of which was placed in 60 days by nine mixers mounted on a trestle built to the full height of the dam. The mixers fed into concrete chutes leading to the forms; the rock, which constituted about 15 per cent of the total volume, being handled by the same derricks that were used for excavating the dam site. All material was dumped into storage bins from standard gauge cars running on the deck of the trestle and fed from there to the mixers. Three 42-in. hand-operated sluice gates provided with screens are placed in the base of the dam for draining the basin.

The two smaller dams, which close depressions in the side of the basin, are respectively 81 ft. high and 1160 ft. long and 126 ft. high and 600 ft. long, and contain 31,000 and 31,300 cu. yds. All dams are set on solid granite foundation, which is found at from 20 to 90 ft. below the surface of the ground. They have a vertical up-stream face, with the down-stream face stepped to afford a better bond for the concrete when the dams are increased in height.

From the reservoir the water passes through an intake tower of reinforced concrete, 104 ft. high by 20 ft. inside diameter and 2 ft. thick. On its up-stream side the tower is provided with three sets of screens, each 7½ ft. wide and extending to the top of the tower. The screens will be provided with motor-driven rakes covering their entire face. Opposite the screens is a 9-ft. outlet to the discharge tunnel, fitted with a heavy gate valve operated by two stems which can be opened or closed against a head of 140½ ft., this head corresponding to the ultimate height of the dam. Just above the main valve is located a 24-in. by-pass valve to equalize the water pressure in the basin and tunnel. This valve discharges into a 36-in. air shaft open to the top of the tower.

Tunnel No. 1 is 12 ft. in diameter and 3880 feet long, bored through solid granite to a grade of 2 feet per 1000. It will supply sufficient water for the operation of six 20,000 h.p. units working under a head of 1900 ft. A record of 95 feet per day and 282 feet per month was made on this work.

At a point 400 ft. back from the outlet this tunnel connects with a 9-ft. steel flow pipe, one end of which is solidly concreted into the bore of the tunnel, and the other terminating just beyond the tunnel portal in an 84-in. by 60-in. steel plate Y, one branch of which is blanked for use with the future development. The other branch connects with an 84-in. riveted steel flow pipe 6484 ft. long, which varies in thickness from ⅜ in. at the upper end to ½ in. at the lower end. It is laid to a grade of 7½ ft. per 1000 and is supported on concrete saddles about every 35 ft.

An unusual feature of the construction of this flow line was the use of a "go-devil," or self-propelled derrick, which spanned the pipe and rested on a wooden track anchored to the pipe to prevent spreading and supported on blocking from the bottom of the trench. A standard gauge track was constructed in the flow line trench and the pipe delivered on cars within reach of the "go-devil," which would lift a section of pipe and hold it while the car and section of track on which it had stood were removed. The pipe was then lowered into place and aligned, after which one rivet on each side was knocked out and a section of wooden track for the "go-devil" set in place. With this arrangement an average of 240 ft. per day was laid, with a maximum of 300 ft. The trench was later back-filled to give at least eighteen inches of soil over the flow pipe.

At the brow of the hill, 1942 ft. above the power house, the flow pipe terminates in four 44-in. outlets, two of which are blanked for future development, and the other two connected to 42-in. motor-operated gate valves arranged for remote control from the power house. Below the gate valves in each line is a 24-in. stand pipe extending 425 ft. up the hill side and ending in a vertical surge tank 36 in. in diameter and 35 ft. high.

Below the stand pipes, the pressure pipes descend to the power house, one for each generating unit, spaced about 7 ft. apart. Each pipe, which is of German make, is of lap welded steel constuction and built in sections of 20 ft. length. At the upper end the diameter is 42 in. and the thickness $\frac{3}{8}$ in., but as the line descends the mountain the thickness increases in proportion to the pressure under which it will have to operate; and as the maximum thickness for one diameter of pipe is reached the next smaller size is used, up to its limit, until the nozzle casing is reached, where a diameter of 24 in. and a thickness of 1 in. is used. A "go-devil," similar to that used for the flow line except that the two penstocks served as the runaway, was utilized in laying the pipes. About 800 ft. above the power house each pressure line branches through a Y having 26-in. outlets that lead to the nozzles of the two wheels driving each generator. Just outside of the main power house is an annex that houses the hydraulic gate valves.

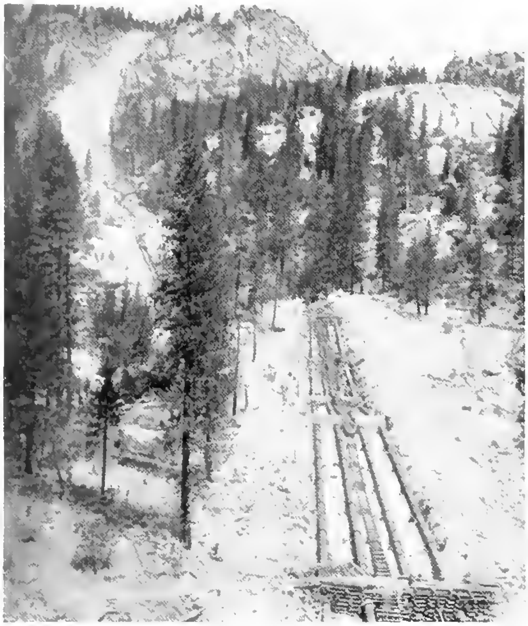


Fig. 5. Penstocks for Power House No. 1

Fig. 6. Penstocks for Power House No. 2

Views from Roof of Power Houses

Each main unit consists of two impulse type waterwheels overhung from either end of the generator shaft outside of the bearings supporting the shaft. Each pair of wheels is designed to deliver 20,000 h.p. when operating under 1900 ft. effective head (2096 ft. static head). The wheels are 94 in. in diameter on the impulse circle and contain 19 cast steel buckets mounted on a nickel steel wheel disk. The shaft for each complete unit is of hollow forged nickel steel, 20 in. in diameter at the bearings, 27 in. in diameter at rotor, by 28 ft. 11 in. long, and is supported by two ring oiled, water-cooled, babbitted bearings 60 in. long. Each pair of wheels with its shaft weighs over 100 tons. Speed control is secured by means of one oil relay or hand-operated governor for each individual wheel so that either wheel may be used alone to drive the generator at partial loads with maximum efficiency and water economy. The speed may also be regulated from the switchboard by remote electric control of the needle valve. The nozzles, which form a jet $5\frac{1}{2}$ in. in diameter having a velocity of about $3\frac{1}{2}$ miles per minute, (over 300 ft. per second), are permanently fixed instead of being deflected for partial loads, and the jet is regulated for varying loads by means of a needle valve. To avoid water hammer or undue pressures in the long pipe lines as a result of sudden changes in the flow, pressure regulators are installed just back of the needle valves and are so constructed as to open a second needle valve in case of excessive rise in pressure, and to close slowly as the pressure is reduced to avoid waste of water. These regulators direct their jet through an energy absorber into the tail race, which is lined with ½ in. steel plates to avoid the destructive action of the water on the concrete under such high heads.

The exciter wheels are also of the impulse type with stationary nozzle and hand-controlled needle valve. Twenty-four buckets are mounted on a 47-in. diameter runner. The 1 5/6-in. jet is supplied from an 8-in. header connecting all four pressure pipes, with a 6-in. connection to the wheel. Speed regulation can be obtained either by hand or automatic governor control, and if the load goes off the jet is deflected by means of a steel hood operated by the speed control device.

The oil for all governors and main bearings is supplied from a central pressure system located in the basement. It consists of two 2½-in. oil pumps, either motor or waterwheel-driven, suction and pressure tanks. Oil flows from the suction tank to the pump, and thence to the pressure tank under a pressure of 200 lb. per sq. in. From the pressure tank it flows to operating valves, cylinders of governors, and lower sides of generator bearings, returning through five stage oil filters and purifiers to the suction tank.

The power house building is 171 ft. long, 84 ft. wide, and 103 ft. high, and is of sufficient size to contain a third generating unit, to be installed at a later date. The operating room is 168 ft. long by 43 ft. wide, and the two units now installed are spaced 44 ft. between centers, while the third unit, when installed, will be placed 62 ft. from No. 2 unit, leaving sufficient space between for work benches, tools, etc. Back of this space is located the exciter bay under the switchboard gallery and in line with the step-up transformer compartments back of their respective generators. At the extreme rear of the building on the main floor are located rooms for storage batteries, rheostats, remote controlled d-c. switchboard and station service transformers. Under these, in the basement, are the rooms for oil storage and treating, while the office and the 6600 volt bus compartments are on the floor above. Directly over the 6600 volt bus compartments are the oil switches for connecting these buses to generators and transformers, and above these the 150,000 volt lightning arresters. On the fourth and fifth floors, directly over the operating room, are located the 150,000 volt buses with their oil and disconnecting switches, while an extension of the roof at the rear of the building forms a canopy under which the lines leave the building without the use of entrance bushings.

The second power house, located about four miles further down stream, is practically a duplicate of the first. From the tail race of power house No. 1 the water flows into a small pool formed by a dam across Big Creek Canyon about 500 ft. below the power house. In addition to impounding the entire flow of Big Creek from the storage reservoir, this dam No. 4 also collects the waters of a small stream known as Pittman Creek, which enters Big Creek Canyon about a quarter of a mile above power house No. 1. The dam is 73 ft. high by 288 ft. long and has one hand-operated 72-inch sluice gate for draining the pool. A syphon intake tower is installed and connects with tunnel No. 2, which is driven through solid granite for a distance of 21,300 ft. to a grade of 3.2 ft. per 1000. This tunnel is also 12 ft. in diameter.

About 250 ft. back from the outlet of tunnel No. 2 a surge chamber 30 ft. in diameter was excavated, the concrete shell extending to a height of 120 ft., or about 30 ft. above the surface of the water in the pool back of dam No. 4. From this surge chamber a 9-ft. gate valve with a by-pass similar to that at No. 1 development controls the flow through the remainder of the tunnel and the penstocks, which begin at the tunnel portal. The arrangement of the penstocks and valves is identical with that at power house No. 1. The effective head at this plant is 120 ft. less than that at the first station, or 1780 ft.; but the increase in water supply at this point, due to the additional flow from Pittman Creek, permits the use of units of the same capacity, although the waterwheels in power house No. 2 have only 17 buckets per wheel. With this exception the equipment of the two stations is identical.

A feature of the construction of the second power house was the removal of about 25,000 cu. yd. of top soil by means of two hydraulic giants delivering a 6-in. stream of water under 250 lb. pressure. (Fig. 4.)

### Electrical Equipment

The general conditions under which the electrical apparatus for this installation was designed are as follows:

"Two power stations, each designed for an ultimate capacity of 105,000 kv-a., generated

Fig. 7. Placing Forms for Anchors for Penstocks, Power House No. 1

Fig. 8 Power House No. 1 showing Line Entrance and Lightning Arrester Horn Gaps on Roof of Building

three-phase, 50 cycles, 6600 volts. This voltage will be raised to 150,000 by step-up transformers and the electrical energy transmitted by a two-circuit line to two substations located respectively, about 135 miles and 275 miles from the generating stations. At the first of these substations approximately 13,500 kv-a. at 72,000 volts will be fed into the system through the 150,000 volt bus by means of suitable step-up transformers. Two transmission lines, each of approximately 60,000 kv-a. capacity, will be connected direct to the station bus without switching or measuring apparatus, and will convey power to the Eagle Rock substation at Los Angeles. From this substation six 18,000-volt and four 72,000-volt outgoing feeders will be supplied through step-down transformers. There will also be installed two 15,000-kv-a. synchronous condensers, with their transformers, to be used for voltage regulation; the condensers to be so arranged that at a future date they may be used as synchronous motors for direct connection to d-c. railway generators. A number of the 18,000 and 72,000-volt feeders will connect this substation with the existing steam and water power stations now in operation on this system. The transmission lines will be about 275 miles long, and will consist of two circuits, each of three steel-core aluminum conductors of 683,000 circular mills. As previously stated, the operating voltage is 150,000, which is about 80 per cent of the critical voltage of the line. The voltage is to be constant at both ends of the line. The transformers, with the exception of the step-up transformers at the power stations, will be connected delta-delta; the power station transformers being delta connected on the low tension side and "Y" on the high tension side, with the neutral grounded. As the system may be operated with ungrounded neutral, all apparatus is to be insulated for the full line voltage and be given a high tension factory test of two and one-half times working voltage for one minute, and twice working voltage test after installation. All apparatus is to be rated on a continuous output basis."

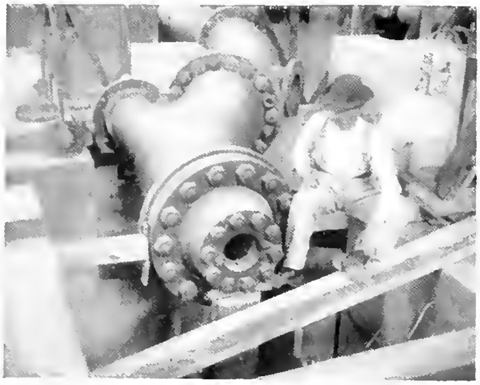


Fig. 9. Lining up a Water-wheel Nozzle. Water issues from the nozzle fitted to this opening with a velocity of 300 ft. per second

To meet these conditions and to care for the initial development, the following equipment was installed: Two main generators for 50-cycle, 6600-volt, three-phase ungrounded "Y" operation, with a continuous rating of 17,500 kv-a. at any power-factor from 80 per cent lagging to 80 per cent leading, and an overload rating of 21,000 kv-a. for one minute, and 25,000 kv-a. momentarily. Each generator is driven by two impulse type waterwheels, mounted on each end of the generator shaft outside of the bearings, and is designed to operate at a normal speed of 375 r.p.m., with a maximum runaway speed of twice normal without excessive strain on the revolving parts. These generators are the largest waterwheel-driven units ever installed. The revolving field of each generator is excited from a separate 250-volt exciter, the exciting current being controlled through a motor-operated rheostat. The guaranteed efficiency of each generator is 97 per cent at full load, exclusive of friction and windage, which were estimated at 180 kw.

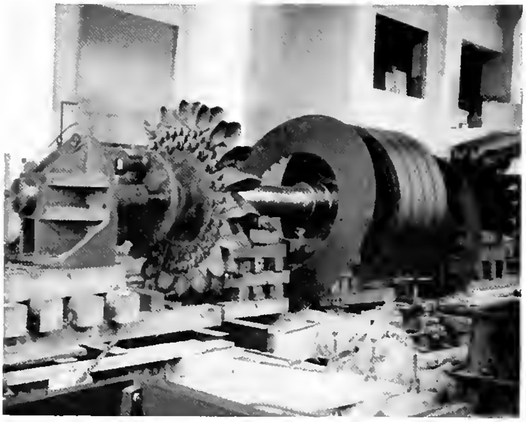


Fig. 10. Assembling Generator and Water-wheel, Power House No. 1

The two exciter units are rated 150 kw. at 250 volts, with a speed of 750 r.p.m. Either unit is capable of exciting both of the main generators. One exciter is waterwheel-driven, with provision for a direct-connected motor at a future date, and the other is both waterwheel and motor-driven. The ultimate installation contemplates the addition of a third motor-driven unit. The exciters are of the interpole compound wound type with shunt winding arranged so that the two halves can be connected in series for self-excitation or in parallel for excitation by means of regulating exciters. In order to secure suitable regulation by means of voltage regulators over the wide range demanded on both the generators and the synchronous condensers, an auxiliary system of excitation for the main exciter units was adopted. The 250-volt main exciters were wound with 125-volt fields, designed for separate excitation from two small auxiliary exciters connected in series, one of which operates at a constant potential of approximately 125 volts, and the other at a varying potential of from 125 to 275 volts. Each of these auxiliary exciters is shunt wound. Therefore, the resulting excitation across the main exciter fields will vary from zero to 150 volts, the voltage regulator operating only on the field of the auxiliary exciter of varying potential. The two auxiliary exciters for the power house consist of three-unit motor-generator sets having a 20 h.p., 220-volt, squirrel cage driving motor direct-connected to a 4-kw., 125-volt generator and an 8-kw., 250-volt d-c. generator. Each of these sets is capable of furnishing excitation for two main exciters.

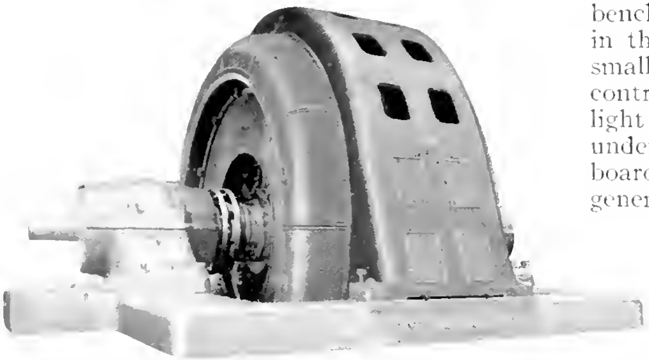


Fig. 11. 15,000 Kv-a. Synchronous Condenser for maintaining equal voltage at both ends of 240 Mile Transmission Line

Two banks of step-up transformers are installed, each consisting of three single-phase water-cooled units having a continuous rating of 5833 kv-a. They are wound for 6600 volts delta on the low tension side, and for 86,700 delta, 150,000-Y on the high tension side, with an additional tap for 135,000 volts. One spare transformer is installed at each power station. The transformers have a guaranteed full load efficiency of 98.3 and a regulation at 100 per cent power-factor of 1.1.

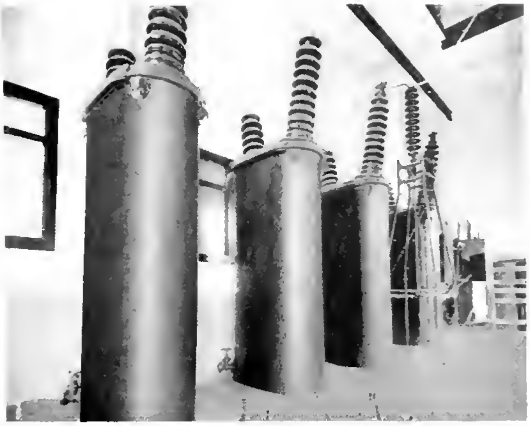


Fig. 12. 150,000 Volt Electrolytic Lightning Arresters, Eagle Rock Substation

The main switchboard, which is of the benchboard type, is located on the gallery in the center of the operating room with a small vertical switchboard near one end to control the storage battery and the station light and power circuits. In the exciter bay under the main switchboard is an auxiliary board for the control of the exciter and generator fields. All of the 6600-volt and 150,000-volt switches are remote controlled, electrically operated, and non-automatic. Duplicate low and high tension buses are installed, with selective disconnecting and oil switches for connecting the generators and transformers to either bus. The 6600-volt buses are installed in separate concrete chambers, while the 150,000-volt bus consists of 2-in. iron pipe mounted on suspension insulators. Each pole of the 150,000-volt oil switches, with its disconnecting switch, is enclosed in a separate compartment. Instrument transformers in the 150,000-volt circuit are of the bushing type, mounted on the oil switches in the outgoing line, the secondaries of these transformers being connected to six ammeters on the line panels, three for each bus selective switch. All control switches are of the twin pull button type and are provided with indicating lamps and a mechanical indicator to show the position of the switch controlled. Mimic buses, showing the complete scheme of connections, are also installed on the benchboard. Disconnecting switches are equipped with a locking device to prevent accidental opening.

Each of the 150,000-volt outgoing lines is equipped with choke coils and an aluminum cell electrolytic lightning arrester, the tanks of which are grounded and are located inside of the building, while the horn gaps are mounted on the roof and operated by mechanical remote control, with an indicator to show the exact position of the horns. A storage battery for operating oil switches and emergency lighting and a battery charging motor-generator set of $3\frac{1}{2}$ kw. capacity are also installed, in addition to four single-phase oil-cooled step-down transformers (one spare) of 125 kv-a. for supplying 220-volt current for station lighting and power circuits.

A complete oil supply system is provided by means of which oil from any transformer, oil switch or lightning arrester may be drawn into tanks in the basement, filtered and returned to any part of the building through a duplicate system of piping operated both by rotary pump and air pressure.

Power house No. 2 is in all respects a duplicate of No. 1 except for the system of excitation. In power house No. 2 each main exciter is of 250 kw. capacity; they are compound wound, with two shunt windings on the same poles, one of which is connected across the armature through a rheostat for self-excitation and the other is separately excited from the storage battery and controlled by a special voltage regulator. Normally the series windings is not in use, but can be switched into circuit from the field control panel in case hand regulation is desired. The 150,000-volt electrolytic arresters have "live" tanks. No choke coils are used, but fuses are installed in series with the horn gaps. The two outgoing lines from power house No. 2 are tapped directly into the lines from power house No. 1.

The duplicate transmission line is 241 miles long, the greater part of which is constructed on private right-of-way cleared to a width of 150 ft. The line crosses two distinct mountain ranges, less than half of the line being in rolling open country. The standard towers are designed to withstand the strains resulting from the breaking of two conductors on the same side, and the anchor towers to withstand breaking of all three conductors and ground wire on the same side. A total of 2214 standard and 187 anchor, angle, or special towers is used. The total weight of a standard tower is 5600 lb. and of an anchor tower 8050 lb. The steel core aluminum cable has an outside diameter of 0.95 in. and weighs 4058 lb. per mile. The total weight of conductor for the two lines is 4,892,000 lb. A seven strand steel ground wire is also installed on both lines, the total weight being 1,306,000 lb. The normal spacing between towers is 660 ft., except where sleet is liable to be encountered, and then the span is reduced to 550 ft. The conductors are located in a horizontal plane about $17\frac{1}{2}$ ft. apart and are strung with a maximum stress in the conductor of 7500 lb., which allows a sag of not less than 25 ft. to the ground, which is increased to 30 ft. at highways. Each line is supported at the tower from nine suspension type insulators on standard towers, and from two sets of eleven insulators each on angle and anchor towers. Each disk has a dry flashover test of 90,000 volts, with a rain test of 56,000 volts, and a net weight, including hardware, of $9\frac{1}{4}$ lb. Where the character of the country requires, the lines are also anchored downward with a similar set of insulators.

Near Bakersfield, and about 135 miles from the generating stations, is located a switching station known as Borel Junction, where tie lines from the Borel station will connect with the Big Creek system. These lines consist of two 72,000-volt circuits from Borel, delivering approximately 13,500 kv-a. through a bank of three single-phase 50-cycle transformers of 4500 kv-a. capacity each. These transformers are wound for 150,000 volts primary and 72,000 volts secondary, with taps for 135,000 and 18,000 volts, and are duplicates of and interchangeable with the main transformers in the Eagle Rock substation. Duplicate sets of hand-operated non-automatic oil switches and disconnecting switches allow for the connection of either Borel line to either of the Big Creek lines. The ultimate arrangement of this switching station allows for the installation of a second bank of step-up transformers and connection to a third 150,000-volt line.

The 150,000 volt transmission line terminates at a step-down substation known as Eagle Rock, about nine miles from Los Angeles, where power from the Big Creek development will be distributed over the various trunk and distributing lines, formerly served by the steam plants. The steam plants will be held in reserve.

The 150,000 volt lines approach the substation from the north, and enter the building one on the east side and one on the west under canopies similar to those for the outgoing lines at the power houses. The lines are connected to the duplicate high tension buses through oil switches located on the fourth and fifth floors of the building. The 150,000 volt lightning arresters are also installed on the fourth floor. The four banks of main step-down transformers, with one spare unit, are placed on the first floor on each side of a central bay, each bank consisting of three single-phase 50-cycle water-cooled units of 4500 kv-a. continuous capacity. They step down the voltage to 72,000 and 18,000 volts, and are provided with taps for 135,000-volt primary operation, it being the intention to use two of these banks for stepping down to 72,000 and 18,000 volts respectively, but to have all transformers interchangeable. All banks are delta connected on both high and low tension sides. Back of the main transformers, on the east and west sides respectively, are located 18,000-volt and 72,000-volt oil switches, duplicate buses, outgoing line switches and lightning arresters. At the south end of the building are located two 15,000-kv-a. synchronous condensers, operating at 6600 volts, 375 r.p.m., for use in regulating the line voltage. With a voltage rise of 9.33 per cent. due to line capacity, and a delivered potential of 150,000 at the substation under conditions of no load, without the use of condensers, would require a charging capacity of 21,000 kv-a. per line. With the use of condensers the potential at both ends of the line can be held at 150,000 volts, the condenser supplying 12,300 kv-a. lagging and the generators 11,750 kv-a. Each condenser is complete with direct-connected exciter, and auxiliary regulating exciters similar to those at the power houses. The condensers are guaranteed to develop their full rated kilovolt-amperes at normal voltage and zero power-factor, leading or lagging. Starting is accomplished by means of half voltage taps in the transformers. Each condenser is connected through oil switches to a bank of three single-phase water-cooled 5000 kv-a. transformers, designed for 18,000 volts primary and 6600 volts secondary, with approximately 33 per cent, 37½ per cent and 45 per cent low voltage starting taps. The following apparatus is also installed: A spare 100-kw. motor-generator set for excitation of both condensers; storage battery with battery charging motor-generator set; station lighting and power transformers (220 volts); a 10,000-kv-a. bank of compensators for paralleling the two Kern River 50,000-volt lines of the same company with the Big Creek system through the 72,000-volt buses at this substation; and a complete duplicate system of oil piping for draining, purifying and storing oil for the various transformers, lightning arresters, and oil switches.

The switchboard, which is of the vertical type, is installed on a gallery overlooking the condenser room and contains the instruments and control switches for the various parts of the system, while integrating wattmeters for the outgoing feeders are mounted on auxiliary panels in the grill work enclosing the rear of the board. The station lighting, power, and storage battery switchboard is installed in the gallery at the right of the main board and the remote control field and exciter panels are mounted on the main floor in the exciter bay. Two sets of buses for the 150,000, 72,000 and 18,000 volt circuits are provided with selective oil and disconnecting switches. All 150,000-volt switches are of the solenoid-operated, non-automatic type; the 72,000-volt switches are of the solenoid-operated type, and are non-automatic for transformer secondaries and automatic for feeders, while the 18,000-volt switches are of the motor-operated type, and are automatic for the outgoing feeders and station lighting and power circuits only. The bus construction is similar to that in the power houses, the 150,000 and 72,000-volt buses being of 2-in. iron pipe, and the 18,000-volt bus installed in concrete chambers. There are six 18,000-volt and three 72,000-volt outgoing feeders of 5000 kv-a. capacity each.

The substation is built of reinforced concrete and structural steel; it is 168 ft. long, 131 ft. wide, and 106 ft. high, and is designed to allow extensions on all four sides to meet the requirements of the ultimate development, which calls for the addition of one 150,000-volt incoming line; two 13,500 kv-a. transformer banks stepping down to 72,000 and 18,000 volts, respectively; four 15,000-kv-a. synchronous condensers, each with its bank of transformers stepping down from 18,000 to 6600 volts; two 72,000 volt; and six 18,000-volt outgoing feeders and possible railway feeder circuits if the condensers are used as synchronous motors direct-connected to railway type generators.

The entire Big Creek development, including power houses, transmission line, switching and substations, was designed and constructed by the Stone & Webster Construction Company and all hydraulic and electrical apparatus was purchased on their specifications.

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# TRANSPORTATION DIFFICULTIES IN HONDURAS, C. A.

By J. W. Barnett

Superintendent of the Electrical Department of the Rosario Mines,
San Juancito, Honduras, C. A.

The writer tells a most interesting story of the difficulties met with in introducing modern machinery into a country as yet undeveloped. A good idea of the general conditions of the country is given and specific data is presented concerning the work incident to moving heavy machinery into the interior. The collection of photographs materially increases the value of the story narrated in the text.—Editor.

In this day of fast freight and express trains one is surprised at the antiquated methods of transportation still employed in some of the Central American republics. This article deals with conditions as they exist today in Honduras, the most backward of all those states.

Fig. 1. Unloading Freight Boats at the Mainland Port. These Have Just Arrived from the Island Seaport, Amapala, 21 Miles Away

The country is very thinly settled with natives of mixed Spanish, Negro, and Indian blood. Spanish is the only language spoken. Rugged mountains and table-lands occupy two-thirds of the entire area, and are of sufficient altitude to make the climate thereon temperate. The other third of the republic is suited to agriculture, but only a small portion of this is under cultivation. The nights are so cool in the highlands, at any time of the year, that one or two woolen blankets are necessary to enable one to sleep comfortably. Neither the rainy nor the dry season is disagreeable and, so far as climate is concerned, the country is ideal.

But Honduras is bankrupt, stagnant, devastated, and loaded with a national debt of $100,000,000 with accrued interest, the money being borrowed largely to build a fifty-seven-mile railroad, the only one in the whole republic. The people themselves are to blame for this condition.

"Senor," said an old Honduranean, "why should our people accumulate more than one shirt apiece, when a revolution may come at any hour and rob them of everything not on their backs?"

Nearly everyone aspires to be the President. The man with the strongest military support always gets the position. At the last election, six months after a revolution was finished, there was only one candidate for President and one for Vice-President—the successful leaders in the revolt. A notice was posted that a fine of five dollars would be imposed on all the men who neglected to vote. Consequently it went down on record that the candidates were unanimously elected. During ninety-two years of independence, only two Presidents have vacated office without at some time having had to resort to force as a means of holding their places. There has never been enough money in the treasury for a sufficient time to carry out improvements. For this and other reasons foreign capital has not been invested, except in a few instances, as in mining and fruit raising. As a result, the four most important cities of the country are not even connected by a cart road.

The problem of rapid transportation still remains unsolved. Not, however, because engineers are unable to cope with it; but because the movement of agricultural products, minerals, and machinery has been so limited, due to the existing conditions, that the large investment necessary for building good highways and railroads would have been unprofitable. The extremely rough, mountainous character of the country makes it impossible to construct roads cheaply.

There are only a few cities of importance in the whole republic. Porto Cortes, Tegucigalpa (the capital), San Juancito, and Amapala rank among the first. Porto Cortes is the Atlantic seaport, and Amapala is the port on the Pacific coast. Tegucigalpa, the capital, has about 30,000 inhabitants and is only twenty-one miles from San Juancito, where the Rosario mines, the largest in the country, are located.

Fig. 2. Twenty-six Oxen Pulling a Wagon Loaded with a 6-ton Rotor of a 38-pole Low-speed Induction Motor. The number of oxen is increased to 40 on steeper grades. Note the disadvantage at which the oxen pull around the curve

Since this article is to deal mainly with the transportation of heavy electrical and mining machinery into the central part of the country, for the New York and Honduras Rosario Mining Company at San Juancito, a description will be given of the transportation facilities from the Atlantic and Pacific coasts inland to that place.

The mines are two hundred and seventeen miles from the Atlantic port and one hundred and twenty miles from the Pacific port. The only railroad in the country runs from Porto Cortes, on the Atlantic coast, fifty-seven miles inland. This railroad is employed mainly for hauling bananas. Outside of this small stretch of track, there is nothing over which to transport freight and passengers except mule trails and cart roads. The only connection between the Rosario mines and the railroad terminal mentioned is a mule trail one hundred and sixty miles long. About thirty miles of it afford fairly level traveling, while the remaining one hundred and thirty miles are over an almost impassable, rocky, mountainous country. During the rainy season, the absence of bridges across the rivers often compel the pack trains to wait several days for the swollen streams to subside sufficiently to permit fording them. At some fords the cargoes are carried across in canoes, and the mules are obliged to swim the river to resume their journey. The mountain ranges have no general direction, and are broken up in such a way as to make traveling very difficult. It is a startling fact, that if it is desired to take an ordinary unloaded ox-cart from the railroad terminal to the Capitol, or to the Rosario mines, it could only be done by packing it upon the backs of mules.

Fig. 3. Wagon loaded with a generator armature on way to the mines, block and tackle being used to assist in the ascent

Thus the capital, Tegucigalpa, and the mines are cut off from traffic with the Atlantic port, except by pack-train. The letter mail is carried by a native on foot, who makes the trip to the railroad terminal in four days. Pack-trains carry the second-class mail and require from seven to ten days for the trip.

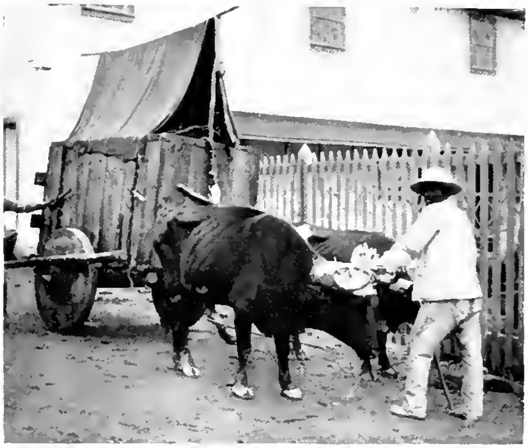
Fig. 4. An Oil Governor for the Pelton Water Wheels at the San Juancito Power Plant. Note the pole resting on the hub of the wheel. This is used as a brake when coming down the mountains

The Rosario Mining Company was confronted with the problem of bringing in machinery for two power-houses, 2200 h.p. capacity, two substations, and a 200-ton stamp mill. The first power-house and substation were installed four years ago. The second power-house, substation, and stamp mill were finished last year. The rotors of the large low-speed compressor motors weighed six tons apiece without their shafts, and the four mortars for the mill weighed four tons each. There were numerous other pieces weighing from 4000 to 10,000 lb., consequently, the idea of bringing in the machinery from the Atlantic coast was out of the question. The machinery, therefore, was shipped from New York to Panama, across the isthmus, and up the Pacific coast to Amapala. Amapala is located on an island, so that all freight must be carried by small boats to the mainland, a distance of twenty miles. These boats are propelled by long sweeps manned by natives. Sails are used when the wind is favorable. The mining company put up its own crane for unloading freight at the mainland. There is a good cart road from the mines to the Pacific port, but even from that side a large mountain range had to be crossed before reaching the mines.


Fig. 5. A piece of good mountain road. A sheer drop of 1000 ft. at the left-hand edge of the road


Fig. 6. A typical Honduranean Cart Road

The transportation facilities of the country offered only two means of bringing the machinery up to the mines, viz., on mule back or on oxcarts. The first method being impossible for the purpose, the mining company had special heavy trucks made to order, in the United States, which would stand the strain of carrying 6-ton pieces over rocky mountain roads.

The quickest and cheapest method of transportation being by pack mules, the companies from whom the equipment was purchased were requested to ship the machinery unassembled, packing as much as possible in boxes weighing 150 lb. or less. A mule will carry 300 lb. but, of course, two 150-lb. boxes balance better on the pack saddle than one 300-lb. box.

Mule freight costs one and a half cents a pound for the trip between the coast and the mines, and the time allowed is fifteen days. Ox carts, which come next to pack mules in cheapness and speed, can handle freight weighing from 300 to 2200 lb. at two cents a pound. Their time limit is twenty-two days and a fine is imposed if they arrive late. Freight generally arrives in half the alloted time but, due to the poor grade of "fuel" used in the mule and ox trains, they are not guaranteed for continuous service. The time limit is made long enough to allow the sore backs and feet of the animals to heal up, and to give them an opportunity to charge their bony "storage batteries" with a little fat. The few horses found in the republic are of a very inferior breed. Mules are used for both pack and saddle animals, in fact they represent both the Pullman and baggage cars for travellers in Honduras.

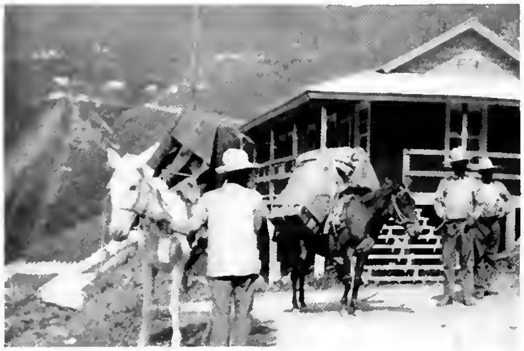

Fig. 7. The only means of transfer of baggage from the mines 160 miles to the railroad terminals on the Atlantic coast. This is the shortest route to the United States

The largest wagons, loaded with the 12,000-lb. pieces, were pulled by thirty or forty oxen. Thirty days were consumed in making the last twenty-one miles of the trip, which was over the highest mountain range. Two revolving fields of the 350 kv-a. generators came assembled on their shafts, and two came entirely dismantled—shafts, spiders, field coils, field poles, wedges, insulation, etc., all being packed in separate boxes. The twelve 125 kv-a. 6600/2200-volt transformers came in a similar unassembled condition, coils, insulation, laminations, etc., being packed in boxes weighing 150 lb. each. The transformer tanks came built up. A wagon loaded with one of the generator fields upset and almost caused the loss of the piece down the mountain side. Profiting by this experience, the remaining generator fields were shipped dismantled, which made them easier to handle and eliminated the danger of springing a shaft.

Fig. 8. One of the three Sections of a tube mill for a 200-ton stamp mill

Forty oxen and twenty-five men were used on each heavy wagon in crossing the mountain range nearest the camp. Blasting out, widening, and repairing the road had been going on for months before the first wagon left the coast on its inland trip. In places the road was blasted out of the faces of cliffs where there was an almost straight drop of a thousand feet. The outside wheels of the wagons ran within a foot of the edge of the precipice at some of the narrowest places. Two oxen were killed at this place, by falling off the road. The cart road twists and winds its way up the rugged mountain side until it reaches an altitude of 7200 feet before it starts to descend the other side by an equally tortuous route to the works of the Rosario mines. Sharp turns occur in the road where the grade is as great as forty per cent, which

Fig. 9. A narrow escape of a 9000-lb. revolving field from a 1000-ft. fall

prevents the oxen from getting a fair chance to pull. Blocks and tackles hitched to anchor posts set at intervals along the road were used at these places, the bulls being hitched to the fall lines of the tackles. Anchor posts were also used in letting the wagons down the mountain sides. In many places a heavy cable had to be fastened from the wagon to trees or rocks farther up the mountain in order to prevent the wagon from going to the bottom of the gulch when the softer sections of the road gave way under the outside wheels. This precaution saved one of the revolving fields, when the wagon carrying it upset on the road near the mines. Each heavy piece of machinery was bolted and lashed with steel cable to the wagon so that it could not fall off regardless of the angle at which the trucks were inclined.


Fig. 10. The Peak of the Hill with the Winding Cart Road on the left-hand side shows the site of the 200-ton stamp mill, shops etc., of the Rosario Mines before construction work began

Twenty-one miles in thirty days is not very fast traveling; but, on account of the condition of the trails, the weight of the machinery, the means at hand, and the fact that not a single piece of apparatus was lost or damaged, speed was not considered a very important item. Not only the roughness and steepness of the road made it tedious work, but other difficulties arose to retard the movement of the wagons. Rains set in and planks had to be dragged along to place under the wheels to prevent them from cutting axle deep into the mud. The oxens' feet were softened by the mud and wore down to the quick, making them unfit for service until leather boots were made for them. At the altitude of the pass, 7200 feet, clouds are present nearly every day, enveloping everything in a dense fog and causing ropes and cables to become muddy and hard to handle. The roads too were slippery.

Parts of machinery which were needed first in the construction work were sometimes unavoidably delayed, which made more work in changing gangs from one job to another before the first was finished.

The works of the New York and Honduras Rosario Mining Company are located on the eastern slope of the San Juancito mountains. The lower Guadalupe power-house is at an altitude of 2900 feet and has a 500-foot head of water. The San Juancito power-house, which runs in parallel with the other, is a mile farther up the mountain at an altitude of 3400 feet and operates under a 1355-foot head. This gives a pressure at the nozzle of 585 lb. The spouting velocity of the water is three miles a minute. A mile and a half above San Juancito are located the stamp mill, offices, quarters, shops, and Rosario substation, at an altitude of 5200 feet. The Pena Blanca substation is half a mile from the mill and its elevation is 6000 feet. Thus, in three miles, the transmission line climbs from an altitude of 2900 feet to an altitude of 6000 feet. Yet, during four years of operation there has not been a single shut down due to lightning, and in fact no serious shut down at all. The power houses are neatly constructed with tile roofs and tile floors, and are equipped with aluminum-cell lightning arresters, traveling cranes, self-contained air compressors for blowing out the machinery, etc. Both patented and "home-made" fool-proof devices have been placed on every piece of apparatus possible to prevent the native operators from damaging it, because from four


Fig. 11. A near view of the mill site when construction work was nearly completed

to six months elapse from the time the repair parts are ordered until they arrive. There are forty-two synchronous and induction motors in operation, ranging from one-half horse power motors to the large thirty-eight-pole, 280 h.p., direct-connected, compressor motors. Two motor-generator sets furnish direct current for the six mining locomotives. Besides these there are six alternators with their exciters and about thirty-five power and light transformers. The wire for the four miles of transmission line was shipped in 125-lb. rolls, so it could be brought in on mule back and handled easier on the steep mountain sides where, in many places, the transmission line runs on an 80 per cent grade.

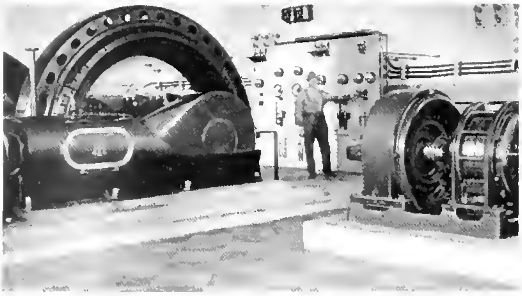

Fig. 12. Two 280 h.p. Induction Motors direct connected to an air compressor, at the Peña Blanca Substation

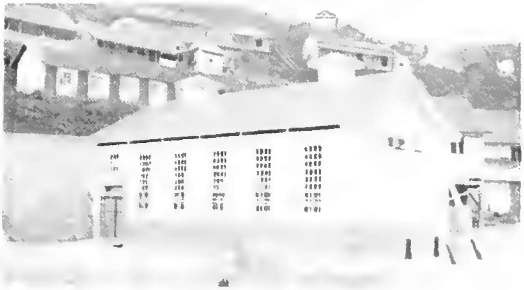

Fig. 13. The San Juancito Power House; one of the two hydro-electric power houses for the mines. This operates under a 1355-foot head water-pressure (585 pounds per square inch). Two 350 kv-a. alternators, 660-volt, 3-phase: two 600-h.p. Pelton Water Wheels

The fruits of all this labor of transportation, construction, and operation often surprises the travelers as they pass the pack-trains from the mines to the coast loaded with bars of gold and silver weighing 125 lb. each, two on the pack saddle of each mule. Every month, from $80,000 to $100,000 worth of bars are sent to the Pacific seaport by the same cart road over which the machinery entered. Only one native with five or six barefooted soldiers are needed to guard the bullion, because the bars are so heavy and the trails are so bad that thieves would find it difficult work to get away with their plunder. Thus the profits of the work are guarded by the largest obstacle to their acquirement, viz., poor methods of transportation.

Honduras has not had a revolution in two years and a railroad will be built into the interior of the country by an English company very soon, so the republic still has hopes for improvement.

Fig. 14. The Arrival of a Pack Train

# A REVIEW OF THE NATIONAL ELECTRIC LIGHT ASSOCIATION'S LAMP COMMITTEE REPORT

By G. F. Morrison

Manager of Works, Edison Lamp Works, General Electric Company

The author shows the growth of the incandescent lamp business in America and the astonishing way in which the tungsten or "Mazda" lamp has superseded the carbon lamp. The average candle-power and watts per lamp are shown in tabular form over a period of years and the steady improvement in efficiency for different sizes of lamps are shown in a striking manner. The improvements which have led to these increases in efficiency are cited. The subject of free lamp renewals is touched upon. This article should be read with much interest by those of our readers who are connected with the electric lighting industry.—**Editor.**

The Lamp Committee's report, which was read at the recent convention of the National Electric Light Association, because of its historical data and comprehensive review of the present situation, was undoubtedly the most interesting report on this subject yet rendered at conventions of this Association.

The manufacture and sale of incandescent lamps have grown to such proportions, and changes have taken place so rapidly that a review of this report will be of vital interest to all persons concerned in electrical development.

The aggregate sales of domestic incandescent lamps, exclusive of miniature lamps, for 1913, was slightly in excess of 100,000,000 lamps. This is an increase of 59 per cent over the total sales for 1907; 20.09 per cent for 1909; 12.40 per cent for 1910; 8.5 per cent for 1911; 5.87 per cent for 1912 and 11 per cent for the year 1913, which latter year shows, therefore, a marked increase in percentage over the two preceding years.

During 1913 the changes in the relative demands for the various classes (carbon, gem, tantalum and mazda) have been most pronounced. The tantalum lamp, for example, has practically gone out of existence. Fig. 1, curves showing yearly sales of domestic incandescent lamps, 1907-1913, is interesting in that it shows that the sale of carbon lamps today is less than 11 per cent of the total lamp business.

The Gem or metallized filament lamp has fallen off slightly in the past year in percentage, probably due to the fact that the Gem lamp was pushed so aggressively by lighting companies in place of the carbon the year before.

The increase in Mazda lamp business during 1913 has been very marked, approximately 60 per cent; the consumption of this lamp exceeding that of all other lamps combined.

In connection with the demand for the different lamps, it is interesting to note the slight change from year to year in the average watts per lamp and the radical increase in the average candle-power per lamp sold. This is brought out clearly in Table I, and is important in emphasizing the increase in the illumination obtained by the use of the Mazda lamp.

Analyzing the sale of Mazda lamps by sizes, it is interesting to note that the 25 watt embraces 29 per cent of the total Mazda lamp business; the 40 watt, 27 per cent and the 60 watt amounts to 15 per cent. In street series lamps we find that the 60 candle-power lamp is the most popular.

The ability of the manufacturer to turn out lamps accurately to a predetermined voltage and efficiency due to the improved methods brought about by drawn wire of exact sizes, makes important the introducing of lamps of the proper size and correct voltage on the lines on which they are to be operated, especially so in view of the rapid increase in the efficiency of Mazda lamps.

There can be no economy and there is an actual loss to the consumer and to the central station company in operating lamps under the voltage for which they are intended and a reasonable amount of attention to securing lamps of proper voltage for the circuits on which they are to be operated will conserve the interests of member companies and improve the service rendered to customers.

It can easily be determined, theoretically, that the total cost of a given amount of light is greater at any efficiency poorer than that of the manufacturer's rating. In fact, the table on this subject given in the report showed that efficiencies even higher than manufacturer's rating are justified from a theoretical cost, but that the manufacturer's selection of efficiency is such as to also give convenient commercial lives. At the same time, it is determined from these tables that when lamps are used whose labeled voltage corresponds to the actual voltage of the socket a higher wattage is consumed than would be the case if the voltage at the socket were lower than that of the lamp label.

Due to the general improvement in quality and the ability to make Mazda lamps for an exact voltage, a change of no little importance has been the abandonment of the three-voltage label and the substitution of a label bearing a single voltage. The efficiency of lamps at the voltage shown on the label corresponds with the high operating efficiency of the three-voltage label. Marked improvements in general lighting should result from this change by having lamps more uniform and operated at a better efficiency.

During the year the quality of Mazda lamps has been greatly improved in several ways. First, by improving the quality of the tungsten wire the filaments have been made stronger, with the result of delaying the condition of brittleness to a much later period in the life of the lamp; second, an improvement has been made in supporting the filament by changing from heavy rigid supports to light semi-flexible or flexible supports, which flexibility protects the filament throughout its life and makes the lamp much stronger; third, the introduction of chemicals into the lamp to prevent or delay the appearance of blackening and to improve the efficiency at which the lamp operates. This practice has been extended to the 25- and 40-watt lamps, and has been greatly improved in the 60 to 500-watt lamps.

The improvements from time to time in the efficiency at which Mazda lamps will operate and yet maintain the same life, the approximate time of the introduction of the various sizes of lamps and the changes in candle-power per watt are shown in Table II

It is to be noted that these improvements in efficiencies have been obtained without any sacrifice of life, which continues to be maintained on the average at not less than a 1000-hour basis.

Through general exhibits at conventions and electrical shows during the Fall of 1913, and description in the GENERAL ELECTRIC REVIEW of October and December, 1913, by Dr. Langmuir, attention was called to developments whereby the efficiency of high amperage Mazda lamps could be greatly increased by the introduction of an inert atmosphere into the lamps. Lamps embodying this improvement differ in appearance from the older lamps, in that they are constructed on what is known as the concentrated filament principle, in which the filament is wound in a small spiral. This spiral filament is supported on anchors so that it is gathered into a very small space, and held away from the stem of the lamp in order to protect the stem from the intense heat.

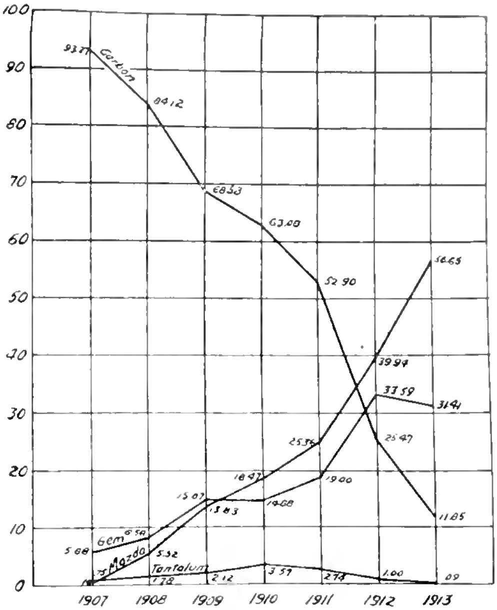

Fig. 1. Curves showing number of lamps of each type, in percentage, in use for years 1907-1913 inclusive

The bulbs used on these lamps are smaller and the shapes may differ somewhat from the bulb shape used on similar wattage vacuum lamps.

The presence of the inert atmosphere in the bulb prevents or delays the volatilization of the filament and any discoloration which takes place is deposited on the upper surface of the bulb, so that it does not interfere with the passage of light through the bulb in the useful zones.

Since May 1, 1913, in addition to the new Mazda lamps referred to, a number of new types and sizes of lamps have been standardized and announced by the manufacturers as additions to their regular schedules and certain types have been removed from the schedule since that time. Tables V and VI indicate these changes.

A number of the larger lighting companies have inaugurated with success during the past year the policy of including within the free renewal list the 100-watt and larger sizes of Mazda lamps. This important step was first

## TABLE I. THE TOTAL CANDLE-POWER AND THE AVERAGE WATTS OF THE TOTAL ANNUAL SALES OF DOMESTIC INCANDESCENT LAMPS, 1907 TO 1913 INCLUSIVE

| | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 |
|---|---|---|---|---|---|---|---|
| Average candle-power of lamps sold | 18 | 19 | 21 | 23 | 25 | 26 | 29.4 |
| Average watts of lamps sold | 53 | 53 | 52 | 51 | 51 | 49 | 47 |

## TABLE II GIVING EFFICIENCIES IN CANDLE-POWER PER WATT OF DIFFERENT SIZES OF MAZDA LAMPS AT DATE OF INTRODUCTION AND AT SUBSEQUENT DATES, THUS SHOWING THE IMPROVEMENTS AND INCREASES IN EFFICIENCY

| Size of Lamp in Watts | Oct. 1, 1907 | Oct. 1, 1908 | July 1, 1909 | Jan. 1, 1910 | July 1, 1910 | Oct. 1, 1912 | April 1, 1913 | Jan. 1, 1914 | April 1, 1914 | June 1, 1914 |
|---|---|---|---|---|---|---|---|---|---|---|
| 25 | | 0.69 | 0.69 | 0.76 | 0.76 | 0.85 | 0.85 | 0.88 | 0.88 | 0.88 |
| 40 | 0.78 | 0.78 | 0.78 | 0.81 | 0.81 | 0.85 | 0.85 | 0.91 | 0.91 | 0.91 |
| 60 | 0.78 | 0.78 | 0.78 | 0.85 | 0.85 | 0.86 | 0.88 | 0.93 | 0.93 | 0.93 |
| 100 | 0.78 | 0.78 | 0.78 | 0.85 | 0.85 | 0.88 | 0.93 | 0.98 | 0.98 | 0.98 |
| 150 | | | 0.78 | 0.85 | 0.85 | 0.89 | 0.97 | 1.11 | 1.11 | 1.11 |
| 250 | | 0.80 | 0.80 | 0.88 | 0.88 | 1.00 | 1.00 | 1.11 | 1.11 | 1.11 |
| 400 | | | | | 0.88 | 1.00 | 1.00 | 1.11 | 1.11 | 1.33 |
| 500 | | | | | 0.88 | 1.00 | 1.00 | 1.11 | 1.11 | 1.43 |
| 750 | | | | | | | | | 1.54 | 1.66 |
| 1000 | | | | | | | | | 1.66 | 1.82 |

## TABLE III. FOR MULTIPLE BURNING ON 100 TO 130-VOLT CIRCUITS

| Size of Lamp in Watts | Max. Size Bulb | Candle-Power per Watt | Candle-Power | Style B No. |
|---|---|---|---|---|
| 400 | S-40 | 1.33 | 535 | 400 |
| 500 | S-40 | 1.43 | 715 | 400 |
| 750 | S-46 | 1.66 | 1250 | 400 |
| 1000 | S-52 | 1.82 | 1820 | 400 |

## TABLE IV. FOR SERIES BURNING ON CONSTANT CURRENT CIRCUITS

| Size of Lamp in Candle-Power | Amperes | Maximum Size Bulb | Candle-Power per Watt | Average Watts | Style B No. |
|---|---|---|---|---|---|
| 60 | 5.5 | S-24½ | 1.26 | 47.5 | 400 |
| 60 | 6.6 and 7.5 | S-24½ | 1.49 | 40.2 | 400 |
| 70 | 5.5 | S-24½ | 1.30 | 62 | 400 |
| 80 | 6.6 and 7.5 | S-24½ | 1.52 | 52.8 | 400 |
| 100 | 5.5 | S-24½ | 1.33 | 75 | 400 |
| 100 | 6.6 | S-24½ | 1.54 | 65 | 400 |
| 250 | 5.5 | S-35 | 1.37 | 182 | 400 |
| 250 | 6.6 and 7.5 | S-35 | 1.59 | 157.5 | 400 |
| 400 | 5.5 | S-40 | 1.41 | 284 | 400 |
| 400 | 6.6 | S-40 | 1.64 | 244 | 400 |
| 600 | 6.6 | S-40 | 1.64 | 366 | 400 |
| 600 | 20 | G-40 | 2 | 300 | 400 |
| | | S-40 | | | |
| 1000 | 20 | S-56 | 2 | 500 | 400 |

### TABLE V. NEW LAMPS STANDARDIZED SINCE MAY 1, 1913. IN ADDITION TO THE NEW LAMPS REFERRED TO, THE FOLLOWING LAMPS HAVE BEEN STANDARDIZED DURING THE YEAR

| Size in Watts | Volts | Class | Bul | Diameter in In. | Overal Length in In. |
|---|---|---|---|---|---|
| 25 | 100–130 | Mazda | T-8 | 1 | 12 |
| 40 | 100–130 | Mazda | T-8 | 1 | 12 |
| 40 | 200–260 | Mazda | S-19 | 2 3/8 | 5 1/8 |
| 60 | 200–260 | Mazda | S-21 | 2 5/8 | 5 7/8 |
| 15 | 100–130 | Mazda | G-25 | 3 1/8 | 4 3/4 |

### TABLE VI. LAMPS WHICH HAVE BEEN ABANDONED SINCE MAY 1, 1913

| Size in Watts | Volts | Class | Bulb | Diameter in In. | Overall Length in In. |
|---|---|---|---|---|---|
| 40 | 100–130 | Mazda | S-21 | 2 5/8 | 5 1/2 |
| 60 | 100–130 | Mazda | S-24 1/2 | 3 1/16 | 7 1/8 |
| 40 | 200–260 | Mazda | S-21 | 2 5/8 | 5 7/8 |
| 60 | 200–260 | Mazda | S-24 1/2 | 3 1/16 | 7 1/4 |
| 60 | 200–260 | Mazda | G-30 | 3 3/4 | 6 3/8 |
| 100 | 200–260 | Mazda | G-35 | 4 3/8 | 7 |
| 150 | 100–130 | Mazda | G-40 | 5 | 8 |
| 80 | 100–130 | Gem | S-24 | 3 | 5 3/4 |
| 100 | 100–130 | Gem | S-24 | 3 | 5 3/4 |
| 50 | 100–130 | Gem | T-10 | 1 1/4 | 5 7/8 |
| 35 | 105–130 | Gem | S-19 | 2 3/8 | 5 1/8 |
| 54 | 105–130 | Gem | S-19 | 2 3/8 | 5 1/8 |

taken by some of the companies on August 1, 1913, when Mazda lamps in sizes of 100 watts and larger were included and quite recently, or about May 1st, the free renewal privilege was extended to the 60-watt lamp. It is recommended that lighting companies continue a liberal policy in furnishing lamps of the Mazda type on free renewal basis and extending this privilege to include other sizes as rapidly as reduction in price and the improvement in quality of the lamps may make possible.

The policy of the central-station companies in maintaining a close supervision over the lamp situation is practically unanimous and they are of one opinion as to the advisability of continuing it. This policy aims to maintain a high standard of illumination, and insure satisfactory performance of lamps, both as to amount and color of light and lamp life. This is accomplished by supplying customers with the best lamps on the market, rather than leaving them to obtain them under conditions which would less surely safeguard lamp efficiency and life. This, in turn, protects the legitimate dealer in his lamp transactions with other users of incandescent lamps.

While there is an ever-increasing tendency in the direction of introducing Mazda lamps and the adoption of a broad and liberal policy on the part of the central station, the movement to popularize modern lighting units should be universal throughout the country and this policy should be continued and augmented wherever possible by central station companies to encourage the use and adoption of the Mazda lamp by its customers.

# ICE

By A. R. Smith

Construction Engineering Department, General Electric Company

In several recent issues of the Review there were articles of special interest dealing with mechanical refrigeration and artificial ice. In the present article, the author makes some direct statements concerning the cost of producing artificial ice; both the investment necessary and the actual cost of production are given. The contamination of natural ice is inevitable, while the contamination of artificial ice is either caused by using improper methods or by carelessness. The manufacture of artificial ice, when its advantages are thoroughly recognized, should form a profitable "valley" or off-peak load for central stations.—**Editor.**

A luxury of today becomes a necessity of tomorrow, and conditions which we are content to endure at present are almost unbearable when one becomes accustomed to better conditions. These statements are pertinent to the users of natural ice. It is strange how critical is a community using artificial ice, but the fact is that artificial ice rejected by the customers in the south would be accepted as good quality ice by the patrons of the natural product. Now, why is it that there is so little competition between natural and artificial products in colder climates? Is it the general belief that artificial ice cannot be sold at the same price as natural ice; or, that there is no market for good ice at a slightly increased cost; or, that the initial investment for an ice plant is so great that capital cannot be readily obtained? The writer will attempt to dispel any such views by comparing the quality of ice and the cost of production.

### Selling Price

The fact that artificial ice is being marketed in the south at the same price and in some cases cheaper than natural ice is sold in the north, is very good evidence that competition is feasible in cold climates. As an example, an ice plant manufacturing ice at the rate of 20,000 tons per year and distributing to a trade within a radius of five miles, retails the ice at $8.00 per ton; whereas, in a northern city of 100,000 inhabitants, a company harvesting approximately 30,000 tons per year and distributing within a radius of two miles, retails it at $12.00 per ton.

It is true that the ice season extends over a longer period in the south, but there is not so great a difference as one might imagine. It is also true that in the south the coal and ice business is frequently combined, and the same help and teams are used all the year round, which condition is not so applicable to northern cities, where the majority of people purchase their winter coal supply in the summer. But the superiority of artificial ice should result in a market the entire year when sold in conjunction with natural ice. And, because of the reduced cost of manufacturing ice under high load factor conditions, it should be possible to make a better price to those who purchase ice at all seasons of the year.

### Investment Costs

For the purpose of comparing the investment costs, let us assume a plant of 120 tons capacity, that is, one capable of producing 120 tons of ice per day, and selling 23,340 tons per year (a load factor of 50 per cent) as shown in Fig. 1, and that the plant is built in connection with a steam turbine generating station and obtains steam therefrom.

The approximate cost of such a plant containing two modern and complete 60-ton equipments housed in a first class fireproof structure would be as follows:

| | |
|---|---|
| Ice machinery consisting of: 18 in. by 28 in. compound Corliss condensing ammonia compressors; ammonia condensers; distilled water reboilers; coolers and storage tanks; ammonia receivers and accumulators; freezing tank, cans and covers; ice dumps and lifts; steam, water and ammonia piping. Installation | $51,400 |
| Steam condensers and auxiliaries consisting of: Surface condensers; circulating pumps and air pumps; piping. Installation | 6,000 |
| Building structures consisting of: 70 ft. by 35 ft. by 30 ft. compressor room; 70 ft. by 70 ft. by 12 ft. tank room; sheet cork insulation around tanks; shelter and basin for ammonia condensers | 14,500 |
| Storage rooms consisting of: Two 300-ton storage rooms; two 60-ton handling rooms; all insulated with sheet cork | 17,500 |
| Land | 3,000 |
| Total | $92,400 |

If capital is skeptical, the storage rooms might be dispensed with temporarily and a cheaper building erected for the plant, thereby reducing the cost to some $72,000.00. Or, if the plant is to generate its own steam, the cost would be approximately $82,000.00.

With interest at 6 per cent, depreciation at 4 per cent, and insurance and taxes at 1½ per cent, the fixed charge cost on $92,400.00 would be $10,600.00 per year.

With an output of 23,340 tons per year, the fixed cost per ton would be 45½ cents. But, if the yearly output could be increased to 29,100 tons, as suggested in Fig. 1, the fixed charge cost would then be 36½ cents per ton.

The investment for a storage house for 23,340 tons of natural ice, allowing 10 per cent shrinkage would be $30,000.00, based on a cheap wooden structure costing 3 cents per cubic foot of contents, or a cost of 14.8 cents per ton with the same rate of interest, depreciation, insurance and taxes.

### Production Costs

Naturally, the greater the output the cheaper the manufacturing cost per ton. Curve shown in Fig. 2 will represent a fair cost; it is not exceptional. For instance, a production of nine tons of ice per ton of coal is figured, whereas, a rate of eleven to one has been attained. Steam is figured at 28 cents per 1000 lb.; water at 10 cents per 1000 gal.; engineers at $4.00 per day, and ice pullers at $2.00 per day. Lubricants, supplies and repairs are also included.

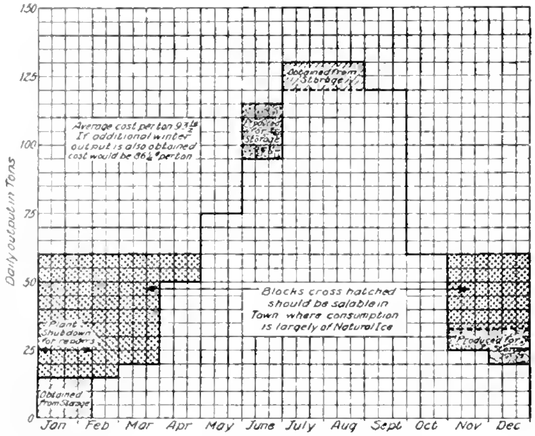

Fig. 1 A Representation of an Average Load Curve for a 120-Ton Ice Plant

Fig. 1 represents what might be termed an average load curve for a city having a six or seven months heating season and which could be handled by a 120-ton plant. It will be observed that the peak during July and August is taken care of by the 600-ton storage capacity and this storage makes possible a complete shut-down during January for repairs, although this is not essential where the apparatus is in duplicate. The average yearly production cost per ton, figured from this and the curve shown in Fig. 2, is 93½ cents.

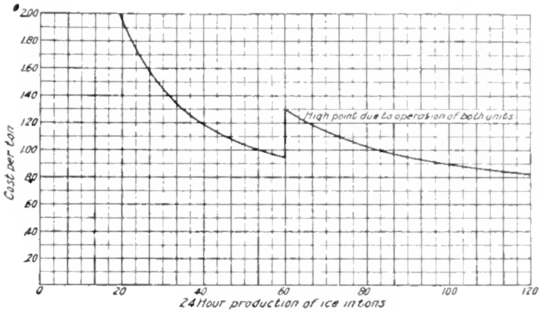

Fig. 2. Curve Showing the Cost per Ton of Ice at Different Rates of Production in a 120-Ton Plant

In a city where the consumption is largely of natural ice, the company could cater to a trade requiring ice in all seasons, and it should not be difficult to improve the load factor as indicated by those sections cross-hatched in Fig. 1. This improved load factor would reduce the cost to 86¼ cents per ton.

There is an expense incident to the harvesting of natural ice and the handling of the ice from the storage to the wagons. Just what this would amount to is rather uncertain, but the writer would hazard a guess of 15 cents per ton. This would not, of course, include the wholesale purchase of part of the quantity, should the winter's crop be insufficient for the trade.

### Total Cost per Ton

| | |
|---|---|
| Artificial ice (23,340 tons output) | |
| Fixed charges | $0.455 |
| Production cost | 0.935 |
| TOTAL | $1.39 |
| Artificial ice (29,100 tons output) | |
| Fixed charges | $0.365 |
| Production cost | 0.8625 |
| TOTAL | $1.2275 |
| Natural ice (any output) | |
| Fixed charges | $0.148 |
| Production cost | 0.15 |
| TOTAL | $0.298 |

From the above it will be noted that if artificial ice is sold at $9.00 per ton and natural ice at $8.00 per ton, the excess cost of the former would be compensated for. Or, if both are sold at \$8.00 per ton, the percentage of the selling price remaining to cover the cost of distribution and profits would be $82\frac{3}{4}$ per cent, $84\frac{1}{2}$ per cent, and 96 per cent respectively. However, the cost of distributing artificial ice should be less than natural ice because the delivery men are not required to cleanse each cake.

Fig. 3. Illustration of a Cake of Artificial Ice Manufactured from Distilled Water.

### Common and Unavoidable Contamination of Natural Ice

Ice is frequently cut from lakes, ponds and streams, the water of which would not be considered suitable for drinking purposes, filtered or unfiltered. This ice may be used in drinking water on the claim that the process of freezing purifies it. Acknowledging that this purification is true under certain conditions, because any visible impurities in artificial ice usually find their way to the core, the last part frozen, there are other considerations which would indicate that impurities can be entrapped. Ice is frequently permeated with particles of coke expelled from passing locomotives; impurities from the air are deposited on top of the ice by falling snow or rain and frozen fast to it; a fracture in the ice often causes the surface to be flooded, carrying with it stream sewage and other impurities, all of which may be entrapped by freezing.

If it is conceded that natural ice should not be used as a direct cooling agent for drinks and edibles, then it loses one of its very important functions. However, it would be quite impractical to legislate against such use and even difficult to evade the use of it personally when eating or drinking in public places. Then there is the straw and dirt which accompanies the ice from the storage and finds its way to the refrigerator of the house, due to the careless washing of the cake by the delivery man.

### Uncommon and Inexcusable Contamination of Artificial Ice

Complaints on artificial ice are not unheard of, and they may be as follows: Salty ice, taste of ammonia, odor in core, presence of oil, presence of iron oxide.

In the can system, the cans are set in a brine consisting usually of common salt water, but sometimes of a solution of calcium chloride. Should a leak develop and the water become salty, it will be detected by its flaky appearance immediately upon the removal of the cake from the can.

Ammonia contamination may occur in the double pipe pre-coolers, or the storage tank. But the former can be entirely dispensed with, with little effect on the cost, and the latter can be absolutely safeguarded by using continuous or welded expansion coils.

The odor in the core which may arise from the presence of oil is entirely eliminated when the water for making ice is obtained from the turbine condensers, as the steam never comes in contact with any lubricating oils. Odor arising from foul boilers is inexcusable if the boilers are properly cleaned and excessive use of boiler compounds avoided.

The presence of rust in the ice can be avoided by using galvanized or tinned piping and utensils for the distilled water, and exercising proper care to prevent oxidation when plant is not in operation, or by using brass piping.

### Treatment of Water for Artificial Ice

Starting with the city drinking water or pure well water, it is first evaporated in the boilers and then, after passing through the turbine, is condensed in a surface condenser. From the condenser it is pumped by means of a centrifugal pump to the reboilers where it is thoroughly boiled to drive off the air and automatically skimmed of any floating material. Thence, it passes through pipe coolers, where contamination from the cooling water can successfully be prevented, to charcoal filters and to the storage tank for filling the cans. In some cases it is again filtered through cheese cloth before entering the cans, but this operation should be unnecessary. The distilling process above mentioned destroys all bacterial life.

### Lasting Qualities of Ice

A quarter to one-third of the natural product is what might be termed "snow ice." This contains usually most of the impurities and melts rapidly because of its spongy nature and consequently more surface exposed to the air. There is no difference in the lasting qualities of the crystal or clear ice, whether produced artificially or by nature.

A good quality of artificial ice contains no air except a slight trace forming the core, thus practically the entire weight represents crystal ice. In fact, cloudy artificial ice which may contain only a thin film of air lines just inside the surface and representing a much better grade than the natural product would be rejected by the trade.

The actual weight of a cake of natural ice is a very uncertain quantity because of the irregular sizes and the loss due to melting in storage and during transportation. A 300-lb. cake of artificial ice ought to weigh from 315 to 320 pounds to provide for shrinkage during delivery; and the weight is determined by setting of the automatic filler. The ice enters the handling room or storage room at approximately the freezing temperature, which should be about 14 deg. F. Both these rooms are refrigerated to a temperature below 32 deg. F. and there is no melting loss or necessity for packing with straw, sawdust or the like. Really, the major portion of the ice is delivered to the wagons at a temperature somewhere between 14 and 30 deg. F., depending on how long it stood in the handling room and how much heat was added to loosen it from the can. Therefore, a certain quantity of heat has to be absorbed by the ice before it reaches melting temperature, a distinct advantage over the natural ice which leaves the storage at just 32 deg. F.

Fig. 4. Another illustration of the cake of ice shown in Fig. 3. The central core which here appears to have considerable width would be only of line width in an edge-on view.

The reader should understand that there are many different and distinct systems of manufacturing ice from raw and distilled water and with and without compressors, and that the foregoing description applies to a comparatively commonplace can system.

# "SAFETY FIRST"

## A FEW INDUSTRIAL EXPERIMENTS ON ACCIDENT PREVENTION SUCCESSFULLY APPLIED AT THE PITTSFIELD WORKS OF THE GENERAL ELECTRIC COMPANY

By Sydney Whitmore Ashe

The following paper is the result of a careful study of the subject of accident prevention extending over a considerable period. It indicates the means taken to analyze this subject, describes the plan followed in reducing certain specific accidents, outlines the method of caring for the injured, gives the educational methods used to carry this work through a large organization and summarizes the results obtained. To give a comprehensive view of this subject various abstracts have been incorporated verbatim in the paper, the author, thinking that they may prove as helpful to others as they have to him in following this work.—Editor.

### Preliminary Study

In systematizing the safety work at the Pittsfield Works of the General Electric Company, a careful study was made of the accidents which occurred over a previous period of several months. To facilitate the study and determine the value of the accident prevention methods instituted, a form was printed and filled out weekly. This form, at a glance, gives the number of accidents which occur and also distinguishes between major and minor accidents. The form also gives data covering welfare trips and medical service which is extended; in fact, it gives at a glance the complete load carried at our emergency hospital each day during the week. In addition to this, a daily record is kept giving the individual detail on the major and minor accidents which occur. A study of this data from week to week revealed the fact that the accidents which occurred seemed to lie in certain groups. These groups consisted mainly of electrical shocks, burned feet in the foundry, eye cases, punch press accidents and strains. Plans were formulated and constructive work begun on each one of these particular groups. After a time, when progress had been made, progress curves, Fig. 1, were plotted for the different departments showing the ratio of accidents to employees. In this way it was possible to detect new fields for endeavor, with the result that in time the rate has been reduced to an extremely low limit.

### Methods Used to Reduce Accidents

There is, at present, a local safety committee, composed of representatives of several departments, the chairman of which is a member of the central safety committee composed of representatives from all of our factories. The purpose of these committees is to meet frequently to talk, standardize guards of various sorts, standardize rules for safety, and issue instructions of all kinds. In addition to the local safety committee, the welfare and educational department publish a works paper. This paper is issued monthly and devotes a large portion of space to safety matters of all kinds. The material is surrounded with interesting notes pertaining to different departments so that the paper will be read regularly by the employees. This paper is given free to every employee. In addition to this, an active educational campaign is carried on continuously, in which the foremen, assistant foremen and employees are drawn together in groups and illustrated talks given them on safety. So soon as any new accident occurs, inspections are made and the cause determined. The manner in which certain classes of accidents have been reduced is described later in detail.

### Electrical Shock

In order to reduce to a minimum cases of electrical shock, a series of meetings were held during which the prone pressure method of resuscitation, as standardized by the National Electric Light Association, was taught. The nurse in charge of the emergency hospital

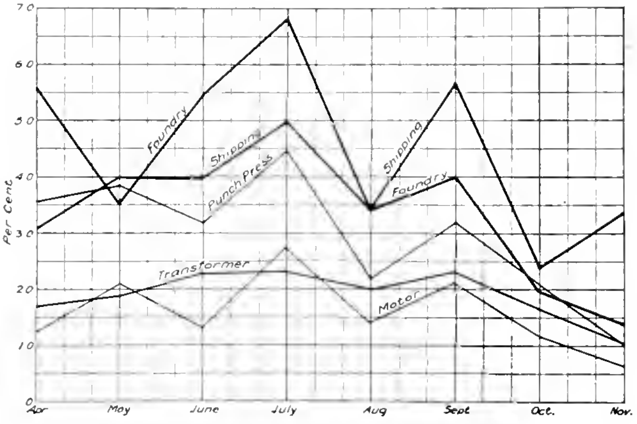

Fig. 1. Progress Curves showing the ratio of accident to employees with regards to time

illustrated the talk with lantern slides, giving the theory of the prone pressure method. This was followed by a demonstration of the method itself. Every three months, a talk is given to the new college men on test, besides giving them a copy of the rules. In this way, every new college man that enters the test is made thoroughly familiar with this method. The foremen and assistant foremen throughout the plant were got together in groups and were likewise instructed in the prone pressure method. From time to time articles describing the method have been printed in the works paper previously referred to.

Five hundred and fifty-volt, two phase current is used for the operation of all machine tools. If we compute the voltages across the outside phases and its maximum value, we find this to be equivalent to about 1093 volts, and in destructive action this is equivalent to about 1500 volts direct current. By calling this fact to the attention of the crane operators, foremen mechanics, carpenters, and electricians, this source of danger has been reduced to a minimum. Calling the danger to the attention of employees and showing them how to resuscitate an individual who has been shocked seems to emphasize the presence of the danger, and keeps the men from getting shocked. In other words, the number of cases of electrical shocks which have occurred during the past year have been reduced considerably, and during this period there have been five cases where the men, receiving voltages up to 15,000 volts, were unconscious and were resuscitated by the prone pressure method by their fellow-employees. One of the most interesting cases was that of a crane man in the foundry, who was resuscitated by a foundry foreman, Mr. Fazakerly, who previous to the shop instructions had been unfamiliar with the method. At the present time there is hardly a shop or an office in which there are not at least three or four men familiar with this method. It is hoped in time, to have every man in the organization trained in the prone pressure method of resuscitation, for it must be remembered that this wonderful, simple and effective method is good not only in cases of electrical shock but also in cases of gas asphyxiation, drowning, and fainting; in fact, in all cases of unconsciousness. In one case it was used by an employee to resuscitate a man who was unconscious from the effects of a fit at a country fair.

Backward Position

Forward Position

Fig. 2. Prone Pressure Method of Resuscitation

An important feature of the prone pressure method is that once an individual has seen a demonstration and has not had occasion to practice it, when the critical situation develops he seems instinctively to know just how to go about doing it. The men are made to feel that the main thing to do with this method is to free the individual, in case of electrical shock, from sources of power and then to begin the method, eliminating as far as possible all lost time. Fig. 2 shows the position of the patient after he has been laid on his stomach, hands stretched over the head and head turned to one side. The second man who appears on the scene removes any articles such as chewing tobacco or false teeth, from the injured's mouth and then places the blanket under him during one of the back strokes of the method. It has been found that the blanket placed under the individual's stomach is quite helpful in increasing the amount of air expelled. Where the prone pressure demonstrations were given to the employees in the foundry, a number of them could not understand the English language. It was necessary, therefore, to demonstrate the method by means of lantern slides and by means of the bell jar experiment showing the action of a cat's lungs. When the demonstration had been completed one of the foundry employees who spoke several languages, addressed the men in several languages. We found as a result of these meetings that the men were intensely interested. In fact, for a time, they carried on meetings of their own during the noon hour. To create additional interest, photographs were taken of the meetings and posted where the men could see them.

Fig. 3. Moulder's Congress Shoe for the Foundry

The use of resuscitation apparatus has been discouraged, owing to its complications of choice of method, time necessary to bring the apparatus to the injured person, and the possibility of having the apparatus used by an inexperienced person. The great factor in resuscitation cases is to "save the seconds" and therefore if every one can be trained in the same system, such as the prone pressure method, and taught to lose no time in using it, it is believed that the greatest efficiency will be reached. The experience at the Pittsfield Works has taught that this is a wise course and by following it, every case, namely five, has been saved since its general introduction. A situation may develop in the future where it will be necessary to modify this practice and supplement it by resuscitation apparatus; but until such a situation develops the present arrangement will be followed. Should occasion arise where it is necessary to use resuscitation methods on a female, instructions have been given the foremen to slit up the waist and corset strings of the injured on the back and apply the method direct to the skin, not standing on any ceremony. In addition to this, individual instruction has been given a number of girls so that they will not lose any time themselves when emergency arises.

### Burned Feet in the Foundry

To reduce foot burns in the foundry, the moulder's shoe, which has been so successfully used by many of our American foundries was introduced. In Fig. 3 it will be seen that this shoe is nothing more than the old fashioned congress shoe. They are arranged so that when metal falls on the toe it will quickly glide off. In case metal should get in the top of the shoe, the shoe can be quickly kicked off. These shoes have some asbestos in the sole, although their principal advantage consists in the point previously mentioned. They are ordinarily sold of a good quality for $2.00, although the cheaper qualities have been sold for as low as $1.50. These shoes were distributed through a local shoe dealer rather than handled by the Company, the dealer giving the employees the benefit of his discount, selling them for $1.80. Quite a number of them have been introduced in this way. Prior to the use of the moulder's shoe, we have had moulders come into the hospital wearing laced shoes with pieces of metal the size of a dollar burned into their feet, the metal having caught in the laces. There has been some thought of using asbestos leggings in addition to the moulder's shoe, and these are now being tried out. A further factor which has contributed towards the reduction of accidents in our work has been the use of a small ladle for carrying metal. Formerly where a ninety-pound ladle was used, there was a tendency to spill the metal, which explodes as soon as it strikes the ground. By using a smaller ladle, less metal has been spilt.

Last November, one of our deputies, who is a practical foundry man, visited one of the largest foundries in the state. The general manager asked him if he could assist him in securing 100 moulders. He said, "I am in great need of moulders. Right now, I have 30 men off with burned feet." The deputy said to him, "Why don't you stop the burns?" And then explained to him how a number of large companies had adopted the plan of purchasing moulders' congress shoes and selling them to the men at cost. This plan enables the foremen of the foundry to enforce the rule regarding the wearing of congress shoes. The manager said he would try the plan and ordered a large quantity of shoes.

The deputy visited the plant a few days ago, and the manager stated to him that the plan of selling shoes had worked out very successfully. All of the foundry men had purchased shoes, also a large percentage of the other shop men. Since the adoption of the plan the manager stated that the burns in the foundry had been reduced 85 per cent.§

### Goggles

There is probably no safety device that pays for itself with a higher rate of interest than that of the safety goggle. These goggles are purchased by the Company and supplied free to any employee who feels that he is in need of them. They are usually used where there is a possibility of flying particles, such as metal chips, molten metal, saw dust, emery, etc., entering an individual's eye. Where possible, the use of these goggles should be compulsory. In the Pittsfield Foundry, there was formerly a very large percentage of eye cases but since the introduction of these goggles, eye accidents have been reduced to a very low minimum. At the present time at least one eye a month is saved from serious injury in this foundry by the use of these goggles. One of the most interesting cases was that of a foundry employee who refused to wear goggles and was discharged. On coming back later he was re-engaged, conditionally, upon his wearing goggles. In about one week's time he came to his foreman with both glasses completely smashed. Both eyes had been saved. He is now one of our most urgent boosters for the use of the safety goggles. Where acetylene torches are used, colored goggles are employed by men so that their eyesight will not be injured by ultra violet light. In a number of cases employees have taken to wearing goggles on their own initiative after reading some of our published literature in our works paper, or after some of our safety talks.

### Emergency Service

The emergency service for the care of the sick and injured at the Pittsfield Works has been very carefully developed over a period of several years and at the present time it seems to be quite efficient. The emergency hospital, Fig. 4, centrally located, is equipped with two rooms, one being used by male patients and the other by female patients. The female nurse and welfare worker has general charge, following up all accidents, re-dressings and sickness in a thoroughly systematic manner. An ambulance is in readiness for service at any hour of the day or night. The hospital handles only emergency work, as the Works have relations with a local surgical hospital where all cases requiring more than temporary treatment are cared for. Instructions are posted at convenient places about the plant covering care of sickness and accidents, and in every large building the emergency service is supplemented by one or two "first aid jars," shown in Fig. 5. These jars are made of glass, are sanitary, and may be used in emergency for carrying water. They are equipped with liquid soap, bi-chloride solution, spirits of ammonia, small scissors, drinking glass, gauze and bandage. When a person is cut and is bleeding, the contents of these jars are to be used to bind up the wound so that the patient can come to the emergency hospital. In all cases where a bandage is

Male Ward

Female Ward

Fig. 4. Interior of Emergency Hospital

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§ R. W. Price of the Wisconsin Industrial Commission.

placed on the individual they must report to the hospital, where the wound is re-dressed in a thoroughly sanitary way. In this manner it is possible to keep down cases of infection, and out of a thousand cases that may be treated at the hospital it is seldom that one case of infection develops subsequently. There are cases, however, in which an individual will refrain from coming to the hospital for two or three days, sometimes a couple of weeks after the wound has occurred, and in this manner an occasional infected case comes up. It requires constant following up to see that the foremen report all cases as soon as they occur. Some men seem to have a dread of going to a hospital of any kind, but it is found that by giving safety talks among these men, and by having our female nurse participate in the demonstration, greater confidence is developed on the part of the men and there is less reluctance on their part to go to the hospital. If at any time an accident should occur when our emergency service from the hospital could not respond promptly enough, there are all the materials in these first aid jars to make a good sanitary dressing. Thisjar was modeled after the First Aid jar developed by the Norton Emery Wheel Company, except that our jar is a little larger.

Fig. 5. First Aid Jars

### Ruptures

One of the most difficult things to control in a large organization is cases of rupture. Quite recently we have had called to our attention, through a little investigation, the fact that a very large percentage of the employees working in ordinary occupations are ruptured from early birth. It has been suggested therefore, that to detect these cases it would be wise to submit all new employees to a complete medical and physical examination. Some companies are now doing this with very successful results. When it is determined that an individual already has a rupture, it is possible to locate that individual in such a place that he will not have to do heavy lifting.

### Miscellaneous Accidents

There are a large number of miscellaneous accidents which occur from time to time in a large manufacturing organization, and the only way in which such accidents can be avoided is to make a continual study of them and call the possibilities of their recurrence to the attention of the employees by educational means. At Pittsfield, this is done by means of lantern slide lectures and the works paper. Some of these accidents, such as those caused by protruding nails through boards, falls from scaffolding, dropping of tools off cranes, improper packing of boxes or apparatus in freight cars, unguarded manholes, unguarded machinery, emery wheels, saws, and numerous things of a similar nature, can only be avoided by developing in the men the habit of caution. From the manufacturing standpoint this is also a particularly good thing to do, for if men get in the habit of being careful of themselves and their fellow-employees to such a point that it forms a habit with them, they will be careful in the manufacture of the apparatus they are working on. Safety, for instance, in transformer manufacture, which forms 50 per cent of the work carried on at the Pittsfield Works, is paramount, and occasional safety notices in the works paper have done much towards cutting down accidents and

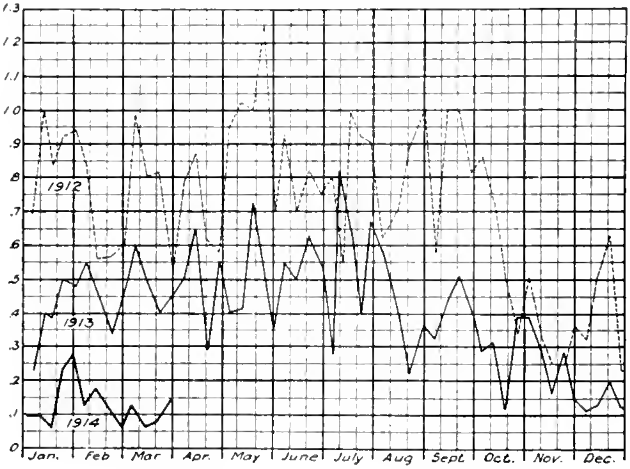

Fig. 6. Curves Showing Progress in Accident Reduction

improving the quality of the goods manufactured.

### Results

The general progress in accident reduction at the Pittsfield Works of the General Electric Company is shown in the ratio curves for 1912, 1913 and 1914, Fig. 6. These curves are plotted in terms of certain accident ratios and the week in the month. The ratio of the number of accidents per week over the average number of employees is used as one ordinate and the week of the month is used as the other ordinate. The progress which is shown in this ratio curve naturally does not make any allowance for variation in production. In times of heavy production where everything is being hurried in the desire to get the product out and make prompt shipment, when the men are tired from working long hours on shifts, the tendency to accidents is naturally greater than when under normal conditions of operation.

Whenever a safety device saves a bad accident, photographs are taken which are useful in many ways. Fig. 7 shows a broken emery wheel, in which the hood no doubt saved a man's life as he was standing directly in front of the wheel when it broke. Fig. 8 shows a pair of pliers used to place materials between the jaws of a punch press. The press repeated and caught the pliers instead of the man's hand, saving several fingers. In addition to safety work, considerable study is made of tuberculosis with a view of detecting all possible incipient cases. The results in this work have been very successful.

Fig. 7. Broken Emery Wheel. The workman was protected by the guard when the wheel exploded

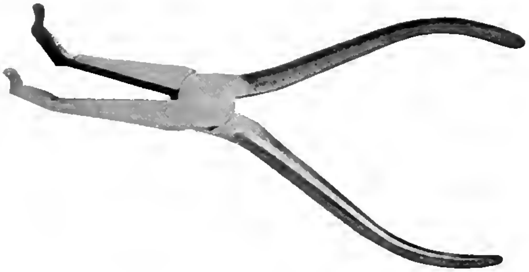

Fig. 8 Pliers Caught in Punch Press. The use of these saves many fingers

### Enthusiasm, Persistency, Co-operative Effort

The quotation, "Remember, gentlemen, what the poet said, that all great movements in the annals of the world are the triumph of enthusiasm, and be enthusiastic safety men," comes near hitting the nail on the head as an effective way of carrying on a successful safety campaign. The American people when stirred seem to have enormous inertia for accomplishment. As a race we are strongly susceptible to appeal, if the appeal is properly made. It is surprising to see how little discipline is really necessary to institute safety measures, and while we occasionally find a man who has to be forced to wear a pair of goggles or to use a pair of pliers under the jaws of a punch press, still as a usual thing the percentage of cases where this is necessary is quite small. It is necessary, however, to be persistent in calling attention to safety measures so as to develop in an individual habits of caution. The method which is used to do this should be occasionally changed. For instance, a series of illustrated lectures and demonstrations can be given the men, followed by occasional articles in a company paper. Inspections can be made and suggestions offered. Co-operative effort, after all, is the key note of success. How to secure the co-operation of the management, the department heads, the foremen, and last but not least the men themselves is the all important problem. In doing this a works paper can be of great assistance as an organ for disseminating information, reaching everywhere, creating good will and in a general way tying the various activities together.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## A MULTI-RECORDER INSTALLATION

A multi-recorder has been installed and is in operation in the power house of the Schenectady works of the General Electric Company. This recording machine, which has been developed by the Consulting Engineering Department's Laboratory, is designed to automatically print a record of switching operations. Its use has been extended so that by means of auxiliary devices it will record normal, excess, or low potential on a high-tension line; excess currents, short circuits, or grounds; the presence and duration of high-frequency surges; the approach of a storm; the charging and discharging of lightning arresters, etc.

A full description of the multi-recorder is given in the, 1912, A.I.E.E. proceedings (page 825: "Human Accuracy; Multi-Recorder for Lightning Phenomena and Switching" by E. E. F. Creighton, H. E. Nichols and P. E. Hosegood). Dr. C. P. Steinmetz in the March, 1914, proceedings has given some applications of this machine, in an article entitled "Recording Devices." It is the purpose of these notes to describe briefly the recorder as installed in the power station named above and to show how to read its record.

The multi-recorder comprises, essentially, a time stamp and a row of type bars, all electromagnetically controlled. The type bar has two symbols, a dash (—) and a number (from 1 to 50). Each number is arbitrarily assigned to a switch. When the record shows the number, the switch is closed; when the dash is printed in place of the numeral, the switch is open.

The time stamp is operated by a solenoid controlled by a seconds clock. It does not print every second, thus uselessly running out large quantities of paper, but prints only when a switching operation has occurred. The paper moves forward only when a record has been printed. In this respect its action is similar to that of a typewriter.

The multi-recorder prints to the second, but if the operations occur at more than a quarter of a second apart their relative occurrence will be shown by separate successive records printed during the same second. If several operations occur within the same quarter of a second, their record will be printed simultaneously.

Any cross line on a multi-recorder record shows the position of every switch at the second printed at the left-hand side. To see what has just occurred, this line is compared with the line immediately below it, the changes from numeral to dash or vice versa immediately indicate the operation.

The multi-recorder installation in the General Electric power station is a very small one, only thirty-three recording points being used at present. Twenty-two of them are connected to oil switches. Electrical connection is made to the magnets controlling these points by means of cheap auxiliary contacts, mechanically attached to the switch framework. By properly placing these auxiliary contacts, the recorder can be made to print whenever the moving parts of the switch are at any given position. The position generally chosen is that just at the point of entry of the oil switch contact into its finger. The auxiliary contacts are mechanically, but not electrically, attached to the switch.

Three points are connected to high-frequency relays. These relays are connected to the Schaghticoke lines Nos. 1 and 2 on the lightning-arrester side of the horn gaps, and thus give records whenever high-frequency surges greater than a certain magnitude are present. They also record on which line the high frequency is the stronger. During a recent arcing-ground, a high-frequency surge lasting for 31 seconds was recorded.

It is in a case like this, when an arcing-ground or similar line disturbance occurs, that the multi-recorder becomes particularly useful. The high-frequency relays show on which line the arcing-ground occurs, and the electrostatic relay records the lowering of the voltage.

After a little experience an operator can tell the difference between a high-frequency record made during an arcing-ground, and one caused by the gradual breaking down of a coil within a transformer. In the latter case, a series of single surges of high frequency of duration of one second or less will occur, with intervals between successive impulses of several seconds. When an arcing-ground occurs, as has been mentioned, the high frequency maintains for from five to thirty seconds.

In case of a station tied into a transmission system, the electrostatic relays are valuable. When the power has been cut off the tie line because of line trouble, the station operates as well as it can on its own resources. At the instant the line voltage returns, the electrostatic relay contact on the multi-recorder notifies the switchboard operator. No time is lost in telephoning; the multi-recorder can be placed directly under the eyes of the attendant. The device has already been used in this manner since its installation.

The most valuable attribute of the multi-recorder, however, is its obtaining a printed record of the switch conditions of the entire station at any instant. This affords a basis for the analysis of trouble and is a safeguard against useless disputes in the case of an attempt to trace the source of the trouble.

C.F.F.

## VARIABLE-VOLTAGE LABORATORY TRANSFORMER

A variable-voltage transformer recently developed for use in the Consulting Engineering Department Laboratory may prove of interest to others engaged in development work. A standard 20 kw. Type "H" core is used. The primary is wound for 115 volts, two coils being provided to give full excitation when connected in parallel and half excitation when connected in series. The secondary is wound for 1000 volts at full excitation, and a number of taps are brought out. The first 19 coils are arranged to give 50 volts each and the last coil is tapped at every turn, giving 25 two-volt taps. Two switches are provided to make connections to these two sets of taps, so that by proper setting of the dials any voltage from 2 to 1000 can be obtained in 2-volt steps with the primary coils in parallel, and any voltage from 1 to 500 in 1-volt steps with the primary coils in series. Double contacts with resistance between are provided to allow the voltage to be varied without breaking the circuit or damaging the coils which are momentarily short-circuited. Oil immersion is not used as the voltage is low and most of the work done does not call for a long continued full load. The incoming and outgoing connections are made with the standard laboratory jacks and plugs, and the transformer and switches are mounted on an open metal frame carried on heavy castors.

G.F.G.

# GENERAL ELECTRIC REVIEW

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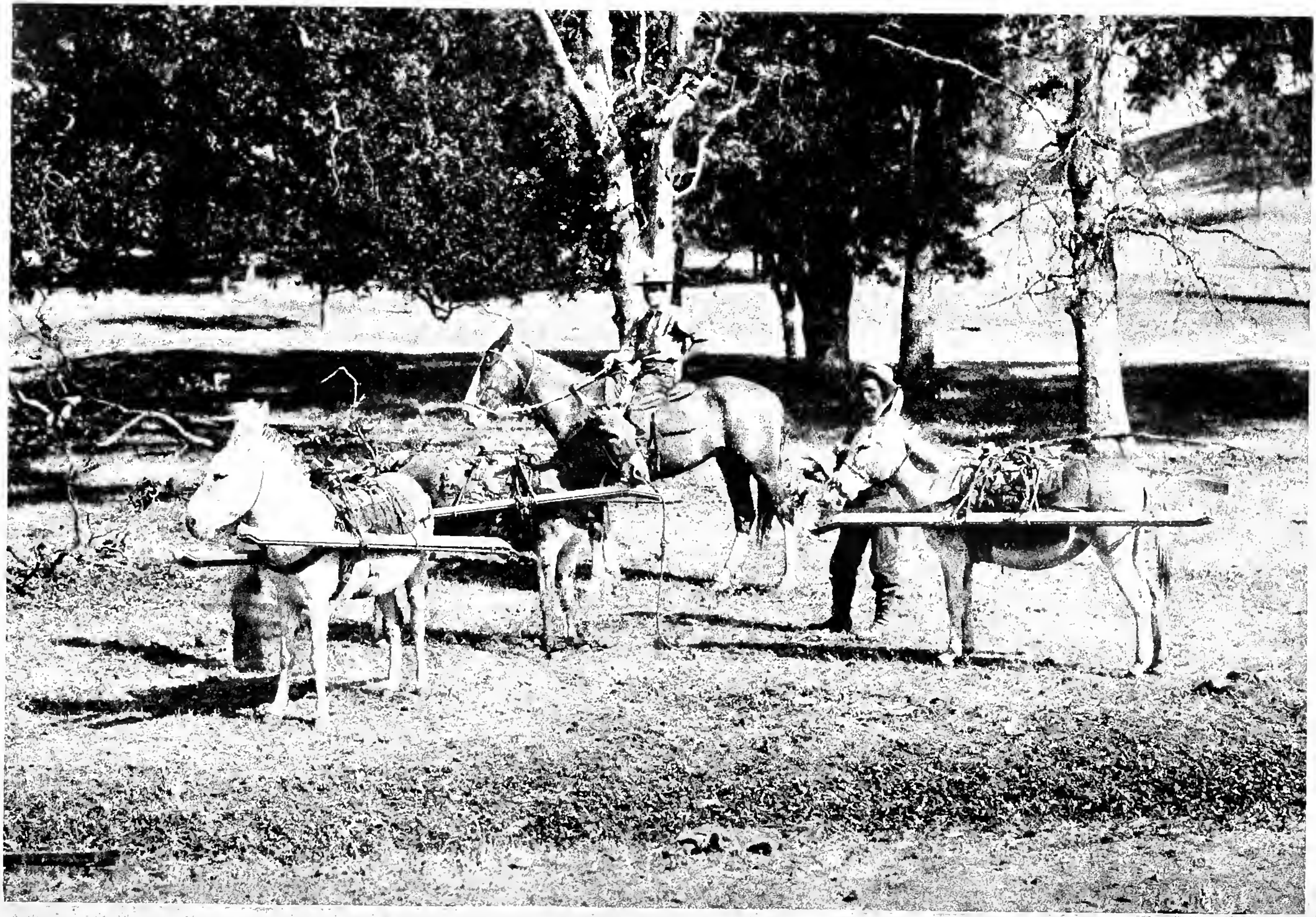


Method of Transporting Material for Towers on the 245-Mile Transmission Line of the Big Creek Development, Pacific Light and Power Corporation

# GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS (?)

When we went to press with our last issue the great powers of Europe were at peace one with the other; today Europe is an armed camp and the most powerful military and naval states of the old world are at war. It may well be that before this issue leaves the press the most momentous battle in the world's history, with armies whose very size staggers our imagination, will have been fought—and won—and lost; such is the uncertainty of human events.

This conflict is in very truth *the battle of the nations*, for it is not the armies and the navies alone that are arrayed against one another, but entire nations are fighting directly and indirectly for their political and commercial existence. The results will be of such tremendous importance to the economic and commercial status of all the countries involved, and indeed to all the world in perhaps a somewhat lesser degree, that we need give no excuse or apology for devoting our editorial this month to such an unusual subject. A technical review has no politics, so it is not our purpose to analyze the events that led to this great catastrophe, or trace the blame to any individual nation for substituting for the inestimable blessings of peace, the horrors of war.

It is our prayer and hope that the conflict may be as short as possible and that when it is over it may prove a blessing in disguise by removing the constant dread and probability of war that has overshadowed Europe for more than a decade, and further that it may eventually lead to a curtailment of the enormous expenditure on armaments and thus advance the useful arts.

It may well be that things had reached such a pass that this war was inevitable, the same as some other great events in history, and that the destiny of the empires must still be worked out in this cruel fashion. By those who would have peace at any price it must be remembered that sometimes the price of a prolonged and sound peace is *war*, and we must all be optimists and trust that after this confusion there may be built up a long and honorable peace under which our sciences and industries may flourish even more than in the past.

Science has lent her aid in developing those terrible instruments of destruction which are now to be tested in so tragic a manner, and it is likely that even in this phase of development science has scored a triumph for the benefit of mankind by reducing the time that such a conflict can last and thus avoiding the greatest curse that could fall upon any nation, a prolonged war.

In times of such worldwide disaster courage and faith must play their part in preventing all unnecessary alarms and in sparing any hindrance to peaceful development where such is possible. Especially those countries that are at peace should continue, and where possible stimulate their activities to the utmost limit that prudence will permit. With so many workers called to arms it seems only logical that those who are still able to work and produce should work the harder and be more productive. The fear of the damage that will be sustained by trade is in all probability greater than the actual damage wrought, so it is to be sincerely hoped that the financial heads of industry will temper their fear with courage and stimulate business activities wherever and whenever opportunity may give occasion.

So many great and bloody conflicts have been fought during that gradual process of evolution wherein nations and empires have been made, that it behooves us all, while we are regretting the tragedies of today, to hope and believe that from the present chaos a brighter and more stable future may evolve. The present duty of every individual and every nation alike is to do what little may be in his or its power to minimize the suffering that must inevitably follow and help keep things in general in as normal a condition as possible; and when peace is proclaimed, the duty of us all will be to help repair the damage and see that we still progress along the "Paths of Progress" with as little loss as possible.

# A DESCRIPTION OF SOME AIR BREAK SWITCH TESTS CONDUCTED AT GAINESVILLE, GEORGIA, FOR THE VIRGINIAN POWER COMPANY

By W. P. Hammond

Northern Contracting Company

Air-break switches have been used for a number of years for opening high-voltage circuits. Owing, however, to their characteristic of producing large, long-sustained, flaring arcs when interrupting such circuits, electrical engineers have been reluctant to use them on important lines. Their characteristics require great spacing between adjacent phases for satisfactory isolation and also a comparatively long time for successful circuit interruption. It has therefore been the standard practice to use oil-break switches for practically all important switching operations, since they will successfully confine an electric arc to narrow limits and thus permit a greater concentration of power control apparatus and a more rapid interruption of the circuit. The recent development, however, of the small outdoor substation has opened an extensive field of application for air-break switches. In this case, the low first cost of maintenance and simplicity of operation of the air-break switch make it ideal, since it is only occasionally used for operations equivalent to emergency service.—Editor.

The question as to the feasibility of the use of air break switches for opening heavily loaded circuits has apparently never been definitely settled, much having been said regarding the danger to equipment attending their use as well as the advantages to be derived therefrom. With the idea of obtaining data from which some definite conclusion might be drawn on this question, there was conducted at Gainesville, Ga., during the months of February and March of this year, a series of experiments extending over three or four weeks. The work was carried out under the direction of Mr. C. E. Bennett, Electrical Engineer for Mr. Charles O. Lenz, Chief Engineer of both the Virginian Power Company and Georgia Railway & Power Company, the former concern desiring this information previous to placing an order for a number of switches for use on their transmission system.

The site chosen for the tests is situated about four miles northwest of the City of Gainesville proper, adjacent to the Old Dunlap Power Plant of the Georgia Railway & Power Company and the new high tension lines of this company between Tallulah Falls and Atlanta. The entire output of this station was available for power purposes during the tests, and the high tension lines could be used after twelve o'clock at night to furnish the necessary load. With such ideal location and facilities no expense was spared in making the tests as exhaustive as possible, and the original report contains data on some 275 tests with more than fifty 8 in. by 10 in. photographs and a number of oscillograph records; the instrument for obtaining these records being loaned by the General Electric Company. The several weeks during which the tests were conducted made it possible to note the behavior of the different switches in all kinds of weather. Some of the tests were conducted during a snow storm, some during rain and wind storms, and others in fair weather with practically no wind.

Fig. 1 shows a general view of the switch structure and the manner of connecting up the switches, the incoming leads from the power house being in the extreme right of the picture and the wires connecting with the high tension tower lines immediately above. The switches tested consisted of one LG-9 110,000-volt General Electric switch, and three or four 44,000-volt air break switches of different types. The tests, however, were not regarded as competitive between the different makes of switches, and were conducted mainly for the purpose of determining how different weather conditions affected the operation of air break switches, and the effect on the lines and other equipment resulting from their use.

### 44,000 Volt Switch Tests

Fig. 3 shows a one-line diagram of connections as made for the 44,000-volt switch tests. The power was taken from 550-kw., two-phase, 60-cycle generators in the Dunlap station at 440 volts. This voltage was stepped up to three-phase 50,000 volts through two banks of Scott connected transformers, each bank consisting of two 550-kw. units. There was also available for use in connection with the oscillograph, a spare 50,000 440-volt, 550-kw. transformer which made it possible to take the voltage curve of the oscillograph record from the high tension side of the power transformers. There was placed in the circuit on the power side of the switch, a 50,000-volt 10 to 1 current transformer which was connected to one of the other oscillograph vibrators for recording the current wave. The third vibrator of the instrument was connected to the load side of the switch through suitable potential transformers, but could only be used when that

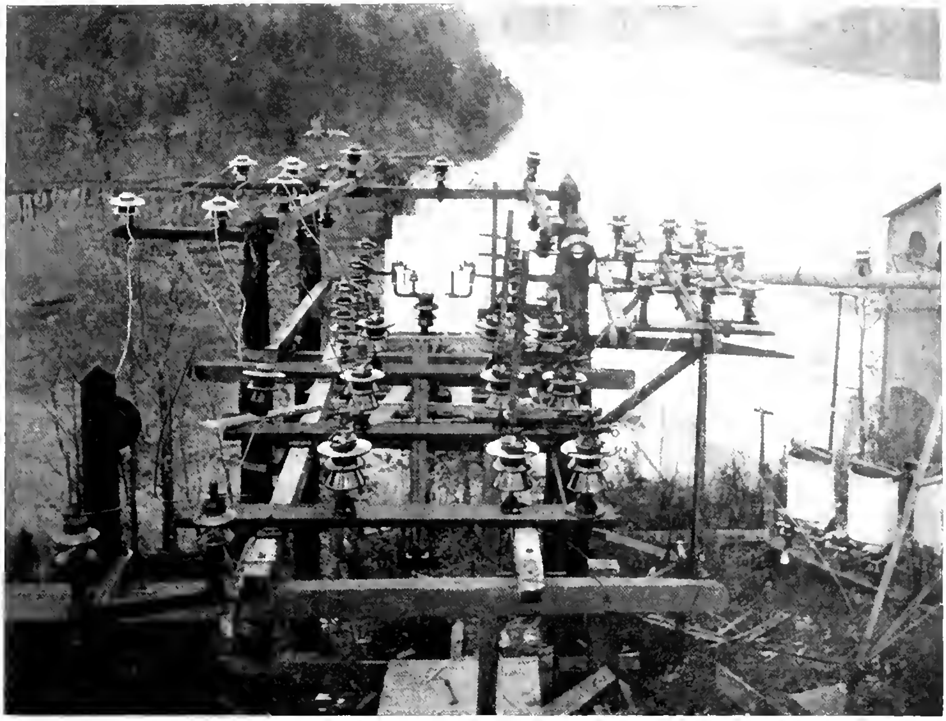


Fig. 1. General View of Switch Structure

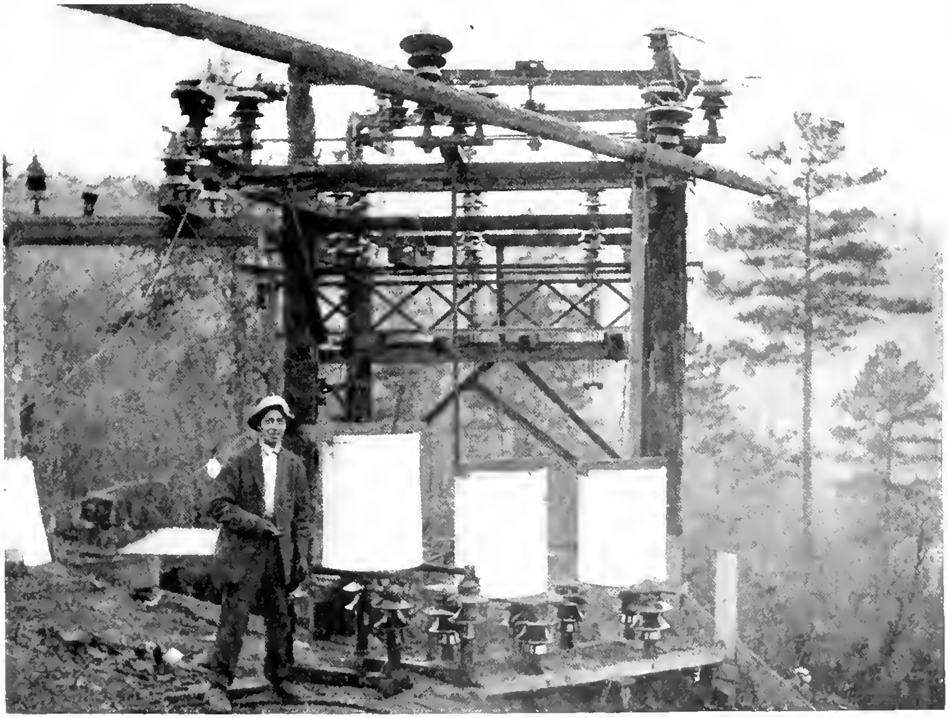


Fig. 2. Water Rheostat

part of the line to which these transformers were connected furnished part of the artificial loading, which was not the case in all of the tests.

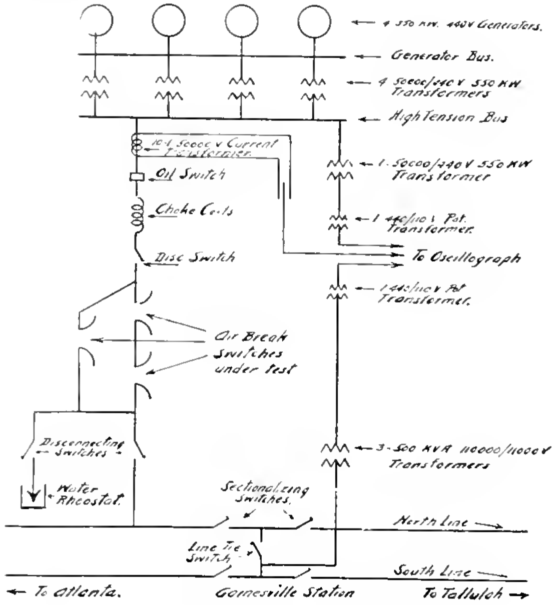


Fig. 3. One-Line Wiring Diagram for 44,000-Volt Switch Tests

As previously stated, the artificial load consisted of the charging current on the high tension lines of the Georgia Railway & Power Company between Tallulah Falls and Atlanta, the tests being conducted after midnight. These lines are constructed of 4/0 stranded copper spaced 9 feet vertically and insulated for 110,000 volts. The distance from Tallulah to Atlanta is approximately 90 miles, the Dunlap station at Gainesville being about midway between. There is a tie switch between the two lines, known as the north and south lines, at this station with sectionalizing switches on both lines on both sides of the station, so that the lines can be easily separated into four different sections right on the grounds where the tests were conducted. Each of these sections of about 45 miles in length furnished approximately 7 amperes charging current at 50,000 volts, making the maximum load with all four sections cut in, 28 amperes, or about 2400-kv-a. of leading power-factor. These four sections, together representing a total of 180 miles, imposed a rather severe load on a 44,000-volt air break switch. It is not often that power is transmitted so great a distance at this voltage, and an air break switch of this rating would probably never be called upon to open a circuit of this length.

A water rheostat was rigged up in the field for furnishing a true energy load, and although rather crude in construction, served the purpose admirably, drawing as high as 50 amperes in some of the tests. See Fig. 2.

In order to get a better check on the voltage surge set up on the load side when opening the circuit with an air break switch, a needle point spark gap was connected between two of the phases, set accurately for different voltages, and the maximum sparking distance noted for each switch under the same load conditions. The same experiment was tried with an oil break switch in the circuit, and the maximum sparking distance recorded when the circuit was opened with this switch was greater than that with the air break switch.

### 110,000-Volt Tests

In Fig. 4 is shown the wiring diagram for connections as made for the 110,000-volt switch tests. The power was taken from one 10,000-kv-a. generator at the Tallulah Falls power house and stepped up through one bank of three 3333-kv-a. transformers delta-Y connected. The switch was connected in the south line at the Gainesville station, as shown in the diagram, and opened under line voltage varying from 65,000 to 120,000, the charging current varying from about 18 to 29 amperes, these readings being taken at the power house. These figures correspond to a kv-a. load of from 2000 to 6000, only half of which was actually interrupted by the switch on account of its location at the mid point of the line.

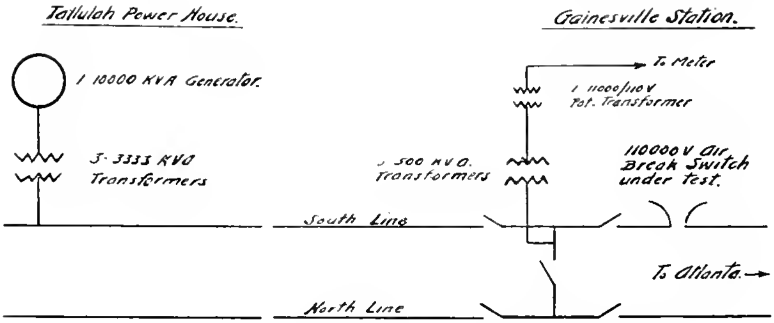
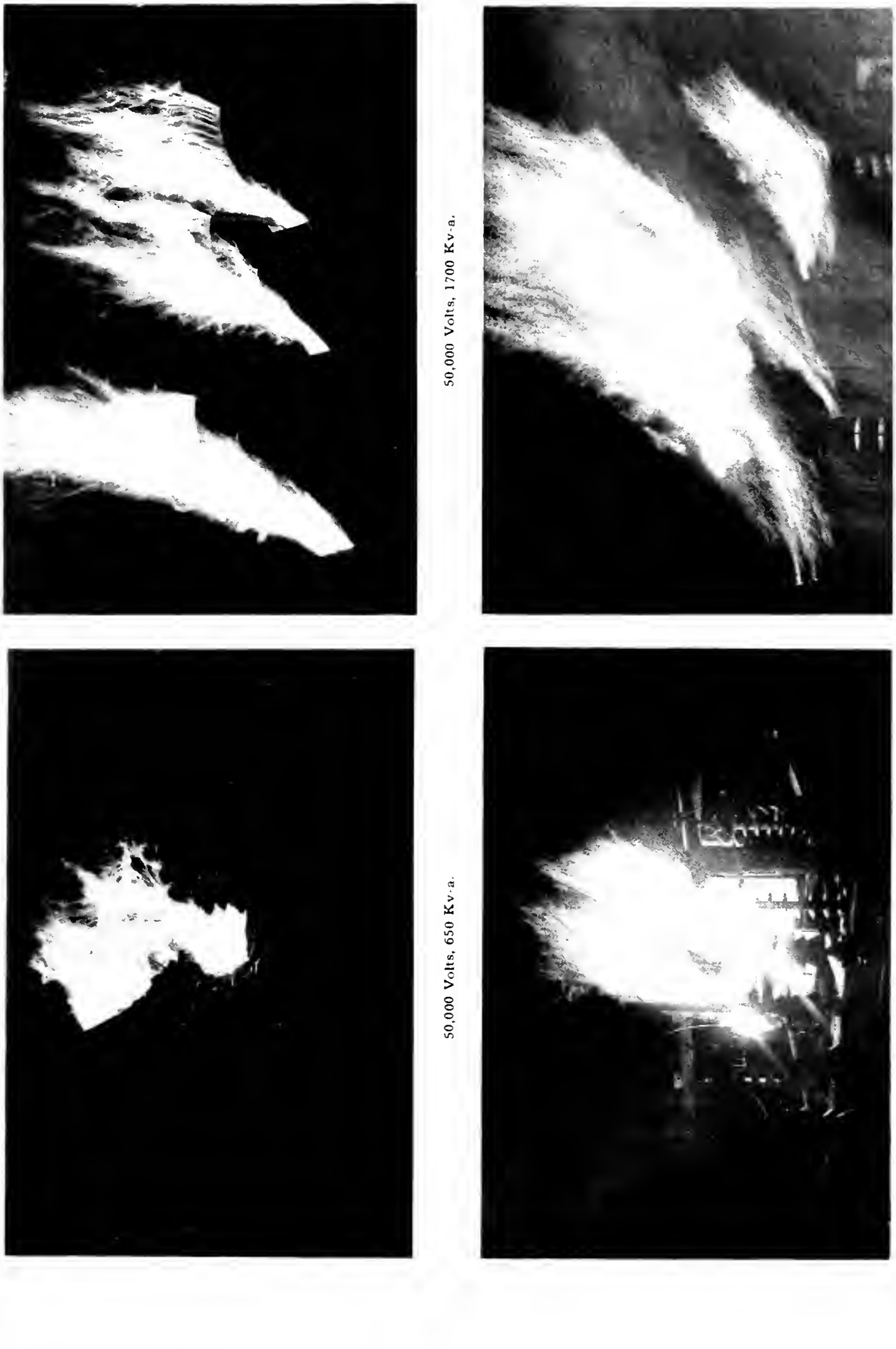


Fig. 4. One-Line Wiring Diagram for 110,000-Volt Switch Tests



112,000 Volts, 5230 Kv-a. C.C. Load

50,000 Volts, 2400 Kv-a.

50,000 Volts, 1700 Kv-a.

50,000 Volts, 650 Kv-a.

**Fig. 5. Photographs of Arcs rising from Air Break Switches under Different Conditions**

**Oscillograph Records**

In Fig. 6 is shown one of the oscillograph records obtained while interrupting a load of 3000 kv-a. at 50,000 volts with one of the 44,000-volt switches, the time required to break the arc being three seconds. The upper curve is the voltage curve on the power side of the switch and the lower one the current on the same side. The load was a true energy load obtained by means of the water rheostat.

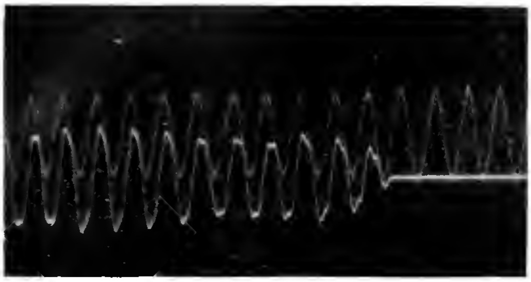


Fig. 6. Oscillogram made at the time of interrupting a 3000-kv-a. Load at 50,000 volts by a 44,000-volt Air-Break Switch

Fig. 7 shows a record obtained while breaking a true energy load of 2500 kv-a. with a different make of air break switch, the time necessary in this case being the same as in the previous one. The upper curve is again the voltage curve on the power side of the switch and the lower one the current.

Fig. 8 shows, for comparison with the foregoing records, a record obtained while interrupting a charging current load of 1720 kv-a. with an oil switch, the voltage and current curves occupying the same relative position as in the records already referred to.

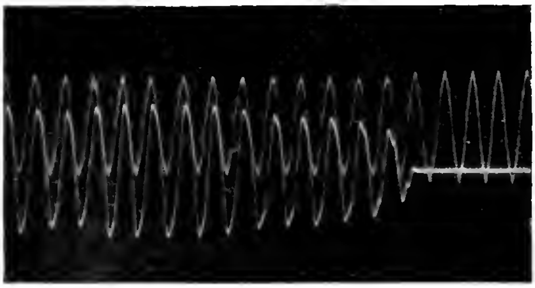


Fig. 7. An Oscillogram made at the time of interrupting an energy load of 2500 kv-a. with an Air-Break Switch

Figs. 9 and 10 are records obtained when opening charging current loads of about 1250 kv-a. with two different makes of air break switches, the upper curve being the voltage, the middle one the current on the power side of the switch, and the bottom one the voltage on the load side.

The remaining cuts shown herewith are actual photographs of the arcs which resulted when opening the circuits under the loads indicated, an explanation of which is hardly necessary.

**General Conclusions**

Complete records were kept of the load and weather conditions of each test, and the actual time in seconds required to break the arc, with a short description of its behavior. The space necessarily forbids the publication of these notes, but several conclusions have been drawn from a careful study of them.

The maximum time necessary in which to interrupt the arc in any of the 50,000-volt tests was 25 seconds and the minimum 2 seconds, the average time for a large number of the tests being 6 seconds. This time period depends more on the weather conditions, especially as regards the velocity of the wind, than the kv-a. load on the lines, this statement being substantiated by the fact that in one series of tests with a certain kv-a. load on the lines, the average time required to break the arcs was much less than the average time in another series under different weather conditions when the kv-a. load was smaller. The average time necessary to interrupt the arcs in the 110,000-volt tests was 7 seconds, the maximum being 16 and the minimum 3.

This means that the air break switch requires anywhere from 120 to 1500 cycles in which to interrupt a circuit, while the oil switch may accomplish this result in half a cycle. This time element in the case of the air break switch produces an effect on the lines similar to a series of light hammer blows, and these blows, although probably not so violent as the one caused by an oil switch,

Fig. 8. An Oscillogram made at the time of interrupting a 1720 kv-a. charging current by an Oil Switch

must nevertheless have a damaging effect on the insulation.

The rating given air break switches by the manufacturers is more or less arbitrary. The spacing adopted, especially as regards the distance between phases, is however, not sufficient, as the lines are easily short circuited by the arcs lapping between the phases. The distance between phases for a 44,000-volt switch should be 6 or 7 feet, and for a 110,000-volt switch certainly not less than 10 feet. The switches tested were spaced 4, 5, 8 and 10 feet, and in many of the tests the arcs lapped between the phases, as shown in some of the photographs. Great care must be exercised in wiring up the switches to prevent the arcs of one phase from lapping the leads to some other phase. In other cases, the arcs are blown directly downwards, and this means that the switch must be properly spaced from the frame or steel structure on which it is mounted to prevent the arcs grounding the lines. The large amount of space necessary for the installation of air break switches because of the foregoing precautions which must be taken is a serious drawback to their use.

It may be safe to advance the opinion that the proper design of an air break switch involves a mechanical movement which will assist in drawing the arcs up the horns, as the heat of the high voltage arcs alone is sufficient to accomplish this only in a very still atmosphere. With the slightest breeze blowing the arcs sometimes hold to one point of the horns for many seconds before exhibiting any tendency to rise. In one of the switches tested, advantage was taken of this point in the mechanical design, and this switch broke the arcs much more readily than the others.

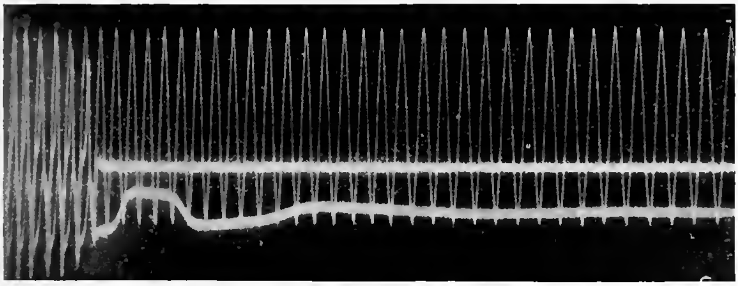


Fig. 9. An Oscillogram made at the time of interrupting a 1250 kv-a. Charging Current by an Air Break Switch

It was found that a true energy current is more easily interrupted than a charging current of the same kv-a. value under the same weather conditions, and that under light loads, high winds materially aid in breaking the arcs, sweeping them from the horns soon after their formation. With heavier loads, or lower winds, however, the arcs lap between phases with the spacing used in these tests before they are blown from the horns.

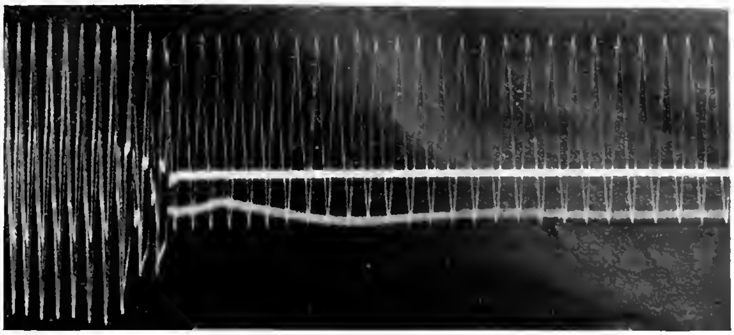


Fig. 10. An Oscillogram made under similar conditions to those prevailing in Fig. 9, except another Air Break Switch was used

The oscillograph records obtained during these tests do not indicate that there is any high frequency set up on the lines by air break switches which is especially dangerous to the equipment. It is possible, however, that the oscillograph does not show such oscillations, and these records cannot be relied upon to establish this fact conclusively. The spark gap test previously referred to in this article would indicate that the surges in the voltage set up by the air break switch are not so violent as those set up by an oil switch, although this statement is not in line with current opinion.

The general conclusion drawn from these tests is that the air break switch will doubtless replace the oil switch for many uses, such as sectionalizing short lines, cutting in and out equipment only occasionally used, for emergency use, etc.; but where frequent switching is necessary and the time element in breaking the circuit of consequence, the air break switch in its present stage of development would hardly prove satisfactory.

# TRAIN HEATING

By Ray Stearns

Railway Equipment Engineering Department, General Electric Company

There are two general types of devices used for train heating: fuel burning heaters and electric heaters. Further subdivision can be made in accordance with the kind of fuel used or with regard to the heat conveying medium employed and its mode of transfer. (In some cases no transfer of heat is made, it being applied directly.) The author of this article discusses these methods of heating with regard to the suitability of each for particular traffic requirements. A large share of the article is then devoted to a detailed description of an actual installation of each of the two most common types of heating devices.—Editor.

Small attention has been paid to the subject of train heating in the discussions of railway electrification; yet, on a basis of energy consumption, the heating problem ranks relatively high in importance when compared with the one of traction. There are many convincing arguments which have led steam road operators to electrify from a traction point of view. The electric locomotive, working at a distance from its source of power, may be shown to out-rank its fuel burning competitor, the steam locomotive. On the other hand, in most cases, the difference in cost between producing the heat electrically and by local combustion of fuels is strongly in favor of the latter.

While there is this relation in cost of producing the heat at a train with electric and fuel heaters, for other reasons of greater importance electric heaters have been adopted in many instances. This article will outline some of the service conditions which must be met in designing train heating apparatus and will point out methods of heating from which certain types of heaters have been selected. Illustrations and diagrams of specific cases will be shown.

Under the heading of train heating we will consider more particularly service conditions where the locomotive must serve both as the tractor and the source of supply for the heating system, the coaches being run on interconnecting steam and electric railways; and conditions where motor cars or coaches are used connected in trains where the heating source may be either local to each car or supplied from a locomotive. The Pennsylvania Railroad heaters on the New York Terminal locomotives are examples of the former case. The Canadian Northern Railway and the Butte, Anaconda & Pacific Railway have heaters illustrating the latter cases.

As pointed out, cost and efficiency are of great importance, yet other features frequently become the deciding factors, as for instance the fire hazard, dust and smoke nuisance with the fuel burning heaters; ease in operating from a point of view of minimum of labor; adaptability to meet conditions of installation and the automatic control of temperature. In the case of electric heaters, voltage affects location and design. General questions of safety to human life are paramount.

The principal problem of design with heating devices is the transmission of the heat through radiation, conduction or convection from the energy transformer to the region to be heated. In meeting railway conditions, the losses in the transformation of the energy, either from fuel or electricity into heat, is very small compared with those of transmission.

Fuel heaters may be gas, oil or coal burning, of which gas should be eliminated in heating trains. Designs vary with the problems of transmission. Electric heaters may be based on generating heat in an electrical conductor with the view of raising the temperature of the entire surroundings and avoiding transmission losses as in the case of the ordinary street car heater with exposed resistance wire. They may be designed with the electrical conductor located at some distance from the region to be heated so that insulating materials are required to confine and direct the heat during transmission. The losses in transmission depend upon the effectiveness of the heat insulating duct. The electric hot-air heater is an example. They may, also, be based on generating heat in a conductor located very remotely from a number of separate regions, the temperature of which is to be raised. An intermediary substance is used in this case to facilitate the transmission of the heat. An example of this is the electric steam unit.

The types of heaters evolved from the above considerations consist chiefly in fuel burners where either hot water, hot air or steam is used in the transmission; electric heaters, using either hot water, hot air or steam; and the direct type where the region to be heated surrounds the heat unit and there is no problem of transmission.

In the case of the fuel burning heaters, the hot air unit and the steam unit have advantages over the hot water unit, since the latter is more troublesome to maintain because of freezing and leakage. The fuel hot-air unit is frequently used on self-contained cars and is one of the most economic ways of heating. The steam unit is adopted where the heating is done from the locomotive and the coaches must be adapted to inter-connecting railway service. A direct unit in the form of a stove is now seldom used.

Where an electric heater is used, the hot water unit is not strongly recommended for reasons of freezing and leakage. The hot water unit may be made up by immersing sheathed wire in a water tank and arranging for a natural circulation of water through pipes. The electric hot-air heater with forced draft is particularly adapted to coaches which operate on an electric zone only. It is safe at all voltages because the unit may be isolated beneath the car floor, or as in the case of a locomotive cab heater, placed in a well grounded iron casing. The transmission of the heat can be done efficiently. The electric steam unit is used when the heater must be installed on the locomotive because of steam-electric operation of trains. Various types of electric steam units have been designed, but the flash boiler takes preference over other types because of the small amount of water heated at one time. This minimizes dangers from escaping steam in case of a damaged boiler. The direct method with resistance units located near the seats is efficient but generally limited to low voltages on account of safety.

Rather than go deeply into the merits of the different schemes, it may be of interest to describe the heaters which have been selected by the Pennsylvania Railroad for their New York Terminal electrification, where the coaches operate in both electric and steam zones, and by the Butte, Anaconda & Pacific Railway and the Canadian Northern Railway, where the coaches operate in an electric zone only.

Fig. 1 shows a type of flash boiler of which twelve have recently been furnished to the Pennsylvania Railroad.

The flash boiler is made up of spiral coils of seamless mild steel tubing, inside diameter 0.494 in., outside diameter 0.675 in. This tubing is connected to the power supply in one continuous circuit to ground and its length is chosen, when thus connected, so as to consume 412 kw. at 650 volts. (See the combined wiring and piping diagram, Fig. 2.) The tubing is divided hydraulically into four sections and so connected that water may be pumped into each of these sections by means of a four cylinder pump. Back pressure at the pump is reduced in this way. When the water, forced by the pump, reaches the tubing, which is heated by the electric circuit, it is evaporated into steam. The amount of water in the tubing is very small at any time. The steam is taken off from each of the four sections and collected in a common pipe for transmission through a thermostat, overflow valve, limiting nozzle, and throttle valve to

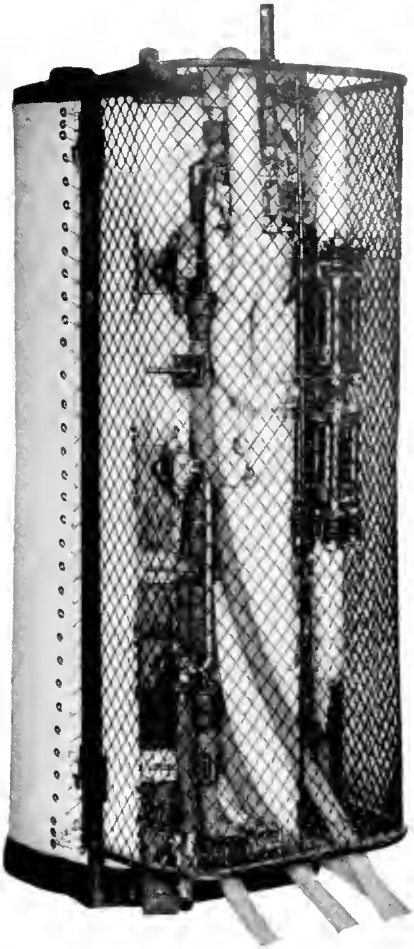


Fig. 1. 412 Kw. Flash Boiler for Train Heating

the steam train line. The boiler absorbing 412 kw. at 650 volts will evaporate water at the rate of 1100 lb. per hour at 100 pounds pressure.

The principal electrical accessory devices consist of the contactors for opening and closing the current supply to the boiler the series motor for driving the pump, which in turn regulates the supply of water to the boiler, and the automatic regulating devices controlling these parts.

The automatic regulation of the boiler must provide for controlling the pressure and temperature of the steam. A governor, similar to those ordinarily used with air compressor systems and protected from overheating by a water column, is used for controlling pressure. By means of this device the electric current and the supply of water to the boiler may be automatically cut off when the pressure rises to a predetermined amount and again supplied when the pressure drops to another predetermined amount. The thermostat which controls the temperature of the steam is designed to displace either of two valves, depending upon its position. These valves control a supply of air from an air reservoir (part of the braking system) to two governors similar to the pressure governor. One of these governors controls the speed of the pump motor and therefore the flow of water, and the other the supply of current to the boiler. By these means the thermostat slows down the pump if the temperature of the steam becomes too low, and cuts off the current with the contactors if the temperature becomes too high.

Relays are provided to protect each section of the heater in case of failure of one of the pump cylinders to properly supply water. These relays function in accordance with the rise in resistance across the different sections of the tubing. The electric circuit is protected with a standard copper ribbon fuse. The steam circuit is provided with a steam gauge for indicating pressure and a safety valve to provide against failures of the automatic equipment. A throttle valve is provided as a cutout when connecting and disconnecting the steam line with the coaches. A limiting nozzle is placed ahead of the throttle valve in the steam line to approximate the generation of steam to the rated capacity of the boiler at 100 lb. pressure. An overflow valve is provided between the limiting nozzle and the boiler for use, as mentioned below, in starting up the boiler.

Referring to Fig. 2, the operation of the boiler is as follows: Water is first pumped

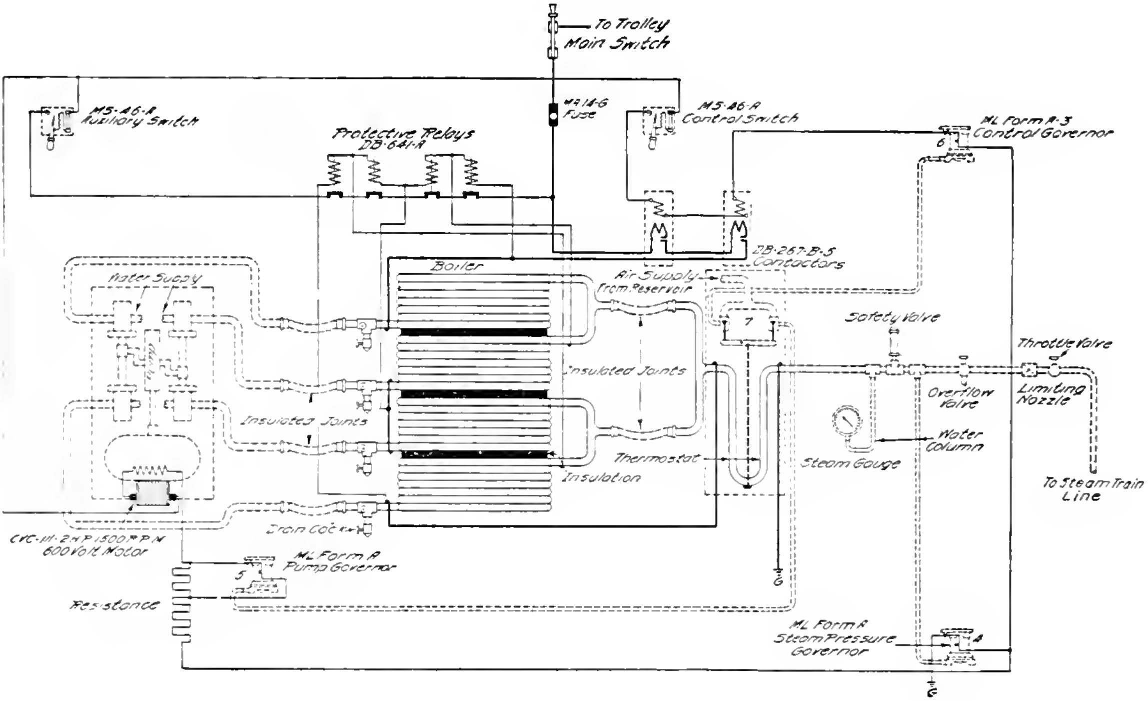


Fig. 2. Connections of Electric Flash Boiler for Train Heating

into the boiler pipes while the latter are disconnected from the electric circuit. This is done by opening the switch in series with the solenoids of the line contactors and closing the main auxiliary switch which controls the power supply to the pump motor. At the same time, the throttle valve in the steam train line is closed and the overflow valve opened. When water appears at the overflow valve, the switch controlling the contactors is closed, causing current to flow in the boiler tubing. When dry steam appears, the throttle valve in the train line is opened and the overflow valve closed.

The steam pressure may then rise to approximately 110 lb., when the steam governor will open, shutting down the pump and opening the circuit feeding current to the boiler. When the pressure drops to 100 lb. this governor will close and the boiler will start generating steam again. If the temperature of the steam rises above a predetermined value as mentioned above, the air valve on the left of the thermostat opens, allowing the air to operate the air governor connected to it. This will in turn open the line contactors, shutting off current to the boiler. When the temperature falls, as a result of this action, this valve will close again and the current will again pass through the boiler. If the temperature continues to drop below a predetermined value, the valve at the right of the thermostat opens, causing air to operate the attached governor, which in turn cuts in resistance in series with the pump motor circuit, slowing down the pump and decreasing the amount of water fed to the boiler. With a rise in temperature, the governor will cut in and the pump will come up to speed again.

It is very essential that clean water be used on account of the pump valves, which are the most sensitive part of the system. Drain cocks connected at the bottom of each section of tubing are provided so that after steam is generated at any time the pipes may be blown out at this point when they require cleaning.

As a result of the experience with a sample boiler on the Pennsylvania Railroad which we have been advised operated equivalent to a year's service, it is not expected that electrolysis will prove a serious factor in the maintenance of the boiler.

The weight of the complete boiler and electrical equipment, not including the water and water tank, is 3500 lb. A supply of 1100 pounds of water per hour, as mentioned above, must be provided for in designing the water tank.

In the case of the Pennsylvania boilers, capacity is not provided for heating the train continuously, since the unit is intended to furnish partial heat either after leaving the New York Terminal, where the train is heated from the station plant, or from the other terminal, where the train is supplied from its steam locomotive. A boiler figured to heat a train to 68 deg. F., during zero weather running 50 miles an hour, must provide for evaporating approximately 200 lb. of water per hour per coach. This provides for heating and losses in transmission, based on the use of steel coaches heat-insulated as much as possible. This figure of course varies considerably with the construction of coaches as practiced on different systems, particularly with regard to the insulation and the ventilation. The figure is given here merely to convey a rough idea of the energy involved in heating a train this way.

Figs. 3 and 4 show the electric hot-air unit furnished the Butte, Anaconda & Pacific Railway for heating their passenger coaches on an all-electric zone. The electrical connections, with a few improvements over those actually furnished, are shown in Fig. 5. The power for the heating unit is taken, in the case of each coach, from a 2400 volt bus line running from the locomotive through the train.

The heater shown in Fig. 5 is divided into three multiple sections, one of which is in series with a series wound fan motor. The two other sections, of different kw. capacity, are used in combination to take care of different weather conditions. The heater, principally because of high voltage, is located beneath the car flooring and air is forced either from the outside atmosphere in mild weather or from the inside of the car in cold weather, through the heater into ducts running the length of the car, with openings at alternate seats. The heater is heavily lagged with heat insulating material, as are also the main ducts, which are located below the floor line. The resistance units are made accessible for removal by dropping the bottom of the heater. A connection box, which may be reached through a hand hole in the bottom cover, is accessible for changes required by radical differences in the weather. The connections for the different weather conditions are indicated on the wiring diagram, Fig. 5.

Generally it may be noted in mild weather that 10 per cent of the total kw. capacity of

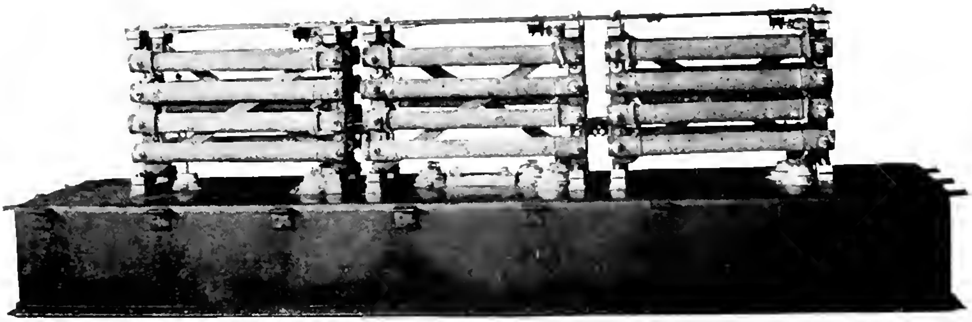


Fig. 3. Electric Hot Air Coach Heater with Cover Removed

the heater is permanently in circuit with the blower. It is thought that under these conditions a certain amount of ventilation will be desired and only a slight amount of heat required. Ordinarily, there is no occasion for running the fan in this service in an electrified zone without some heat in circuit, since the necessity for ventilation results from the car being closed because of a chill in the atmosphere. In summer weather, ventilation without the blower would be provided by opening the windows. With this type of heater it would be very easy, however, to operate the fan independently of the heating unit from the same low voltage circuit which supplies the automatic equipment, and in this way gain ventilation without heat. There does not seem to be many cases where this is necessary, however.

A thermostat, as shown in the wiring diagram, controls, through the means of a contactor, one of the three sections of the heater which represents 50 per cent of the capacity. In case of a sudden change in temperature, which would cause the thermostat to operate, this 50 per cent section is cut in or out of circuit. It is not expected that the thermostat would operate this section, however, in mild weather.

In cold weather, the third section of the heater is connected in multiple with the same circuit which supplies the fan motor section, so that the total permanent heating element, not controlled by the thermostat, is 50 per cent of the total capacity. Then, with 50 per cent permanently connected in circuit for cold weather, the thermostat cuts in and out the remaining 50 per cent.

It is expected that during mild and cold weather the fan motor will operate at the same speed. During zero weather, the third season for which the heater is designed, the

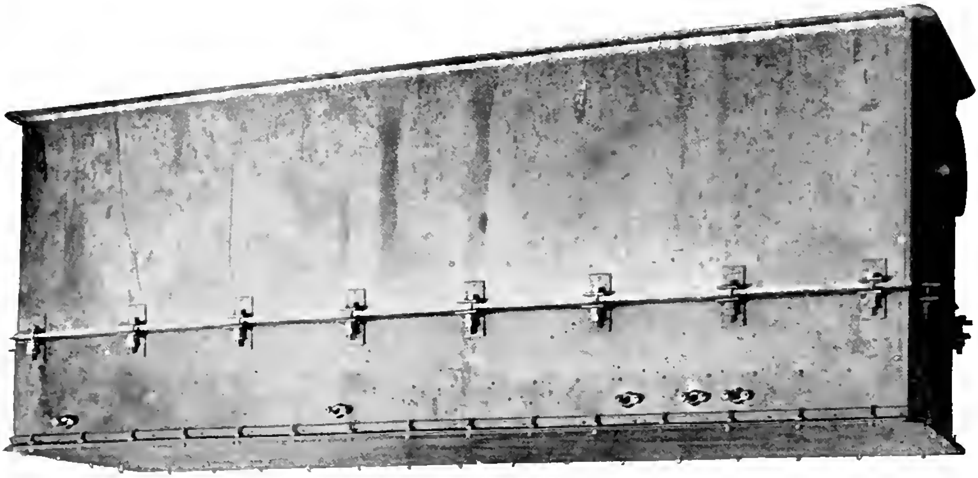
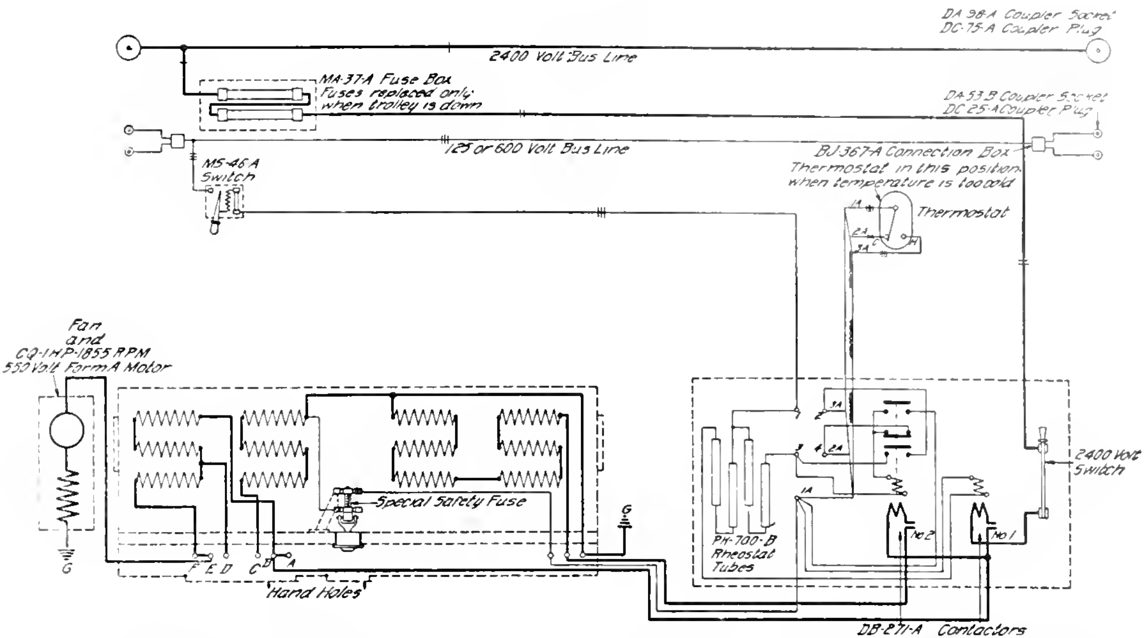


Fig. 4. Electric Hot Air Coach Heater



| Weather | Connected | Disconnected |
|---|---|---|
| Mild | A-B, D-E | B-C, E-F |
| Cold | B-C D-E | A-B, E-F |
| Zero | B-C, E-F | A-B, D-E |

| Size of Cables | | |
|---|---|---|
| I | 000 | 2400 V |
| II | 50/25 | 2400 V |
| III | 50/25 | 600 V |
| IIII | 19/25 | 600 V. |

| Fuses | In | | No Required |
|---|---|---|---|
| 25 Amp | MA 37-A Fuse Box | Cat No 145816 | 2 |
| 5 Amp | MS-46-A Switch | Cat No 34995 | 2 |
| Safety | Heater | Dr K-1194554 Gr 1 | 1 |

Fig. 5. Connections of 2400 Volt Electric Hot Air Coach Heater

fan speed is reduced by changing the resistance in series with its motor at the connection box. This reduces the ventilating qualities, but increases the heating of the system, to meet this severe service. Furthermore dampers are to be used to take the air from either the inside of the coach or outside atmosphere, depending upon weather conditions.

The wiring is protected close up to the bus line by cartridge fuses which are installed in a grounded iron box. The bus line is located along the roofs of the coaches. The high voltage lead, running from these fuses to the heater, passes through a grounded conduit to the point below the flooring where the heating unit is located. The high tension parts of the wiring are, therefore, isolated in grounded casings, either on the roof or beneath the car. Besides the contactor, which is controlled by the thermostat, there is a second contactor and a disconnecting switch located in the same grounded box. Ordinarily, the heater may be cut out of circuit by means of the switch, giving remote control of the contactors. In case of a heater failure or during inspection the knife blade disconnecting switch is used. As a protection to the heater, in case the fan motor fails, a safety fuse is placed inside of the heater casing, so as to open the circuit leading to the operating coils of the contactors when the temperature in the heater exceeds a predetermined value.

The capacity of this electric hot-air heater is approximately 30 kw. While the information we have available on the subject varies considerably, we estimate that in the case of a wooden car, approximately 70 ft. over buffer plates and 61 ft. over end sills, 30 kw. will give satisfactory heat with this method. This is in zero weather running at as high speeds as 50 miles per hour. At least twice this amount of heat would be required in the case of the average steel coach of the same dimensions to give the same results.

# THE NATURE OF ELECTRICAL DISTURBANCES IN POWER TRANSMISSION WORK

## Part II

By David B. Rushmore and Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The first part of this article appeared in the August issue of the Review, and dealt with the disturbances caused by excessive currents. The present installment, on the other hand, deals with the disturbances caused by high voltages. These are divided into two broad classes: first, that covering those cases of high voltage in which the excess voltage exists between the phase conductors or between the phase conductors and ground; second, that covering those instances of localized high voltage in which the excess potential conditions exist between two points along the same conductor. To the first class belong those disturbances which are caused by poor regulation and resonance. The disturbances caused by switching or lightning may be of such a nature that they may belong to either class. For instance, where the impulses or traveling waves set up are of comparatively low frequency and have a sloping wave front, the disturbance can generally be classed with the former, and where they are of high frequency and have a steep wave front, with the latter.—Editor.

### Excessive Voltages

High voltage disturbances may also be divided in two broad classes. First, that covering actual high voltages in which the excess voltage exists between the phase conductors or between the phase conductors and ground. Second, that covering localized high voltages in which the excessive potential difference exists between two points along the same conductor. In these cases the "conductor" is supposed to include the line wires as well as the generator and transformer windings.

To the first class belong those disturbances which are caused by overspeeds, poor regulation and resonance, while the nature of disturbances caused by switching, arcing grounds, and lightning may be such that they may belong to either class. Where the impulses or traveling waves set up are of comparatively low frequency and consequently of sloping wave front, the disturbance can, however, generally be classed with the former and when of high frequency and steep wave front with the latter.

Excessive over voltages are very apt to occur when waterwheel-driven generators run away, especially if they are provided with direct connected exciters. Actual experience has thus demonstrated that under such conditions the generator and transmission voltages may reach three times their normal value, which of course subjects the apparatus to unreasonable strains. To provide against this, automatic brake equipments are provided or else high voltage cut-out relays which as previously mentioned insert resistances in the exciter fields if the voltage exceeds a certain predetermined value.

In the design of modern long distance transmission lines it is generally the regulation, or the variation in voltage which occurs when the load is thrown on or off, that is the governing factor, rather than the energy loss. Not only may the voltage drop under load be quite large, especially when the load has a low power-factor, but with the high transmission voltages now in use, the capacity effect of the lines becomes very high, which in turn may result in a considerable voltage rise at the substation at light loads. This is now one of the chief arguments against isolated delta connection for long distance high tension lines. It was formerly claimed that such a system could be temporarily operated with one line grounded. Recent experiences on large systems, however, indicate that this is not feasible, as in the event of a ground the charging current, which is a function of the voltage from wire to neutral, will be increased because the neutral is shifted from the center of the delta to one corner. This increase will be about 73 per cent and will of course in turn cause an additional voltage rise at no load, which is not permissible.

The voltage rise caused by the charging current in a long line may cause a breakdown of the air nearest the line conductor and cause corona which may seriously increase the transmission losses. They may also unduly strain other insulations on the system and affect the operation of the lightning arresters, the normal voltage range of which should be kept within reasonable limits for satisfactory operation. On the other hand it is well known how the operation of motors is affected by voltage variations and that the life of lamps is seriously reduced if the voltage is too high, not to speak of the unpleasantness of a variation in the intensity of the illumination, which of course accompanies a fluctuation in the voltage.

From the above it is imperative that the regulation of a modern system be kept within certain permissible limits, and with high voltage systems this is most readily accomplished by installing synchronous condensers with automatic voltage regulators in the substations. As previously stated, the large capacity currents of long distance lines cause a rise of voltage from the generator to receiver at light load, while at full load the lagging current taken by the load will cause a drop of voltage from generator to receiver. It is therefore evident that the voltage may be kept constant or within certain limits at the receiving end, if a synchronous condenser is installed there and its field adjusted so as to make it take a lagging current at no load and a leading current at full load—in the first case to offset the effect of the line capacity and in the second to offset the surplus lagging load current.

The characteristic curves in Figs. 7 and 8 strikingly illustrate the improved regulation which could be obtained on a 130-mile 120,000-volt line by the use of a synchronous condenser.*

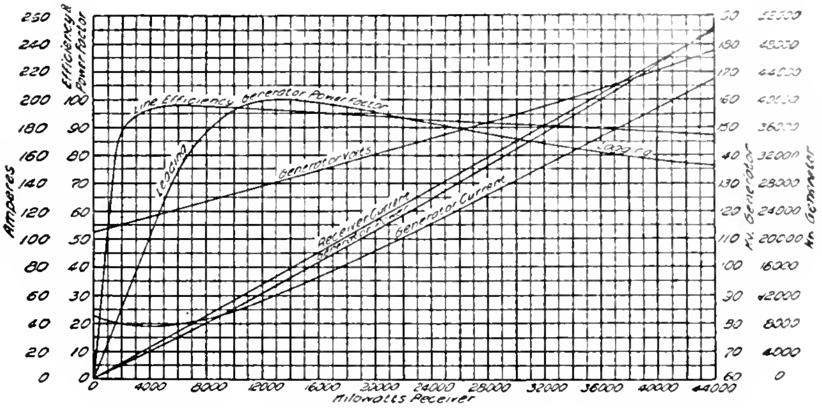


Fig. 7. Transmission Line Characteristic Curves for a receiver voltage of 120 kv. No condenser regulation

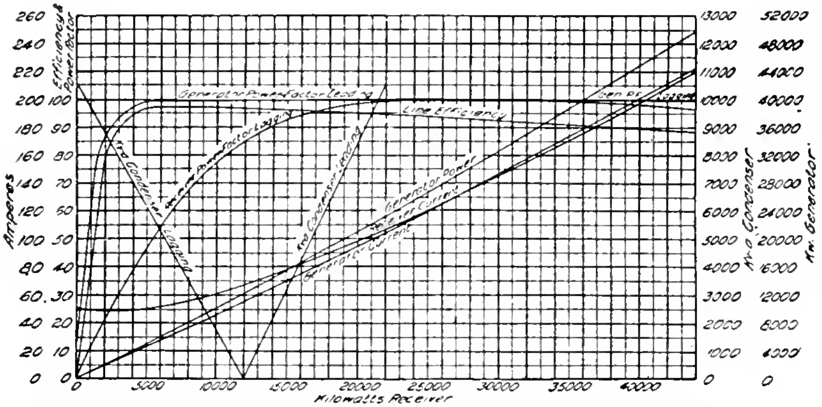


Fig. 8. Transmission Line Curves for a receiver voltage of 120 kv. and a generator voltage of 128.6 kv. Condenser regulation utilized

Resonance must also be guarded against, as it may give rise to large currents which may open the circuit protecting devices and interrupt the service, or the potential may be raised to a value at which the insulation of the system will be broken down. In an electric circuit the inductive reactance and the capacity reactance oppose each other. If of equal value they neutralize each other, in which case the resistance of the circuit limits the value of the current. This may, therefore, reach very high values and when passing through the inductance and capacity the voltage would become very high.

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* See Practical Calculations of Long Distance Transmission Line Characteristics, GENERAL ELECTRIC REVIEW, June, 1913, and Notes on Selection of Synchronous Condensers, GENERAL ELECTRIC REVIEW, June, 1914.

To illustrate this further; assume a circuit having a resistance of say 50 ohms and a capacity reactance of 1000 ohms; then the total impedance would be equal to $\sqrt{50^2+1000^2} = 1000$ ohms approximately. With 100,000 volts impressed on this circuit the current flow would be $\frac{100,000}{1000} = 100$. If now in addition the circuit contains an inductive reactance of 1000 ohms, it is evident that this entirely neutralizes the capacity reactance and that the current is only limited by the 50-ohm resistance, and in this case would be equal to $\frac{100,000}{50} = 2000$ amperes. With this current flowing the voltage across either the inductance or capacity becomes equal to $2000 \times 1000 = 2,000,000$ volts, which of course, is far beyond destruction.

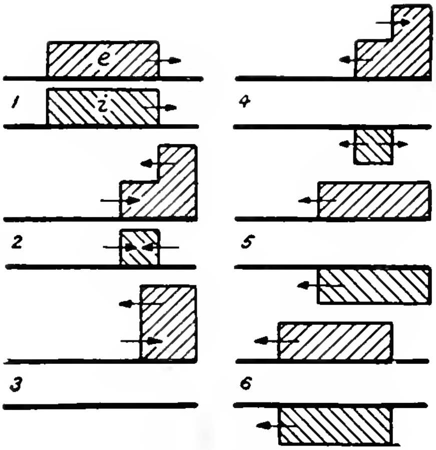

Fig. 9. Reflection of a traveling wave at the open-circuited end of a line

Fortunately the characteristics of transmission systems are such that their inductive reactance is not large enough to neutralize the capacity reactance at the fundamental generator frequency. Since, however, the inductive reactance increases and the capacity reactance decreases proportionally with the frequency, the two reactances come nearer together at high frequencies, such as the high harmonies of the generator wave. These may, therefore, be the cause of resonance rise of voltage between the line capacity and circuit inductance. With modern alternators, however, the higher harmonics are generally so small that there is not much danger from resonance.

Abnormal voltages are also often caused by traveling waves which are set up when the equilibrium of an electric circuit is disturbed. Such disturbances may originate in the circuit itself, as by switching, or they may be due to external causes, such as atmospheric lightning phenomena.

When an electric circuit is connected to a generator or other source of energy, a wave of voltage and current shoots out along the line with a very high velocity and charges the same. If the maximum value of the voltage is $e$ and the maximum value of the current $i$, the wave possesses per unit length an electrostatic energy of $\frac{Ce^2}{2}$ watt seconds and an electro-magnetic energy of $\frac{Li^2}{2}$ watt seconds, $C$ being the capacity in farads and $L$ the inductance in henrys per unit length of the circuit. These two quantities are equal or

$$\frac{Li^2}{2} = \frac{Ce^2}{2}$$

and the relation between the voltage and current at a certain point of the traveling wave is therefore,

$$e = \sqrt{\frac{L}{C}}\, i$$

$\sqrt{\frac{L}{C}}$ is termed the "natural impedance" of the circuit, and is of great value in the study of transient phenomena.

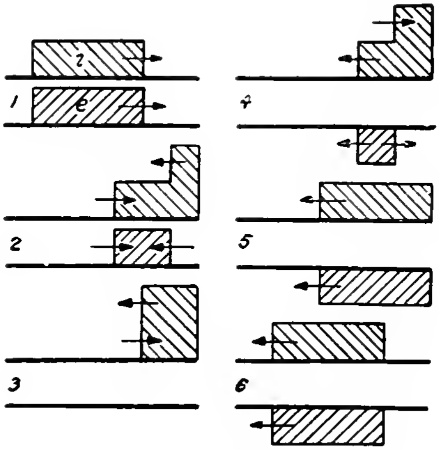

Fig. 10. Reflection of a traveling wave at the short-circuited end of a line

If the line is open-circuited at the farther end, it is obvious that when the wave reaches this point it can not flow any further, but is reflected, the voltage and current of the reflected wave being of the same values as in the original waves, because the energy remains constant. The total current of the incoming and reflected wave must, however, be zero on account of the open-circuited line, and the whole energy is, therefore, stored at this point in the electrostatic field. The reflected current wave must therefore be reserved and its value is —$i$, while the value of the reflected voltage wave at the end of the line where the original and reflected waves overlap is, therefore, equal to $2e$, as shown in Fig. 9.

When the end of the line is short-circuited, however, the conditions are entirely reversed. In that case the voltage at this point must be zero, and all the energy is stored in the electromagnetic field, the value of the total current at the end of the line being equal to $2i$, Fig. 10.

The wave travels twice forth and back over the entire length of the line, after which the conditions return to the same state as at the beginning, Fig. 11. It will, however, continue to oscillate forth and back until damped out by the resistance and leakage of the line, after which it assumes a stationary condition with a charge corresponding to the voltage of the generator.

The wave length is obviously equal to four times the length of the line, and the frequency of the oscillation is,

$$\frac{v}{4l} \text{ or } \frac{1}{4l\sqrt{LC}}$$

where $l$ is the length of the line, and $v$ or $\frac{1}{\sqrt{LC}}$ the velocity at which electric energy travels through a circuit whose inductance and capacity per unit length are $L$ and $C$. This velocity for overhead lines is equal to the velocity of light or 188,000 miles per second.

In the above it was assumed that the end of the line was either open or short-circuited. If a non-inductive resistance, $R$, however, is connected across the end, the voltage of the reflected wave, and thus the total voltage at this point, necessarily depends on the value of this resistance. When $R = \infty$, it naturally resembles an open-circuit, in which case the maximum voltage is equal to double the normal value, while if $R = O$, or negligible, thus resembling a short-circuit, the voltage is zero. With $R = \sqrt{\frac{L}{C}}$ there is no reflected wave at all. If $R > \sqrt{\frac{L}{C}}$ there is a partial reflection with reversal of current, while if $R < \sqrt{\frac{L}{C}}$ there is a partial reflection with reversal of voltage. With an inductive receiving circuit, this acts in the first instant as a resistance of infinite value, and the voltage reaches double value, while a condenser under similar conditions would act as a short-circuit, and the voltage be zero.

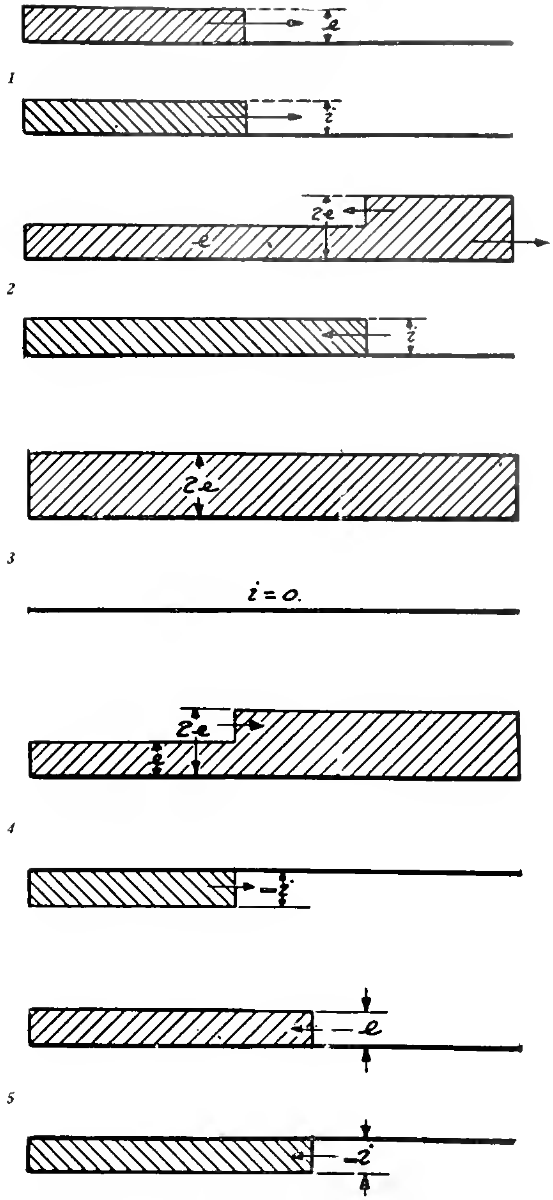

Fig. 11. One complete oscillation of a traveling wave set up when switching in an open circuited line

It is of greatest importance to consider the changes which take place at a transition point between two circuits of different characteristics, when a traveling wave passes from one to the other, such as for example where an underground circuit joins an overhead, or where a transmission line is connected to a transformer.

Assume that a traveling wave with the voltage $e$ and the current $i$ approaches from a circuit having a natural impedance $Z_1 = \sqrt{\frac{L_1}{C_1}}$ and enters a second circuit with a natural impedance of $Z_2 = \sqrt{\frac{L_2}{C_2}}$. Part of the wave will then be reflected and part transmitted. It is also evident that at the transition point the potential will be the sum of the incoming and reflected waves, while the current will be represented by the difference of the two waves since they travel in opposite direction. If we thus denote the voltage and current of the reflected wave by $e_2$ and $i_2$ and of the transmitted wave by $e_1$ and $i_1$, we get the following relations at the transition point:

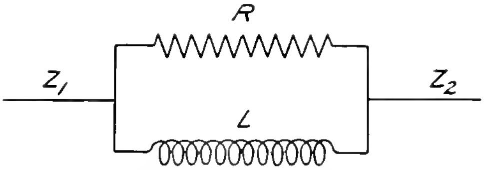

Fig. 12. Protective device, consisting of an inductance shunted by a resistance

$$e + e_2 = e_1$$
$$i - i_2 = i_1$$

but

$$i = \frac{e}{Z_1}$$
$$i_1 = \frac{e_1}{Z_2}$$
$$i_2 = \frac{e_2}{Z_1}$$

The amplitude of the transmitted voltage wave is therefore

$$e_1 = \frac{2Z_2}{Z_1 + Z_2} e$$

and of the reflected voltage wave

$$e_2 = \frac{Z_2 - Z_1}{Z_1 + Z_2} e$$

Similarly we get for the current

$$i_1 = \frac{2Z_2}{Z_1 + Z_2} i$$

and

$$i_2 = \frac{Z_2 - Z_1}{Z_1 + Z_2} i$$

If, therefore, $Z_2$ has a higher value than $Z_1$ it follows that the voltage of the traveling wave is transmitted to the second circuit at an increased amplitude and vice versa. A traveling wave originating in an underground cable will, therefore, enter an overhead circuit with an increase in voltage, while a wave originating in an overhead circuit will pass into a cable system with a lower voltage.

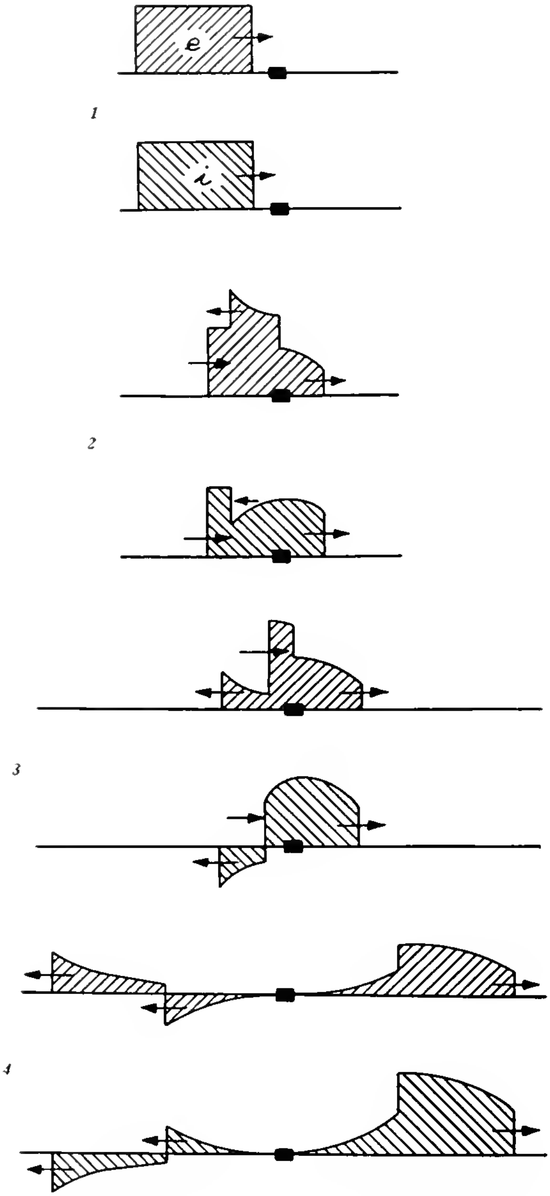

Fig. 13. The reflection and transmission of a traveling wave with concentrated inductance and resistance at the transition point

These relations between the reflected and transmitted waves to the incoming wave are, however, only applicable to cases where the wave in passing the transition point continues its travel in the form of a wave; that is in case we have distributed inductance and capacity on both sides of the transition point. If, on the other hand, resistance, inductance and capacity are concentrated at the transition point, the conditions become entirely different, and it is being suggested that such a scheme should be used for protecting transformers and machinery against the traveling waves entering from the line.

The use of inductance and capacity has been advocated for some time, and both have the properties of changing the wave front of the transmitted wave so that it begins with zero and rises successively. The reflected wave, however, will have a rectangular or steep wave front, similar to the incoming wave.

The energy of the incoming wave is naturally also split up in two parts, corresponding to the transmitted and reflected waves, but there is no reduction in the total energy. This has led to the suggestion by Eino Campo to use a resistance and shunt the same across an inductance, see Fig. 12. In addition to considerably smoothing out the wave front of the transmitted wave, it causes some of the electro-magnetic energy to be dissipated. The inductance forces a wave with steep front to pass through the resistance. This in turn results in a drop in voltage and gives the transmitted wave a lower value than the incoming, while on the other hand part of the energy of the wave is dissipated into heat. The working current, however, passes through the inductance with a negligible drop. Fig. 13 shows how the reflection and transmission of a traveling wave takes place in a particular case with inductance and resistance concentrated at the transition point. The amplitude of the waves as well as their wave fronts are of course dependent on the natural impedances of the circuits on either side of the transition point, as well as on the value of the inductance and resistance concentrated at this point. The calculations are, however, of a rather intricate nature and beyond the scope of this article. It is seen, however, that with a protective device of this kind, both the transmitted and reflected waves have steep fronts although of less height than the original wave. This has led to the suggestion of adding a condenser to Campo's combination, in which case the voltage at the front of both the reflected and transmitted waves would be zero. Both these devices are patented.

The above has dealt with the excess voltages which could occur when a line is connected to a source of energy. Dangerous voltages are, however, also liable to be set up when a loaded or short circuited line is suddenly broken. In this case the voltage rise depends on the value of the interrupted current, and the rapidity with which the circuit is broken, and again on the natural impedance of the circuit.

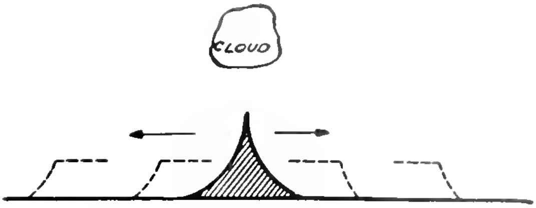

**Fig. 14.** Static charge of a transmission line

It was previously shown that the energy of a circuit was stored in both the magnetic and dielectric fields, corresponding to the current and voltage values. At a certain instant, therefore, the two stored quantities are equal, while if the current is zero all the energy must of course be stored in the dielectric field and vice versa. We thus had:

$$\frac{Li^2}{2} = \frac{Ce^2}{2}$$

and the relation between voltage and current

$$e = \sqrt{\frac{L}{C}}\, i$$

For transmission work the ratio

$$\frac{L}{C} = 138 \log. \frac{D}{r} \text{ ohms}$$

and this value generally falls between 400 and 200 ohms. For transformers, however, it is considerably higher, being around 3000, while an underground cable has a much lower natural impedance than an overhead circuit.

For example if in a circuit having a natural impedance of 400 ohms, a current with a maximum value of 200 amperes is suddenly broken, the surge pressure cannot exceed 200×400=80,000 volts, because this is the maximum value of the voltage wave which is necessary for storing in the dielectric field the whole amount of energy which was previously stored in the electro-magnetic field.

Traveling waves similar to the above are also set up by atmospheric lightning phenomena. The gradual accumulation of static charge on a line from the neighboring atmosphere increases its potential with respect to the earth, which may ultimately become so great as to puncture the insulators. Suppose now that there is a lightning discharge between cloud and cloud or between cloud and ground. This is followed immediately by a redistribution of the electrostatic field, and a general equalization of potential occurs. The static charge so set free moves along the line as an impulse or traveling wave, Fig. 14. Such waves may have a potential many times greater than that caused by switching, and they may have a very steep wave front and thus produce high potential differences between points along the conductor, such as across individual transformer coils or group of coils.

Several forms of protective devices of more or less value have been devised to guard against abnormal voltage conditions. Of these the aluminum cell electrolytic lightning arrester possesses ideal characteristics against such high voltage disturbances, where the excess voltage occurs between the phase conductors or between the phase conductors and ground. The films of the arrester introduce a barrier to the normal potential of the system, but allow the energy of an abnormal disturbance to readily discharge. The arrester is generally used in connection with choke coils, the function of which is to retard and reflect the incoming waves sufficiently to allow the arrester to better perform its duty.

Overhead ground wires are also very generally used to protect transmission lines against excessive static charges, the cost of high voltage lightning arresters making their installation along the line impractical.

The nature of high frequency disturbances is a comparatively recent discovery, and the means and methods for preventing them and protecting against them is still being studied and investigated. The greatest damage caused by such high frequency disturbances has occurred in high voltage transformers, as would naturally be expected. The best protection against them therefore, is, to heavily insulate the individual coil groups, while inductances and energy absorbing devices may, as stated, have to be relied upon for further protection.

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# NOTES ON THE CORROSION OF CONDENSER TUBES

By E. Bate

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While the subject of condenser tube corrosion has received close attention by a few investigators and a moderate degree of attention by many engineers, the complexity of the possible causes of corrosion has prevented the subject from being analyzed so thoroughly that completely satisfactory methods of design and operation may be deduced. A great amount of patience and time is required by the individual investigator. It is the object of the author to present in this article a record of an extensive investigation which he has made and which, in conjunction with quotations from authorities, ought to increase our knowledge of the subject. By a careful reading of this article and a study of the preventive and remedial measures discussed it is hoped that many engineers, who use brackish or salt water in condensers, will find relief from corrosion troubles.—Editor.

The question of condenser-tube corrosion, a problem which has been of very great and anxious interest to power-station engineers for many years, became a matter for special consideration upon the part of the author, as a consequence of troubles experienced at the Ultimo Power House. With a daily load of over 30,000 horse power, and a condenser equipment having a total of 18,000 tubes, it will be realised that occasional outbreaks of corrosion trouble, that threatened at times to develop into a serious epidemic, were the cause of the gravest concern to the management.

In order to avoid confusion with investigations carried out elsewhere, it is proposed to deal with such results as have been obtained by the author, and the theory on which the direction of his work has been based, even though at the present time the case for the author's theories may not be admitted as definitely proved. As much conflicting evidence is forthcoming on this subject, due possibly to unappreciated details, the author proposes to deal simply with his own experience, in the hope that, after due consideration of the same, other engineers may be able to throw further light on the subject by their experience.

Modern condensers of the surface type are very similar in construction. Cooling water is pumped through interior tubes of about ¾ in. diameter, No. 18 gauge in thickness, and from 10 feet upwards in length. Most condensers have the inlet and outlet branches at one end of the condenser, and a water-box at each end, the one at the inlet-outlet end being divided by a horizontal diaphragm.

In the author's experience, condenser tubes have suffered in the following ways, each being a form of corrosion or erosion, as the case may be, and not all necessarily susceptible of the same explanations.

1. The Pit-hole Corrosion.—This is the form of corrosion which has been responsible for nearly all the trouble under the author's notice. It consists of a hole, starting from the water side, and gradually penetrating the metal until a puncture develops and circulating water is admitted to the condensed-steam space. When salt circulating water is used, the condensed steam has to be rejected, forthwith, as unfit for boiler feed; and the tube is of course useless.

2. Some cases have come under my notice of tubes in which the zinc appeared to have completely dissolved away from the interior surface of the tube, leaving a porous and spongy copper residue of no mechanical strength. This form of corrosion is so rare that no opportunity has been given to observe under what conditions it occurs. It seems to be similar to the trouble known as "copper spot," which, however, generally originates from the steam side, and is probably caused by acids in the oily exhaust from reciprocating engines.

Possibly the makers of the tubes could give information that would act as a clue to the explanation why one tube only in a batch of 3,000 should suffer in this way. Conditions inside a condenser must be fairly uniform, so that the peculiarity would seem to exist in the tube as it leaves the maker.

3. There is a considerable tendency for tubes to suffer at the ends where water enters them, and there is a strong tendency for a general loss of metal from the interior surfaces of all tubes at the end remote from inlet-outlet circulating water branches. This seems to be originally an erosion, as distinct from corrosion, aggravated by the high velocities of circulating water demanded by modern designs. The presence of sand or grit in the circulating water would naturally aid this action, and it is significant that erosion is most pronounced at the end remote from inlet-outlet branches, where the stream lines of water flow are likely to be most confused. The remedy would seem to be plain to the engineer, but the question arises as to whether a tube thus eroded tends to corrode at the surface where the skin of metallic oxide has been removed. This can be tested by experiment, and results will be given later.

These three forms of trouble are all of great interest, but the first is of greatest urgency, and will be dealt with almost exclusively in the following notes.

Condenser tubes are commonly made of a brass whose composition is, approximately, 70 per cent copper and 30 per cent zinc. The alloy is cast, drilled, and hard drawn. Almost all the tubes used in the condensers under the author's observation are made to a specification demanding an Admiralty mixture. Four tubes made to this specification were analyzed, and gave the following compositions:

| | PER CENT | | | |
|---|---|---|---|---|
| | No. 1 | No. 2 | No. 3 | No. 4 |
| Cu... | 70.7 | 72.02 | 71.06 | 70.9 |
| Zn...... | 28.65 | 26.65 | 27.05 | 27.24 |
| Sn...... | 0.25 | 0.15 | 0.92 | 1.53 |
| Pb........ | 0.18 | 0.53 | 0.31 | 0.17 |
| Fe..... | 0.07 | 0.35 | 0.37 | 0.06 |

These tubes were all supposed to contain 1 per cent of tin, but, as can be seen, their composition is by no means uniform. Samples Nos. 1 and 4, it may be mentioned, were two out of very few which failed in a certain condenser.

Makers claim that such care and uniformity exists in the practice of tube manufacture, and composition varies so little that the failure of tubes is due to something having no reference to the manufacture. Experience has shown that tubes which last perfectly well in the condensers of one plant may fail rapidly in the condensers of another plant. The converse proposition has also been demonstrated. At the same time, it is undeniable that some tubes will last much longer in a given condenser than others, so that the tube equation is not absolutely negligible.

In the plant under notice, all tubes are of the Admiralty mixture, two condensers having tubes coated inside and out with tin, while the remainder have plain brass tubes, without any tin coating. Since they were first put into service, four years ago, two condensers on the 5000 kw. turbo units have given continuous trouble. These condensers have the tinned tubes of Admiralty mixture. From the first, a considerable amount of work has been carried out in the endeavor to diminish or prevent corrosion. In England, a special research committee, under the direction of G. D. Bengough, has been investigating the subject from a metallurgical point of view for some considerable time, and reports have been published in the technical press, though no very positive results appear to be available as yet.

In a lengthy report, privately prepared by the experts of a leading German company, in 1910, the conclusion is definitely stated that corrosion in condensers is due to two causes only.

(1) Galvanic currents, resulting from a difference of potentials between the different metals in the condenser with sea water as electrolyte.

(2) Stray currents from grounded direct-current systems.

Both are sources of trouble, but are not of the importance in the cases under observation that might be supposed. This report, prepared in the offices of a firm of the very highest repute, seems to emphasize, by its lack of suggestiveness, the necessity for studying the problem at first hand, and neglecting no facts that may be essential to an elucidation of the problem.

The author would suggest that the following possible causes of corrosion be considered:

1. Stray currents from grounded systems.
2. Galvanic currents of general distribution, due to the natural potential difference between the dissimilar metals of which the condenser is constructed.
3. Local galvanic effects, due to some deposit of electrically active material in the tubes.
4. Local galvanic effects, due to the segregation of one metal in an alloy.
5. The use of an alloy which is radically unsuitable to withstand the action of salt water, and which therefore, suffers a general loss of metal.

In addition to these causes, which seem probable, theories have been advanced at various times to account for corrosion, which do not appeal to the engineer as probable, but nevertheless are of interest.

Milton and Larke, in their paper, "The Decay of Metals," Proc. Inst. C.E., Vol. cliv., distinguish carefully between corrosion and decay. Decay is defined as the form of corrosion in which one metal of the alloy is selectively eaten away, as distinguished from the case in which the metal is attacked as a whole. Possibly, these authorities would look upon pit-hole corrosion as a decay, and most certainly "copper-spot" would come within this category. The conclusions of Milton and Larke are as follows:

(1) Decay is more frequent in metals that have a duplex or more complex structure than in those which are comparatively homogeneous.

(2) Decay is due to slower or less energetic action than that causing corrosion. Moreover, it requires an action which removes part only of the constituents of the metal, whereas corrosion removes all the metal attacked.

(3) Both decay and corrosion may result from chemical action alone, or from chemical and electrolytic action combined.

(4) Pitting, or intense local corrosion, is probably often due to local segregation of impurities in the metal, but it may also in some places be due to favorable conditions, furnished by local irregularities, of surface or structure, producing local irregularities in the distribution of galvanic currents.

(5) A percentage of tin in brass, exposed to sea water, is distinctly preservative, while lead and iron are injurious.

(6) To obtain a minimum of corrosion, the internal surfaces of condenser tubes should be as smooth and uniform as possible; and, in order to insure this condition, the cast pipe from which they are drawn should be smoothly bored inside, either before the drawing is commenced or in an early stage of the process.

(7) Experiments with an applied electric current show that electrolytic action alone, even where exceedingly minute currents are employed, may result in severe corrosion or decay.

Most investigators have worked along the lines that, given a suitable alloy, corrosion will be eliminated or greatly reduced. They have experimented in the usual way by suspending pieces of different alloys in salt or fresh water, or in weak acid, and noting the loss of weight in a given time. Such work is undoubtedly very valuable, but the fact always remains that, where one or two condensers in a plant are immune from pit-hole corrosion while others suffer, all using the same kind of tube, purely local conditions must be of much greater importance than the general considerations of alloy suitability.

It is of interest to note the work and theories of Mr. Rhodin (*The Engineer*, July 19th, 26th, and Aug. 2nd, 1907) in connection with the solution of alloys, and they are of special interest to the author since, quite independently, he formulated a theory on an identical basis which gave interesting results. Mr. Rhodin divides alloys into two classes—balanced and unbalanced. From an energy point of view, it would appear reasonable to suppose that an alloy in which both constituents tend to dissolve with the evolution of the same amount of heat would be more stable than one in which the amounts are different for each constituent. Or, looking at the question in the light in which it occurred to the author, assume a copper-zinc alloy, immersed in salt water. The tendency is for oxidation of the metal surface to take place. If the seat of electromotive force of solution is at the surface where oxidation is taking place, particles of the two constituents, infinitesimally close together, will have each a definite solution potential. If these solution potentials balance, then the minimum rate of corrosion is obtained, for if they do not balance, local currents are set up and electrolytic corrosion assists the purely solution or oxidation corrosion. On this theory, and by using the heats of oxidation and molecular weights of copper and zinc, the author arrived at the result that 70 per cent Cu and 30 per cent. Zn is the best alloy of these two metals. Mr. Rhodin assumed that both metals tend to form a chloride initially, and that the weight of metal dissolved will be proportional to the conductivities of the respective metals; and on this basis calculated that a mixture of 61 per cent Cu to 39 per cent Zn was the most stable.

The theory is interesting in that it affords some explanation of the fact, experimentally observed, that corrosion tends to progress at a spot where it has been started by galvanic action, even when the exciting element has been removed. The preceding theory which has been stated quite roughly, appears to the author to be instructive from an electro-chemical point of view, even when pushed to limits. Thus, it is undeniable that perfectly homogeneous metals have very little tendency to lose weight when immersed in an electrolyte, whereas the presence of even slight quantities of impurities is conductive to corrosion. The metals, or pseudo metals, which are least oxidizable are called electro-negative to the more oxidizable metals, such as potassium, sodium, zinc, iron, hydrogen, lead, copper and silver.

The following table of electro-chemical characteristics of the common metals is taken from Prof. S. Thompson's Text Book:

| Substance | Heat of Oxidation of Equivalent | CALCULATED E.M.F. RELATIVE TO | | E.M.F. Observed in Dilute $H_2SO_4$ |
|---|---|---|---|---|
| | | Oxygen | Zinc | |
| Potassium | 69.800 | 3.01 | +1.18 | +1.13 |
| Sodium | 67.800 | 2.91 | +1.09 | |
| Zinc | 42.700 | 1.83 | . . . | |
| Iron | 34.120 | 1.55 | −0.28 | |
| Hydrogen | 34.000 | 1.47 | −0.36 | |
| Lead | 25.100 | 1.12 | −0.71 | −0.54 |
| Copper | 18.760 | 0.80 | −1.08 | −1.047 |
| Silver | 9.000 | 0.39 | −1.44 | . |
| Platinum | 7.500 | 0.33 | −1.50 | −1.53 |
| Carbon | 2.000 | 0.09 | −1.74 | . |
| Oxygen | . . . | . . . | −1.83 | −1.85 |
| Nitric acid | − 6.000 | −0.26 | −2.09 | −1.94 |
| Black oxide of manganese | − 6.500 | −0.29 | −2.12 | −2.23 |
| Peroxide of lead | −12.150 | −0.52 | −2.35 | −2.52 |
| Ozone | −14.800 | −0.63 | −2.46 | −2.64 |
| Permanganic acid | −25.070 | −1.93 | −2.92 | −3.03 |

It is, therefore, quite consistent with the theory of unbalanced alloys that a small segregation of less oxidizable metal in any metallic surface should be the seat of local galvanic action and of corrosion. The segregation is, in such a case, an electronegative segregation and, since the more electro-positive (or more oxidizable) surface immediately surrounding the segregation will continuously dissolve, leaving the electronegative particles undissolved, a corrosion similar to observed pit-hole corrosion could be anticipated. The interesting consideration in connection with the idea of a "balanced" alloy is, however, that by scientifically mixing two metals we may produce an alloy which possesses desirable physical characteristics, and is so proportioned that there is a balance of oxidizability, and therefore a diminished tendency to corrosion.

There is very strong evidence to support the calculation, that the 70 per cent Cu and 30 per cent Zn mixture is stable. Three very prominent station engineers state that a mixture of 70 per cent Cu, 29 per cent Zn, and 1 per cent Sn is the most satisfactory mixture they have used, and this mixture is also favored by the British Admiralty. The function of the 1 per cent Sn is not very well known, but metallurgists insist upon it. It may possibly toughen the alloy by forming the separating film between molecules. Personally, I have observed this alloy to be very satisfactory for condenser tubes, if used as finished from the mill without tinning, but where local conditions are conducive to erosion, an alloy having a tougher surface could be desired, and that question is now receiving considerable attention.

I have observed that there is always a tendency for slow erosion, at the ends of the tubes made from this mixture, in the condensers at Ultimo. Possibly, the comparatively large amount of silt and grit in the circulating water may cause this trouble to be peculiar to that station. It should be understood, however, that while it would be satisfactory to find no traces of erosion, the amount that does take place cannot be considered as of very serious moment.

When confronted with the problem of determining the cause of tube corrosion in two condensers at Ultimo power-house, the possible reasons outlined above were set down and a process of elimination attempted.

A theory was advanced that corrosion might be due to charges of electricity induced in the tubes by the impinging exhaust steam. This theory was investigated by the author, with all the precautions as regards insulation which will suggest themselves to the electrician, but no sign of any change could be detected by the most sensitive instruments available, or by the electroscope.

Dealing with the more probable causes of trouble which have been specified, it has always appeared to the author that it should be possible to determine, by careful observation, to what particular cause any case of trouble can be attributed. For instance, if leakage currents are the source of trouble, this means that currents are finding their way through the circulating water, and are flowing at the places where corrosion occurs, from tube to water. In such a case, we should expect corrosion to occur in patches, and in such a position in the condenser as corresponds to a point where the current is compelled to leave the tube, due to some resistance to its further path through metal. This would naturally be near the tube plate, where, possibly, the contact between tube and tube plate might be poor electrically. If such effects were actually noticed, then careful potential measurements should determine the path of current flow by detecting the differences of potential maintaining the flow.

In a paper before the American Association for the Advancement of Science, June 29th, 1906, at Ithaca, N. Y., Mr. W. W. Churchill discussed the case of condenser trouble due to leakage currents from railroad systems, with special reference to the Bayridge Station of the Brooklyn Edison Co. In this case it was found that rails in the freight yard of the Long Island R.R. were at a potential of 9 volts above the river during peak load. The power-house is situated between the railroad and the river, and conditions were such that the condensers formed part of the path of current flow. Undoubtedly in such a case, there are several elements liable to cause the trouble so frequently experienced in water mains before careful bonding and negative boosting with suitable provision of negative copper was insisted upon. Mr. Churchill installed an arrangement for providing an e.m.f. to counteract this potential with good results. His claim was that, by increasing this counter e.m.f. suitably, the natural potential between the zinc and copper of the alloy composing the tubes was overcome. Corrosion prevented by this means will be dealt with later. The author would suggest that corrosion due to conditions similar to those mentioned would occur in patches, causing widespread weakening of the tube walls and, finally, large irregular holes. Modern condenser tubes are so clean, smooth, and uniform that the claim that slight irregularities of the surface cause the pit-hole phenomena under such conditions seems weak.

The point where current enters the tube should not be a seat of corrosion, and this type of corrosion can therefore, be differentiated in this way from those due to causes (2) or (5). In view of the care taken to provide negative boosters and reduce the potentials of boosting points to within four or five volts of the negative busses in tramway stations, it can confidently be asserted that stray currents are not now a very serious contributing factor to the sum total of condenser-tube corrosion.

General galvanic currents from tubes to water, due to the natural potential difference between the tube metal, the metal of the tube plate, and the metal of the shell, covers and piping (generally cast iron) are possible when the metal of the tube is electro-positive to the other metals. In this fact lies the secret of mistakes often made in considering this question. Generally speaking, the alloy of which tubes are composed is electro-negative to cast iron. Admiralty mixture tubes are most certainly negative to cast iron in sea water, and will, therefore, not be subject to any loss of metal when in contact with cast iron in sea water. On the contrary, it would be expected, and is actually the case, that cast iron covers and water boxes are very strongly attacked and corroded. Here, again, I venture to think that most of the corrosion of cast iron is due, not to the fact that it is in contact with gunmetal in an electrolyte, but to the fact that cast iron is very similar to an "unbalanced" alloy. It contains a percentage of carbon, a strongly electro-negative element (which is a matter of common knowledge because of its use in certain primary cells).

By degrees, during the observation of the phenomena of pit-hole corrosion, the extremely local character of the action was forced under observation, and the conviction grew that some electro-negative material must be responsible for the trouble. The form of failure is just that which could be anticipated from local action due to an electro-negative particle on a surface positive to it. If this is correct, then there seems only two ways in which such a condition can be set up.

1. By segregation in the alloy.
2. By deposit of electro-negative particles on the tube surface.

To determine between these two seemed quite simple, and accordingly great care was taken to have all the faulty tubes removed from the condensers carefully examined.

Before giving particulars of the observations actually made in faulty condenser tubes I wish to point out the extreme importance in the determination of the cause of corrosion of a factor in the action which is not generally thought vital, I mean the question, "How long does it take for a tube, say No. 18 gauge, to become pitted completely through?" The importance of this question can be seen by considering the alternatives named, to which the investigation appears to have been reduced. If segregation in the alloy is the cause of trouble, and if we can definitely say that tubes so affected will corrode, and fail within a certain limit of time, then we should certainly expect all tubes in a condenser to fail within a definite period. It can hardly be that one batch of, say, 30 tubes would fail within three months after being put in service, and that another 30 of the same batch, which, by hypothesis, fail from the same cause, should last three years. It seems impossible that such a discrepancy, or such a wide variation, in corrosion period of tubes whose failure is due to an inherent fault in the metal could exist. But if corrosion is due to some deposit of electro-negative material, and if complete piercing of a tube normally takes place in a short space of time, then it would be reasonable to expect failures to occur just as fast as such deposit takes place and according to the number of tubes so affected. It may be argued that the difference in mass of segregated particles will account for the difference in corrosion period; but, since the segregation must be electro-negative to account for the form of pit-hole, it follows that the mass of the particles will affect only the size of the pit-hole, and not the speed of corrosion, since the electro-negative element is not wasted in such galvanic action, and the wasting of the electro-positive material is governed by the potential between the two elements, which is independent of the size of the element. Engineers whose condensers have suffered from pit-hole corrosion will probably have had a similar experience. Failures start to take place within a month or two after the condenser is put in service, and the average failures per week gradually increase to a steady average rate of failure, with heavy failures now and again. In some cases the trouble may cease after a few months, and the engineer usually concludes that corrosion was due to faulty tubes, which have been eliminated. In several cases I have found that, about the time when failures ceased, some certain treatment of the condensers had been started, which the engineer generally did not connect in any way with the improved conditions. I wish to establish the fact that it is possible to stop failures by methods whose only effect would be to prevent the possible deposit of electro-negative material in the tubes, and, furthermore, to establish the fact that the effect is noticeable very rapidly, which points to the fact that corrosion is a phenomenon whose action is very rapid.

Now turn to another aspect of the discussion of these alternative causes. If corrosion is due to segregation, then it is reasonable to expect that corrosion spots will occur anywhere in a tube. There is no more reason why pit-holes, due to segregation, should be located, say, above the horizontal diametrical plane of the tube surface than below it. But if corrosion is due to a deposit, then, undoubtedly, we can expect with confidence that the majority of holes will be in the lower half of the tube. This anticipation is most strikingly verified as a result of the author's observations. The author's practice has been to have all tubes marked before being withdrawn from the condenser, by making a chisel nick in the tube on the upper end of the vertical diameter at a particular end of the condenser.

Of 468 tubes thus marked and examined, I found that only 21 had a corrosion hole in the upper half of the tube, the remainder were in the lower half. The percentage of failures in the bottom half, being about 96, enormously strengthens the case for the second alternative. In regard to the location of failure holes with reference to the length of the tube, I find that no part can be said to be very much more vulnerable than another. Sometimes a batch will have a decided preference for the center of the tube, sometimes for the ends. The sag of tubes is not sufficient to bring gravity into account in selecting the lowest point of the tube for a location of the action.

This interesting fact, i.e., that corrosion of the tubes under notice took place on the bottom half of the tube, has been corroborated by other engineers whose condensers suffered in the same way, and it became important, since the very strongest grounds were present for suspecting that a dangerous deposit was being left in the tubes, to determine from what source this deposit came.

The author's attention was directed to the corroding cast iron of the circulating system and condensers as a source of troublesome deposit for the following reasons:

1. Although the circulating water brought through the condensers in question is always very dirty, certain condensers taking the same water have been free from trouble.
2. If, therefore, we consider the water at intake in the harbor as free from deleterious material, the troublesome particles must come from the metal in contact with the water on its way to the condenser.
3. Cast iron, unless carefully protected, corrodes severely when exposed to the action of sea water and, as cast iron is a so-called alloy of carbon and iron with traces of other impurities, the products of corrosion will be mainly oxide of iron and carbon. Carbon is, as previously pointed out, strongly electro-negative, and, therefore, of just the nature to cause the trouble experienced.
4. The condensers under particular observation, which gave very serious trouble, were provided with 22 copper stays between tube plate and water box cover at each end, and these copper stays had cast iron sleeves to form distance pieces between tube plates and covers. There were thus 44 cast-iron distance pieces in the water space of the condenser, all of which were found to be badly corroded, especially close to the tube plate, where they were in close contact with the gun-metal surface.

To test this theory, the cast-iron distance pieces were removed, and gun-metal distance pieces substituted, while, at the same time, the cast-iron surfaces in contact with circulating water were all cleaned and painted with a protective coating. It must, however, be understood that the station in question possesses a circulating water system peculiarly liable to produce the trouble which it is required to avoid, for the circulating water is pumped through a distance of, roughly, 300 yards in 36 in. diameter cast iron pipes. To insure that the pipes are not constantly fostering trouble seems impossible. Stations that take circulating water to the condensers, or to the circulating pump intake in concrete or brick ducts, and use either short cast-iron or entirely gun-metal intakes, should therefore not suffer to any appreciable extent from tube corrosion. At the White Bay power-house this policy can be pursued, as the circulating water ducts are entirely of concrete, and the short intake is of gun-metal, the pump body and impeller being of a yellow metal mixture. Inquiries have elicited the information that several plants, which have been free from trouble, have consistently protected their cast iron on general grounds without any idea of thereby preventing the corrosion of condenser tubes.

The measures above outlined were soon productive of marked diminution in the number of tube failures in these condensers, and it can be definitely stated that, up to the present, no tube put in the condensers since the alterations were made has failed. A further trial of the system was rendered possible by the installation, in the same station November last, of an additional condenser, connected to the same pumping plant and containing 3000 tubes, each 15 ft. 3 in. long. This condenser was treated as the above investigation would dictate, and was in no other way specially treated. Up to the present time the condenser has been in continuous service and has not yet suffered a single tube failure. The troublesome condensers, on the contrary, showed tube failures within a few weeks of being put in service.

Another condenser, of somewhat larger surface, and which having been in service for a period of ten months, up to September, 1912, at that date began to show indications that tube trouble might be experienced. This one was taken in hand, forthwith, and treated carefully on the lines suggested by the author's work, with the gratifying result that, to date, the trouble has not reappeared.

It is possible, therefore, to instance four large condensers in one station treated according to this simple process, all of which have given satisfactory results. Additional corroboration should be forthcoming as a result of the operation of the new station at White Bay.

Beside the New South Wales Tramways, I have assurance that in the station of the Adelaide Tramways, which was suffering very severely from tube corrosion, the process was immediately productive of satisfaction.

The report of the Adelaide Tramways Trust Power Station, reads as follows:

"After the power station had been running for nine months without any trouble of this kind, the tubes in all three condensers began to leak, gradually getting worse and worse. The tubes were cleaned periodically, and in November, 1911, all the tubes were thoroughly cleaned and scraped, and all the ferrules were tightened, with the object of improving the contact between ferrule and tube. This, however, had no effect. Zinc plates were hung in the water boxes at both ends of No. 1 condenser in November, 1911. The tubes soon after this began to corrode rapidly, and in February, March, and April, 1912, the electrolytic process was tried on No. 3 condenser. Tubes were hung vertically and horizontally in the intake sump, and also in the Port Adelaide River, adjacent to the Power Station from which the circulating water is taken. All these tubes corroded badly, particularly in the more stagnant water in the sump. In these cases the tubes were suspended by marlin, and no contact whatever with any other metal was possible.

Up to this time none of the attempts which had been made to overcome the corrosion had been successful, and improved results could only be obtained by retubing. In April, 1913 the method of protection employed at Ultimo was tried, and No. 2 condenser was painted inside the water boxes, covers, and pipes with three coats of biturine solution. The result was that corrosion ceased until the paint washed off. No. 3 condenser was treated in a similar manner in the beginning of May, with a similar result. No. 1 condenser, however, was treated in the beginning of May with three coats of Hartmann's Red Hand Anti-corrosive Paint. This lasted three times as long as biturine solution. Whenever an application of paint was made, the trouble immediately ceased, and after a while when the paint washed off, the trouble began again; and it is now only a question of time before the paint is washed off, and corrosion starts again."

The engineer whose plant is suffering from tube corrosion troubles will naturally ask whether, granting the correctness of the theory as to the cause of trouble, it is possible to save tubes which have already started to corrode. It may be that a large number of tubes in a condenser have started to pit, and a saving could be effected by preventing the further corrosion, even if some slight expense were involved. Personally, I am of opinion that local corrosion, once started, can not practically be stopped. It has been proposed and attempted to stop corrosion by the application of electric current to the condenser in such a manner that electrodes in the water space form the anode for the passage of an electric current whose cathode is the tubes. The idea is that, by forcing current into the tubes at all parts of the wetted surface the dissolution of the tube is prevented. For a similar purpose blocks of electro-positive metal are sometimes advised to be suspended in the water space, externally connected to the tube plates, which in turn make metallic contact with the tubes through metallic grummets in the tube packing.

If pit-hole corrosion were a simple matter of electrolytic solution, due to the general potential of the tube, relative to other metallic parts of the condenser in an electrolyte, then these methods of protection would be logical. If, however, as contended above, pit-hole corrosion is due to extremely local galvanic couples, then it seems quite illogical to expect any protection from electro-positive masses, or from the application of electric current, for obviously no general distribution of current can overcome the potential between two parts of the surface almost infinitesimally close together. It has been claimed that the potential of the electrodes, when current is applied, must have a definite value to obtain the best results.

In tests made by the author, it was found that absolutely no diminution of the rate of tube failures was effected by the use of this method although the tubes were undoubtedly receiving current, since a deposit of copper from the copper electrodes was found in the interior surfaces of the tubes. Further, tubes which failed during the time that this test was made, were cut up and were found to be coated with deposited copper right up to the failure hole; in the opinion of the author, most conclusive proof that applied current did not protect the tube from pit-hole corrosion.

An interesting sidelight on the claim that the use of electrode current can prevent pitting is furnished by the following extract from the paper by Mr. W. W. Churchill, mentioned above:

"By this means (i.e., by applying an electro-motive force to balance the potential between railroad rails and river water at all times), we succeeded in properly adapting the sizes of the generating and other apparatus. All corrections were made in a manner to insure a uniform voltage of the various parts of the condenser, to prevent local action, each connection being so made and provided with such measuring instruments as to insure ready adjustment to effect this. The apparatus was designed in accordance with the above statements. Its operation has extended over a period of fourteen months, and with the exception of *about 10 tubes, which have pitted,* the results have been satisfactory."

The paper quoted is the only one which I have been able to find in which an attempt is made to argue the theory that electrode current can overcome pitting, or can overcome the natural potential between zinc and copper at atomic distances apart in an alloy. The words italicized lead very clearly to the assumption that the undertaking succeeded in counter-balancing the railroad leakage potential, but that the method had no effect in preventing the true pitting action.

The author trusts that if the logic of his theory is sound, the result will be a greater confidence in installing large condensing plants, and less anxiety as to the possibility of serious and expensive trouble. It should lead to a modification of those conditions under which large stations draw supplies of sea water through considerable lengths of cast-iron piping, often quite untreated internally, and thus liable to continuous corrosion. The suitability of the Admiralty tube for plants using sea water, when supplied by good makers is, in the opinion of the author, well established, but tinning of the tube seems unnecessary and dangerous.

# THE ELECTRIFICATION OF THE J. G. BRILL CAR MANUFACTURING PLANT

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This article furnishes a detailed description of the sources of power and the means of energy distribution which have been adopted by the J. G. Brill Company in the electrification of its plant. The electrical installation is a model one, being very flexible to meet the varying conditions of daily load and capable of systematic growth in keeping with the increased demands in production. The following information which is contained in the article will be of particular interest to those who are contemplating the design of a system to supply electric energy throughout a factory: Ratings and other electrical dimensions of the various units comprising the system; diagrams of the relative location of the parts of the equipment; wiring diagrams of the connections between the pieces of apparatus; and photographs of interesting parts of the installation.—Editor.

The J. G. Brill Car Manufacturing Company, located at 62nd Street and Woodlawn Avenue, Philadelphia, Pa., affords a noteworthy example of the modern practice of laying the foundations for future extensions in plant operation as well as in the commercial departments. Due to the many changes in production methods and to the rapid increase of output, this company has at various times found it necessary to remodel and enlarge its power equipment. In view of this past experience, provision for the conditions peculiar to the plant were incorporated in the design of the new scheme of power distribution.

Of paramount importance was the insistance upon safety to employees, which necessitated first, the isolation of all high-tension apparatus beyond access of any other than authorized attendants, and second, the installation of a low-voltage remote control for operating the high-tension switches.

To preclude any possibility of service interruption, arrangements were made for a reserve source of power and for a distribution system wherein any one unit may be cut out without interfering with the whole. To avoid expensive alterations in the future, it was essential that the system be designed with sufficient flexibility to permit of regrouping or of additions without disturbing the other units of the system. Moreover, provision was made whereby such changes may be accomplished without the high expense entailed in laying or taking up long feeder lines. The best solution of this problem was the adoption of a unit basis of design which would readily permit of additions to the generating capacity, or of changes in the location of power consuming elements, without disturbing the present equipment as installed. The system, as finally worked out and installed, is as follows:

Current may be supplied from two sources: The Company's steam plant, capacity 800 kw., 250 volts direct-current; and the synchronous-converter substation, total capacity 1600 kw., 250 volts direct-current (present installed capacity, 600 kw.). Power is supplied to the substation by the Philadelphia Electric Company through two feeder circuits at 13,200 volts, three-phase, 60 cycles. Tracing the distribution in terms of a one-line diagram, the current is taken through a disconnecting switch, through the oil switch, and through a second disconnecting switch to the 13,200-volt station busbar. From there it is taken through a disconnecting switch, through an oil switch to either bank of converter transformers, which lower the voltage from 13,200 to 180, 120, 60 volts, providing one-third and two-thirds starting tap and one hundred per cent running tap for the synchronous converters. The connections as described are shown in Fig. 1. From the synchronous converters, the current is taken at 250 volts through the direct-current converter panels to the direct-current station bus and through the yard bus panels to the main plant distributing system. Paralleled with this source is the Company's steam plant, comprising two 300-kw. and one 200-kw., direct-connected, engine-type, 250-volt, two-wire direct-current generators.

The principal shops are served from this bus through solenoid-operated circuit breaker panels (one panel being located at each important shop distributing point), controlled from the steam plant and from the substation by the multiple control system of connections shown in Fig. 2.

### The Substation

The substation, Fig. 3, located along the Woodlawn Avenue yard-line, is 65 feet 3 inches long by 18 feet 8 inches wide by 37½ feet high. The construction is of concrete and structural steel with brick curtain walls and cement floors and roof. Light is provided by large steel-sash windows of wire glass protected by wire screening. These swing on horizontal pivots to admit air. Proper ventilation is insured by four 24 inch diameter globe ventilators equally spaced along the center line of the roof, in addition to the louvres extending the entire length of the south wall back of the transformer banks.

Large door openings fitted with rolling steel shutters are provided in front of the synchronous converters to facilitate the setting and moving of the machines. Directly over the converters, and extending the entire length of the room, is a trolley crane beam for moving the machines or machine parts.

The wall columns are of 8-inch Bethlehem H-section steel bolted to concrete foundations extending below the frost-line. The 15-inch I-beams supporting the floor of the second story are riveted to the H-section columns and both are encased in concrete.

The foundations for the synchronous converters, both future and installed, are of heavy concrete construction. Between the switchboard and the Woodland Avenue wall is a cable pit 4½ feet wide by 4 feet deep, provided with a removable cover of oak planking which forms the flooring back of the switch-board; all remaining floor space is of concrete. The floor of the pit, the converter foundations, and the floor proper are provided with screened drains leading to the sewer. The spiral stairway leading to the second story is of iron. All cables are enclosed in ducts running along, or imbedded in the walls and floors, and the whole is made as nearly fire-proof as possible.

The lines of the Philadelphia Electric Company are brought underground to a manhole located just outside the yard-line. From this manhole the 13,200-volt circuits are brought underground in lead-sheathed

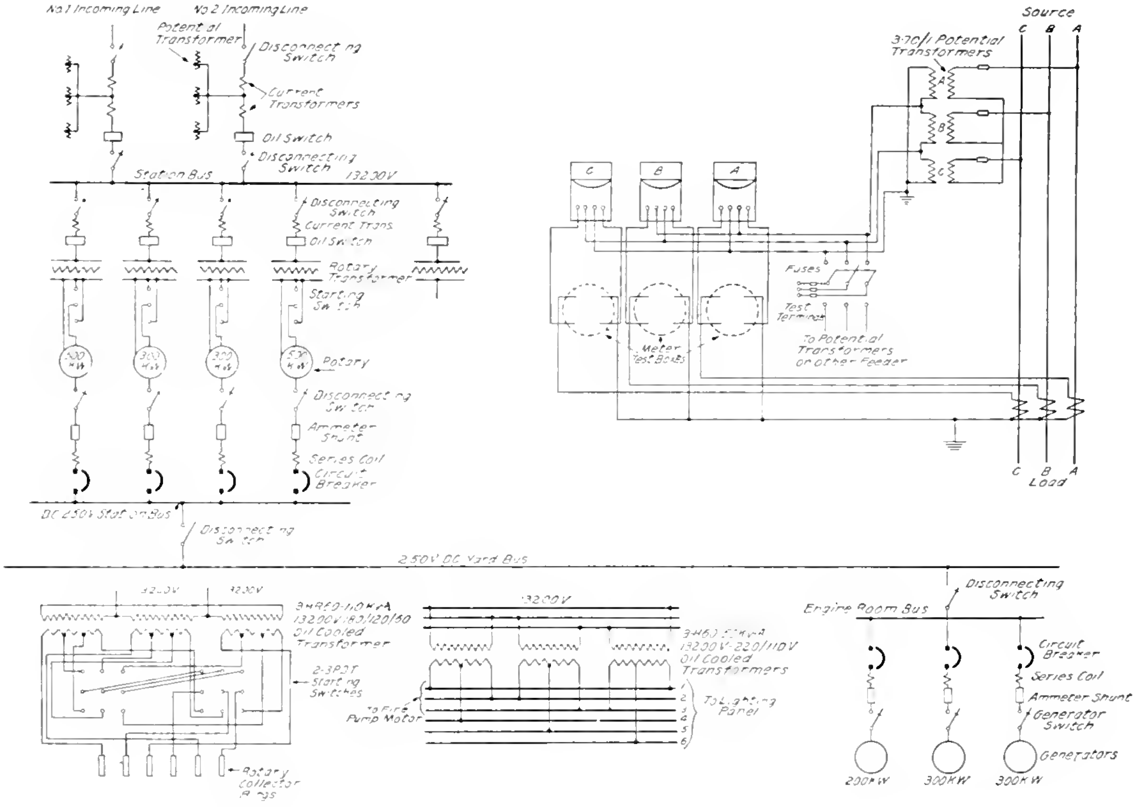

Fig. 1. General Wiring Diagram

cables into the substation, and are carried direct to the high-tension floor through vitrolite conduits moulded to the wall in plaster casing. This casing, flanked by metal conduits containing the control and instrument circuits, can be seen on the back wall of the first floor as shown in Fig. 4.

All high-tension apparatus and connections are located in the second story of the substation. Here are installed the oil switches and the two banks of transformers for the synchronous converters, with spare cells and settings for two additional complete units. In addition there are three single-phase, 60-cycle, 13,200-220/110-volt, 50 kv-a. oil-cooled transformers for the fire pump and yard lighting service. This bank of transformers is shown in Fig. 5.

The oil switches are of the t-p. s-t. type, are of 300 ampere 15,000 volts capacity, and are made up of three single-pole units, solenoid-operated; the solenoid is controlled from the switchboard on the first floor by low-voltage direct current. Each pole is housed in a fire-proof brick chamber with top suspension swinging-type doors made of asbestos lumber. Hand-operated disconnecting switches provide means of isolating any switch for inspection or regular repair work without interfering with the operation of the other circuits.

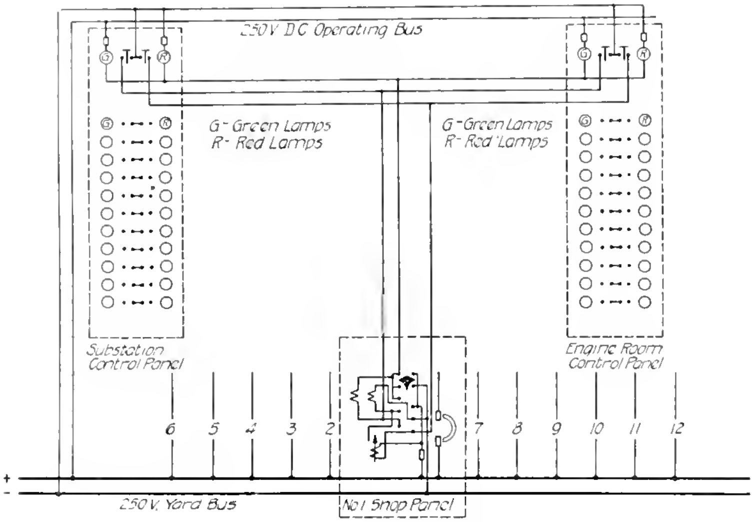

Fig. 2. Shop Control Diagram

Each bank of transformers for the converters is composed of three 110-kv-a., 13,200-volt primary, 180-volt secondary, 60-cycle, oil-cooled transformers of the inherent reactance type, having delta connected primaries, with one-third and two-thirds secondary starting taps and two 5 per cent high-tension taps to permit adjustment of voltage ratio to compensate for variation of the incoming feeder voltage. Like the oil switches, either bank of transformers for the converters can be isolated by disconnecting switches to permit of inspection or repairs.

Fig. 3. Substation Building, Front View from Yard

Fig. 6 shows the setting for these transformers, so graded that, in case of fire, the oil can be emptied direct to the drain pipes. The drain pipes are protected by wire gauze to prevent the flames entering the drains.

Fig. 7 is a diagram of the high-tension floor, showing location of switching equipment, transformers, and space reserved for future installations.

The arrangement of busses and switching apparatus is shown in Fig. 8.

On the first floor are located two synchronous converters and the substation switchboard. The plan of this floor is shown in Fig. 7A. The converters are six-phase, eight-pole, 300-kw., 900-r.p.m., 250-volt machines complete with end-play and speed limiting devices, and provided with break-up switches, equalizing switches, and field rheostats. The panels containing the converter starting switches are mounted near the machines independent of the station switchboard, as shown in Fig. 10. Each of these is equipped with one t-p. d-t., 1000-ampere, 440-volt lever switch and one t-p. d-t., 600-ampere lever switch.

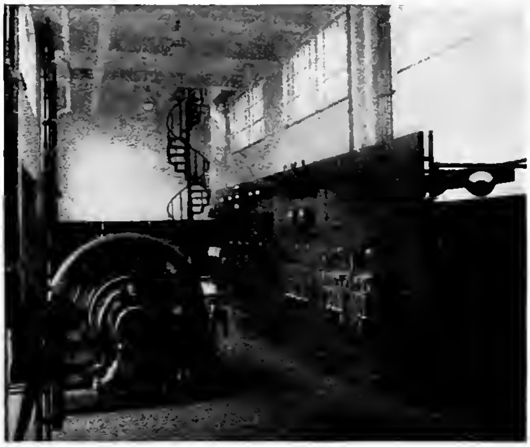

Fig. 4. First Floor of Substation

Fig. 16 shows a photograph of the switchboard as installed; Fig. 11 is back view of direct-current end. Panel 1 is the totalizing instrument panel mounting six single-phase watthour meters arranged in two banks, each bank registering the load of an incoming feeder. Fig. 1 shows the details of meter connections. The instrument transformers for these are located between the disconnecting switches and the oil switches on the incoming lines. Panels 2 and 3 are the incoming line panels of 1000 kw., 13,200 volts capacity, from which are controlled the solenoids operating the oil switches that connect the incoming feeders to the high-tension busbars. Panel 4 is the high-tension control panel for the fire pump and yard lighting circuits, capacity 150 kw., 13,200/220 volts. Panels 5 and 6 are blank alternating-current converter panels, and 6 and 7 are the equipped converter panels of 300 kw., 13,200/180 volts capacity. Panels 9 and 12 are blank direct-current rotary panels, and 10 and 11 are the equipped direct-current rotary panels of 300 kw., 250 volts capacity. Panels 13 and 14 are the direct-current yard bus panels, each mounting four 2000-ampere, 250-volt lever switches for picking up the sections of the yard bus. The alternating-current yard lighting panel No. 15 is provided with two sets of 3-phase busses; one set, 110 volts; the other, 220 volts. This arrangement

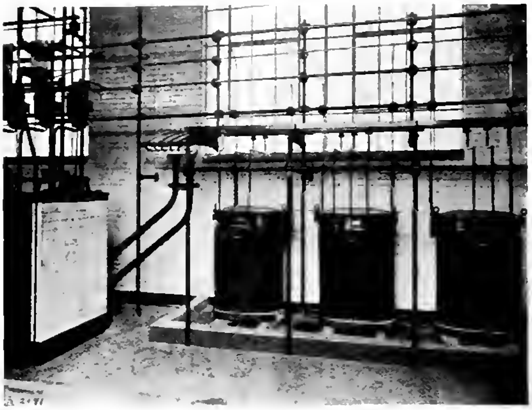

Fig. 5. A Bank of 13200-220/110 Volt, 50-Kv-a. Transformers for Fire Pump and Yard Lighting

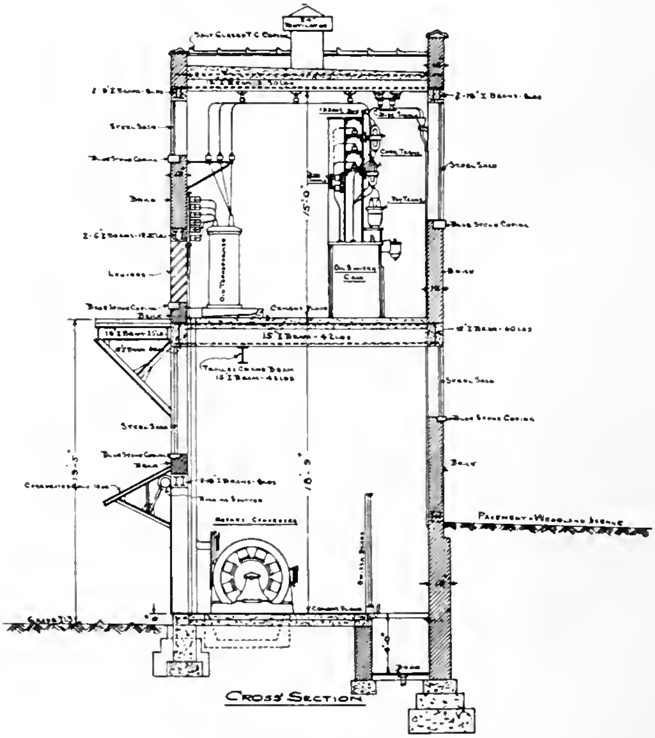

Fig. 6. Cross-Sectional View of the Substation

renders available three-phase 110 volts, three-phase 220 volts, and three-wire 110/220 volts. The transformer connections to this panel are shown in Fig. 1. The shop circuit control panel No. 16 is equipped with 12 s-p. d-t., 250-volt remote-control switches, operating the circuit breakers on the shop panels and tied in parallel with the switches on the duplicate panel, No. 24, in the steam plant. Red and green indicating lamps, showing what shops are thrown on, give the attendant at either place accurate information as to the operation of either board. Panel 17 has a swinging bracket mounting a 300-volt, direct-current voltmeter, which by the use of proper potential plugs will show the voltage of either machine or of the yard bus.

### Yard Bus

In deciding upon a means of serving the various shops of the plant, mature deliberation was given to the advantages of many practical systems compatible with the plant conditions. As stated in an introductory paragraph, provision for future extensions was the objective of the design of the whole system; this is best attained in this particular installation by the use of a yard bus. The location of the substation at the center of the distributed load makes possible the maintenance of a balance on both sides of the bus. As the load diminishes towards either end, the bus can be so tapered that the maximum capacity is utilized at all points. Under any other system, an increase of load upon any section would necessitate running

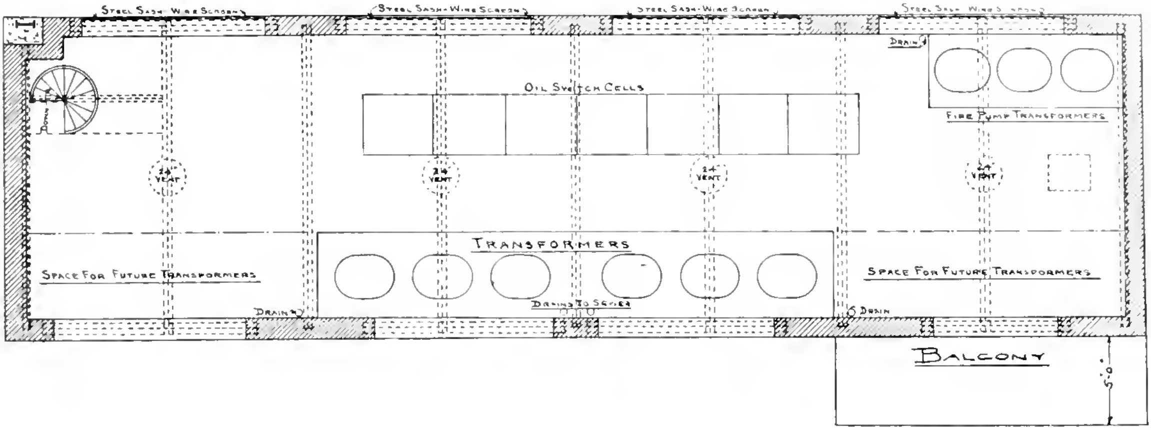

Fig. 7. Plan of the Second Floor of the Substation

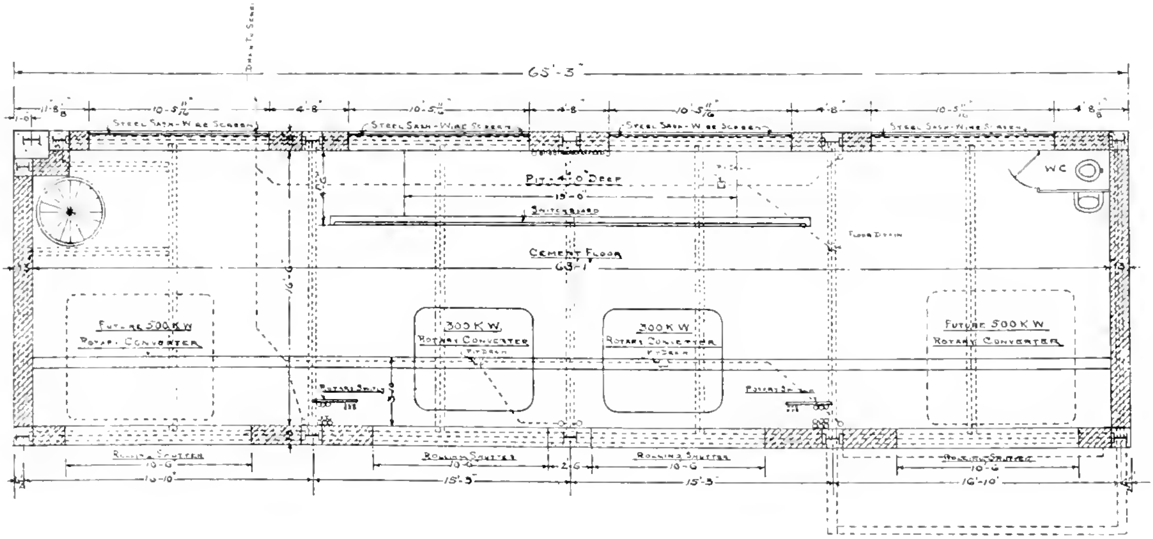

Fig. 7A. Plan of the First Floor of the Substation

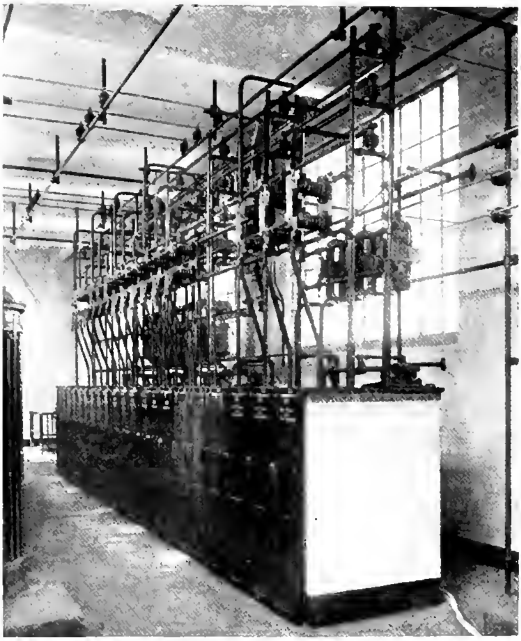

Fig. 8. Front View of Switch Cells

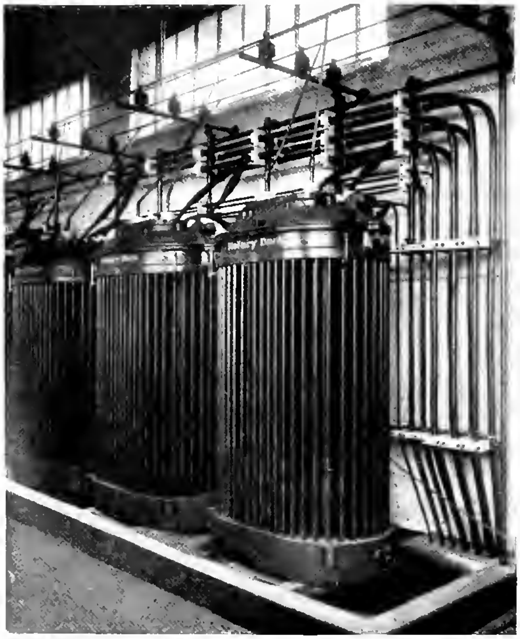

Fig. 9. Main Transformers. Left Front Angle View from West

feeders from the station to the shop, involving a great amount of labor in placing the cables, in addition to the expense of the materials. Under this system, such an increase simply means withdrawing idle cables from one part of the system and pulling them through spare ducts to serve the section upon which the load is thrown; likewise, an increase of the total load calls for no expense other than the cost of the cable and the small installation cost incident to drawing the cable through the ducts provided. Moreover, by the system used, control of all shops is secured from two points and power may be supplied from either or both with no added outlay for copper.

Fig. 12 shows the arrangement of the yard bus and feeder system. The bus, composed of eight 1,000,000 circular mil, varnished cambric, lead-covered cables (four positive

Fig. 10. Synchronous Converters. General View from West

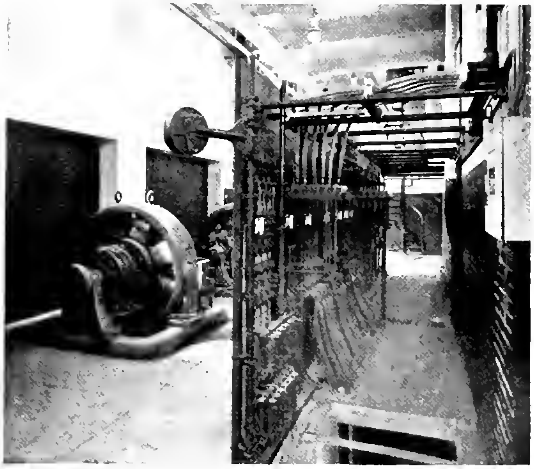

Fig. 11. Back View of the Synchronous Converter Switchboard (Front View, Fig. 16)

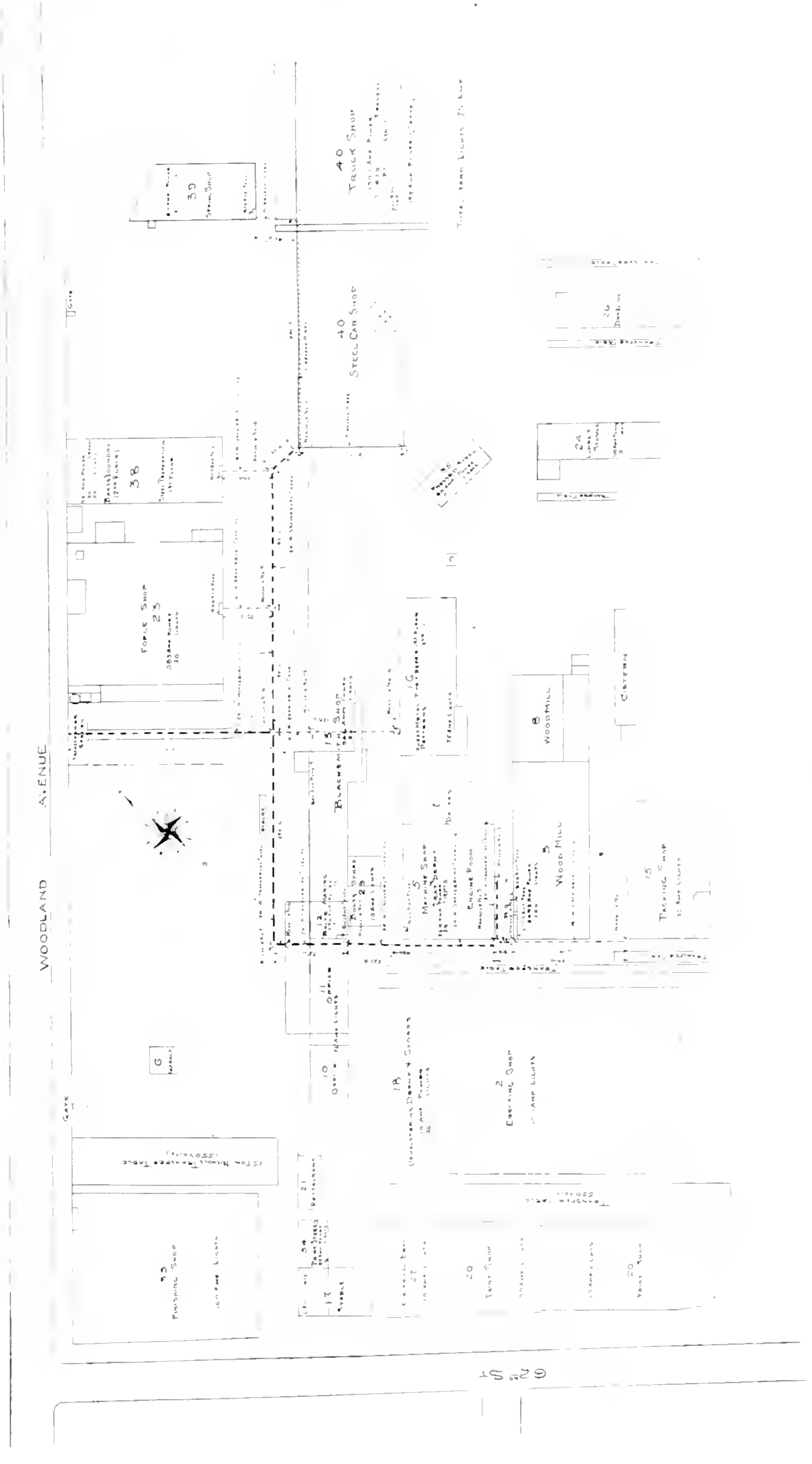

Fig. 12. Layout of the Buildings Showing the Arrangement of the Yard Bus and Feeder System

and four negative), is supplied with direct current at 250 volts from either the substation or the steam plant or from both.

The main bus line ducts consist of twenty-four 4-inch Orangeburg fiber conduits surrounded by concrete, forming a monolith as shown in Fig. 13. This main bus line extends from the substation 212 feet south to manhole No. 8. At a point 300 feet east is manhole No. 11, from which is tapped the overhead lines running under the roof of the truck shops. Manhole No. 12 lies 225 feet west and 235 feet south of manhole No. 8 and from it one branch extends to the wood mill and beyond, the other branch connecting to the steam power-plant switchboard.

As the bus is sectionalized through junction boxes at each manhole, any section may be cut out for faults or for repairs. The standard manhole, shown in Fig. 15, is 7-feet 10-inches long by 4-feet wide by 5-feet 8-inches deep. Fig. 15A shows a standard corner manhole. The floor is of concrete 4-inches thick. Any accumulation of water is drained to the sewer from the manhole at the floor level, which is connected to all manholes by a 4-inch terra-cotta drain. The roof of each manhole consists of a 6-inch slab of reinforced

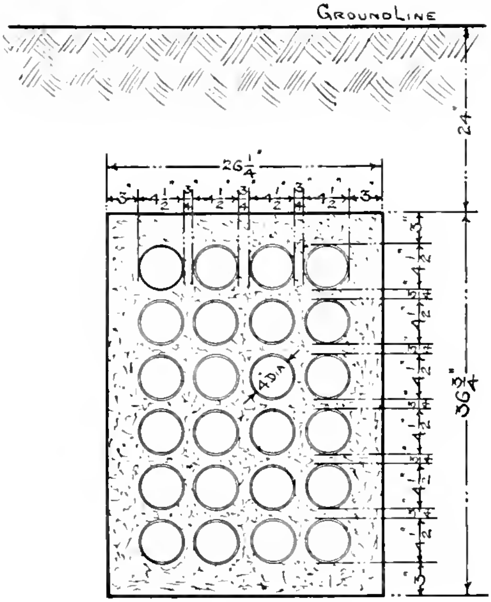

Fig. 13. Vertical Section of the Main Bus Line Ducts

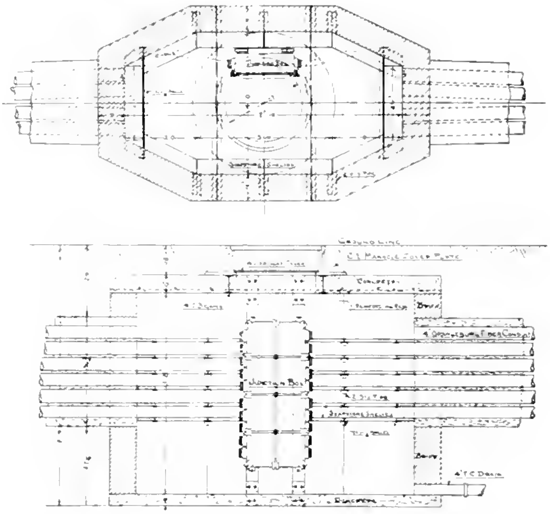

Fig. 15. Sectional Plan and Elevation of the Standard Manhole

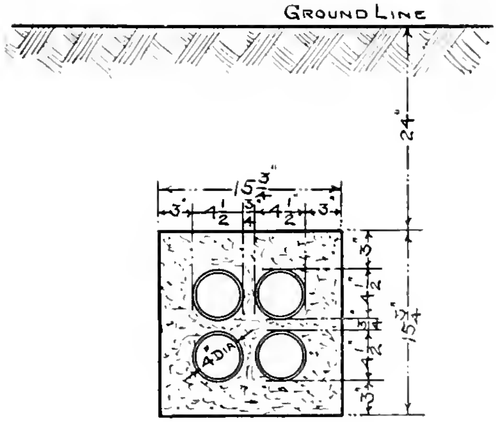

Fig. 14. Vertical Section of the Feeder Ducts

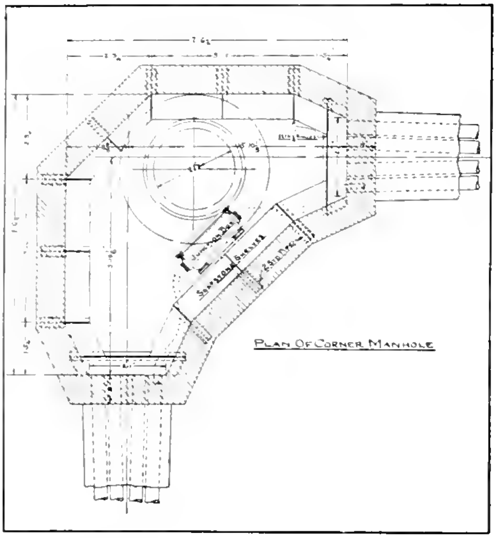

Fig. 15A. Sectional Plan of a Corner Manhole concrete; the cover plate is carried on a 6-inch I-beam imbedded in the roof. The cables are carried on removable soap-stone shelves extending around the sides of the manhole at the level of the lowest part of each row of ducts. These shelves are 1-inch thick, are arranged in sections about 24 inches wide, and are supported by 1-inch angles set in 2-inch pipe thimbles imbedded in the brick walls. The angles may be adjusted in the thimbles for the accommodation of additional shelves. The walls are built of hard-fired iron brick, set in Portland cement mortar. The junction boxes are placed high enough in the manholes to be out of the reach of any accumulation of water that might be expected under conditions incident to any ordinary storm; however, even should the manholes be flooded and the junction boxes be completely submerged during the short time necessary for the drains to relieve these conditions, no damage would be incurred, for the cables are taken into the junctions through stuffing boxes and a gasketed cover is provided, making the junction box water-proof.

Fig. 15 shows the connections for a single junction box. In manholes No. 3 and No. 8 (Fig. 12), it was necessary to use two single-polarity junction boxes, one tying all negative cables and one tying all positive cables. Each of the remaining manholes has one double-polarity junction box containing two busbars, to one of which is connected all the negative cables and to the other is connected all the positive cables.

### Feeders

The feeder ducts consist of four Orangeburg fiber conduits surrounded by concrete. The shop circuits are tapped off the yard bus at the junction boxes as shown in the diagram of the yard bus system, Fig. 14. At present there are installed seven 800-ampere and two 2000-ampere shop distributing panels. Each shop circuit is controlled from both the substation and from the engine room by a 250-volt direct-current circuit.

The control circuits consist of one 5-conductor lead-covered cable between the control panels and each shop panel, one 3-conductor cable and one 2-conductor lead-covered control cable which forms the tie line between the substation and engine room control panels. This tie line places the two panels in multiple and also parallels all signal lights on both panels. Details of two point control of shop panels are shown in Fig. 2.

### Shop Panels

Fig. 17 shows a 2000-ampere and an 800-ampere shop panel located in the lumber mill. These are typical of all shop panels and are equipped with solenoid-operated circuit breakers. Should emergency demand, these can be thrown out by hand, but they can be thrown in only from the substation or from the engine room; however a special lever is kept in the substation by means of which the breakers can be thrown in mechanically should the electrical control break down or fail for any reason. This gives the operator absolute control, precluding the possibility of any load being thrown on without his knowledge. On each shop panel are mounted totalizing meters, registering the load of the circuits which they supply. In order that shop charges may be segregated, the various departments are served through individual watthour meters.

### Steam Power Plant

The present steam power plant consists of two 300-kw. continuous current generators, 130 r.p.m., 225 volts, 1200 amperes capacity, direct-connected to horizontal single-acting non-condensing engine; and one 200-kw. direct-current generator, 175 r.p.m., 225 volts, 800 amperes capacity, direct-connected to a horizontal single-acting, non-condensing engine. Power for operating these generators, as well as the air compressors and hydraulic pumps, is obtained from six 400 h.p. Babcock & Wilcox horizontal water-tube boilers operating at 120 pounds pressure.

The present system is designed to permit the multiple operation of the generators in the steam plant and the converters in the substation.

Fig. 18 shows the switchboard in the steam plant. The diagram of connections is shown in Fig. 1. Panels 19, 20, and 21 are the direct-current generator panels. Panels 22 and 23 are the switch panels mounting the knife switches which pick up the sections of the yard bus. Control panel No. 24 in multiple with its duplicate No. 16 in the substation, controls the solenoid-operated shop panels.

The equalizer switches in this station are mounted on pedestals, each near its respective generator.

### Fire Pump Motor

The fire pump will be connected direct to the city mains and will be operated by a 100-h.p., 220-volt, three-phase, 60-cycle motor, controlled by an automatic starting panel in accordance with standard requirements of the Board of Fire Underwriters. This will be operated from several remote-control, push-button stations located in various parts of the plant.

Fig. 16. Front View of the Synchronous Converter Switchboard. (Back View, Fig. 11)

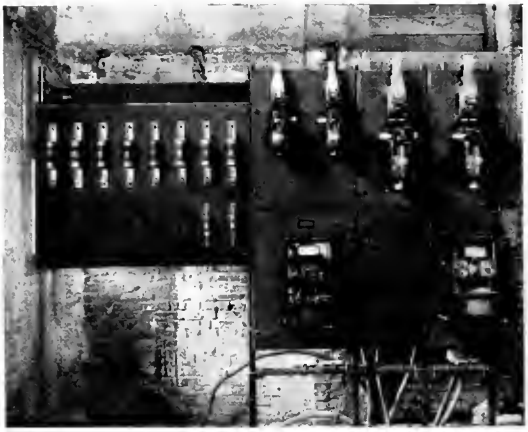

Fig. 17. An 800 and a 2000-ampere Shop Panel Located in the Lumber Mill

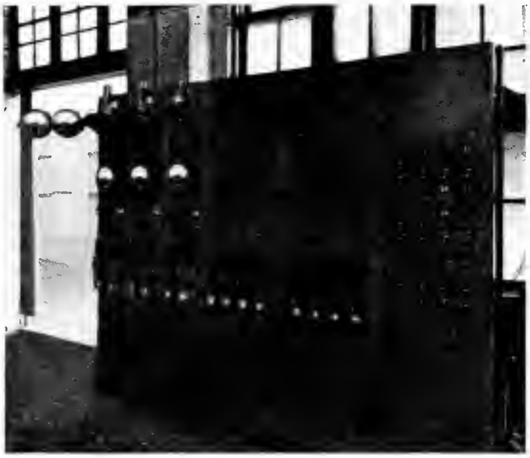

Fig. 18. New Switchboard in Engine Room, Building 5

The transformers and switchboard serving the motor are located in the substation and have been described in preceding paragraphs; the motor, however, will be housed in a separate building of fire-proof construction provided with entrances so located that access may be had in spite of fires in adjoining buildings. Every effort will be made to preclude any possibility of accidents disabling the fire-fighting equipment.

### Standard Equipment

Throughout the plant all electrical equipment is standard, taken directly from stock. This assures prompt duplication of the various devices when required for expansion or spares.

The whole installation has proved to be thoroughly satisfactory and furnishes a striking example of the flexibility that can be obtained from combinations of standard-unit parts.

# RECENT VIEWS ON MATTER AND ENERGY

By Dr. Saul Dushman

Research Laboratory, General Electric Company

## Part II

In this issue the author discusses the experimental evidence which has led to the view that energy is not capable of infinite subdivision. This leads to an atomistic theory of energy which is quite analogous to the older atomic theories of the structure of matter and electricity. The classical dynamics has been found to be inadequate in explaining a large number of recent observations. The necessity has therefore arisen of questioning the validity of some of the so-called fundamental principles, and in propounding the quantum theory, Planck, who is one of the greatest living physicists, has started a movement which promises to radically change all our previous concepts of matter and energy. In subsequent issues, the author will discuss the applications of the quantum theory to a number of problems in physics and chemistry.—Editor.

## ATOMISTIC THEORY OF ENERGY

In the first part we discussed the experimental evidence which has led to an atomistic theory of electricity. We now turn to the discussion of another series of experiments which have apparently led to the necessity of assuming a similar theory of energy; we say *apparently*, because the theory is as yet in a state of transition, and while a certain line of evidence may force physicists to assume an atomistic point of view of energy at the present time, it must not be forgotten that the near future may bring to light another explanation which correlates all the known observations just as well as the quantum theory and yet does not present as radical a departure from previous concepts.

The immediate necessity for a quantum theory arose as a result of investigations that were carried out between 1897 and 1901, by Lummer and Pringsheim, on the laws of distribution of energy in the spectrum of black body radiation. It will therefore be necessary to explain rather briefly what is meant by a "black body" and then discuss at greater length the different attempts that were made to explain theoretically the results of the above mentioned investigations on black body radiation.

### "Black Body" Radiation

A solid or liquid heated to a temperature above that of its environment radiates energy to the surrounding bodies, and as the temperature of the radiating source increases, the energy radiated per unit area increases very rapidly. In general the amount of energy radiated depends not only upon the temperature but also upon the nature of the material of which the radiator is composed. It is always, however, less than that emitted by a "full" radiator or "black body." Such a radiator is defined as one which completely absorbs all radiations incident upon it. No substance is known which is a perfect black body in this sense, although some substances, such as lamp black, approach it quite closely, while platinum and white oxides depart to quite an extent from black body radiation. It was pointed out by Balfour Stewart and Kirchoff independently that the radiation emitted from an enclosed space, the walls of which are maintained at a constant temperature, possesses all the characteristics of black body radiation. For it is evident that inside such an enclosure the energy radiated is equal to that absorbed, and consequently a body situated inside the enclosure attains a temperature which depends only upon the temperature of the walls and on nothing else.

### Stefan-Boltzmann Law

About 1879 Stefan concluded from previous measurements of Tyndall that the total energy radiated per unit area of black body radiator varies as the fourth power of the absolute temperature. Subsequently Boltzmann deduced the same law from thermodynamical considerations on the basis of the electromagnetic theory of light. The most accurate determinations so far made lead to the following expression for the Stefan-Boltzmann law:

$$E = 5.7 \times 10^{-5}\ (T^4 - T_0^4) \text{ ergs per cm}^2 \text{ per sec.} \quad (1)$$

where $E$ denotes the total energy radiated, and $T$ and $T_0$ denote the absolute temperatures of the radiator and the body receiving radiation respectively.

### Distribution of Energy in the Spectrum of a Black Body

At low temperatures the energy emitted by a black body radiator is in the form of heat waves only. When the temperature exceeds 600 deg. C., the radiations having a wave length below 0.76 $\mu$[1] become intense enough to affect the retina of the eye, and as the temperature increases still more the color of the body varies from a dull red heat, through cherry red and orange, up to a bright white heat (about 1500 deg. C.). The energy emitted at any temperature may be resolved into a continuous spectrum and the variation of intensity in different parts of this spectrum can be determined by means of an instrument like the thermopile or bolometer.*

The laws governing the distribution of energy in the spectrum of the radiation from an enclosed space at uniform temperature have been experimentally investigated by Paschen[2], Lummer and Pringsheim[3] and Rubens and Kurlbaum[4], and still more recently by W. W. Colblentz[5]. The results of Lummer and Pringsheim's observations are shown in Fig. 1†, where the ordinates correspond to intensities or emissive powers, which are proportional, and the abscissae denote wave-lengths in microns[6].

The area contained between any curve and the $\mu$-axis is proportional to the total amount of energy radiated by a black body at the corresponding temperature, and the above-mentioned observations were found to be in good accord with the Stefan-Boltzmann law.

It will be noted that by far the largest portion of the spectrum is found in the infra-red region; but as the temperature is increased the position of the wave-length at which the maximum emissivity occurs shifts towards the region of shorter wave-lengths or higher frequencies. This is the explanation of the gradual change in color of a heated body as the temperature changes.

### Wien's Displacement Law

Regarding the manner in which the position of maximum intensity changes with change in temperature, Wien was able to deduce theoretically a relation which is of extreme importance.

He made use of the following well-grounded principles:

1. That according to the electro-magnetic theory there exists a radiation pressure which is equal to the energy per unit volume.
2. That the second law of thermodynamics is applicable to radiation problems.
3. That the Doppler effect, according to which the frequency of monochromatic radiation changes with changing position of the radiating source, is applicable.

Starting with these assumptions, for which there is every experimental evidence, he showed that the wave-length at which maximum intensity occurs, (which can be denoted by $\lambda_m$) varies inversely as the absolute temperature, that is,

$$\lambda_m = \frac{A}{T} \qquad (2)$$

where $A$ is a constant. This is known as Wien's "displacement law." Careful measurements by Lummer and Pringsheim and others have shown that the value of the constant $A$ is 2900 where $\lambda$ is measured in microns. That is, at the temperature of 2900 deg. abs., the maximum intensity occurs at 1 $\mu$, or well in the infra-red region, and the temperature of the radiator has to attain a value of about 5300 deg. abs., before the wave-length of maximum intensity coincides with that wave-length for which the normal eye is most sensitive (about 0.55 $\mu$).

Wien also showed that the maximum intensity varies as the fifth power of the absolute temperature, that is,

$$E_m = B\,T^5 \qquad (3)$$

where $E_m$ denotes the intensity corresponding to maximum wave-length ($\lambda_m$) and $B$ is a constant.

As both these relations have been found to be in splendid agreement with the experimental observations, there is no reason for doubting the validity of the three principles used in deducing them.

### Formulae for the Law of Distribution

While the Stefan-Boltzmann law and Wien's "displacement law" represented great advances in the theoretical treatment of the laws of radiation, there still remained the main problem of obtaining a formula which should express the intensity of any monochromatic radiation as a function of both the frequency, or wave-length, of that radiation and its temperature, in other words, a formula that would adequately fit the curves obtained by Lummer and Pringsheim as in Fig. 1†.

Three formulae have been suggested and each of these is of extreme importance:

The first of these is known as Rayleigh's formula. Written in terms of the wave-length ($\lambda$), the intensity $E_\lambda$, at any wave-length is given by the relation:

---

* The bolometer consists essentially of a series of thin strips of platinum covered with soot. The electrical resistance of these strips changes when they are exposed to the radiation whose intensity is to be measured.

[1] The longest visible wave-length.

[2] Ann. der Phys. *4*, 277 (1901).

[3] Ann. der Phys. *6*, 210 (1901).

[4] Ann. der Phys. *4*, 649 (1901).

[5] Bull. Bur. Standards, *10*, 1 (1913). This paper also contains a complete description of a sensitive form of bolometer.

[6] 1$\mu$ (micron) = $10^{-4}$ cm. The visible spectrum is comprised between 0.4 $\mu$ and 0.76 $\mu$

† Page 187, GENERAL ELECTRIC REVIEW, March, 1914.

$$E_\lambda = \frac{ckT}{\lambda^4} \tag{4}$$

where $c$ denotes the velocity of light and $k$ is the so-called elementary gas constant.

The second formula was deduced by Wien. According to this formula:

$$E_\lambda = \frac{c^2 h \lambda^{-5}}{\epsilon^{ch/k\lambda T}} \tag{5}$$

where $h$ is a universal constant and $\epsilon$ denotes the base of the natural system of logarithms.

Finally, the third formula was deduced by Planck and states that

$$E_\lambda = \frac{c^2 h \lambda^{-5}}{\epsilon^{\frac{ch}{k\lambda T}} - 1} \tag{6}$$

Written in terms of the frequency $\nu$ instead of $\lambda$ these equations become

$$E_\nu = \frac{\nu^2}{c^2} kT \text{ (Rayleigh)} \tag{4a}$$

$$E_\nu = \frac{h\nu^3}{c^2} \epsilon^{-\frac{h\nu}{kT}} \text{ (Wien)} \tag{5a}$$

$$E_\nu = \frac{h\nu^3}{c^2} \frac{1}{\epsilon^{\frac{h\nu}{kT}} - 1} \text{ (Planck)} \tag{6a}$$

The products $c^2h$ and $ch/k$ are usually denoted by $c_1$ and $c_2$ respectively. The introduction of the constant $h$ is due to Planck and the reason for introducing the same constant in Wien's equation is to indicate the close relationship between the latter and that of Planck.

The measurements of Lummer and Pringsheim and others have shown that of these three formulae, that of Planck is the only one that is valid over the whole range of the spectrum. It is easily seen that Rayleigh's formula cannot be correct, for according to this formula the intensity at any given temperature ought to increase rapidly with increase in frequency, and this increase ought to continue *indefinitely*. The occurrence of a maximum intensity at a frequency which is given by the displacement law shows that the Rayleigh formula cannot be valid over the whole range. Another way of looking at the same facts is to state that the Rayleigh formula is in direct contradiction with the Stefan-Boltzmann law, for according to the Rayleigh formula the total area under any curve would be infinite, instead of being actually a finite quantity that increases regularly with the fourth power of the absolute temperature. As a matter of fact the formula agrees with Lummer and Pringsheim's results, see Fig. 1,* only for large values of $\lambda T$, that is, in the region of long wavelengths and low temperatures, in other words, it describes accurately only the right-hand portions of the curves shown.

Wien's equation on the other hand fits the experimental data only in the visible and ultra-violet regions, that is, in the case of low values of $\lambda T$, but for values of $\lambda T$ greater than 3000, $\lambda$ being reckoned in microns, the emissivities as calculated by this formula are found to be smaller than those observed.

It would therefore appear, at first glance, as if Planck's equation is merely a successful empirical formula for bridging over the gap between the regions in which formulae (4) and (5) respectively are valid. The method of derivation of each of these formulae shows, however, that there is more than pure empiricism in Planck's formula. Now what are the considerations which have led to each of the above formulae?

It is obvious that black body radiation may be regarded from two points of view: Firstly, any body emitting or absorbing radiation must, in the stationary state, be in thermal equilibrium with the radiation in the surrounding space. Secondly, it ought to be possible to apply to these radiations, since they are electro-magnetic waves, the equations derived from the fundamental principles of electrodynamics. The first set of considerations give a *relation between the energy of any source of radiation and its temperature*; the second set of considerations lead to a *relation between the energy of the radiator and the frequency of the radiation emitted or absorbed by it.* Consequently, by combining these two relations it ought to be possible to deduce the desired relation between energy of monochromatic radiation, and its temperature and frequency.

### The Principle of Equipartition of Energy

The simplest relations between the energy of a system and its temperature are found to hold for the case of gases obeying Boyle's and Charles' laws. If $N$ denotes the number of molecules in a gram-molecular[1] weight of gas, $V$ the volume at pressure $P$ and temperature $T$, then the above gas laws can be expressed by the relation

$$PV = NkT = RT \tag{7}$$

---

*Page 187, General Electric Review, March, 1914.

[1] The gram-molecular weight (or mol) of a gas is defined as the weight of 22.24 liters of the gas when measured at 0°C. and 760 mms mercury. Thus the gram-molar weight of $H_2O$ is 2.016+16=18.016, while that of oxygen ($O_2$) is 32. On the other hand, the observed gram-molar weight of mercury vapor is the same as its atomic weight, indicating that the mercury molecule is monatomic. Similar results are found to hold for the rare gases Ne, Ar, He, etc., which are all monatomic.

where $k$ is the so-called elementary gas constant and $R$ is known as the molecular gas constant.

According to Prof. Millikan's most recent determinations[1], the values of the constants involved in equation (7) are as follows:

$N = 6.06 \times 10^{23}$ molecules per gram-mol.
$R = 8.30 \times 10^7$ ergs per mol per degree.
$= 1.99$ calories per mol per degree.
$k = 1.37 \times 10^{-16}$ ergs per degree.

One of the conclusions drawn from the application of dynamical laws to gases is that the kinetic energy ($U$) of a gram-molecular weight of any gas due to the translational velocity of the molecules is given by the relation

$$U = \frac{3}{2} RT \tag{8}$$

or the average kinetic energy of each molecule is

$$U_0 = \frac{3}{2} \frac{R}{N} T = \frac{3}{2} kT \tag{9}$$

Now in all cases we are dealing with large numbers of molecules, and if we resolve their velocities in three directions at right angles to each other, it is evident that the average velocity in each of these directions will be the same, otherwise there would be a drift of molecules in some one direction and consequently a greater pressure in that direction. It also follows from the relation that exists between a given velocity and the three component velocities at right angles to each other, that the average kinetic energy of motion along each of the three directions chosen as axes of reference is the same. In other words, the average kinetic energy per molecule is $\frac{1}{2} kT$ for each of the three directions along which it is capable of motion.

Maxwell and Boltzmann showed that this conclusion could be extended to systems in which the constituent particles are capable of other than translational motion. Starting with the assumption of the validity of the fundamental laws of dynamics, they showed that for any system in equilibrium the kinetic energy will on the average be equally distributed among the different degrees of movability or freedom of the system, and furthermore the *average kinetic energy for each of these different degrees of freedom will be* $\frac{1}{2} kT$. This is the generalization known as the *Principle of Equipartition of Energy.*

The number of degrees of freedom corresponds to the total number of terms required to define exactly the state of the molecule or other component at any instant. As illustrations of the application of this principle may be given the calculation of some specific heats.

### Applications of the Principle of Equipartition

From the dynamical point of view, the heat absorbed by a mass of gas maintained at constant volume is converted into increased kinetic energy of the molecules. Therefore the specific heat at constant volume ought to be equal to the rate of increase of kinetic energy with increase in temperature.

Now let us consider the case of a monatomic gas. According to Boltzmann's principle the average kinetic energy per mol due to translational velocity of the molecules is $\frac{3}{2} RT$. Unless additional energy is absorbed by the molecules as rotational energy, the specific heat per mol at constant volume ought to be $\frac{3}{2} R$, that is, 2.98 calories. This is actually found to be the case for monatomic gases like argon and mercury. The conclusion is therefore drawn that any rotational energy which the molecules may possess adds nothing to the total amount of kinetic energy, which is important in the consideration of the specific heat of monatomic gases.

In the case of diatomic gases, Boltzmann considered the molecule as having a dumb-bell sort of structure. Such a molecule may be assumed to have five degrees of freedom; for not only can the molecule as a whole move in three different directions, but the atoms within the molecule can rotate in two directions which are at right angles to the axis of the dumb-bell. If the average kinetic energy of the molecule is $\frac{1}{2} kT$ for each degree of freedom, the heat capacity per mol of a diatomic gas ought to be $\frac{5}{2} R$. This deduction was again found to be in agreement with experimental data.

But not only was Boltzmann able in this manner to calculate the specific heats of gases, he also applied the same considerations to solids and thus arrived at an explanation of the Dulong and Petit law. According to this law the product of specific heat and atomic weight in the case of elements in the solid state is a constant which has a value of about 6 calories. This law had been derived empirically at the beginning of the nineteenth century; but until Boltzmann enunciated his theory, there appeared to be no reasonable

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[1] Phys. Rev. 2, 147, (1913).

explanation of such a relation. His argument was to this effect:

Consider an elementary substance in the solid state in equilibrium with its vapor. Assume for the sake of simplicity that the vapor is monatomic. We know that this is actually true in the case of metals like mercury, zinc and cadmium, whose densities in the vapor state have been measured. Now the energy of the atom in the solid state must depend upon the vibration of this atom about a position of equilibrium. It also follows from the fundamental principles of dynamics that in the case of any such source of periodic vibrations, and oscillation, the *average* kinetic energy is equal to the *average* potential energy.

But it is evident that the only conditions under which thermal equilibrium can exist between the atoms in the solid phase and those in the gaseous is that the average kinetic energy of the atom in each state should be the same, and since the average energy of an atom in the gas is $\frac{3}{2}kT$ per atom it follows that the total energy per atom in the solid is $3\,kT$, or $3\,RT$ per gram atom. Consequently the atomic heat must be $3\,R$, that is, 5.96 calories.

Summing up the above discussion it is concluded from the fundamental principle of ordinary dynamics that in any system at equilibrium, the average energy is $\frac{1}{2}kT$ for each degree of freedom. This therefore answers the question as to the relation between energy and temperature.

### Rayleigh's Distribution Formula

Turning to the consideration of radiation as an electromagnetic phenomenon, we may consider as Planck does, that the radiation is produced by means of linear oscillators, similar to those used in the production of Hertzian waves, which emit linear harmonic vibrations.

It is evident from what has been stated in the first section of this paper that the electrons within the atoms can constitute such oscillators, for they vibrate or rotate about a mean position of equilibrium and are held by quasi-elastic forces to the positive nucleus. Such an electron possesses therefore both kinetic and potential energy, the average value of each being the same, and furthermore the average kinetic energy depends only on the frequency.

According to the equations of electrodynamics the relation between the total average energy, $U_\nu$, of an oscillator emitting radiation of frequency $\nu$ as the instensity, $E\nu$, of the radiation emitted is

$$U_\nu = \frac{c^2}{\nu^2} E_\nu \qquad (10)$$

Now consider an enclosure surrounded by absolutely opaque walls and containing black body radiation of the same nature as that emitted by a body at the temperature $T$. The radiation emitted by the oscillators is in thermal equilibrium with the walls of the enclosure and any bodies contained in it. According to the principle of equipartition of energy the average energy of each oscillator must be the same, that is, independent of the frequency, and equal to that of a body with two degrees of freedom. This is evident from the above considerations.

Consequently, the average energy of the oscillator must be

$$U_\nu = kT \qquad (11)$$

Combining (10) and (11) we obtain the Rayleigh equation

$$E_\nu = \frac{\nu^3}{c^3} kT \qquad (4a)$$

In other words, the principle of equipartition combined with the deductions from the electromagnetic theory of light leads to an equation for the distribution of energy in black body radiation which, as stated above, is not in accord with the actual facts.

The question therefore arises: Why should the agreement between Rayleigh's formula and experiment hold only for large values of $\lambda T$? The only assumption made in the above argument is that the principle of equipartition is valid in all cases. Evidently this assumption is justified for a certain upper range of values of $\lambda T$ and not for lower values.

### Wien's Formula

As was mentioned in a previous paragraph, the principles made use of by Wien in deducing his "displacement law" are amongst the most fundamental generalizations of physical science, and the agreement between the results predicted by this law and the experimental observations can be regarded as additional confirmation of the validity of the original assumptions upon which the law is based. It was also shown by Wien from considerations based on the main laws of thermodynamics and electrodynamics that any distribution formula must be of the form

$$E_\nu = \frac{\nu^3}{c^2} \cdot F\left(\frac{T}{\nu}\right) \qquad (12)$$

where $F$ denotes some function of $T/\nu$, whose exact form could only be determined by introducing other assumptions.

In order to determine the form of the function $F$, Wien introduced some "arbitrary assumptions as to the radiations sent out by vibrating molecules," and arrived at an equation of the form

$$E_\nu = \frac{h\nu^3}{c^2} \epsilon^{-\frac{h\nu}{kT}} \tag{5a}$$

or as it is more usually written

$$E_\lambda = c_1\lambda^{-5}\epsilon^{-\frac{c_2}{\lambda T}} \tag{5}$$

This equation thus has no theoretical basis, but it is of interest because it represents the observations quite accurately throughout the range of the visible and ultraviolet portion of the spectrum and has been found to be of great use in photometrical investigations. The discrepancies between the observed and calculated intensities occur only in the region of longer wave-lengths.

### Failure of the Principle of Equipartition of Energy

While the reason for the failure of Wien's formula is thus obvious, there appears to be no such *a priori* reason for the failure of Rayleigh's formula. Although the deduction of this formula as given above brings in the additional concept of the existence of linear oscillators, the same formula may be arrived at independently of this concept, as was actually done by Rayleigh and Jeans[1].

Moreover, *all attempts to deduce a distribution law by applying the principles of classical dynamics and electro-dynamics lead invariably to the Jean-Rayleigh equation.* Hence arises the necessity, as has been pointed out by Planck, of adopting some radical modification of the classical theory. Granted this conclusion, the next question arises as to the particular respects in which the older theories shall be altered, and Planck perceives a way out of the difficulty by discarding the principle of equipartition of energy[2].

Now for a number of years a gradually increasing number of facts had led many physicists to question the general validity of Boltzmann's principle. For one thing, while the law of Dulong and Petit is pretty generally true, the number of exceptions to it had been accumulating during the past century. Thus it was known that carbon, boron, and silicon have atomic heats lower than 6; but it was also observed that the atomic heats of these elements increased with temperature, and at high enough temperatures they behave "normally." Furthermore, the molecular heats of some diatomic gases like chlorine and bromine are nearly a calorie too high, even at ordinary temperatures, and they become even greater at higher temperatures. On the other hand, the molecular heat of hydrogen and other gases decreases to 3 as the temperature is lowered.

To explain these facts it would be necessary to assume that the number of degrees of freedom of a carbon atom or chlorine molecule increases gradually with the temperature. But the Boltzmann concept leaves no room for such a transition stage. An atom or molecule must possess a certain integral number of degrees of freedom; a degree of movability in any definite manner is either absent or present. There can *be no gradual acquisition* by any body of a degree of freedom. The conception of integral degrees of freedom thus presents many difficulties.

These difficulties exist, moreover, not only in the field of specific heats but also in that of radiation, as shown above.

### Planck's Formula

These considerations as well as others, based on the statistical theory of entropy, lead Planck to conclude that the principle of equipartition cannot be as universally applicable as hitherto assumed. Especially does he deny its validity in those cases where we are dealing with oscillators, whether electronic or atomic, which are executing periodic vibrations and in which there is a constant interchange between kinetic and potential energy.

The method of derivation of Planck's formula thus differs from that of Rayleigh in denying that each linear oscillator in the enclosure possesses an average energy $kT$. According to Planck it is only at very high temperatures and for long wave lengths that the average energy of each oscillator approximates to the value $kT$.

Thus the fundamental assumption made by Planck may be stated as follows: *Any oscillator cannot absorb or emit energy continuously, but discontinuously in multiples of a unit quantum* $\delta$, and the total amount of energy possessed by an oscillator at any instant may vary from 0 to any multiple, $n\delta$, of the unit quantum. As the temperature increases, the value of this multiple approximates more and more nearly to $kT$. The problem therefore to be solved is this: What is the average energy of an oscillator when it can take up or

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[1] Lord Rayleigh, Phil. Mag. *49*, 539 (1900).
J. H. Jeans, Phil. Mag. *49*, 229 (1909).

[2] M. Planck, Abhandlungen d. deutsch, Bunsen Ges. Nr. 7, p. 80 (1911).

give out only a definite fraction, $\delta$, of this energy at any instant? The theory of probability leads to the conclusion that

$$U_\nu = \frac{\delta}{\epsilon^{\frac{\delta}{kT}} - 1} \qquad (13)$$

Combining this with (11), it follows that

$$E_\nu = \frac{\nu^2}{c^2} \cdot \frac{\delta}{\epsilon^{\frac{\delta}{kT}} - 1} \qquad (14)$$

For $\delta = 0$, this equation becomes the same as the Rayleigh equation, as we would expect, since the theory of Planck differs from that of Rayleigh in the fact that the former assumes a discontinuous variation of energy in an oscillator, while Rayleigh assumes the variation to be continuous.

The similarity of equation (17) with Wien's formula leads to the next assumption made by Planck, viz: that the unit quantum which the oscillator can emit or absorb is proportional to its frequency, $\nu$; that is,

$\delta = h\nu$

where $h$ is a universal constant.

Substituting $h_\nu$ for $\delta$ in equation (17) leads to the Planck equation, which is the most satisfactory formula over the complete range of radiations.

### The Quantum Theory

These in brief are the essential arguments used by Planck in deriving his distribution formula. In postulating this so-called *quantum theory* of energy, he discards one of those assumptions of physics whose validity has hitherto never been questioned. The principle of the "Continuity of all Dynamical Effects" has always been tacitly assumed by all physical investigators. As Planck has pointed out in a recent address[1]:

"This principle was formerly taken for granted as the basis of all physical theories, and, in close correspondence with Aristotle, was condensed into the well-known dogma, *Natura non facit saltus* (Nature makes no leaps). But even in this venerable stronghold of Physical Science present-day investigation has made a considerable breach. This time it is the principles of thermo-dynamics with which that theorem has been brought into collision by new facts, and unless all signs are misleading, the days of its validity are numbered. Nature does indeed seem to make jumps—and very extraordinary ones."

The obvious weakness in Planck's arguments is the fact that while he denies validity to the principle of equipartition, he yet assumes the validity of the electrodynamical equations, although both of these are deduced by perfectly similar lines of reasoning from the Principle of Least Action which is the cornerstone, as it were, upon which has been built up the Science of Dynamics. It may be, as Sommerfeld has suggested[2], that this latter principle will have to be restated in another way, so as to satisfy the Maxwell equations on the one hand, and the statistical point of view on the other.

Planck, indeed, has more recently modified his theory in this respect, that he assumes the discontinuity to exist only in the case of the emission of energy, while the absorption is supposed to be continuous. He arrives, in this manner, at the following relation for the average energy, $U_\nu$ of an oscillator.

$$U_\nu = \frac{h\nu}{2} + \frac{h\nu}{\epsilon^{\frac{h\nu}{kT}} - 1} \qquad (15)$$

That is, the average value of the energy approaches $\frac{h\nu}{2}$ as the temperature decreases to absolute zero. The conclusion that such a *residual or latent energy* exists which is independent of temperature is quite in accord with the results of investigations in the fields of specific heats, photo-electric effect and X-ray emission by cathode rays.

From the physical point of view the significance of the constant $h$ is difficult to interpret. Whether the discontinuity exists in the emission of energy only or in both emission and absorption, the conclusion that such a discontinuity exists requires a complete reversal of our previous ideas on the nature and mode of propagation of radiation.

It is therefore no surprise that there exist a number of different interpretations of the quantum theory, and Prof. Millikan enumerates no less than five "different brands" of the theory[3]. Some of these views are evidently at variance with new facts which have been discovered since their orginators first postulated them, and the least radical concept is that the radiant energy is emitted discontinuously in time, in amounts which correspond to multiple of $h\nu$. An oscillator absorbs energy continuously until a total amount $h\nu$ has been absorbed. It then has a chance of emitting the whole of this unit, otherwise the energy absorbed will go on increasing till it reaches $2h\nu$, $3h\nu$, etc., and as

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[1] New Paths of Physical Knowledge, Phil. Mag., July, 1914.

[2] Abh. d. deutsch. Bunsen Ges. Nr. 7, (1911).

[3] Science, *37*, 119, 1913.

the amount of this energy reaches an exact multiple of $h\nu$ the oscillator has again the chance of emitting the whole of its energy. The quantity $h\nu$ is known as an energy quantum and it may perhaps make matters a little clearer if its value be calculated for some monochromatic radiations.

The dimensions of $h$ are those of *energy* × *time*, and according to the most recent determinations its value is $6.62 \times 10^{-27}$ ergs × second. The yellow line $D_1$ in the spectrum of sodium has a wave length of $0.5896\,\mu$. Hence,

$$\nu = \frac{3 \times 10^{10}}{0.5896 \times 10^{-4}} = 5.088 \times 10^{14},$$

and therefore

$$h\nu = 6.62 \times 10^{-27} \times 5.088 \times 10^{14} = 33.69 \times 10^{-13} \text{ ergs.}$$

Again, the wave-length of X-rays corresponding to 40,000 volts is about $3 \times 10^{-9}$ cms. The frequency of these radiations is therefore $10^{19}$, and

$$h\nu = 10^{19} \times 6.62 \times 10^{-27} = 6.62 \times 10^{-8} \text{ ergs.}$$

When it is remembered that 1 watt $= 10^7$ ergs per sec., it is seen that even in the case of very high frequencies the energy quanta involved are very small, and in the case of all ordinary energy transformations the effect of such minute subdivision would be very insignificant.

In a subsequent section we shall show that this disintegration into energy quanta does become quite pronounced in those cases where we are dealing with the absorption of heat waves at very low temperatures, such as the boiling point of liquid hydrogen and where the total quantities of energy involved are very small. We shall also discuss some applications of the quantum theory which have yielded results that are among the most wonderful achievements of theoretical physics.

## SUMMARY

The quantum theory thus represents an attempt to account for the observed variation of intensity with wave-length and temperature in the radiation from a black body. All attempts to reconcile these observations with deductions based on the older dynamical concepts have so far ended in failure, and it therefore appears necessary to discard the Principle of Continuity of Dynamical Effects in physical science. The recent observations in the fields of radiation, specific heats, photoelectric effect and X-ray emission by cathode particles seem to be best accounted for by the hypothesis that the disintegration of energy is limited in a similar manner to the subdivision of matter. For a long time we have had the atomic theory of matter and the facts in support of this theory have become so numerous that the theory has for most physicists become an article of faith. In a previous section we discussed the evidence which has led to the formulation of an atomic structure for electric charges, and in the above paper we have shown that *there are strong reasons for ascribing an atomic structure to energy*. As yet the physical interpretation of the quantum theory is very indefinite. As Planck states:

"In what way we are to conceive the nature of quanta of a purely dynamical nature, we cannot yet say for certain. Possibly such quanta might be accounted for if each source of radiation can only emit energy when that energy attains at least a certain minimum value; just as a rubber pipe, into which air is gradually compressed, bursts and scatters its contents only when the elastic energy in it attains a certain value."

"In any case, the hypothesis of quanta has led to the idea that there are changes in nature which do not occur continuously but in an explosive manner. I need hardly remind you that this view has become much more conceivable since the discovery and investigation of Radio-active Phenomena. Besides, all difficulties connected with detailed explanation are at present overshadowed by the circumstance that the Quantum Hypothesis has yielded results which are in closer agreement with radiation-measurements than are all previous theories."

## REFERENCES

(1) N. Campbell, *Modern Electrical Theory.* Second edition, 1913. Chapter X. This chapter contains the best summary of the Quantum Theory in English.

(2) R. A. Millikan, Science, *37*, *119*, *(1913)*, *Atomic Theories of Radiation.* An address before the American Association for the Advancement of Science, December, 1912.

(3) Max Planck, *New Paths of Physical Knowledge.* Phil. Mag., July, 1914.

Both Millikan's and Planck's papers are inspiring. The former goes into much more detail and is more difficult to follow at times; but both papers are well worth serious study.

(4) Abhandlugen der deutschen Bunsen Gesellschaft, Nr. 7, 1911. Theorien der Strahlung und Quanten. This contains papers by Planck, Jeans, Sommerfeld and others. Very mathematical. The subject is brought up to date (November, 1913), in an appendix by A. Eucken.

# PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

By E. C. Parham

Construction Department, General Electric Company

## Part I

In this issue we begin a series of articles based on practical experience in operation, which we believe will be of great interest and use to a number of our readers. The author has made a practice of collecting valuable operating data and notes for some years and has had much experience in "electrical troubles", so many of which can be traced to oversight in operation. The short articles given in this series will be written in plain concise language so that they may be readily understood and appreciated.—Editor.

### TESTING FOR GROUNDS ON A SECONDARY THREE-PHASE LINE

Fig. 1 illustrates the connections of three single-phase transformers as operated on a three-phase supply circuit. Both the primary and the secondary are star connected; the primary neutral is maintained isolated, but the secondary neutral is perfectly connected to ground in order to realize certain advantages incident to that connection. It will be noted that, when a secondary is grounded, an insulation fault to ground on any of the phase wires, as at $g_1$, or at $g_2$, or at $g_3$, will cause a short circuit and will blow the fuse of whichever line is involved.

In a certain instance, an operator called in an inspector to locate a ground on a three-phase distributing line which served a number of mill motors. The inspector did not give the matter of grounded neutral any attention. In applying a test wire, such as $t^1$ in Fig. 2, to flash the three wires of the three-phase line to ground one at a time, all three flashed, indicating a short circuit. Then, suspecting the cause, the inspector applied a voltmeter between each phase wire and ground, and in each case measured about 133 volts. Since 230 volts was the line voltage given by the secondaries of two transformers in series, the voltage of a single coil was equal to $\frac{230}{\sqrt{3}} = 133$ volts. This value, being equal to that measured by the voltmeter, indicated that the voltmeter was figuratively applied across the secondary of one transformer. A grounded neutral, on the secondary side of the transformer, is the only possible condition that would permit of the voltmeter reading a voltage between any line and ground equal to the secondary voltage of only one transformer.

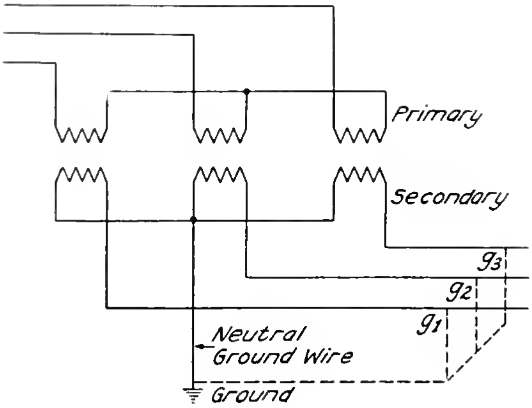

Fig. 1

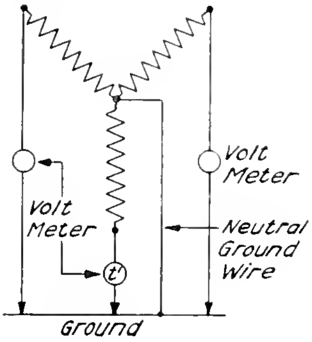

Fig. 2

The possibility of a man getting burned when applying test lines to a transformer service, the neutral of which is grounded without his knowledge, is evident. For this reason, a test for grounded neutral should be the first one to be applied in the absence of any previous information as to whether it is grounded or not.

### INABILITY TO MAINTAIN LOAD BECAUSE OF REVERSED SERIES FIELD

Assuming the shunt field of a compound-wound machine to be correctly connected, the machine will build up its field and promptly generate normal no-load voltage, even if the series winding is connected in reversed. This is true in case the series field opposes the shunt field, even though a *long shunt* connection is used, that is, a shunt field connected outside of the series field, for the small shunt field current in the few series field turns has but little effect. If the shunt field is reverse connected, the machine will not generate at all.

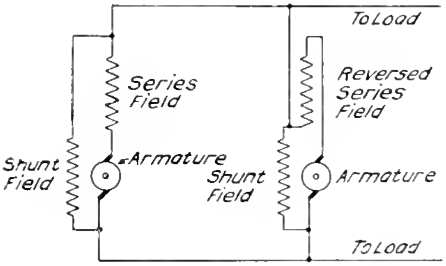

Fig. 3

Many of us fail to make a distinction between a dynamo having the wrong polarity and a dynamo having reversed field connections. With correct connections—and there is only one correct field connection for a given rotation and armature connection—the polarity of the voltage available at the machine depends upon the polarity of the residual magnetism. This polarity is liable to be either positive (+) or negative (−). The polarity of the voltage available at the switchboard may be reversed by reversing the cables between the machine and the board, but in doing this care must be taken to maintain the original shunt field connection at the board, otherwise the result will be no polarity at all.

An inspector went up into a mining camp on an operator's complaint that his machine would not take load. If the operator had taken the trouble to state that he had reversed the direction of rotation of the unit, the inspector need not have made the trip, because he could have instructed the operator by letter. The trouble was merely that the operator had reversed the shunt field but had failed to reverse the series field when he changed the direction of rotation of the dynamo; and the result was that the machine would pick up its no-load voltage but, as soon as an effort was made to put on load, the armature current passing through the series winding in the wrong direction would weaken the field. Had it been necessary to operate the machine in parallel with another dynamo, further complications would have arisen for, as indicated in Fig. 3, the reversed series winding would have caused the equalizing current from the machine No. 1 to pass through the series winding of the machine No. 2 in the reverse direction, thereby tending to decrease the very voltage that the equalizing current should tend to increase. In any instance where a change is made in the direction of rotation of the armature, in the position of brush-holders, or in the connections of the field windings, if, after the change has been made, the machine promptly builds up its field and generates no-load normal voltage with the field rheostat in its usual marked position, but refuses to support the load when the main switch is closed, it probably means that the connections of the series windings must be reversed in order to make them magnetize the field cores in the same direction that the shunt winding is magnetizing them.

### A BURNED OUT SHUNT

The series field shunts of the small and medium sizes of generators are made of german silver ribbon; for the large generators, they may be made up of iron-grid resistance units which afford better radiation. In either case, when making up a shunt due regard must be paid, not only to *resistance*, which determines the amount of current to be by-passed from the machine's series winding, but also to the current-carrying capacity required by the shunted current. In other words, it is possible to build a shunt which will by-pass a current that will result in a favorable degree of compound or over-compound, but which because of running at too high a current density will become so hot as to ultimately burn out, or at least to affect the correct proportional division of the current with another machine in parallel.

In a certain case, an operator complained that he could not keep up voltage on an exciter and sent for an inspector to determine the cause. By the time the inspector arrived, the series field shunt of the affected exciter had burned out and the operator had pressed another exciter of the same rating into service. This exciter was maintaining its voltage. A glance at the burned out shunt showed that it was home-made. When the burned out shunt was replaced with the shunt from the other machine and the discarded machine was placed again in service, the compounding was almost perfect, although a considerable difference might have been expected owing to the differences in two machines which are unavoidable, even though built as nearly as possible alike.

It seems that the operator had scrapped the original shunt as the result of a ground that had burned it beyond repair. In making up a new shunt, with the ribbon he had available, he not only made it of too low resistance, thereby undercompounding the machine, but he used too small a cross-section, and the excessive current by-passed by the shunt finally burned it out.

The inspector took some of the same ribbon and made a satisfactory shunt of correct resistance and of ample current carrying capacity.

### ARMATURE RUBBING POLE PIECES

The readiness with which trouble may be located in a piece of apparatus often depends upon its accessibility. Where careful inspection is made difficult by reason of the location of a device, it is quite certain that no thorough inspection is ever made.

The following will describe a case in which a large direct-current motor was installed near the ceiling in the darkest corner of a forge room. At times it was with difficulty that even the outline of the motor could be seen from the floor. Only one end of the motor was accessible for air-gap inspection, and even then that end was partly obscured by end shield brackets; these conditions made air-gap sighting or gauging difficult, and it would only be a conscientious man with patience, and determination who would complete a thorough examination of the condition of the air-gap. Before serious trouble developed the motor had blown fuses at intervals, the frequency of which increased until production was hampered. The air-gap clearance had been tested, but the man who did the testing was not competent, as is evidenced by the fact that the armature lost a band wire a few days afterwards. Without careful investigation as to whether or not excessive bearing wear was responsible for the trouble, the bearings were believed to be at fault and a new set was installed. The motor then operated for about a week, after which it began to blow fuses again and then lost another band wire, but not in the same place as the first.

The operator then called in an inspector who determined that the second band wire gave way because it had been injured at the time the first one was rubbed off, and further found that the cause of the initial and subsequent trouble was a thin brass jam-nut which had been trapped between one of the pole pieces and its frame seat. This had entered at the time of reassembling the machine after an overhauling sometime previously. It had allowed just enough clearance to permit of installing the armature, but a very little bearing wear had in each case brought the armature band wire and pole-piece hornfiber into rubbing contact. By its braking action this had first caused the fuse blowing and then the weakening of the band wire, until it broke. It speaks well for the motor that the distorted field incident to the displaced pole-piece did not cause sparking at the commutator.

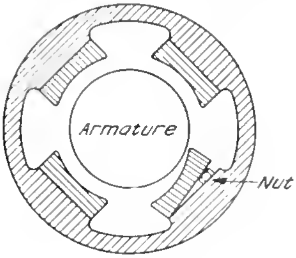

Fig. 4

### A NOISY TRANSFORMER

Since the value of an alternating current passes through zero twice during a cycle, the strength of the magnetic field set up by that current also equals zero twice during the same period. The resulting alternate stressing and releasing of the magnetic bodies that are within the influence of the field, which is periodically reversing in direction and varying in strength, tends to set up vibrations that are audible.

To illustrate: The armature of a solenoid brake, the operating coil of which is energized by single-phase current, may chatter badly unless measures are taken to prevent it. Since the weight of the armature tends to release it when the magnetic flux is passing through the zero value but is prevented from doing so by the quick return of the holding magnetism to a value sufficient to exert a holding pull, the armature, although it cannot actually drop, vibrates enough to hammer the field core. This results in a disagreeable noise.

The core of a single-phase transformer is under similar stresses that vary in strength and direction with the current producing them, and any loose parts within the influence of these periodically varying stresses will become nominally armatures which for the same reason will vibrate just as a poorly adjusted brake armature.

In a certain installation one single-phase transformer in a bank of three, connected to operate on a three-phase circuit, was noisy, but its mates were quiet. On removing the three elements from the tanks of this bank and inspecting them, no difference could be detected except that the core-plate nuts of the noisy transformer were loose. After tightening the nuts and again placing the bank into service, the previously noisy unit operated quietly.

# LOAD DISPATCHING SYSTEM OF THE COLUMBUS RAILWAY, POWER AND LIGHT COMPANY

By Harold W. Clapp

General Superintendent, The Columbus Railway, Power and Light Company

Continuity of service and economical operation are prime requisites for success in the generation and distribution of electric energy. After the equipment for an electrical installation has been selected and installed, there is no surer means of maintaining these desirable qualifications than by the employment of an efficient load dispatching system. This article describes a recently designed system of this type, its various kinds of indicating devices, its means of communication with the parts of the plants and substations that it controls, and the method in which its operations are carried on.—Editor.

The electric energy for the operation of the railway system and for supplying the numerous power and light customers of the Columbus Railway, Power & Light Company, is furnished by a system of six power stations, ranging in size from 250 to 14,350 kw., rated capacity. Current for the railway load is generated at 575 volts, and for power and lighting loads at 4150 volts; while some direct current is furnished at 220 volts on the Edison three-wire system for lighting the central district of the city. The Spring Street station is the largest and contains four a-c. turbo-generators rated at 11,000 kw., and four engine-driven d-c. units rated at 3350 kw. The second largest station has four 220-volt d-c. engine-driven units with a total rating of 2560 kw. The next station in size contains three engine-driven and one turbine-driven alternators, with a total rating of 2100 kw. Located at these stations are seven motor-generator sets varying in size from 300 to 750 kw. capacity; while six other motor-generator sets and four rotary converters are located at points on the system convenient for the proper distribution of energy. The other three stations are very small and are seldom used except in periods of very heavy loads in the winter season, or in case of serious breakdown in the larger stations.

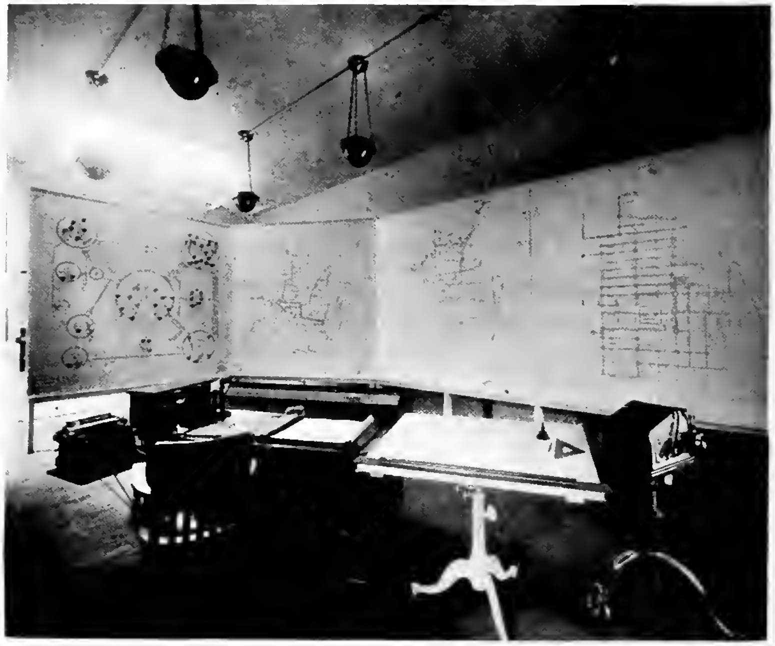

Fig. 1. General View of the Load Dispatcher's Office

All the power stations and substations are tied together by both high and low tension transmission lines, in such a manner as to make a shut-down for more than a few minutes an unknown thing under all ordinary conditions.

The Spring Street station, containing the largest units, is the most economical to operate, and therefore a practice is made of carrying all the load possible on this one station. At times, on Sundays and during the after part of the night, for instance, the load decreases to such a point that it is possible to cut out the prime movers in the second largest or the 220-volt station, and carry its load on its motor-generators from the alternators at the Spring Street station. The load formerly carried by the third largest station, which is also used in winter as a hot water heating plant, is handled during the summer time by Spring Street.

Owing to the fact that the generating equipment was so widely scattered, and that the nature of the service required was so exacting, it was deemed advisable to place the responsibility for its proper handling in the hands of a load dispatcher. Consequently, a load dispatching system was recently placed in operation which it is firmly believed will result in an increased reliability and the production of further economies in general power station load handling over the old methods. An office adjacent to the second largest station was fitted up with maps, telephones, recording barograph, recording electrical instruments and other necessary equipment for the dispatchers to properly supervise the load dispatching and from which to make out detailed daily reports covering their operations. They are kept advised from time to time through the day, by each station, of the amount of load carried and are given a daily report of the generators in service and their current output, from which the load curve for the day is made. Typewritten reports up to 6 o'clock in the morning must be in the hands of the Superintendent of Power by 9:30. The practice is followed of noting on these reports, in red, cases of trouble and fire alarms received over a private line. This office is also supplied with daily and monthly forecasts of the weather conditions. Wireless antennae are now being installed to give advice of approaching thunder storms.

A separate telephone system connects the dispatchers direct with all power stations and all substations except two, the latter being reached through the general office operator. The telephone system is so arranged that the load dispatcher may hold a telephone conference with the switchboard operators at all stations. This has already proved a very valuable adjunct as a time saver in connection with certain phases of daily procedure in the handling of the dispatching system.

The three load dispatchers, who work on eight-hour shifts, are switchboard operators of about ten years' experience and have been given several months of additional preparation for this work by being transferred from station to station in order to become familiar with the load conditions of each.

The photograph of the load dispatcher's office, see Fig. 1, shows at the left a graphic outline of the power station and substation system, giving the manner in which stations are tied together. The next three boards give maps of the city, showing the distributing lines, for railway and power and light. Having this information visibly at hand on the boards, the load dispatcher keeps directly in

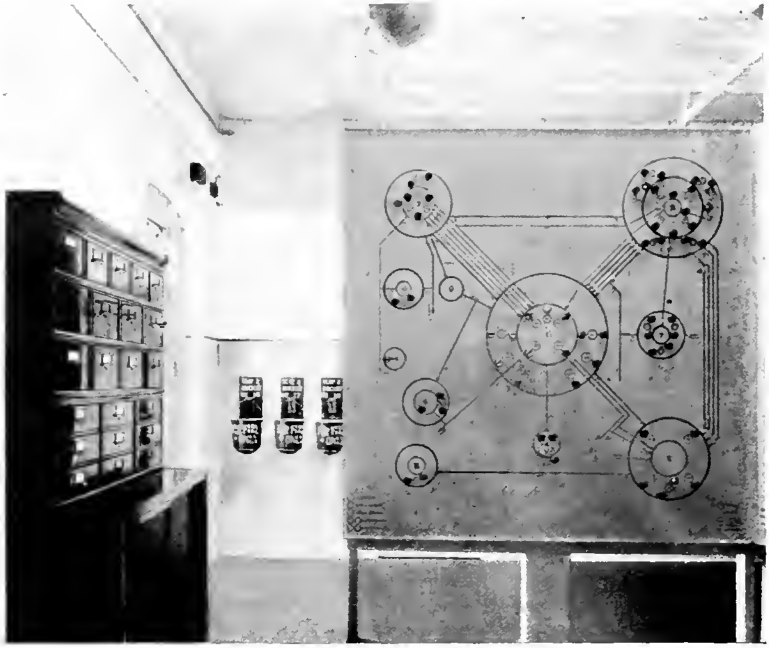
Fig. 2. A Near View of that Section of the Dispatching Board shown at the left of Fig. 1

touch with the changes made at the different stations. In case of trouble on any of the lines, his maps indicate at once how he can get around such difficulties with the use of certain line switches and still make it possible to furnish current with the least possible interruption of service.

The No. 1 board shows the power generating system, each power station and substation being indicated by a large circle. The different tie lines between stations are indicated by lines drawn upon the board in the proper color, and line switches are shown by small spring buttons, which can be turned as occasion demands to indicate whether the line is in or out of service. There are sufficient tie lines between the stations so that, in case of trouble on any line, service may still be furnished by using another line. Within the large circle and indicated by smaller circles, are shown each of the generators, motor-generators, rotaries, boosters, or batteries in that station. Close to these smaller circles are placed lamps under different colored lenses, the colors indicating the class of current delivered; for instance, railway current is shown by a green lens, and alternating current for power and light by a red lens, other colors being used to show rotaries, boosters, etc. At the outer edge of the dispatcher's desk is placed a double row of push button switches, which are connected to the lamps on the board; when he orders a certain generator placed on the line, he simply touches the proper button in the bottom row for that machine and its lamp is lighted. When this machine is cut out of service, he presses the top button and the light is put out; the lighted lamps giving the number of machines in service and the kind of current each is delivering.

The second board shows the alternating current system, giving the station to station tie lines and all primary lines, whether one, two- or three-phase; no secondary lines are shown. The power stations, substations and the largest consumers are also located on this board. This board is used for following up troubles which may arise from time to time and gives the dispatcher a graphic outline of the means which have been provided to supply current at such times.

The Line Department is required to co-operate fully with the dispatchers in handling cases of trouble arising from storms or otherwise, and must also work in conjunction with them in the proper handling of current while any new installations are being made. The load dispatching system has proved its worth several times this summer during lightning and wind storms, because it has brought the dispatchers and Line Department so closely in touch with each other.

No. 3 board outlines the trolley and feeder system, showing in one color the railway feeders, and in another color the double and single trolley lines. This board also locates section insulators, and is intended to be used in case of trouble on the lines, helping the dispatcher at such times to devise a method of supplying current sufficient to operate the cars.

Board No. 4 shows the underground system in the central district of the city. All manholes and junction boxes are located, while the underground and overhead feeders and distributing lines are shown by lines.

Before the load dispatching system was placed in operation, the heavy peaks in the load were handled by the engineers at the different stations as each saw fit, subject at times to approval of the Superintendent of Power, advice of changes made being given from one to another by telephone. In emergencies or in cases of breakdown especially, this system often proved ineffective, resulting sometimes in confusion at a time when machines should have been replaced on the line promptly; this has now been avoided by making one man, the load dispatcher, responsible for getting the machines on or off the line. The load dispatcher knows the steam consumption of each of the steam units, and can so order the plan of operation, in the great majority of cases, so that certain units may be used in preference to others which otherwise might be operated at a greater expense. The great economy resulting from the use of the load dispatching system comes from the fact that the dispatcher can formulate in advance methods of handling the average daily loads, using at all times possible those machines which are most economical in steam consumption. The experience which he accumulates from day to day in handling the system makes his movements in times of trouble, decisive and rapid, the whole tending toward a non-interruption of service plus economical generation of energy, the final goal to be attained being *never-failing service.*

# THE WHITE RIVER DEVELOPMENT OF THE OZARK POWER & WATER COMPANY

By G. W. Saathoff and C. P. Cummings

Ozark Power and Water Company, Joplin, Mo.

As the possibilities for further large water power developments become scarce, the engineer and promoter turn their attention to the smaller streams, where in many cases, by means of storage basins, sufficient water can be obtained for the generation of electricity in profitable quantities near a ready market. The development described in this article is of such a nature. The ultimate capacity of the plant will be 18,000 kw. generated by eight units. The energy is transmitted to distances as great as 150 miles; a ready market being found in the smaller cities thus reached, and in the surrounding lead, zinc and coal mines. The power house, transmission lines and substations are described in detail.—Editor.

The power possibilities of the White River in Southern Missouri have been known in a general way for a great many years, but it was comparatively recently that any definite work was done and a chain of dam possibilities located. About the time of the completion of the general survey, late in 1911, the Ozark Power & Water Company selected a site about two and one half miles up stream from Forsyth, Missouri, and about seventeen miles by water down stream, or seven miles overland from Branson, the nearest railroad station. They soon began active construction work on what is now the largest plant of this character totally within the state.

Fig. 1. General View of the Hydro-Electric Power House and Dam

The construction of the camp was one of the first difficult problems successfully solved by the management. This camp was finally constructed and operated in such a manner as to bring about more healthful conditions than existed in any other community in the immediate district. The successful solution of this problem has proven beyond a doubt that labor trouble may be entirely eliminated and better and steadier labor secured by providing good living quarters for the laborers.

During the early stages of the dam construction practically all of the materials and equipment, with the possible exception of the gravel and sand, were hauled seven miles overland from Branson. Later, however, after the dam had been partially closed, it was possible to handle the heavy machinery and other equipment on gasolene boats and barges over the seventeen-mile water route from Branson.

Fig. 2. An Interior View of Power House. Note the Oil-Drying Apparatus in Operation on the Gallery

On September 1, 1913, the development was first put in commercial operation. The maximum capacity of the plant is computed on a basis of 18,000 kw. in eight units of 2250 kw. each, five of which are running at the present time.

The transmission system extends a total distance of 150 miles from the power site by way of Springfield, Mo., to Joplin, Mo., where connection is made with the 32,000-kw. steam and hydraulic system of the Empire District Electric Company of that city, in a substation jointly owned and operated, and located on West Seventh Street. Other substations are completed in Springfield, Aurora, and Diamond, and plans are prepared for serving all cities and towns along the line.

The principal market for the service is located in the lead and zinc mining fields, of which Joplin, Mo., is the center; the coal mining fields of Cherokee County, Kansas and Barton County, Mo.; the City of Springfield; and the towns and cities between Springfield and Joplin. The population of these communities within reach of the transmission line will aggregate approximately 250,000, and an industrial power load of approximately 50,000 h.p. is now operating by electricity, while the available power business will probably total 200,000 kw. in connected load.

The drainage area of the basin of the White River above the dam approximates 4,350 square miles, extending from the northwestern part of Arkansas to the south central part of Missouri, and having a mean precipitation of forty to forty-five inches per year. The discharge of the river is not always in proportion to the precipitation, but is augmented in a great measure by the infiltration of water from other drainage areas, especially at times of minimum flow.

The White River has been studied, as noted above, very carefully relative to the characteristics of its drainage area and possible power developments, both above and below the present installation. Some preliminary work has already been done on a possible storage reservoir of approximately 10,000 acres in area which will, when completed, provide abundant storage for the present development. The possibilities below are equally as attrac-

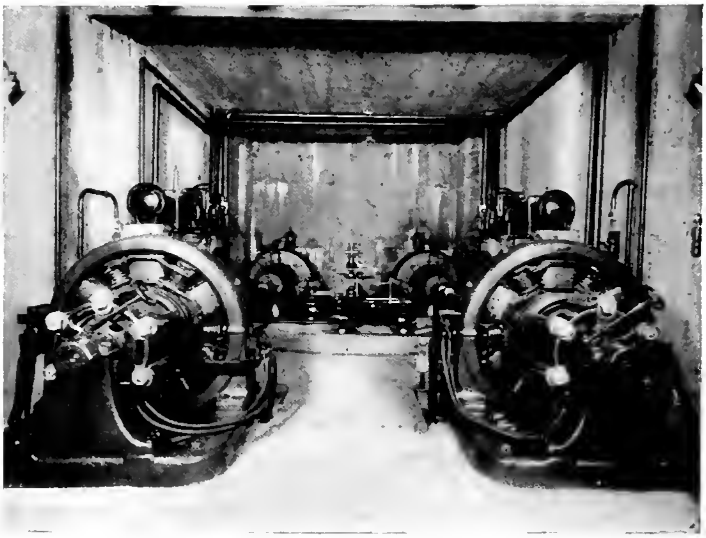

Fig. 3. Exciter Room at Power House

tive and some idea of the available power may be gained from the fact that the crest of the present dam is seven hundred feet above the sea.

The pond formed above the dam is about twenty-two miles long and is by far the largest lake in the state. The lake on one side is lined by high, rocky cliffs, in some places reaching a height of two hundred feet; on the other, by rolling land which, in nearly every case, reaches a height of one hundred feet or more above the bed of the stream. This section of the state now offers to the people one of the finest pieces of natural beauty and a most excellent outing center and is being rapidly settled by summer homeseekers.

The spillway is five hundred and ninety-four feet long, and is of the Ambursen type, with a maximum height of fifty-six feet. The reinforced concrete deck is supported at an angle of about forty-five degrees by vertical, tapering concrete buttresses, spaced with eighteen foot centers and resting on solid close grained limestone with heavy, horizontal strata. A cutoff wall about eight feet deep and four feet wide runs the entire length of the dam at the heel of the deck. The down stream side is open and the water is allowed to fall free after passing the crest. Two openings through the deck, five feet wide by five feet long, are fitted with sliding cast iron gates which are operated electrically and serve as permanent sluiceways. The power house extends from well into the east bank to the middle of the old stream bed. From this point the spillway begins and extends across the river, terminating in a cellular reinforced concrete abutment which projects twenty-five feet above the crest of the spillway. A concrete core wall, resting on rock, extends from the buttress four hundred feet into the west bank, and a heavy earth fill is made both above and below it, preventing any possibility of water overflowing any section of the west bank.

**Fig. 4. Front View of Switchboard Installed at Power House**

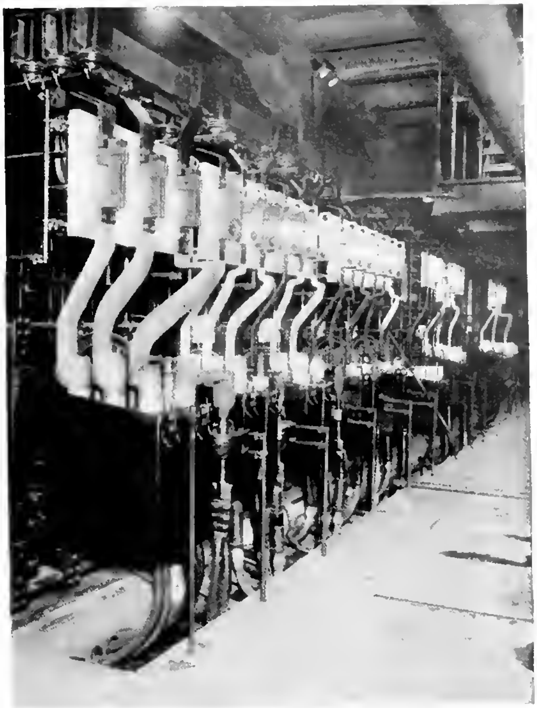

**Fig. 5. Rear View of Switchboard Installed at Power House**

The power house is a reinforced concrete structure, the upper sections of which, on the down stream side, are skeleton frame with brick panels. The roof is supported on steel trusses and covered with book tile and composition roofing. The windows and frames are steel and are operated from the generator floor. The plant equipment is installed on three floors; the lower floor carrying the generators, governors, and exciters, the second floor transformers, switchboard, etc., and the upper floor the high voltage switches and lightning arresters. The main generating station is provided with a thirty-ton traveling crane.

Fig. 6. 66,000-Volt Switches and Lightning Arresters Located at Power House

A four-foot partition wall is placed between the openings for the several wheels. Each opening is twenty-three feet by eighteen feet and has a curtain wall extending several feet below the crest of the dam, which acts as a skimmer to prevent floating debris, ice, etc., from reaching the racks. The openings may conveniently be closed in case it is necessary to work on the head gates, racks, etc.

The trash racks are placed in the intake compartments on a slope of three and one-half horizontal to twelve vertical. The screen is eighteen feet wide and the bars are two and three-quarter inches by one-fourth inch in cross section, and are forty feet long, spaced one and one-half inches on center. The racks are supported on heavy beams and trusses fastened directly to the power house structure.

The head gates are seventeen feet high and nine feet wide; two for each wheel opening, and are made of eight inch steel beams covered with three-eighths inch skin plate. At the bottom of the gate a six- by eight inch timber is attached so that it closes against the back of a ten inch channel, which is placed in the concrete across the opening. The frames and guides are made of rolled channel and beam sections and each gate is provided with a small filler gate to equalize the pressure and prevent excessive friction in opening and closing the main gates. The gate operating mechanism is connected to the gate by a sixty-foot stem, made of ten inch channel, reinforced by six inch beam. This mechanism is arranged for motor or hand power and is mounted on a seven foot platform five feet above extreme high water.

The tailrace has been excavated below the old river channel and the bed and sidewalls have been so built that the water is directed to the center of the stream, thereby minimizing the friction loss in the tailrace.

Each of the five main units now operating consists of twin Francis turbines with fifty-two-inch runners, manufactured by the S. Morgan-Smith Company and designed to operate under working heads from forty to fifty-four feet. The output will vary from 2600 h.p. at forty feet to 4000 h.p. at fifty-four feet, and at the mean effective head of fifty feet the units will develop 3600 h.p. The speed of each of the units is controlled by a Type NS Lombard governor, with an independent belt-driven pump. The wheels are set in a concrete chamber and the discharge is conducted to the tailrace through a single eighteen foot conical steel draft tube flaring from a diameter of nine feet six inches at the wheel to seventeen feet at the outlet, and is inclined on a slope of one horizontal to four vertical. This slope directs the tail water down stream and further eliminates excess friction loss in the tailrace. Two single-runner exciter units with eighteen inch wheels, capable of developing 200 h.p. under fifty-foot head, are used to drive two independent exciter sets. The speed of each of these units is controlled by a suitable Lombard governor.

The generators, which are direct connected to the turbines, were manufactured by the General Electric Company, and are rated at 2250 kv-a. three-phase, 25-cycle, 2300 volts when operating at 214 r. p. m. Each machine is designed for a thirty per cent overload, giving a capacity approximating that of the wheels. The exciters are rated at 175 kw. at 125 volts when operating at 600 r.p.m., and are directly connected to the exciter wheels.

Fig. 7. Double-Circuit Steel Poles

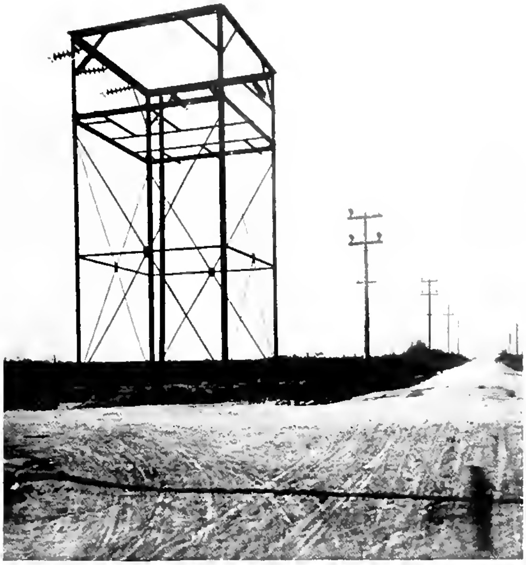

Fig. 9. Steel Four-Pole Tower

Fig. 8. Square Towers

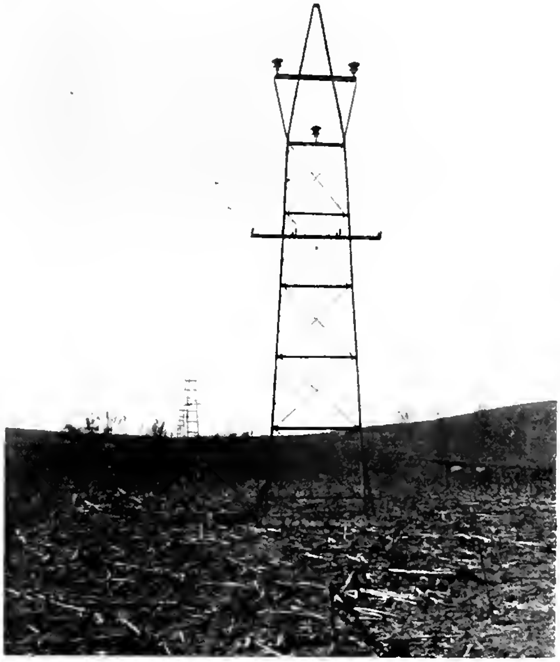

Fig. 10. Standard "A" Frame Tower

Various Types of Towers used on the 66,000-volt Transmission Line

The transformer equipment consists of seven single-phase units rated at 2000 kv-a. each, when operating on 2300 volts to 66,000 volts, and were manufactured by the General Electric Company. The units are arranged in two banks of three transformers each, with one spare. Each bank is provided with individual water circulating pumps, but, under ordinary operating conditions, the water is supplied from the pond above the dam under a sufficient head to guarantee good circulation.

The switchboard is mounted on a transformer gallery overlooking the generator room floor. The main low tension buses and switches are mounted on pipe supports several feet back of the board. The buses and connecting straps to the switches are flat copper while the conductors to the generators and transformers are lead covered cable. The oil switches are electrically operated by energy taken from the exciter buses and are in every case provided with air break isolating switches. All of the switching apparatus, switchboards, etc., was supplied by the General Electric Company. The high tension wiring is on the third floor. Each transformer in the outgoing line is controlled on the high tension side by General Electric solenoid-operated oil circuit breakers, manipulated from the main switchboard. The plant equipment is protected by choke coils and electrolytic lightning arresters on the outgoing line, this apparatus being also located on the third floor. The horn gaps, however, are installed outside, and the conductors from the gaps to the cone stacks are taken into the room through roof bushings.

Fig. 11. The West Seventh St. Substation with Trouble Cars in the Foreground

The plant is connected by a 66,000-volt transmission line with the lines of the Empire District Electric Company at Joplin and the Springfield Gas & Electric Company at Springfield. The line loops through substations at Springfield, Aurora, and Diamond, thus allowing each station to be fed from either direction, although, normally, the line is cut straight through.

The transmission line extends in a northwesterly direction from the hydraulic plant, a distance of approximately forty-six miles, to the Springfield substation. The first twenty-two miles traverses a very rough section of the Ozark Mountains and is carried on steel A frames over a privately owned right of way. From the end of the A frame section the line is carried through a fairly open country and along the county roads on wooden pole construction to the city limits of Springfield. Within the city limits of Springfield the circuits to and from the substation are carried on a single steel pole line.

The line from Springfield to Joplin is built along the public highways under franchises granted by the county courts of the several counties through which the line passes. It is carried on wooden pole construction from the city limits of Springfield to the city limits of Joplin. That part of the line within the city limits of Joplin is similar in construction to that part in the city of Springfield.

The steel A frames used in the mountain district are from forty to sixty feet in height. The legs are built of single seven inch, nine and three-quarter pound channels, and the structures are securely braced by horizontal members with tie rods provided with turnbuckles. The cross arms are made of two angles, three inch by two-and-one-half inch, bolted to the frames, six feet below the apex. Two insulators are carried on this cross arm and a third insulator is carried on the upper horizontal member between the channels. A steel ground wire is clamped to the apex and another below the cross arm. The average span in the steel A frame section of the line is approximately four hundred feet; however, there are some spans that run over one thousand feet. Square strain towers are set about every two miles in a straight run of line and all corners on the entire system are provided with heavy steel "four-poles."

The wooden pole line is constructed mainly of forty-foot Idaho cedar poles, with not less than eight inch tops. That part of the pole below the surface of the ground is treated with Carbolineum and is set in broken stone. The cross arms are of clear Oregon fir, four and one-half inches by six inches by eighty-four inches. The braces are made of one-and-one-half inch galvanized angle iron and are arranged to fasten to the bottom of the cross arm.

The poles used inside the city limits of Springfield and Joplin are of steel latticed construction, fifty feet high, and are made of two nine-pound channels spread two feet six inches on centers. These poles are set on concrete bases and anchored with four one-and-one-quarter inch anchor bolts. The cross arms are seven feet long, made of nine-and-three-quarter pound angle, and are arranged for two circuits. Disconnecting switches are placed on the corner "four-poles" and at intervals in the line, to aid in isolating the several sections for the location of trouble.

Fig. 12. Transformer Room at the Substation

The main power conductors from the hydraulic plant to Springfield consist of three 2/0 stranded hard drawn copper wires. From Springfield to Joplin conductors are 1/0 solid hard drawn copper, except over railway crossings, where 1/0 stranded copper is used. Two complete metallic circuit telephone lines are strung on the transmission structures for the entire length of the line. No. 10 hard drawn copper is used for telephone conductors on the wooden pole construction and is transposed at every other pole, while No. 8 copper clad wire is used on the A frame construction and is transposed at every tower.

The insulators over the entire line are of the pin type, manufactured by the Thomas or Ohio Brass Companies, except the insulators on the dead ends, which are 100,000-volt, suspension type. The pins are the Lee type and the thimbles are cemented directly into the insulators.

The West Seventh Street station forms the connecting link between the 66,000-volt Ozark system and the 33,000-volt Empire system. The building is one hundred and four feet by one hundred and eight feet, forty-two feet high, built of concrete, brick, and structural steel. The roof is of book tile and composition.

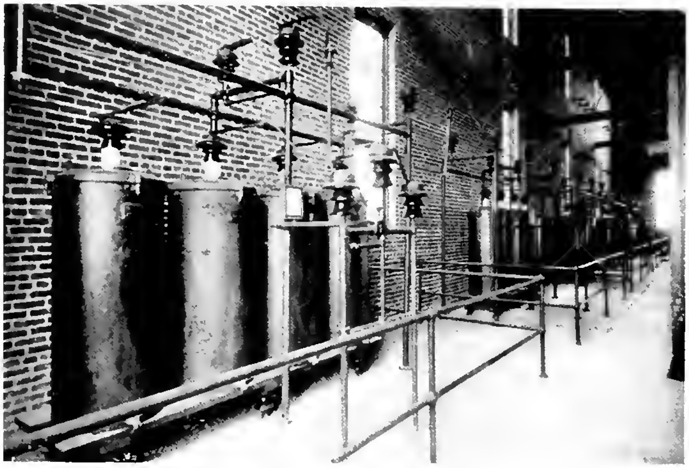

Fig. 13. Lightning Arrester Apparatus at the Substation

The building is divided into three rooms and a basement. The first room contains only the 66,000-volt busbars, oil switches, disconnecting switches, lightning arresters, etc. The layout provides for two outgoing feeders and three transformer switches.

The second and middle room is the transformer room and contains only the transformers, and is laid out for three banks of water-cooled transformers, 66,000 to 33,000 volts, having a total capacity of 30,000 kv-a. and two banks of water-cooled transformers, 33,000 to 2300, having a capacity of 6000 kv-a.

The basement contains a fifty-five-cell battery for the control circuits and emergency lighting, and also rooms for oil storage.

The third room has two stories, the upper floor carrying the 33,000-volt switching apparatus, and choke coils for five 33,000-volt feeders and five transformer banks. The lower floor contains five sets of 33,000-volt electrolytic lightning arresters, two sets of busbars arranged in brick and slate compartments on structural steel columns, one thirteen-panel switchboard carrying the control switches, and four 2300-volt distribution feeders, one motor-generator set for battery charging, and two circulating pumps.

The entire station is operated by remote control.

Fourteen telephone lines from both the Empire and Ozark systems center at this station on a suitable plug board. The attendant at this point also acts as load dispatcher for both systems.

Connection is made with the lines of the Springfield Gas & Electric Company at a station in Springfield, built adjacent to the plant of the above operating company. The building is of brick and steel, with concrete floors, and is eighty by fifty-six feet, with a twenty-four by twenty-five foot wing, and is approximately fifty feet high. The roof is of book tile with composition covering. The station is divided into two rooms, one of which contains the lightning arresters, and the other, which is provided with galleries for switchboard and switches, carries on the main floor a bank of three 1550-kv-a., 66,000-volt to 2300-volt, 25-cycle, single-phase, water-

Fig. 14. Duplicate 33,000-Volt Bus Structure showing Transite Barriers

cooled transformers and one spare unit, two 1250-kv-a. frequency changer sets, rated at 2200 volts, 25-cycle, to 2300 volts, 60-cycle; and one 500-kilowatt rotary converter, necessary transformers, etc. The high tension lines are controlled by General Electric K-15 oil circuit breakers throughout.

The switchboard, which is mounted on a gallery on a level with the operating floor of the Springfield station, consists of twenty-three panels, and controls both the high and low voltage switches of the twenty-five-cycle system, and the twenty-three-hundred volt, sixty-cycle system, as well as the five-hundred volt direct current service. This equipment as well as the transformers, frequency changers, etc., was supplied by the General Electric Company.

The Diamond and Aurora substations are duplicates. The former is located twenty miles southeast of Joplin and the latter about one mile south of the town of Aurora. The Diamond station will supply the cities of Granby, Neosho, and Diamond, Mo., and the mining load in that immediate district. The Aurora station will supply the present operating company at Aurora, which has transmission lines extending to Verona on the west and Marionville on the east. In addition, the extensive mining load which promises to be developed in this section will also be carried.

The substation buildings are of brick and structural steel, forty-eight feet wide, fifty-four feet long and thirty-nine feet high, and are divided into two rooms by a brick partition. In one room are installed the 66,000-volt oil switches and lightning arresters. In the other, space is provided for two banks of 250-kw. transformers and the switchboard.

In connection with the Diamond station a four-room house and frame barn have been built for the use of the patrolman who inspects the adjacent lines and operates the substation.

The operating force at the hydraulic plant consists of a superintendent and seven operators, one operator acting as a relief man. The Springfield station is operated by three men and the Joplin station by the same number. However, the men in the Joplin plant divide their time equally between the apparatus owned by the Empire District Electric Company and the Ozark Power & Water Company. Eight patrolmen, each equipped with a horse and buggy, portable telephone and Prestolite searchlight, make careful inspection of the total line at least twice each week. In addition, two six-cylinder automobiles, fully equipped with all necessary tools and repair equipment, are kept at convenient points, ready to go out at a moment's notice.

Satisfactory arrangements have been made with the Empire District Electric Company by which the latter provides standby service from its large steam plant located at Riverton, Kansas, through the West Seventh Street station in Joplin. However, up to this time, the service has been most excellent, even during the early stages of commercial operation, as well as through some of the severe electrical storms which are quite frequent in the district traversed by the line.

During the first eight months of operation the system has more than met the expectations and estimates of the builders with respect to output, reliability of service, and general operating characteristics.

The company is operated by the Doherty organization.

# THE EVOLUTION OF THE RAILROAD SHOP

By A. I. Totten

Railway and Traction Engineering Department, General Electric Company

The railroad shop of the present day is constructed according to a radically different design than that in vogue only a decade and a half ago. Among the many causes contributing to produce this change, the following have had the greatest influence: heavier rolling stock by reason of more powerful and massive constructions employed, a change in the policy of the management whereby many small shops have been replaced by a few large ones, and the electrification of the shops. In the following article the author explains the changes through which the railroad shop has passed and shows how the old methods of power supply have been supplanted to great advantage by electrification.—Editor.

This country has just passed through an era of steam railroad shop construction unparalleled in the history of railroads. The poorly lighted, antiquated buildings located at division points have been demolished, and in their places there have been erected structures which are representative of the best engineering practice, and which are designed to provide maximum economy in the performance of repairs on cars and locomotives. When we consider these modern shops it is difficult to realize that but a brief fifteen or sixteen years have passed since the first shop to be built along present lines was placed in operation.

In older days it was the custom to locate small shops at objective points on the system, where changes in locomotives on through trains were effected. These shops were designed not only to take care of the general overhauling of locomotives and cars but also to provide storage facilities, for engines when not in service, in the form of a roundhouse and the necessary adjuncts consisting of turntable, coaling station, sand house, oil house, water tank, etc. This is what might be termed the "unit system," inasmuch as each division had the exclusive handling and repairing of all locomotives assigned to it. With the introduction of cranes and other labor saving devices it was ascertained that, in order to reduce the unit cost of repairs, this expensive machinery which was provided must be worked at its full capacity. Therefore, the practice was instituted of placing large main shops at central points for the performance of the heavy general repairs on locomotives assigned to several divisions, and the light running repair work was done at small shops or in roundhouses located at terminals or division points.

The handling of the various parts of the older types of locomotives and cars did not entail the difficulties now encountered in the transference of material in and around the various buildings, which must of necessity be scattered to a considerable degree to allow for trackage space and also to reduce the fire risk which might otherwise prevail. The weights of engines have steadily increased from 135,000 pounds in 1890 to 830,000 pounds, which represents the weight of the triplex locomotive recently constructed for the Erie Railroad. With the increase in size of the rolling stock, the various components comprising the complete units have become heavier and heavier, and parts which were formerly handled readily by manual labor must now be lifted and transferred to the point desired by hoists and cranes.

The introduction of electricity in the shop was made initially for the purpose of producing artificial illumination which would supplant that furnished by oil, candles or gas. The development of the direct-current motor provided a means for driving shafting in the various buildings; and thus made it possible to discard the numerous boiler and engine installations that were distributed throughout the plant and to supplant them by a central power-house from which the current could be transmitted over wires to the motors in the different buildings. This did not materially affect the output of the shop, but it reduced the cost of power by decreasing the amount of fuel and labor required for its generation.

In view of the general satisfaction which resulted from the successful operation of the "group drive" system just described, railroad engineers as well as electrical manufacturers perceived the advantages that would accrue by equipping the larger machines, having variable-speed characteristics, with individual motors. An individual equipment of this sort would provide means by which speed variation could be readily obtained by a controller and resistance, thereby conserving the operator's time through eliminating the necessity for shifting belts on cone pulleys as had been required previously. This was accomplished by what is known as the "multiple-voltage system," so called because several line voltages were provided by balancer sets installed in the power house and connected across the terminals of the generating apparatus. The application of the proper potential for the motor speed desired was obtained by a controller located at a convenient point for manipulation by the machine tool operator. Inasmuch as the motor capacity varied in almost direct proportion to the voltage applied, it will be readily appreciated that this system was not wholly suited for machine tool operation where practically constant horse power should be maintained over the entire speed range. In fact, the difficulties experienced in the operation of the multiple-voltage system demonstrated the inapplicability of this method of speed control for machine tool operation. A further study of the subject resulted in the introduction of the adjustable field control motors, which admirably fulfilled the requirements of the service and are representative of standard up-to-date practice.

With the introduction of electricity for power purposes in railroad shops came the traveling crane, varying from five tons to one hundred and fifty tons in capacity. This replaced the hand jack, pneumatic hoist and manual labor. The work of lifting locomotives from their wheels and replacing them thereon was accomplished in seconds instead of hours, and the handling of heavy parts through the shops and yards was performed rapidly and with a minimum amount of labor and cost. The individual machine hoists were discarded as unnecessary; but, strange to relate they are now being replaced, as it was ascertained that a considerable amount of the tool operator's time was lost while waiting for the traveling crane to handle material around the machine.

We have up to this point mentioned direct current only for shop operation; but with the introduction of alternating-current motors on a cost and operating basis comparable with

Fig. 1. Interior of a Typical Locomotive Shop

direct-current motors, as regards constant speed service, they naturally became quite a factor in railroad shop installations. It is difficult to compare the relative merits of alternating and direct current as applied to railroad shop operation. The alternating-current motors must receive credit for the absence of commutators and consequent freedom from trouble due to this source, but they have not the adjustable speed characteristics of the direct-current motors and hence are not as well adapted to the operation of variable-speed machinery. There are a number of shops entirely operated by alternating current where the speed adjustment of machine tools, having variable-speed characteristics, must be obtained with gear change devices. In the majority of the larger shops both alternating and direct current are used, the former being either purchased or obtained from prime generating units and the latter furnished by motor generator sets or rotary converters driven by alternating current. A number of shops, however, especially the smaller ones, are operated exclusively by direct current. As a general proposition, under average conditions, the alternating-current direct-current combination is preferable for large installations; alternating current exclusively for small shops where current is purchased from central stations, and direct current for small shops where current is generated on the premises. Where the alternating-current direct-current combination is installed, the use of direct current should be confined exclusively to the variable-speed machine tools and alternating current should be used for the operation of transfer tables, cranes, turntables, etc., as well as for the constant-speed drives and illumination of the premises. Under these conditions the proportion of alternating-current to direct-current generator capacity would be about three to one.

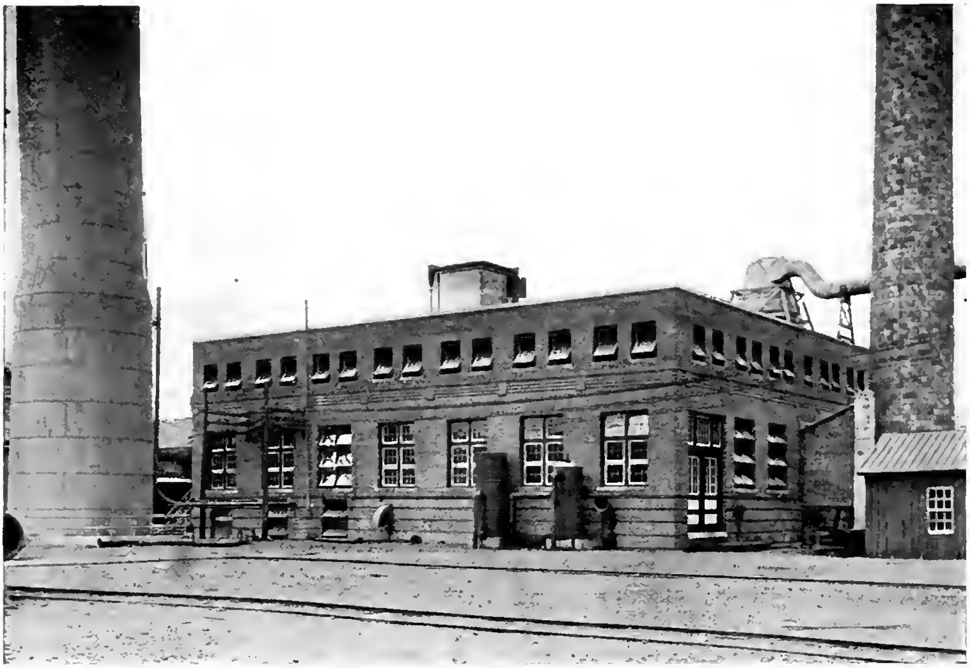

Fig. 2. Power Station for the Chesapeake and Ohio Railroad Shops

In addition to the electrical energy requirements for railroad shops, a large quantity of compressed air is necessary for the operation of pneumatic riveters, drills, chipping hammers, etc., which are used in large numbers throughout the plant. It is also required in lesser quantities for numerous other purposes such as painting, glass frosting, sand hoisting, train testing, cleaning motors and machines, pneumatic hoists, etc. The air compressors, ranging in capacity from 500 to 3000 cu. ft. of free air per minute, are generally placed in the main power house and are connected by pipes to the various outlets located in such a manner as to best fulfill the requirements of the service. These compressors are, for the most part, steam-driven but the growing tendency of railroad companies to purchase current from an outside source has created a demand for motor-driven compressors, the rotating element of the motor being mounted directly upon the crank shaft of the compressor and transmitting power thereto without the interposition of gears or belts. There is a serious objection to large motor-driven compressors, however, due to the wide range of compressed air consumption which prevails in railroad shop plants. In the case of the steam-driven machine, the governing apparatus admirably controls the speed of the compressor to suit the existing demand but, with the motor-driven machine, the speed remains constant and a throttling suction governor or by-pass control relieves the machine when the compressed air consumption falls below the capacity at the fixed speed. This is not an economical arrangement from a current consumption standpoint and the wear on the machine is practically constant regardless of the amount of air supplied. In view of the large size of these compressor units, which require the supply of from 80 to 500 kw. of energy, it would not be feasible to have them start and stop automatically with the rise and fall of air pressure. To overcome the objections cited, and also to reduce the losses caused by long lengths of pipe connecting the various buildings, there now seems to be a tendency to distribute throughout the various departments small air compressor units which have a capacity of from 50 to 200 cu. ft. With units of this size, the motors can be automatically regulated without imposing undue strains on the machinery or the transmission line.

The innovations as heretofore illustrated in shop design and operation were not effected without radical changes in the operating organization. The division master mechanic, who formerly had exclusive supervision of the locomotives assigned to his division, was compelled to release his sovereignty during the time they were undergoing heavy repairs in the main shops, for these shops were governed by shop superintendents who were responsible only for the economical and satisfactory repairs to the equipment.

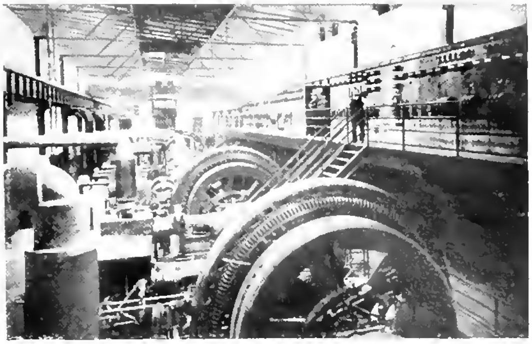
Fig. 3. Interior View of One of the Reciprocating-Engine Driven Power Plants

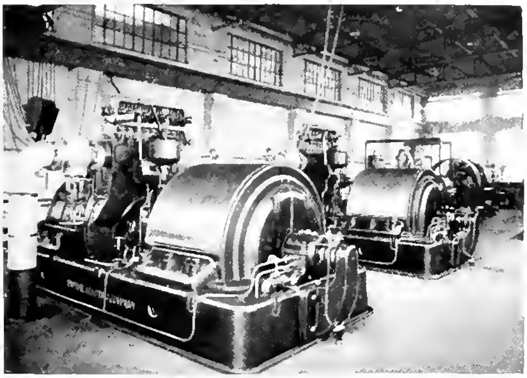
Fig. 4. Interior View of a Recent Steam-Turbine Driven Power Plant for Railroad Shops

The designs of the shops have not been symbolic of unity of sentiment with respect to the various features of construction. The greatest divergence of opinion existed with respect to the arrangement of tracks in the erecting shop which, it might be explained, comprises the keynote of the entire building arrangement and equipment. The longitudinal track design demands two cranes in the erecting shop, each capable of lifting one-half of the weight of a locomotive. The transverse track design requires only one crane of such capacity as to lift the entire weight of the heaviest locomotive in service. With the transverse arrangement, transfer tables were sometimes installed so that the functions of the cranes were limited to the hoisting of engines only after they had been placed on the track upon which the repairs would be conducted. The transfer table is not required if sufficient clearance between the floor and the roof trusses is provided to handle locomotives over each other for the length of the shop. It is not entirely the personal preference of the engineer which decides the arrangement to be followed for, in some cases, the plan of the available land upon which the shops are to be erected proves to be the governing factor.

The locomotive repair shop capacity is generally stated with respect to the number of tracks or pits in a transverse erecting shop and in terms of the number of locomotives that can be accommodated in a longitudinal erecting shop. It is apparent that a certain approximate fixed relation should exist between the floor space required in the different departments and the number of locomotives accommodated in the erecting shop. This relation must be correct and the capacity of the machinery must be properly proportioned in order that maximum efficiency and consequently maximum output for the capital expended may be obtained.

Fig. 5. An example of a Motor-Driven Double-Wheel Lathe in a Locomotive Shop

The output of a railroad repair shop is generally expressed by the relation between the number of locomotives which can be contained in the erecting shop and the number of locomotives repaired in each month, or is defined as the number of locomotives per pit per month. This figure will vary from 0.5 to 3.0, depending upon the average amount of repairs to be performed and the floor space together with the machinery available in the departments contingent to the erecting shop. It is clearly evident that the highest efficiency will be obtained, as well as the maximum output for capital expended, if the installed machinery is such as to enable the erecting shop to turn out the largest number of engines per unit of floor space.

It is not essential to combine the locomotive repair shop and car repair shop in one plant, and the tendency in recent years has been to separate the locomotive and car departments. From a labor standpoint, it is not desirable to operate jointly a car and a locomotive repair shop as dissatisfaction is likely to result between the lesser skilled and lower priced labor employed on the former and the more skilled and higher priced labor employed on the latter.

In contemplating the advisability of purchasing current from central station plants for driving the shops, the question arises as to whether or not the operation of high-pressure boilers can be discontinued when steam for running the generating units is not required. The stumbling block to the discontinuance of high-pressure boiler operation has heretofore consisted of the steam hammers in the blacksmith shop. These could not be economically operated by compressed air under the existing conditions. A recent design, covering a motor and air compressor combination which forms a part of the hammer equipment and furnishes compressed air instead of steam to the hammer cylinder, may overcome this contingency. The use of steam will generally be required for shop heating in winter and also for heating the lye vat solution during the entire year. These conditions can best be fulfilled by the

Fig. 6. A 120-Ton Electric Crane in Use in a Locomotive Shop

installation of low-pressure boiler units of suitable capacity to take care of these requirements.

We are now confronted with questions respecting the future development of the locomotive repair shop. Will further progress be made or is the era of the steam locomotive rapidly passing, to be pointed out to the next generation as an ancient system of propulsion for railroad trains?

Few industries, if any, have been benefited to a greater extent by electricity than have the railroads. It is the agent that operates the signals which guarantee a safe passage for the trains; it operates the shops; it illuminates the shops and yards; it pumps the water to fill the tenders; and it propels the freight and passenger trains in increasing numbers every year. We can now purchase electric locomotives at a cost per pound less than twice as great as the cost per pound for steam locomotives and obtain from them a yearly mileage two times that of the steam locomotives which makes the net first cost of motive power approximately the same for a definite service.

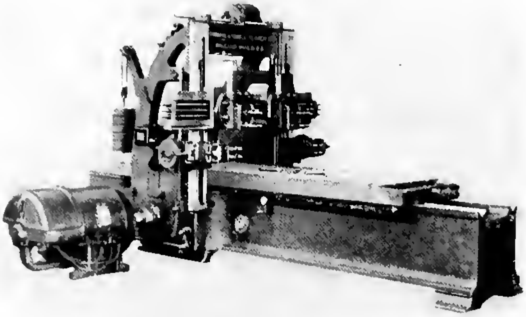
Fig. 7. An Example of a Reversing-Motor Planer Drive in a Railroad Shop


Fig. 8. An Example of the Use of Electricity in Signal Service

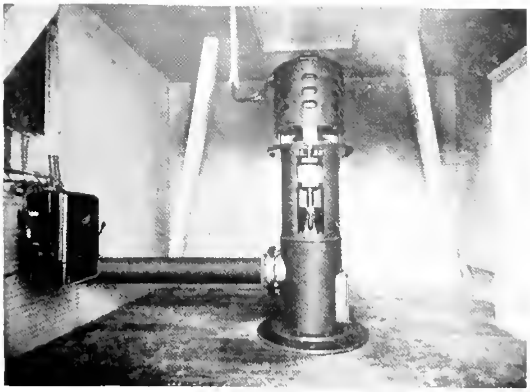
Fig. 9. An Installation of a Direct-Connected Motor-Driven Propeller Water Pump

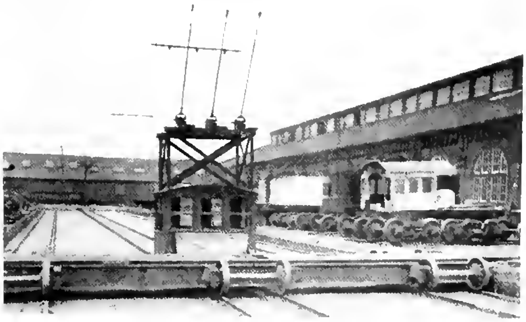
Fig. 10. A Transfer Table Driven by a 10 H. P. Squirrel-Cage Induction Motor

Will the elaborate steam locomotive repair plants be superseded by more simple shops for the electric locomotives costing not more than one-fourth as much as the present steam locomotive shops? Will the average cost of repairs for electric locomotives, namely, 4 cents per mile as compared with the average cost of repairs for steam locomotives of about 9 cents per mile, be a large governing factor in the future of the transportation problem? The next decade should provide the solution.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## ENERGY OF THE RADIO-ATOM

While in the highest explosives the chemical energy per unit weight, as per gram, amounts to thousands of calories, the energy developed by the spontaneous disintegration of the radio-atoms, as those of radium, thorium, uranium, etc., amounts to many millions of calories, that is, is many thousand times higher than that of the highest explosive. Nevertheless, while in the explosive the energy development when once started becomes cumulative, that is, all the energy is set free suddenly by explosion, all attempts to vary the energy development and therewith the decay of radio-atoms have failed and neither extreme heat nor extreme cold have any appreciable effect on the rate of energy production. The internal energy of the radio-atom is thus of an essentially different character from chemical energy: it follows the probability law; the exponential function. This is the law of energy development of cosmic forces, and, if we consider the solar system of the universe as atoms, the same laws of energy development involved in hurling planetary masses into the universe would occur as when radio-atoms hurl $\alpha$ or $\beta$ particles into space. When a number of masses attract each other by central forces, as the sun and planets and comets in our solar system, or possibly the positive and the negative electrons in the atom, they circle around each other with more or less complex motions. If then in these orbital motions two of the masses approach close to each other, an exchange of energy occurs between them; and it is merely a question of probability when, by such energy exchange, one of the masses receives a velocity sufficient to carry it away from the attraction of the system, into infinite space; that is, a particle is thrown out by the atom, or the solar system.

Our solar system is a stable atom, as it has only one central mass, the sun, and the planets circle around it in nearly circular orbits, thus can never approach sufficiently close to each other to affect each others' velocity materially. It is only the comets, which by their eccentric orbits, may exchange energy with other masses; and comets, once traversing the sun in elliptical orbits as parts of the solar system, have been hurled into infinite space in open orbits. In solar systems having two or more large central bodies—as is not infrequently the case—planets may approach each other so as to exchange considerable energy and disintegration of such systems by particles—planets—being sent out into infinite space, is possible: unstable atoms.

Thus, if we assume the constitution of the atom as similar to that of the cosmic atoms (the solar systems), the internal energy of the atom, which is set free in the electron by atomic disintegration, would be the energy of orbital motions. This would explain the magnitude of the energy, and would also explain the entire independence of atomic disintegration from external influences: it follows the probability law of such coincidence of relative positions and velocities of the particles, which constitute the atom, as would give to one of them a velocity sufficient to escape.

In connection, herewith, it is significant to note that radio activity, that is, instability, is a property of the heaviest atoms.

Incidentally, when we consider the extremely high intra-atomic energy of the radio elements, we must realize that the stable atoms have equally high or even higher internal energies. For instance, uranium, which is considered as the parent of radium, sets energy free in changing to radium, and the internal energy of the uranium atom thus must be higher than that of the radium atom, though the radio activity of the former is millions of times less.

C. P. STEINMETZ

## A SPECIAL TYPE MULTI-RECORDER

The standard multi-recorder is a device that is arranged to print, on a paper ribbon, the exact time an oil switch operates. A single recorder can take care of fifty oil switches, making individual records for each. While this is its particular field, it can be connected to suitable devices for recording lightning, station signals, the stopping and starting of feed-water pumps, etc. However, in some cases it is desirable to have a machine that gives the total number of operations, instead of the exact time that any particular one occurred. For this service a new type of multi-recorder has been developed. It is particularly applicable to screw machines, punch presses, etc., in fact to any machine where it is desired to show the total, instead of the individual happenings. This machine does not make a permanent record, but simply indicates the number of operations completed at the time the record is observed. Each element of the device is nothing more than an electrically-operated Veeder counter. A number of these elements are combined and mounted in a glass case to form a complete machine.

A life run was made on one of the units at a speed of 350 counts per minute. After 2,500,000 operations the Veeder counter failed. If the counter had been run at the normal speed of 40 operations per minute, it is probable that it would have lasted twice if not three times as long. Because the operating mechanism was in good shape, another counter was put on and run at the same speed. This counter also lasted about 2,500,000 operations, checking the first test very closely. The operating mechanism showed almost no signs of wear and could have run four or five times as long.

At the speed that an average punch press operates if the press ran continuously ten hours a day and five and one-half days a week, the counter would last a year. After this twelve months' run, the only replacement that would be needed would be a new counter, which could be easily installed on the old mechanism by removing two screws and one pin. The mechanism should be good for from five to ten years, depending on the speed at which the punch press operates.

A. H. DAVIS

## QUESTION AND ANSWER SECTION

The purpose of this department of the REVIEW is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the REVIEW.

Second, it publishes for the benefit of all REVIEW readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting subject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

### THREE-PHASE TRANSFORMERS: PHASING-OUT

**(111) Having two three-phase transformers to be connected in parallel, as shown in Fig. 1, please explain in detail what preliminary precautions must be taken, and describe how to phase them out, giving size of potential transformers that should be used, range of instruments or voltage of lamps, etc.**

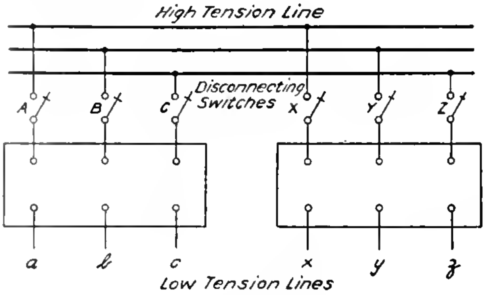

Fig. 1

**In addition, please state what combinations of delta and Y can be used in the parallel operation of the primaries and of the secondaries of the transformers.**

In order to operate satisfactorily two three-phase transformers in parallel, they should have like ratios, impedances, polarities, and phase rotations.

When connecting two transformers of different manufacture, it cannot be assumed that the similar leads of the two transformers will be the ones that should be joined. Before making any electrical tests, it should be made certain, in order to have proper phase relation of the secondary voltages, that the transformers are properly connected. Next, each transformer when connected to the high-voltage line should give equal voltages between the low-voltage terminals, and the values should be equal in both transformers, that is,

$$ab = bc = ca$$

and

$$xy = yz = zx$$

also

$$ab = xy, \; bc = yz, \text{ and } ca = zx.$$

Before the low-voltage leads are connected together, the phase rotation of each set of these leads should be checked so that, when $a$, $b$, and $c$ are connected in that order to the same terminals as $x$, $y$, and $z$, the same direction of rotation will be produced on whatever device is used, whether it be a so-called phase-rotation indicator or a three-phase motor. (Phase rotation can be reversed by interchanging any two of the external leads on one side of a transformer.)

When the voltage and phase rotation are correct, polarity must be determined before all of the low-voltage leads are joined together in the final connection. To make a positive test for polarity, first connect two leads together which are supposed to go together, for instance, $a$ and $x$. Now if zero voltage is indicated across $b$ and $y$ and across $c$ and $z$, $b$ may be connected to $y$ and $c$ to $z$, and the phasing-out is complete.

If, however, the polarity of $x$, $y$, $z$ is opposite to that of $a$, $b$, $c$, even though the phase rotation is the same, twice the line voltage will be read across $b$-$y$ and $c$-$z$. The phase connections on one side of one transformer must then be reversed. That means, if a delta, the delta must be opened at each corner and each coil reversed; if a Y, the neutral must be broken and each coil have its opposite end connected to the neutral point. However, only one side of either transformer should be changed in the case of different polarities. This case also assumes that $a$ and $x$, $b$ and $y$, $c$ and $z$ are the proper terminals to be finally joined.

It may happen that $x$, $y$, and $z$ do not correspond in order with $a$, $b$, and $c$, but should be

$a$, $b$, and $c$ to $y$, $z$, and $x$

or

$a$, $b$, and $c$ to $z$, $x$, and $y$.

In such a case, where the polarity is the same in the two transformers, the voltage readings $b$-$y$ and $c$-$z$ will be 1.73 times line voltage when $a$ and $x$ are joined. The proper relation of $x$, $y$, and $z$ to $a$, $b$, and $c$ may be determined by joining $y$ and $z$ in turn to $a$ and measuring the voltages $b$ to $z$, and $c$ to $x$, or $b$ to $x$, and $c$ to $y$ respectively.

The foregoing, briefly stated, means that if the two leads which are joined together *are the correct ones to be connected*, then the voltage readings taken between the others (corresponding according to phase rotation,) indicate if equal to zero, the proper terminals to be joined; while, if of twice normal voltage, indicate opposite polarity. If any other indication is given, *the leads are not the correct ones to be joined;* and other connections should be tried until either zero or twice normal voltage is read between the leads of the second pair and the leads of the third pair, when the leads of the first pair are connected together. When the reading twice-normal-voltage is obtained, a reversal of the polarity of one transformer should be the only change necessary to prepare the machines for parallel operation.

In measuring the voltages, enough capacity is required to measure twice the normal line voltage. Potential transformers, if used, would most likely be rated at the line voltage and should, therefore, be connected two-in-series when taking the readings during the process of phasing-out. Voltmeters or lamps used on the secondary side of the potential transformer would have to cover the range of voltage of those windings. It should be borne in mind, however, that when only one voltmeter is employed and that one being connected across the secondary of only one of the potential transformers where there are two in series, its readings will have to be multiplied by twice the ratio of the transformer to give the voltage of the high side.

In case the voltage of the low-tension sides of the main transformers is sufficiently low to enable the use of lamps without potential transformers for testing out, enough lamps should be connected in series to properly burn on twice the low-tension voltage.

The following table gives the possible combinations of two three-phase transformers or banks; those marked with an "✓" will operate in parallel, the ones marked with a "×" will not.

Transformer or Bank "A"

| Transformer or Bank "B" | Δ Δ | Δ Y | Y Δ | Y Y |
|---|---|---|---|---|
| Δ Δ | ✓ | × | × | ✓ |
| Δ Y | × | ✓ | ✓ | × |
| Y Δ | × | ✓ | ✓ | × |
| Y Y | ✓ | × | × | ✓ |

R.K.W.

### TRANSFORMERS: PHASING-OUT SMALL POLYPHASE POLE TYPE

**(112) What is the most convenient yet satisfactory method of phasing-out small three-phase, pole type transformers, preparatory to connecting them to the line?**

Since in small three-phase transformers the internal connections are likely to be permanent, mistakes in connection are not as liable to occur as in large transformers, where various methods of internal connection may be used. The simplest way of phasing-out the small transformers referred to is to check their ratio, polarity, and phase rotation before they are taken to the point of installation. When connection is to be made, the primaries should be joined to the line and one secondary terminal joined to its corresponding low-voltage line. If voltages are shown between the other terminals and their corresponding lines, then further combinations of lines and terminals should be tried until the proper ones giving a zero indication are found. For this work, a voltmeter with a range sufficient for indicating approximately twice the secondary or line voltage, or sufficient lamps for the same voltage, are necessary. R.K.W.

### RESISTANCE: TEMPERATURE COEFFICIENT OF COPPER

**(113) When the temperature rise of an electrical machine is to be determined by the increase in the resistance of its windings, what values should be employed for the temperature coefficient of copper?**

At the last meeting of the International Electro-Technical Commission held at Berlin in September, 1913, the following rule, relating to the temperature coefficient to be employed, was adopted.

> For making resistance measurements, there has been adopted as the coefficient of temperature-resistance of copper the value indicated in the table below, which has been deduced from the formula $1/(234.5+t)$. Thus, at an initial temperature of 30 deg. C., the coefficient per degree Centigrade becomes $1/264.5(=0.00378)$.

| Temperature of Windings in Degrees C. at which the Initial Resistance is Measured | Copper—Increase in Resistance per Ohm per Degree C. |
|---|---|
| 0 | 0.00427 |
| 5 | 0.00418 |
| 10 | 0.00409 |
| 15 | 0.00401 |
| 20 | 0.00393 |
| 25 | 0.00385 |
| 30 | 0.00378 |
| 35 | 0.00371 |
| 40 | 0.00364 |

H.M.H.

### AUTOMOBILE LIGHTING GENERATOR: VOLTAGE REGULATION

**(114) Some types of automobile lighting generators have a "third-brush" bearing on the commutator for the purpose of maintaining constant voltage in spite of a variable driving speed. How is this accomplished?**

In the "third-brush" method of regulation two shunt fields are utilized, one being wound so as to oppose the other. Referring to Fig. 1, a main field coil *M* is connected between the load brush *A* and the so-called "third-brush" *C*, while a reversed field coil *R* is connected between brush *C* and the second load brush *B*. Under operating conditions no current flows from the "third-brush," and the two field coils are so balanced that normal voltage is produced. At speeds above normal the armature reaction is sufficient to distort the field flux, thereby giving a higher armature voltage between *B*-*C* than between *A*-*C*. This causes more current to flow in *R* and less in *M*, thereby weakening the field flux and restoring the voltage to approximately the normal value. Since the armature reaction depends primarily on armature current, better voltage regulation is obtained when the generator is under-load. H.S.B.

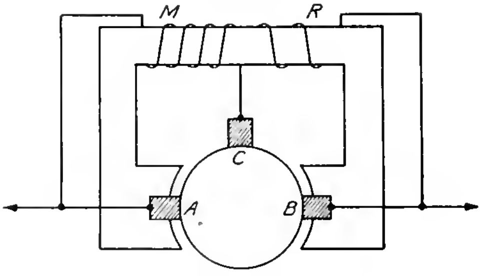

Fig. 1

# GENERAL ELECTRIC REVIEW

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GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

The march of events in Europe has already gone far enough for us to gain some idea of how business in general can withstand the shock of the greatest calamity that has befallen the world in the memory of man. It seems safe to infer that, although undoubtedly some industries are seriously affected and others have not yet "found themselves" under the new strained conditions, on the whole the country has met a disaster that might have been expected to cause an economic and industrial upheaval, with better results than might have been anticipated.

In our last issue we expressed the thought that the fear of dire results would in all probability be worse than the damage actually sustained. Now that another month has passed we become more convinced that this is to be the case, and it seems more plain than at the start that if all idle fears are dispelled the country can still keep a great percentage of its working millions engaged in profitable undertakings.

There is no doubt that in America alone there is ample work to be done for providing for our own needs, and that beyond this we must meet the demands of many markets now not being served by some of those countries that are engaged in war.

The manufacturing facilities of America are enormous, and they are fully prepared to keep full speed ahead if capital and credit will brave the situation and not permit undue discretion to bring about unnecessary curtailments of orders and hindrance to useful developments. There was at the first naturally a tendency to delay all orders that were not immediately required and to postpone as long as possible all expenditures that were not actually imperative, but we have reason to hope that now the basic conditions will appear sounder to those that have orders to place and that business will be brought to as normal a condition as possible without delay.

In all cases where there is work that is to be done and the capital is available it would seem both wise and patriotic to avoid delay; wise because it often happens that after the "valley" loads such as many large industrial concerns are carrying now, very large "peak" loads have to be provided for and orders cannot be filled as quickly as desired; and patriotic because it is a real service to the country to keep the wheels of industry running at normal speed and to avoid all unemployment as far as possible.

Such times of stress as we are now passing through will be a real test as to whether the country is the gainer or the loser by big business enterprises. We venture to believe that an order of retrenchment or advance in the production of a large industrial army, like the enterprises of a fighting machine, can be managed better where the forces are carefully organized than where innumerable individual units shift hap-hazard for themselves.

The industrial world as a whole has become so thoroughly organized during the last half century and the inter-communication between the nations has become so complete, that today we can regulate production to meet the varying requirements of the world's markets in a way that was previously quite impossible. The progress that we have made in this direction is so great that we are in a far better position to understand and meet successfully the unusual and unfortunate phase through which we are passing.

It should be specially remembered that large corporations and nations are built up of individual units and that therefore the attitude of each individual is of importance. The employer and the employee each has his duty to perform. In each individual case a little courage will bring better results than much fear.

We sincerely hope that before another month has passed industrial conditions will so far improve that we shall be talking about an increase rather than a decrease in trade, for when we contemplate the markets which must be supplied both here and abroad it seems only reasonable to suppose that a great industrial nation at peace with all the world will find plenty of calls for her manufactured products.

# BEARING CURRENTS

By E. G. Merrick

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The causes for the presence and the behavior of bearing currents has always been more or less of a mystery to those who have had no time nor opportunity to pursue a thorough investigation of the subject. The author of this article presents his findings, and those of other independent investigators, as being the latest accepted information on the subject. It is believed that a careful reading of them will equip a manufacturer, engineer, or station attendant with such knowledge concerning continuous-current, synchronous, and asynchronous machines as will enable him to eliminate or at least to minimize the annoyance resulting from this undesirable current flow.—Editor.

Trouble is frequently experienced with rotative electrical machinery, due to the destructive effect of current in the bearings. Such current causes a pitting of the bearing linings and even of the journals, which eventually leads to failure of these parts.

As will be explained later, there are certain conditions which give rise to an induced voltage in the shaft. If the circuit, consisting of shaft, bearings and base (or generator frame), is complete, see Fig. 1, it is evident that a current may be produced whose magnitude is limited only by the resistance of the path provided; and, since this resistance is ordinarily of a very low order, frequently currents are induced of sufficient magnitude to produce the destructive effects mentioned.

The theory of the production of these currents is not generally understood and comparatively little data on this subject has been published.

The phenomena have been studied by Punga and Hess,* by Fleishmann† and by Adler;‡ and the writer desires to present briefly the general theory as developed by these authors and to supplement this with comments and the results of his own further investigations.

Consider, first, the case of a four-pole revolving-field alternator as indicated in Fig. 2.

Since the flux $= \dfrac{\text{magnetomotive force}}{\text{magnetic resistance}}$

we have

$$\phi_1 = \frac{\frac{4}{10} NI}{\Sigma \frac{l_1}{\mu_1 q_1}} \quad \text{and} \quad \phi_2 = \frac{\frac{4}{10} NI}{\Sigma \frac{l_2}{\mu_2 q_2}},$$

where $NI$ is the ampere-turns, $l$ is the length, $\mu$ the permeability, and $q$ the cross-section of the various parts of each circuit.

If the reluctances of the two circuits are equal then $\phi_1 = \phi_2$; but these reluctances may be different due to pecularities in the design (which will be explained later), by variations in the permeability of the iron, or even by faulty machining or assembly of the parts. Referring to Fig. 3, if the reluctance of the joints between the two halves of the stator frame is appreciable, the total reluctances of the two circuits will be different and $\phi_1$ will be greater than $\phi_2$ by an amount which we may represent by $X$, i.e., $\phi_2 = \phi_1 - X$. The result of this new condition will be more clearly understood if the flux lines are re-arranged as shown in Fig. 4, the total flux of course remaining unchanged. Each of these fluxes encircle the shaft; at the instant shown, the flux represented by the dotted line $\phi_1$ is turning in a clockwise direction and that represented by the full line $\phi_2$ is turning in a counter-clockwise direction. When the rotor revolves by an amount equal to one pole pitch, it is evident that the direction of both fluxes reverse; each flux has then gone through a half cycle and the resultant field around the shaft, whose intensity equals $X$, has therefore the same frequency as that of the machine;

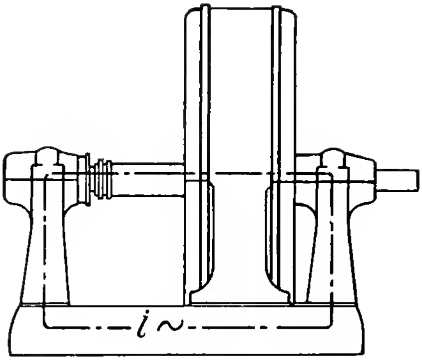

Fig. 1

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* Elektrotechnik und Maschinenbau, 1907.

† Elektrische Kraftbetriebe und Bahnen. 1909.

‡ Elektrotechnik und Maschinenbau, 1910.

such a condition will of course give rise to an electromotive force along the shaft.

In the case of a six-pole machine, as shown in Fig. 5, the flux $\phi_2$ cuts the joint on one side, while the flux $\phi_2$ cuts the joint diametrically opposite. If the reluctances of the two joints are equal, there will be no difference in the values of the fluxes and no electromotive force will be induced in the shaft.

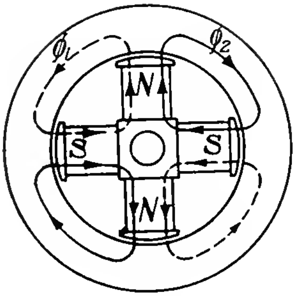

Fig. 2

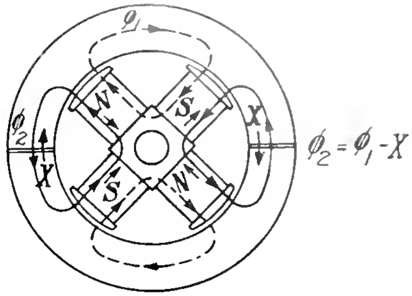

Fig. 3

Fig. 6 shows the case of an eight-pole machine with two joints; and here it is seen that the same condition exists as that indicated in Fig. 4.

An analysis of these conditions shows that:

(a) Where the number of poles is a multiple of twice the number of joints, an electromotive force may be expected to occur in the shaft.

(b) If the number of poles is not a multiple of twice the number of joints, the joints will be evenly distributed between the two flux circuits; therefore, there will be no variation in flux around the shaft and consequently no electromotive force induced in it.

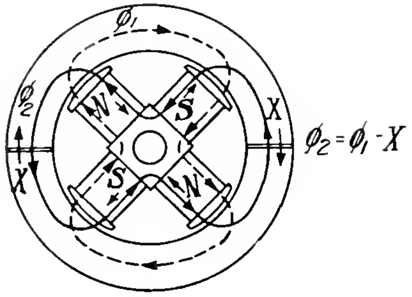

Fig. 4

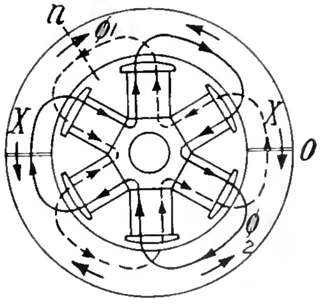

Fig. 5

The conclusions under (a) and (b) are based on a symmetrical distribution of the frame joints; mechanical considerations, however, sometimes require an unsymmetrical arrangement of the joints and this, under certain conditions, may be such as to reverse the rules just stated. Referring to Fig. 5, it will be seen that if the joints had been made at *n* and *o*, instead of diametrically opposite each other, the reluctances of the two circuits would have been different and the conditions therefore would have been such as to give rise to a shaft electromotive force.

This explanation covers the general cases where dissymmetry in the magnetic circuits originates from actual mechanical joints in the stator, which is the principal cause of induced voltage in the shaft; it is evident, however, that a more or less unsymmetrical condition may be produced in other ways; for instance, by a difference in the permeability of the magnetic material constituting the two flux paths, or by a difference in the effective lengths of these paths. The result is the same, however, regardless of what is the cause of the dissymmetry.

It is evident that, in the case of direct-current machines, the conditions are exactly analogous to those given above.

Figs. 7 and 8 show that where the magnetic fields are produced by *alternating currents*, the results are again the same as already described. As indicated in these figures, the arrangement of the stator coils in an asynchronous machine is such that, for each pair of coils, a circuit is formed similar to that of two consecutive poles of the synchronous machine.

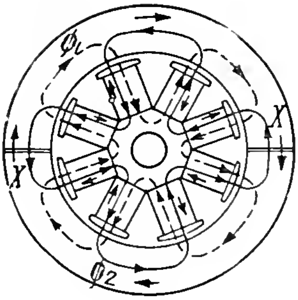

Fig. 6

If the stator shown in Fig. 7 is split at the heavy joint lines, as indicated, $\phi_1$ will be greater than $\phi_2$, which gives, as before, a resultant flux $X$, having the same frequency as that of the incoming line, and which therefore will produce an electromotive force in the shaft. Had the joints been made at the points marked $n$, there would have been no dissymmetry of the circuits and consequently no resulting electromotive force.

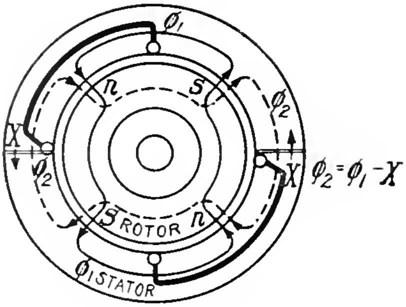

Fig. 7

In the three-phase machine shown in Fig. 8, it will be noticed that phase I is symmetrically placed with respect to the joints and that only phases II and III are effective in producing a shaft electromotive force.

In the case of a two-phase motor, the coils of one phase will be symmetrically placed with respect to the joints and the shaft electromotive force will be due to the other phase only.

As regards the generation of shaft currents, the only difference between machines in which the field is produced by direct current and those in which the field is produced by alternating current lies in the fact that in the former type a shaft electromotive force can be generated only when the machine is running, whereas in the latter type an electromotive force is present whether the machine is running or at rest, its magnitude depending on the relative values of the stator fluxes for the standing and running conditions. Due to the fact that the oil film between the shaft and bearing is maintained only when the machine is running, the standing current of a synchronous machine will be greater than the running current on account of the lower bearing resistance offered when the machine is at rest. Fig. 9 shows the variation of bearing current in a twelve-pole, 700 h.p., 450 r.p.m., 3000 volt induction motor at different voltages for both standing and running conditions.

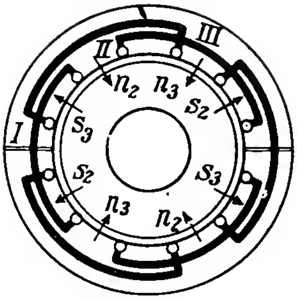

Fig. 8

If $R$ is the reluctance of one of the main flux paths and $r$ that of the joint, or any other cause producing dissymmetry, then

$$\phi_1=\frac{\frac{4}{10}\,\Sigma NI}{R}$$

and

$$\phi_1-\underline{X}=\frac{\frac{4}{10}\,\Sigma NI}{R+r}.$$

Therefore,

$$\underline{X}=\phi_1-\frac{\frac{4}{10}\,\Sigma NI}{R+r}.$$

which shows the importance of the ratio $\frac{r}{R}$ and permits of the following conclusions:

(1) As the diameter at the air gap or the number of poles increases, $R$ becomes greater and $\frac{r}{R}$ smaller and the unbalancing effect due to joints or other causes for dissymmetry therefore diminishes.

(2) The ratio $\frac{r}{R}$ decreases as the ratio of air-gap ampere-turns to total ampere-turns increases.

As the air gap of an induction motor is small in comparison with that usually found in a synchronous machine, it is evident from (2) that induction motors are especially susceptible to the effect of unsymmetrical conditions in their magnetic circuits.

Although, in general, it is possible to predetermine the cases in which shaft currents may be expected to occur, it is absolutely impossible to calculate the magnitude of these currents. This is due to the fact that the bases for calculating either the induced voltage in the shaft or the resistance of the circuit formed by the shaft, bearings, pedestals, base, etc., are indeterminate quantities.

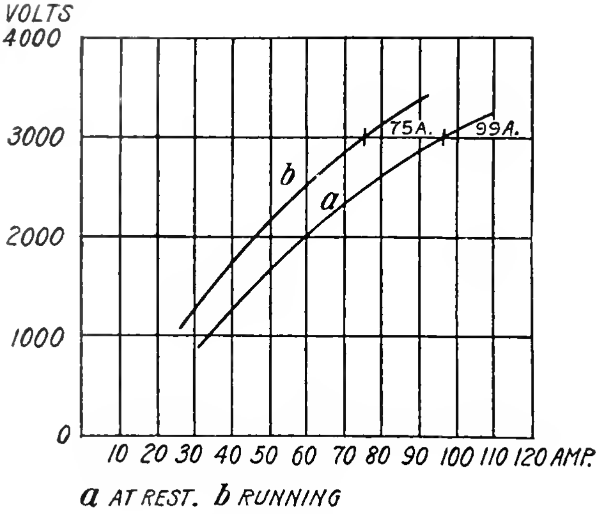

Fig. 9. Variation of bearing current in a 12 pole, 700 h.p. 450 r.p.m., 300 volt induction motor

The voltage factor is influenced by variations in the permeability of the metal comprising the flux paths, and especially by the great variation in the reluctance of the mechanical joints (resulting from imperfect machining or assembling). The predetermination of the value of the resistance is impossible, not only on account of the variations in the oil film between shaft and bearings but also because of the difficulty in determining the true effective lengths and cross-sections of the parts comprising the current path.

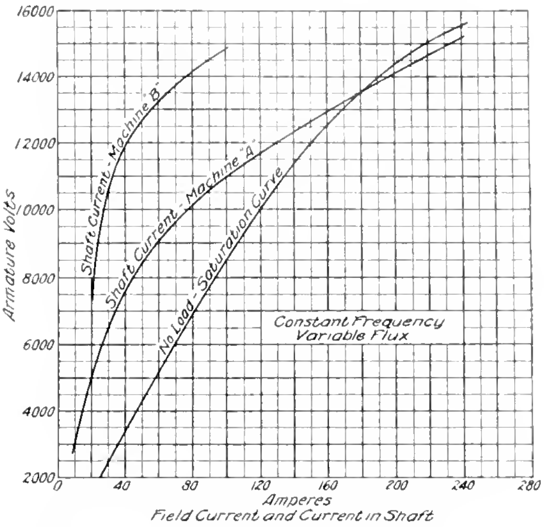

Fig. 10. No-load saturation and bearing curves of 62 pole, 4000 kv-a., 116 r.p.m., 13,200 three-phase alternator

As an illustration of the impossibility of predetermining these factors, the shaft current in an 860 kw. alternator cited by Adler was reduced from 200 amperes to 35 amperes simply by scraping the bearing lining so as to obtain a more perfect oil film over the entire surface of contact. The writer has also found variations of several hundred per cent in the value of these currents as measured on machines of exactly identical design, operating in parallel. This is shown by the curves of Fig. 10 which give the no-load characteristic of two 62-pole, 4000-kv-a., 116-r.p.m., 13,200-volt, 3-phase alternators and the shaft currents in the two machines at normal speed and variable voltage. At normal voltage the shaft currents of machines "A" and "B" are 170 amperes and 60 amperes respectively. Fig. 11 shows the variation of shaft current in machine "A" when running at constant excitation and, therefore, at practically constant flux but at different speeds. The actual observed values are shown by the full-line curve "X." It is interesting here to note again the effect of the oil film between shaft and bearing; the resistance of this film decreases with decreasing speed of the machine, which explains the higher proportionate values of current at low speeds. If this film resistance had remained constant, the shaft current would have decreased in direct proportion to the frequency and would have given a curve approximately as indicated by the dotted line "Y." These machines have an unsymmetrical division of the stator frames, corresponding to joints *n* and *o* of Fig. 5, and prove the exception to the general conclusion (b) regarding the relation of the number of poles to the number of joints.

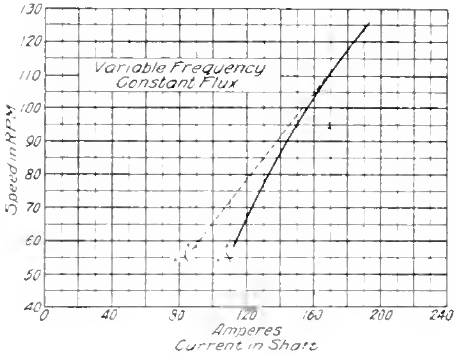

Fig. 11. Variation in shaft current of a 62 pole, 4000 kv-a., 116 r.p.m., 13,200 volt three-phase alternator at constant flux and variable frequency

Extended tests made by the Allgemeine Elecktrizitats Gesellschaft-Union Elecktrizitats Gesellschaft of Stadlau showed that, when the current density in the bearing exceeds about one ampere per square inch of contact, appreciable pitting of the journal takes place; for lower values of current density the pitting is limited to the bearing babbitt.

Of the means adopted by different manufacturers to protect shafts and bearings against the destructive effects of these currents, only two methods are of practical interest, viz.:

Method (A). Brushes are placed on both ends of the shaft and are either grounded on the bearing pedestals or connected together by a heavy copper conductor. The result in either case is to shunt more or less of the shaft current through this path and thus reduce the amount passing between the shaft and bearings. As the resistance of this latter path varies greatly, depending on whether the oil film is more or less perfect, and may be very low as compared with the contact resistance of the brushes, the amount of current shunted by the brushes is indeterminate and the protection afforded is therefore uncertain.

Method (B). In the case of horizontal machines, insulation is inserted between one or more of the bearing pedestals and the machine base, as shown in Fig. 12, the number of points at which the circuit is to be broken depending on the number of bearings and the number and type of machines mounted on the same shaft. This method, applied to vertical machines, necessitates the placing of insulation between the upper bearing bracket

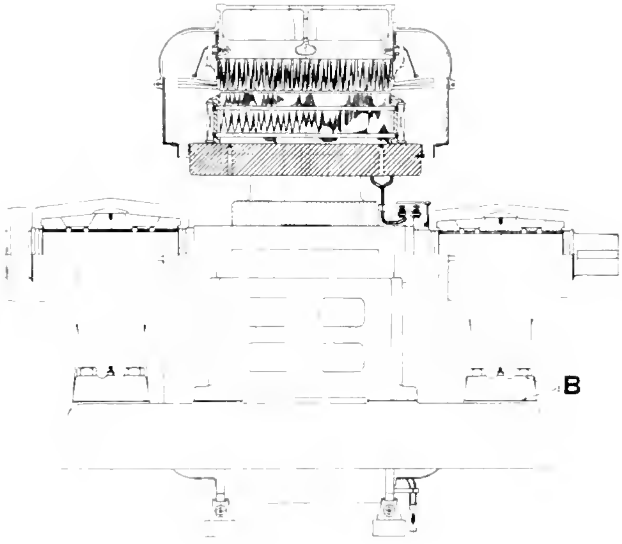

Fig. 12

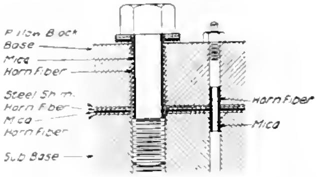

Fig. 12-A. Detail of insulation between pedestal and base shown at B in Fig. 12

and the armature spider and the insulating of holding-down bolts, as shown in Fig. 13. In addition it is of course necessary to insulate all piping, stairs, handrails, etc., which would otherwise complete the electrical circuit. Details of the construction at the points indicated by the arrows in Figs. 12 and 13 are given in Figs. 14 and 15 respectively.

Method (B) does not of course reduce the induced voltage in the shaft, but as this varies from a fraction of a volt to a maximum of possibly ten volts, it is of no consequence, providing the insulation described above remains intact. This method, if properly applied, therefore provides an absolute protection to journals and bearings against the destructive effects of the induced currents which have been discussed.

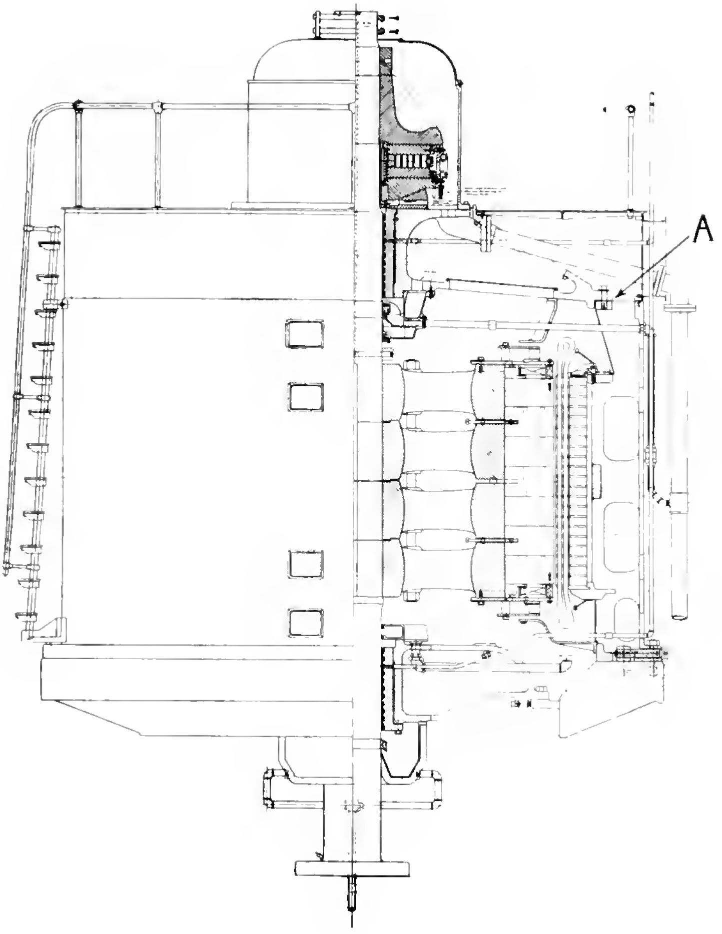

Fig. 13

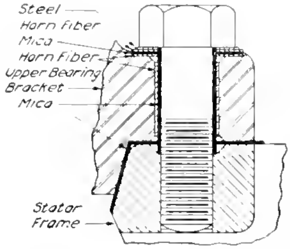

Fig. 13-A. Detail of insulation between bearing bracket and stator frame shown at A in Fig. 13

# SELECTING RAILWAY MOTOR EQUIPMENTS

By J. F. Layng

Railway and Traction Engineering Department, General Electric Company

The following article furnishes outlines of several calculations which have been selected for the purpose of emphasizing the importance of a complete appreciation of all the governing factors (especially the so-called minor ones) which must be considered when figuring on a railway motor equipment that is to fulfill given conditions. Each new railway problem entails the satisfying of a great number of complex factors and if it does not receive the most minute attention, the best results are not likely to be attained. The author of this article, therefore, points out briefly the effects of local conditions and the characteristics of apparatus which must not be overlooked in calculations.—Editor.

When selecting railway motor equipments it is necessary to have a definite picture of the service or of the work to be performed in order to choose a motor of the proper size and correct gearing, for successful performance. Sometimes the failure to appreciate what schedule speeds, maximum free running speeds, stops per mile and car weights mean, causes electrical equipments to be purchased which are either too large or too small. Consequently in some cases an equipment that is more expensive either in first cost or in maintenance than is required is purchased.

To make any schedule speed with a certain number of stops per mile, there is one definite free running speed that will perform the service most economically, not only in regard to power consumption, but also with reference to the size of equipment selected. The variations in the amount of power required for a car operating on free running speed can be illustrated by taking a 40-ton car as an example: When running at constant speed on level tangent track at twenty miles an hour, this car will require 23.1 kw. input. Providing this speed is increased to thirty miles an hour under the same conditions, this car will take 44.1 kw., and at forty miles an hour 76.2 kw., at fifty miles an hour 124 kw., and at sixty miles an hour 188 kw.

It can readily be seen from these figures that an increase in free running speed, which will bear a certain relation to an increase in schedule speeds, shows a very rapid increase in power consumption, and consequently a much larger equipment is required as the faster speeds are approached. Of course the longer the time that can be allowed to perform a certain schedule the smaller will be the equipment, and the cheaper will be the operation.

It is frequently found when investigating service conditions that the stops per mile made by any equipment vary widely from estimates based on superficial observation. The answers that will be given by different train crews as to the number of stops which they make on a particular trip will be surprising, unless they are especially requested to keep an actual record. Frequently answers to this question vary by more than 100 per cent for the same run. The number of stops per mile in interurban work is a much more deciding factor than in city work. In city service, where eight to nine stops per mile are made, variation in the number does not so seriously affect the size of the equipment. The reason for this is obvious from the following: Suppose a car is operating on an eight mile per hour schedule, with ten stops per mile, within an hour it would make a total of eighty stops. With stops of 10 seconds this would mean that the car was standing still for 13.35 minutes, or 22.2 per cent of the total time. Providing the same car is making nine miles per hour, and six stops per mile, the car would be standing still 9 minutes of the time, or 15 per cent. Strange as it may seem, if the stops per mile were sufficiently great, and the schedule speed were reduced, the size of the motor could be greatly decreased.

The information which it is necessary to have in selecting a car equipment is as follows:

1st, Car weight without live load, but including all equipment accessories, except the electrical equipment, which can be added by the engineer.

2nd, Seating capacity.

3rd, Schedule speed.

4th, Stops per mile.

5th, Length of stops.

6th, Grades.

7th, Voltage.

8th, Diameter of wheel.

9th, Layovers either ends of line, or at any point during the run.

Providing cars are to operate in a mixed city, suburban and interurban service, the data insofar as actual running time, number of stops, and length of stops are concerned should be divided into zones. Securing the information in this way makes it possible to have the proper calculations made for the equipment to be selected. The choosing of a proper motor equipment must be based on experience, and is not simply a mathematical calculation which can be determined by a fixed formula. To make a proper selection one must appreciate the large number of operating conditions that exist, and should also investigate the natural growth of the district as well as the future service that the equipment will have to perform. After securing the information to which we have referred, it is customary for the engineer to look over the data he has on equipments of similar size which is doing approximately the same work. Previous experience would also largely guide the engineer in the selection of the gearing, and thus enable him to make a trial calculation to determine whether the equipment he has selected will fulfill the requirements of the service.

Frequently a motor will be selected that can be geared to give the schedule requirements, but the heating may be excessive, or vice versa, the motor being too large for the service, and it will be found that a smaller and consequently lower cost equipment could be chosen for the service.

Manufacturing companies in every case make careful calculations to determine positively that, insofar as the data as presented are concerned, the correct equipment is furnished. Assume that we are to select a motor for city service, on which the general data are as follows:

| | |
|---|---|
| Car weight complete with all equipment | 42,000 lb. |
| Live load | 6000 lb. |
| Schedule speed | 10 m.p.hr. |
| Stops per mile | 7 |
| Length of stop | 10 sec. |
| Average voltage | 500 |
| Diameter of wheels | 33 in. |

By taking the total weight of the car, including the live load, it will be found we have 24 tons. Provided the grades are more than 5 per cent, ordinarily a four-motor equipment would be selected. If this is the case we should have a weight of 6 tons per motor.

In starting an equipment there is a retardation due to the rotary elements, which is commonly figured at 7 per cent additional to the car weight. In this particular case this addition would make a total of 6.42 tons per motor. Previous experience shows that this weight of car in the schedules specified, could be successfully handled by 40 h.p. 600 volt motors having a gearing of 67 to 14.

As a rule city cars accelerate at 1½ miles per hour per second. For the purpose of the trial calculation we will assume that accelerating 1½ miles per hour per second will give the desired schedule speed. In order to accelerate one ton at one mile per hour per second, 91.1 lb. per ton tractive effort are required. It can therefore be seen that if we desire to accelerate at 1½ miles per hour per second 137 pounds tractive effort will be required.

If we refer to the characteristic curve of this motor it will be seen that this will require, for the car weight which we have selected, 1026 lb. tractive effort, or 61 amperes input. This ampere input is approximately the hourly rating of the motor, and should, of course produce satisfactory commutation. Generally speaking it is not good practice, insofar as calculations of schedules are concerned, to have a motor accelerate much in excess of its hourly rating, unless the motor has been specially designed to have a sufficient margin in commutation. With the tractive effort definitely determined from the characteristic curve, it is a simple calculation to find what will be the maximum speed attained with this particular input and the time required to attain this speed. From the average speed and time the distance is readily figured.

After the car has reached the speed corresponding to this first calculation the current gradually decreases, and the increments of speed, time and distance are simply a matter of continued calculation to a point where it is deemed best to throw off power, and coast or brake. The usual rate of braking for a city service is 1½ miles per hour per second. The first figures may show that the calculations with power on have been carried either too far or too short to give the required distance and schedule speed. Usually it is necessary to make several calculations in order to get the values for time and distance, to make the schedule desired. Curves and grades greatly influence the calculations, but to explain the different allowances to be made for them would complicate the discussion, and therefore the explanation has not been included.

Providing the information which we have previously mentioned is given correctly, and the service is actually performed as outlined, it is possible to calculate the actual temperature rise of the different parts of the motor within 2 or 3 degrees. This fact has frequently been proven by actual test in service.

From the figures which have been made to find the speed from the characteristic curve all the different losses in a motor can be definitely determined. These consist of copper losses, iron losses and friction. The sum of these three losses determines the heating for any particular motor.

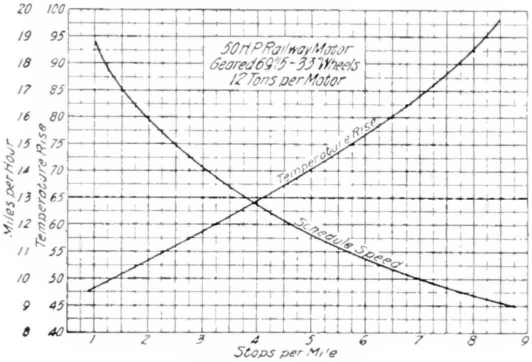

**Fig. 1.** Effect of Stops per mile on schedule speed and temperature for 50 h.p. motor

With closed motors, in making calculations for temperatures, allowance should be made for differences in schedule. A motor when tested on a test stand at the factory will radiate a certain amount of heat. When operating on a car with a schedule speed of 10 m.p.hr. this same motor will run approximately 10 per cent cooler. If the schedule speed is increased to twenty m.p.hr. it will run approximately 18 per cent cooler than if it were tested upon the stand. With ventilated motors the temperature is directly affected by the armature speed, and much greater cooling is obtained. This greater cooling is not only realized in interurban service, but also in slow speed city service. Improvements in methods of ventilation will greatly increase this difference.

Fig. 1 shows the effect of stops per mile on schedule speed and of temperature in the case of a 50 h.p. motor. This particular curve is based on a car weighing 12 tons per motor, 550 volts (average), 33 in. wheels, 69/15 gearing and no coasting. With cotton insulation it is not advisable, as a rule, to run motors much in excess of 65 degrees C. rise. By making slightly more than 4 stops per mile with a 12.6 m.p.hr. schedule it can be seen that the particular motor in question will have a temperature rise of 65 degrees. Providing the stops per mile are increased to 8, the schedule speed will necessarily fall to 9.4 m.p.hr. and the temperature rise will increase to 92½ deg. C. This excess in temperature rise indicates the necessity for correctly stating the service conditions. Providing the car weight had been reduced to a reasonable limit, the equipment would not only be capable of making faster schedule speeds, but would also have a reasonable temperature rise.

Fig. 2 shows the accelerating horse-power in different services for a car having a total weight of 10 tons, and illustrates the effect that stops per mile on this car will have on a required input. With 12 m.p.hr. schedule and 3 stops per mile, 36½ h.p. is required to accelerate this weight at approximately 1½ miles per hour per second. Providing the same schedule speed is maintained and the car makes 5½ stops per mile, 72½ h.p. will be required. With a 9 m.p.hr. schedule and 5 stops per mile, 28 h.p. will be required. If the stops are increased to 8 per mile with the same schedule, 46½ h.p. will be required. With an 8 m.p.hr. schedule and 7 stops per mile, 27½ h.p. will be required. If the stops are increased to 10 per mile, 43 h.p. will be required.

The second curve illustrates the effect of schedule stops per mile on a certain weight of car. The variation of the service requirements shown on this curve illustrates the variation in horsepower required to accelerate cars having a weight of 10 tons per motor, and shows how careful we should be in getting together the facts for the purchase of equipments.

The facts as brought out in this article are intended to illustrate the real necessity for securing accurate service data and the realization that the points which are necessarily covered, while apparently very simple and unimportant, are really the deciding factors in determining the most economical equipment that will give satisfaction in the work it is intended to do.

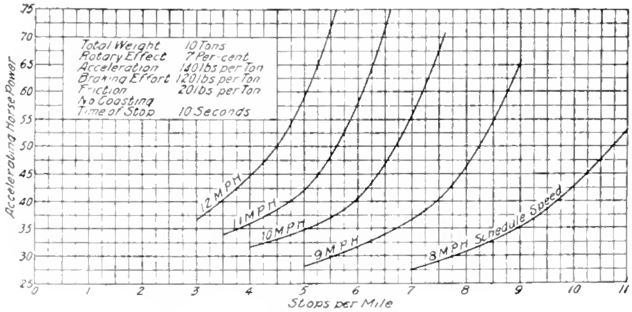

**Fig. 2.** Accelerating Horse power for 10-ton car

# THE KILOWATT RATING OF MOTORS

By H. M. Hobart

Consulting Engineer, General Electric Company

During the past two decades the number of electrical machines placed in use has reached an enormous figure, and, as a consequence, the use of electrical terms and units has become as common as that of mechanical ones—perhaps more so. The *horse power* rating of electrical motors has never been satisfactory and therefore many of the electrical societies of the world, after thorough deliberation, have agreed to specify that all electric motors should be rated in kilowatts. The reasons for making the change and the advantages gained thereby form the text of this article.—**Editor.**

The 1914 Standardization Rules of the American Institute of Electrical Engineers require (see paragraph 139) that motors shall be rated in kilowatts. On account, however, of the hitherto prevailing practice of expressing mechanical output in horse power, the rules recommend that the rating of motors shall, for the present, be expressed both in kilowatts and in horse power until such time as the industry shall become sufficiently accustomed to the new rating. As a convenient and closely correct equivalent, it is useful to remember that the horse power rating of a motor may, for practical purposes, be taken as 4/3 of the kilowatt rating. In order to lay stress upon the preferred future basis, it is considered in the rules that it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the rating in horse power.

In taking this step the American Institute of Electrical Engineers is simply falling in line with authoritative precedents. The subject was taken up by the International Electrotechnical Commission (I. E. C.), at the meeting held in Turin in September, 1911. In the fourth edition (Published in 1914 by Julius Springer, Berlin) of Dettmar's little handbook dealing with the interpretation of the rules of the Society of German Electrical Engineers (Verband Deutscher Elektrotechniker) the latest (1913) standardization rules of that society are considered. The subject of the kilowatt rating of motors is there discussed at some little length.

The following is a translation of that part:

> "The horse power, the old unit for the output of motors, was replaced by the kW in the new edition of the standardization rules adopted at the 1913 annual meeting of the V.D.E. In taking this step, the Commission has accepted the following conclusion of the Sub-Committee on Units and Formulae:
>
> "'The technical unit of output is the kilowatt. It is practically equal to 102 kilogrammeters per second and corresponds to $10^{10}$ ergs per second. The abbreviation is kW.'
>
> "Furthermore the Commission is in agreement with the resolution adopted by the I. E. C. in 1911. This resolution reads:
>
> "'1. The output of electric generators is defined as the electrical power available at the terminals.
>
> "'2. The output of electric motors is defined as the mechanical power available at the shaft.
>
> "'3. Both electrical and mechanical powers shall be expressed in International watts.'
>
> "The introduction of the kW rating of motors will undoubtedly be attended with great difficulties. Indeed, it has taken 20 years to reach the decision to replace the horse power by the kW. Already in 1891 W. Kohlrausch made the proposal at the International Electro-Technical Congress at Frankfort.
>
> "During the transition stage until the kW has become established as the unit of mechanical output, difficulties and misunderstandings with the purchasers can easily occur. A good many motor manufacturers have always considered that these difficulties could be best overcome in giving a horse power designation to the motors in addition to the kW designation of their output. The Commission has given this view careful consideration and has concluded that such a plan is not to be recommended, since it would only result in materially lengthening the transition period. As long as the horse power still appears on the rating plate, the purchaser will not accustom himself to the kW. In order to abbreviate the transition period as much as possible, it is therefore advisable to exclusively employ the kW. Consequently the Commission unanimously passed a resolution that the kW rating shall be exclusively employed upon the rating plate.
>
> "The members of the V.D.E. were made acquainted with this resolution in the columns of the E.T.Z. A desirable means of simplifying the calculation of the equivalent rating on the part of the purchaser during the transition stage consists in arranging that for several years a card shall be attached to each machine on which the following conversion figures are given:
>
> "1 kW = 1.36 hp
> "1 hp = 0.735 kW
>
> "For the sake of completeness the equivalents in kilogrammeters per second should be included. The corresponding conversion factors are as follows:
>
> "1 kW = 1.36 hp = 102 kgm per second
> "1 hp = 0.735 kW = 75 kgm per second
> "1 kgm per sec. = 0.0098 kW = 0.0133 hp."

It will be noted that the above conversion factors relate to the *continental* horse power. While the continental horse power is equal to only 735 watts, the horse power employed in America and Great Britain is equal to 746 watts. This difference and the confusion thereby involved constitute an additional reason for preferring the kw. rating of motors. For America and Great Britain the conversion factors become as follows:

1 kw. = 1.34 h.p. = 102 kg-m. per second
1 h.p. = 0.746 kw. = 76.0 kg-m. per second
1 kg-m. per sec. = 0.0098 kw. = 0.0131 h.p.

In a paper entitled "Method of Rating Electrical Apparatus" by Merrill, Powell and Robbins, published at p. 127 of the February, 1913, issue of the Proceedings of the A. I. E. E., the authors, (who constituted the sub-committee appointed by the Standards Committee of the A. I. E. E. to report on the subject of "Rating Electrical Machinery"), put the case as follows:

> "From the pure science standpoint, the kilowatt is a better unit of power than the horse power since it is based directly upon the absolute c.g.s. system, the watt being equal to $10^7$ dyne-centimeters per sec., while if we accept the definition of the horse power as being 550 ft-lb. per sec., it is a gravitational unit and so is not strictly constant, but varies slightly with the latitude.
>
> "Also the kilowatt is the practically universal unit for the measurement of electrical power throughout the civilized world, while the "horse power" besides varying on account of its being a gravitational unit is defined differently in different countries. In several European countries it is defined as 75 kg-m. per sec., while here it is 550 ft-lb. per sec. The difference is about 1½ per cent.
>
> "Then too there seems to be no real reason why both electrical and mechanical power should not be expressed in the same units, and since the kilowatt is much more desirable as a universal unit than the horse power for the reasons enumerated, it is recommended that the output of motors be expressed in kilowatts instead of in horse power."

To assist in facilitating the use of the kilowatt and the watt as universal units of power as well for the physicist as for the engineer and the layman, the following more extended table of equivalents has been prepared:

It is unfortunate that there should be so many alternative units of power in use. To fix ideas as to their relative magnitude they are arranged in the following table with the smallest unit of power at the head of the table and the largest unit of power at the foot of the table. In the second and third columns are given their equivalents in watts and kilowatts.*

1 watt = 1.000 watts = 0.001000 kw.
1 ft-lb. per sec. = 1.36 watts = 0.00136 kw.
1 kg-m. per sec. = 9.81 watts = 0.00981 kw.
1 Continental h.p. = 735. watts = 0.735 kw.
1 English (and American) h.p. = 746. watts = 0.746 kw.
1 kw. = 1000. watts = 1.000 kw.
1 B.t.u. per sec. = 1055. watts = 1.055 kw.
1 kg-cal. per sec. = 4200. watts = 4.20 kw.

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* Incidentally it should be mentioned that the watt is equal to 1 joule per second and that the joule is equal to $10^7$ ergs, the joule and the erg being units of energy. The erg is the energy expended when a force of one dyne is overcome through a distance of one cm.

## TABLE OF EQUIVALENT VALUES FOR POWER EXPRESSED IN VARIOUS ENGLISH AND METRIC UNITS

| | Watt | Kw. | English H.P. | Continental H.P. | Kg-M. per Sec. | Ft-Lb. per Sec. | Kg-Cal. per Sec. | B.t.u. per Sec. |
|---|---|---|---|---|---|---|---|---|
| 1 watt is equal to | 1.000 | 0.001000 | 0.00134 | 0.00136 | 0.102 | 0.737 | 0.000238 | 0.000947 |
| 1 kw. is equal to | 1000. | 1.000 | 1.34 | 1.36 | 102.0 | 737. | 0.238 | 0.947 |
| 1 English (and American) h.p. | 746. | 0.746 | 1.000 | 1.015 | 76.0 | 550. | 0.178 | 0.707 |
| 1 Continental h.p. | 735. | 0.735 | 0.985 | 1.000 | 75.0 | 541. | 0.175 | 0.696 |
| 1 kg-m. per sec. | 9.81 | 0.00981 | 0.0131 | 0.0133 | 1.000 | 7.23 | 0.00234 | 0.00930 |
| 1 ft-lb. per sec. | 1.36 | 0.00136 | 0.00182 | 0.00185 | 0.138 | 1.000 | 0.000324 | 0.00129 |
| 1 kg-cal. per sec. | 4200. | 4.20 | 5.61 | 5.70 | 427. | 3090. | 1.000 | 3.97 |
| 1 B.t.u. per sec. | 1055. | 1.055 | 0.415 | 0.422 | 107.6 | 778. | 0.252 | 1.000 |

# CALORIZING: A PROTECTIVE TREATMENT FOR METAL

By H. B. C. Allison and L. A. Hawkins

Research Laboratory, General Electric Company

Calorizing will undoubtedly find a wide and varied use in many industries and is a development which will lead to economies in numerous processes of manufacture. Briefly stated, it will prevent metals, especially iron, from burning when subjected to high temperatures for either long or short periods of time, and for one or many heats. The authors give data and illustrations which will interest a large section of the engineering and manufacturing fraternity.—Editor.

Since the close of the bronze age iron has been used for ovens, utensils and tools of every kind for all temperatures up to dull red; but for higher temperatures there has been, even up to the present day, no cheap metal available. Platinum, because of its cost, has been quite limited in application, and the cheaper metals, such as copper, and most of the alloys, such as brasses and bronzes, will not withstand heating in the air to red heat. Nickel and cobalt are the most stable of those metals which may be worked or cast and are fairly cheap and will withstand moderately high temperatures. Some of the alloys containing nickel are also quite permanent in the air at red heat.

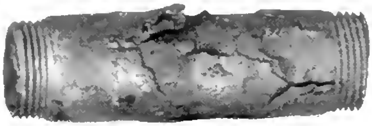
Mr. T. Van Aller has discovered a process of heating metals in revolving drums with mixtures containing, among other things, finely divided aluminum, by which a surface alloy containing aluminum is produced. In the case of copper, this alloy is of the nature of an aluminum bronze, but richer in aluminum than the ordinary alloy of that name and more resistant to heat, so that copper thus treated is protected up to the melting period of the alloy from the scaling which occurs when untreated copper is heated above 300 deg. C. The same general result was obtained in the case of iron and steel. Some use was made of this process, which has been called "calorizing," for treating copper soldering irons and iron resistance wires for heating devices.

Modifications of the process, extending it to further applications, were made by Mr. E. G. Gilson of the Schenectady Research Laboratory. Pieces which, because of their shape or size, are not adapted for tumbling, may be calorized by packing them in, or painting them with, a suitable mixture, and heating them. Thus, the size of the heater is the only limitation on the size of the piece that may be calorized. Wire or ribbon may be treated by a continuous process, by passing it through a heated pipe containing the proper calorizing mixture. There appear to be many places where it is desirable to use iron vessels or apparatus at temperatures above red heat, and at such temperatures, ordinary iron rapidly oxidizes and scales away. After iron is calorized the effect of heating is slight. Instead of burning and the scale falling off, as in the case of untreated iron, practically no effect can be detected after a considerable time—certainly none which injures the surface. This is well illustrated by the two pieces of iron pipe shown in Fig. 1, both from the same kind of pipe, but one of which (B) was calorized. The two were heated side by side, with an ordinary laboratory blast lamp to a temperature of about 900 deg. C. for a period of four hours, then cooled and the heat once more applied for another period of four hours. At the end of that time the untreated pipe (a) was badly burned, the point where the flame was directly applied having been reduced to one-half the original thickness, while the whole surface was blistered. The contrast between this piece and that which was calorized (b) is very marked, for even upon close examination the calorized pipe appears to be unchanged.

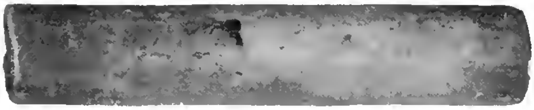
In connection with the piece of calorized pipe used in this experiment, it should be stated that it had previously been used in other work, where it had been alternately heated to 1000 deg. C. and cooled, in an electric resistance furnace open to the air. The total time during which the maximum temperature was maintained was about 50 hours. A rather extreme test has been applied to this same piece lately, by heating it to about 900 deg. C. and plunging it into cold water, after it had cooled to a dull red. This has been repeated three times and the surface shows no signs of cracks or any tendency to scale.

Fig. 2 shows a similar comparison between two pieces of sheet iron tube, one calorized and the other not, which were both subjected to a temperature of 800 deg. C. in a gas furnace for 100 hours. The uncalorized piece is practically destroyed, while the calorized piece is unharmed.

As evidence of the performance of calorized iron under actual working conditions, the tubes shown in Fig. 3 were photographed. These tubes are part of a small nitrogen purification plant which is in use during each working day. They are both heated by gas in a brick furnace, the larger tube to a temperature of about 800 deg. C. and the smaller to about 650 deg. C. The larger tube was calorized and has been in use over 400 hours with no observable deterioration, while the smaller tube, which was not calorized and which has also run 400 hours, is badly burned. The spots on the calorized tube are carbon deposits due to poor combustion in the burners. In Fig. 4 are shown these same tubes after they have run over 650 hours. The calorized tube still shows no evidence of scale while the other tube is almost burned through.



(*a*) Uncalorized Iron Pipe



(*b*) Calorized Iron Pipe

Fig. 1. A Piece of Plain Iron Pipe and a piece cut from the same Tube, but calorized, after being subjected to the same degree of temperature for the same length of time

Another application of this process is to iron wire or ribbon such as is used in electrical heating units. An untreated piece of this ribbon will burn out in four or five hours at the most, whereas tests upon calorized pieces have shown that the life is increased at least fifty fold, and in the best instances over one hundred fold. The results of tests made at Pittsfield indicate that a life of over 500 hours may be expected from calorized heating units run at a temperature of 800 deg. C.

Calorized seamless iron tubing is being used for combustion tubes in the research analytical laboratory where pure oxygen is brought in contact with the metal at temperatures from 900 to 1000 deg. C. These have thus far operated all right and still appear unaltered after nearly 100 hours' use.

The above facts seem to indicate that this is a simple method for extending the use of iron under oxidizing conditions at high temperatures, and for greatly prolonging the life in those instances where it is now used, but must be renewed at frequent intervals. In the case of small muffles on crucibles, where temperatures are below 1000 deg. C., this treatment of cheap cast or wrought iron shapes seems very promising. While the life of the coating depends on the temperature at which it is used, as well as on the duration of time taken in its preparation, i.e., the quantity of aluminum which alloys with the surface of the iron, it does not permit of long use at temperatures much in excess of 1100 deg. C.

Copper parts also, which are exposed to high temperatures, can have their life increased by calorizing. In some cases calorized copper may be used advantageously in place of aluminum bronze. For instance, a large power station had trouble from early corrosion of its condenser tubes. These tubes were aluminum bronze and were supposed to last at least a year. As a matter of fact while occasionally tubes would last as long as six years, other tubes would fail in four to six weeks after they were installed. About two and a half years ago a set of calorized copper tubes was installed and so far not a tube has failed.

Fig. 2. Effect of 800° C. in a Gas Furnace for 100 Hours on a Section of Calorized and of Uncalorized Sheet Iron Tubes

In some cases the life of copper contacts can be increased by calorizing. For instance a set of railway controller contacts which were calorized showed double the life of the ordinary untreated contacts.

As has been said, the effect of calorizing is to produce a surface alloy containing aluminum. The thickness of this alloy varies with the length of time to which the piece is subjected to the calorizing process, and the percentage of aluminum varies through the coating being greatest at the surface. This is shown clearly by a cross-section of a calorized copper rod. The line between the alloy and the unchanged copper is sharp, but the color of the alloy varies from a rich golden-yellow next to the copper to a silvery-white at the surface.

Fig. 5 shows cross-section views of a number of copper rods 1¼ in. in diameter, which were calorized for about two hours. The depth of the alloy is sharply defined.

Fig. 6 shows two cross-sectional photo-micrographs of a calorized copper bar. These photographs are magnified fifty-five diameters. One of them shows the large crystals of the calorized surface, and the other shows the unaltered crystalline structure of the copper a short distance below the surface. In the first of these photographs the blistering of the copper immediately below the calorized surface is shown by the spaces between the crystals of copper. This effect is characteristic of calorizing.

Fig. 7 shows cross-sectional photo-micrographs magnified forty diameters of an iron pipe which was used for some time as a heater for calorizing wire by the continuous process above mentioned. This pipe was packed with calorizing mixture, and its inner surface was therefore subjected to long calorizing treatment. The growth of the long crystals of the aluminum alloy is clearly shown.

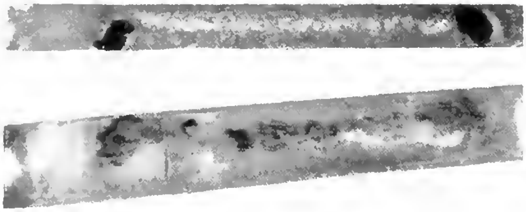


Fig. 3. A Section of calorized Iron Pipe (lower) and a Section of Uncalorized Iron Pipe (upper) after being treated to operating temperature for 400 hours

If the calorizing process is conducted at a high temperature in a mixture rich in aluminum, two layers of different alloys may result. Fig. 8 shows photo-micrographs, enlarged twenty diameters, of a cross-section of an iron combustion tube thus calorized. The first figure shows three layers, or rather five. The outer layers are probably mostly aluminum with a little iron, the next aluminum and iron with the iron predominating, and the middle layer the unchanged iron. The lines bounding the middle layer are especially sharply defined. The second figure shows the same tube after heating in the air at 1100 deg. for 50 hours. The sharp lines bounding the middle layer have disappeared and the crystals now have a radial structure. This is characteristic of all samples fired at this

Fig. 4. Photograph of the same Tubes as shown in Fig. 3 (upper uncalorized), but after 650 hours at operating temperature

Fig 5 Cross-sectional view of several 1¼ inch diameter copper rods after being calorized for two hours

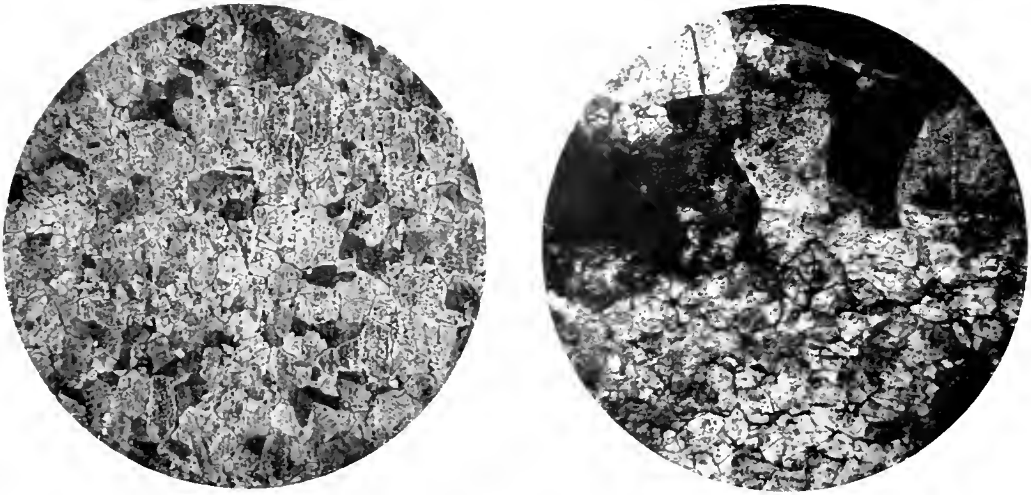


Fig. 6. Photo-micrographs (55 dia. magnification) of sections of a calorized copper bar

high temperature, and is due to a diffusion of the aluminum into the iron, making a more homogeneous structure. The outside layer is still distinct, however, and this is probably due to the oxidation of the aluminum.

When an iron pipe or ribbon is calorized for a heating unit, a portion of the iron becomes alloyed with the aluminum. Naturally this results in changing both the resistance and the temperature co-efficient. The thicker the calorizing coat the greater is the change. This is shown by the following table, in which No. 1 was given a lighter coat than No. 2.

| Sample | Ohms per M (19°) | Temp. Co-ef. Elec. Resis. (0–150°) $+10^{-3}$ |
|---|---|---|
| Iron ribbon | 0.905 | 5.61 |
| Same calorized No. 1 | 2.45 | 1.72 |
| Same calorized No. 2 | 7.6 | 0.151 |

A thin ribbon may easily be calorized all the way through, and then becomes quite brittle.

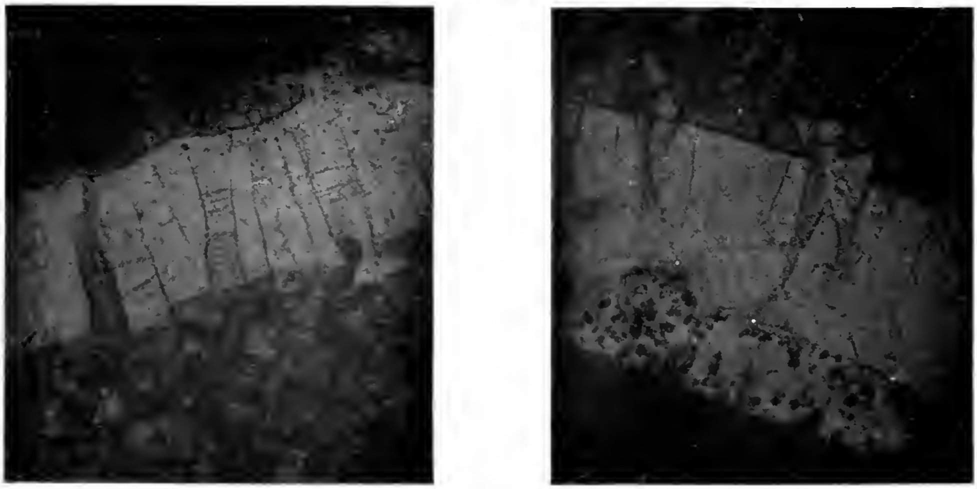


Fig 7. Photo-micrographs (40 dia. magnification) of sections of an iron pipe which has been subjcted to calorizing action for a long period

The dimensions and weight of either a copper or iron piece are slightly increased by calorizing. The increase of dimension is much less than the thickness of the alloy coat, the greater part of which simply takes the place of the original metal. The dimensions may, however, increase several mils and there is a tendency to a greater increase at the edges than on flat surfaces.

For iron, calorizing is intended only for protection at high temperatures. It does not compete with galvanizing, sherardizing, and other similar processes for protection against oxidation or corrosion at low temperatures. Its usefulness lies within a range of temperature much higher than a galvanized or sherardized coat could stand. For copper, calorizing is effective against corrosion at low temperature as well as against oxidation at high temperature. The upper limit is determined by the melting point of the alloy, which is somewhat lower the heavier the calorizing treatment, since that means an alloy with a higher aluminum content.

The probable explanation of the effect of the aluminum in the surface alloy is that a thin coat of alumina forms which prevents further burning of the metal beneath. It is well known that a pure aluminum wire may be heated in the air to a temperature several hundred degrees above its melting-point, without flowing, when the thin alumina shell which surrounds and supports the molten metal is easily seen.

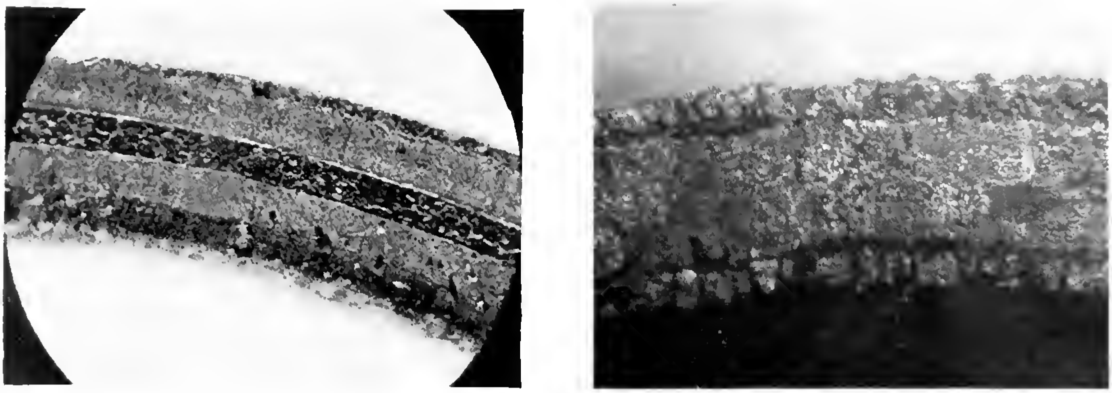


Fig. 8. Photo-micrograph (20 dia. magnification) of cross-sections of an iron tube calorized at high temperature with a mixture rich in aluminum. Left-hand view, before heating; right-hand view, after heating at 1100 deg. for 50 hours

# RECENT VIEWS ON MATTER AND ENERGY

## PART III

By Dr. Saul Dushman

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In the previous issue the author discussed the experimental evidence which has led to an atomistic theory of energy, and in the following paragraphs deals with a number of applications of the theory. A glance at the headings of the different sections is sufficient to indicate what an important place has been attained by the new theory in the consideration of physical and chemical phenomena.—EDITOR.

## APPLICATIONS OF THE QUANTUM THEORY

### A Calculation of Specific Heats at Low Temperatures

It has already been mentioned that according to Boltzmann's principle of equipartition, the average energy per molecule or atom of any substance ought to be $\frac{1}{2}\, kT$ for each degree of movability or freedom. Denoting the number of molecules per gram-molecular weight (mol) by $N$, it follows that the total energy per mol ought to be $\frac{1}{2}\, NkT = \frac{1}{2}\, RT$ for each degree of freedom.

Now, the specific heat of a substance is defined as the rate of increase in energy with increase in temperature. It therefore follows that the specific heat at constant volume per mol of any substance ought to be $\frac{1}{2}\, R$ for each degree of freedom.

On this basis, as shown in Part II, Boltzmann was able to deduce values for the specific heats of monatomic and diatomic gases in substantial agreement with those observed, and he was also able to account for the Dulong and Petit law for the specific heats of solids.[1]

### Specific Heats at Low Temperatures

But the gradual accumulation of the results of more accurate investigations showed that not only are there numerous exceptions to the Dulong and Petit law even at ordinary temperatures, but in the case of some diatomic gases the observed molecular heats are much higher than those deduced by Boltzmann. It was known for a long time that the atomic heats (atomic weight × specific heat) of carbon boron and silicon are much lower than the value 5.96 ($=3R$) which they ought to have in accordance with the Dulong and Petit law. But is was observed that the atomic heats of these elements increased with temperature, and at high enough temperatures they behave "normally." More recent investigations by Nernst and his students showed, moreover that at sufficiently low temperatures all the elements begin to exhibit atomic heats lower than 5.96, and that as the temperature decreases the atmoic heats decrease and tend to become equal to zero. Furthermore, the lower the atomic weight, the higher the temperature at which this low atomic heat begins to appear.

As typical of the results actually obtained in these investigations, the atomic heats at constant volume (denoted by $C_V$) of diamond, aluminum and lead are shown in Fig. 1.

It will be observed that while the atomic heat of lead rises very rapidly towards the limiting value as demanded by the Dulong and Petit law, the atomic heat of diamond is 0.00 up to 40 deg. abs., and then rises so gradually that even at 413 deg. abs. it is only 2.53, while it reaches a value of 5.19 at 1169 deg. abs.

### Einstein's Formula for the Atomic Heat of a Solid

According to Einstein these observations are quite in accordance with what one would expect if the atoms of these solids are capable of absorbing or emitting energy only in multiples of a unit quantum, $h\nu$. Now there are good reasons for believing that the longer heat waves emitted by solids are due to vibrations of the atoms themselves. Moreover, consideration of the elastic properties of solids leads also to the conclusion that the atoms in these cases are held together by quasi-elastic forces so that they vibrate about a mean position of equilibrium. Such an atom possesses therefore both kinetic and potential energy and is similar to a Hertzian oscillator. We are therefore justified in applying to the atomic vibrator considerations similar to those used by Planck in deducing his distribution formula. Since the atom of the solid can absorb or emit at

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[1] See Part II General Electric Review, Sept., 1914, p. 903.

the maximum 3 $kT$ calories, it is evident from the analogy between Planck's linear oscillator and Einstein's vibrating atom that the average energy of an atom will be

$$U_\nu = \frac{3\,h\nu}{\epsilon^{\frac{h\nu}{kT}} - 1} \qquad (1)$$

The only difference between this equation and that derived for the electro-magnetic oscillator, (Part II, equation 13), outside of the substitution of $h\nu$ for $\delta$ in the latter, is due to the fact that the linear oscillator considered in deriving Planck's equation has only two degrees of freedom, while that considered above has six degrees of freedom.

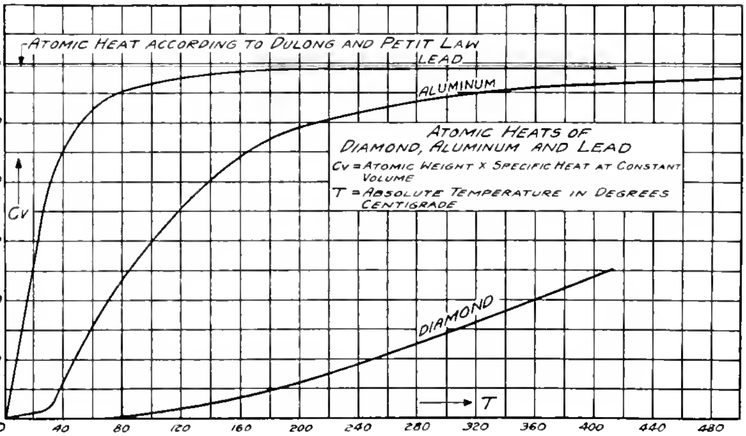

Fig. 1

The total energy per gram atom may be denoted by $W$, where

$$W = \frac{3\,N\,h\nu}{\epsilon^{\frac{h\nu}{kT}} - 1}$$

$$= 3\,R \cdot \frac{\frac{h\nu}{k}}{\epsilon^{\frac{h\nu}{kT}} - 1} \qquad (2)$$

At very high temperatures, where $T$ is large compared to $\frac{h\nu}{k}$, equation (2) becomes,

$$W = 3\,R\,T = 6\,T \text{ calories} \qquad (2a)$$

But this is the Dulong and Petit law, and it is seen that this law has the same validity in the realm of specific heats as the Rayleigh equation in that of black-body radiation.

Differentiating (2) we obtain the equation for the atomic heat at constant volume[2],

$$C_v = \frac{dW}{dT} = 3\,R\, \frac{\epsilon^{\frac{h\nu}{kT}}\left(\frac{h\nu}{kT}\right)^2}{\left(\epsilon^{\frac{h\nu}{kT}} - 1\right)^2} \qquad (3)$$

**Nernst and Lindemann's Formula**

However, the actual observations of Nernst and those working with him were found to be only in qualitative agreement with Einstein's formula. The discrepancies between observed and calculated values were found to increase as the temperature decreased, and consequently Nernst and Lindemann were led to suggest a modification of equation (3) of the following form

$$C_v = \frac{3}{2}\,R \left[ \frac{\epsilon^{\frac{h\nu}{kT}}\left(\frac{h\nu}{kT}\right)^2}{\left(\epsilon^{\frac{h\nu}{kT}} - 1\right)^2} + \frac{\epsilon^{\frac{h\nu}{2kT}}\left(\frac{h\nu}{2kT}\right)^2}{\left(\epsilon^{\frac{h\nu}{2kT}} - 1\right)^2} \right] \qquad (4)$$

This equation agrees splendidly with the data obtained, down to the very lowest temperatures.

The conclusion to be drawn from these results is that in the case of absorption and emission of heat at low temperatures, where the quantities of energy dealt with are very small, it is necessary to assume that this energy is absorbed or emitted only in multiples of a unit quantum $h\nu$, and not continuously as hitherto assumed.

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[2] Z. f. Elektrochem. *17*, 265 (1911).

### Graphic Illustration of Einstein's Equation

The difference between the old and new theories may be illustrated graphically as follows:

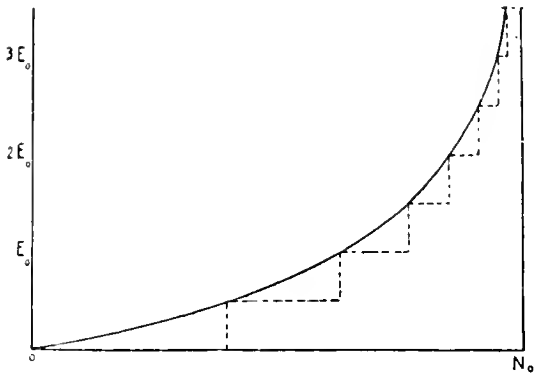

Fig. 2

Consider a gram-atom of an element in the solid state. According to Boltzmann's principle the average energy of each atom is 3 $kT$. Resolving the vibrations of the atoms into three planes at right angles to one another, it follows that the average energy per atom in any plane is equal to

$$E_0 = kT$$

or the total energy for $N_0$ atoms (1 gram-atom) is

$$N_0E_0 = N_0kT = RT$$

This average energy is divided equally into kinetic and potential.

However, the different atoms vibrating in one plane at any instant do not all possess the same kinetic energy. As is well known, the velocities of a large number of molecules moving in any direction vary from zero to infinity, in accordance with Maxwell's distribution law. From considerations based on this law, it can be shown that the distribution of energy among the $N_0$ atoms will follow a curve such as that shown in Fig. 2. The equation to this curve is of the form

$$N = N_0(1 - \epsilon^{\frac{E}{E_0}}) \qquad (5)$$

where $N$ denotes the number of atoms whose kinetic energy lies between the values $O$ and $E$. It is evident that $N_0$ corresponds to the value $E = \infty$, while the total area under the curve is equal to $N_0E_0 = RT$.

But such a law of distribution of energy among the $N_0$ atoms holds only under the assumption that the energy of an atom can vary *continuously*. If, however, we introduce the assumption that the energy of an atom can vary only in integral multiples of a unit quantum $h\nu$, it follows that the distribution law must be represented by a stair-case shaped line such as shown in Fig. 2 under the exponential curve; for those atoms which according to Maxwell's distribution law ought to possess an energy less than $h\nu$ will remain at rest. Similarly as there is no gradation in energy between the values $h\nu$ and 2 $h\nu$, there will be a number of atoms having the same energy $h\nu$, and similar considerations hold for the other groups of atoms. It is easily shown that for such a distribution of energy the average energy is not $kT$ but a smaller quantity, viz:

$$E_0 = \frac{h\nu}{\epsilon^{\frac{h\nu}{kT}} - 1} \qquad (6)$$

### Methods of Determining the Vibration-Frequency

A word or two about the determination of $\nu$, the so-called "Schwingungszahl" or vibration-frequency:[3] Three methods have been used. The first depends upon the determination of the frequencies of the longest heat waves as shown by the dispersion spectrum of the metal. The second one was suggested by Lindemann.[4] Assuming that at the melting point the radius of the orbit of the vibrating atom about its position of equilibrium becomes equal to the distance between neighboring atoms, he deduced a relation between the frequency $\nu$, the melting point $T_m$, the atomic weight $A$, and the atomic volume $V$ of the following form:

$$\nu = 2.8 \times 10^{12} \sqrt{\frac{T_m}{A V^{2/3}}} \qquad (7)$$

The third method which was developed by E. Madelung,[5] W. Sutherland[6] and A. Einstein,[7] assumes a relation between the frequencies of vibration and the elastic properties of the solid. According to the last-named authority the relation is of the form

$$\nu = \frac{2.8 \times 10^7}{A^{\frac{1}{3}} K^{\frac{1}{2}} \rho^{\frac{1}{6}}} \qquad (8)$$

where $A$ denotes the atomic weight, $K$ the compressibility and $\rho$ the density.

On the average the values of $\nu$ obtained by these different methods agree pretty well.

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[3] See K. Jellinek, Physik. Chem. d. Gasreaktionen, p. 393–414.

[4] Physik. Zeit. *11*, 609 (1910).

[5] Phys. Zeit. *11*, 898, 1910.

[6] Phil. Mag. *20*, 657, 1910.

[7] Ann. Phys. *34*, 170, 1911.

### Debye's Formula for the Atomic Heat of Solids

More recently Debye[8] has shown that instead of one definite value of $\nu$ it is necessary to take into account a whole range of values. According to his argument, the number of frequencies for $N$ atoms per unit volume cannot exceed $3N$. At the highest temperatures, where each frequency has the same average energy $kT$ (corresponding to both kinetic and potential energy), the total energy is therefore $3NkT$ as demanded by the Dulong and Petit law. As the temperature is lowered, the average energy taken up by the higher frequencies is less than that taken up by smaller frequencies, so that finally at the lowest temperatures attainable only those atoms executing vibrations of extremely low frequencies (for which $h\nu$ is very small) can obtain enough energy to vibrate. Now the lowest frequencies are obviously those corresponding to ordinary sound vibrations, and the other frequencies represent overtones. Debye shows that the maximum frequency and the distribution of lines in this "acoustical spectrum" may be calculated from the elastic constants of the material. He thus identifies the *thermal oscillations of the atoms with the elastic properties of the solid.*

Introducing Planck's conclusion that each frequency possesses on the average the quantity of energy given by equation (6) above, and integrating this over the whole range of frequencies corresponding to the acoustical spectrum, Debye obtains an expression for the atomic heat which is much more complicated than that of Nernst and Lindemann. The latter is, however, shown to be a good approximation to Debye's formula at lower values of $T$. Furthermore, the interesting conclusion is obtained by Debye that at very low temperatures the atomic heats vary as the third power of the absolute temperature; in other words, the total energy of a solid at temperatures near the absolute zero is proportional to the fourth power of the absolute temperature. This relation is thus analogous to the Stefan-Boltzmann law for the total energy radiated by a black body.

### (B) Applications of the Quantum Theory to Chemistry

The problem of the determination of specific heats down to the very lowest temperatures is of even greater importance to the chemist than to the physicist. This is due to the fact that a knowledge of specific heat is necessary in connection with the solution of the great problem of chemical affinity. As a matter of fact, Nernst and his pupils had begun their investigations on specific heats even before anyone thought of applying the quantum theory in this field. However, Einstein's suggestion certainly gave added impulse to these investigations, and the result is that not only has the quantum theory been brought to the notice of physical chemists as a possible method of calculating specific heats down to the lowest temperatures, but the new theory has also been applied to the determination of the so-called "chemical constants"—a knowledge of which is also essential towards a complete solution of the problem of chemical affinity.

In the following section we hope to show in what respects the quantum theory has been applied successfully to the solution of this problem.

### Meaning of "Chemical Affinity." Free Energy

The introduction of the term affinity is usually ascribed to Boerhave. He gave this term a meaning that it has retained ever since, viz.: The force that holds together chemically dissimilar substances. The investigations of Wenzell (1777) of Berthollet (1803) and of Guldberg and Waage (1867–1879) led to a clearer understanding of some of the factors influencing chemical affinity. The investigations of Ostwald on the affinity of acids and bases, together with the far-reaching speculations of Arrhenius led to precise methods of measuring chemical affinity in the case of reactions between electrolytes.

It is to Van't Hoff, however, that we owe an exact definition of affinity, based upon the two fundamental laws of thermodynamics. Since it is customary in mechanics to measure forces by determining the magnitude of the forces necessary to just balance them, Van't Hoff suggested that we determine the magnitude of chemical affinity from the amount of work that a reaction can yield when it is carried out in a perfectly reversible manner; that is, under such conditions that the driving forces of the reaction are always balanced by equal and opposite external forces. The affinity of a chemical reaction is therefore to be measured by means of the amount of work that can be obtained when the reaction is carried out at constant temperature in a reversible manner. If a number of substances constituting any isolated system are capable of reacting in more than one way, then in accordance with the principle just enunciated, that reaction will be most

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[8] Ann. Physik, *39*, 789–839 (1912).

likely to occur from which the greatest amount of work is available when it is carried out reversibly.

Unfortunately, it is not always possible to determine by direct methods the magnitude of this available work, or "free energy" as it has been designated. In the case of gases, the free energy is very easily calculated. In the case of solutions to which the gas laws apply such a calculation is also possible and the dissociation theory of Arrhenius may be regarded as a theory which enables us to determine from the conductivity of an electrolyte its chemical affinity. The measurement of electromotive forces of chemical reactions is a third method of determining chemical affinity, which is of great practical importance. Thus the chemical affinity of the reaction,

$$H_2+Cl_2=2\ HCl$$

may be determined by measuring the electromotive force of a cell whose electrodes are hydrogen and chlorine gas, with hydrochloric acid as electrolyte. These are practically the only cases in which the free energy can be determined directly.

But it is possible to measure directly or calculate in the case of all reactions the total energy evolved or absorbed, for it is only necessary to allow the reaction to occur in a calorimeter and the total heat evolved or absorbed in a measure of the change in total energy.

### Relation Between Total Energy and Free Energy

Is there any relation between the total energy of a chemical reaction and that available as work when the reaction is carried out reversibly? Berthellot (1879) answered this question by stating that the two quantities of energy are equal. This was enunciated by him as the third principle of thermodynamics. Disregarding even the existence of reactions which occur with an absorption of heat and of other reactions which proceed in one direction or the other, depending upon concentration, the "third principle" is shown to be in disagreement with the second law of the thermodynamics.

Let us denote the total energy of a reaction by $Q$, and the free energy (or work available at constant temperature and constant volume) by $A$. Since $A$ is not necessarily equal to $Q$, heat will be either absorbed or given out when the reaction is carried out reversibly (at constant temperature and constant volume), the amount of this "latent heat" corresponding to $A$-$Q$.

Now let us assume that the reaction takes place in one direction at temperature $T_1$ and in the other direction at $T_2$. Let $A_1$ and $Q_1$ denote the free and total energy respectively at $T_1$ and $A_2$, and $Q_2$ denote the corresponding values for the temperature $T_2$. If the transition from $T_1$ to $T_2$ and that in the reverse direction are adiabatic, the whole chain of operations will constitute a Carnot's cycle, and it therefore follows from the second law of thermodynamics that for such a cycle:

$$\frac{\text{Work gained during cycle}}{\text{heat absorbed at higher temperature}}=\frac{\text{difference in temperature}}{\text{higher temperature}}$$

or,

$$\frac{A_1-A_2}{A_1-Q_1}=\frac{T_1-T_2}{T_1}$$

When the difference $T_1-T_2$ becomes very small and equal to $\triangle T$, this equation can be written as

$$\frac{\triangle A}{A-Q}=\frac{\triangle T}{T},$$

or, in the limit,

$$A-Q=T\frac{dA}{dT} \qquad (9)$$

That is, the free energy differs from the total energy by the product of the temperature-coefficient of the free energy $(dA\ dT)$ and the absolute temperature. It is evident that only at the absolute zero are the free and total energy equal, that is,

$$A_0=Q_0 \qquad (10)$$

But at any other temperature this is not generally true, and it is therefore impossible, without the aid of some other assumptions, to calculate $A$ from $Q$.

This is still more evident from the following considerations:

Equation (9) can be written in the form

$$\frac{A}{T}-\frac{dA}{dT}=-\frac{Q}{T} \qquad (9a)$$

Dividing each side of this equation by $T$, the left-hand side becomes the complete differential of $A\ T$, and consequently the equation may be written in the form,

$$\frac{d}{dT}\left(\frac{A}{T}\right)=-\frac{Q}{T^2} \qquad (9b)$$

That is, the second law of thermodynamics leads to a relation between the rate of change of the quantity $A\ T$ on the one hand and the quantity $Q\ T^2$ on the other. In other words, the second law of thermodyanmics gives us the slope at each point of a curve whose ordinates are equal to $A/T$ and abscissae to $Q/T^2$. But it is evident that the slope alone is not sufficient to define the position of a curve absolutely; we require, in addition to this information, the intercept on either of the two axes of co-ordinates. Using the language of the integral calculus, this can be stated as follows:

$$\frac{A}{T} = -\int_0^T \frac{Q}{T^2}\,dT + C \qquad (11)$$

where $C$ is the so-called integration constant and corresponds to the intercept mentioned above.

This equation shows that in order to calculate $A$, it is necessary to know $Q$ for the range of temperatures $0$ to $T$ and also a constant $C$. The variations in $Q$ with temperature depends, however, upon the difference between the specific heats of the substances entering into the chemical reaction and those that are produced,[9] so that

$$\frac{dQ}{dT} = \Sigma C_v \qquad (12)$$

where $C_v$ denotes the specific heat at constant volume per gram-atom of any one of the substances involved.

Hence, the calculation of $A$ depends, in the final analysis, upon three sets of data:

(1) Thermochemical data, giving $Q$.
(2) Specific heats down to absolute zero.
(3) Integration constants, known as chemical constants, $C$.

### Nernst Heat Theorem

There are, however, certain types of reactions for which the constants are equal to zero. A few years ago Nernst put forward the suggestion that in the case of reactions involving solids or liquids, the temperature coefficients of both the free and total energy must tend to decrease indefinitely as the absolute zero is approached. On the basis of this assumption, which is known as the Nernst heat theorem, it can be readily shown that for the above class of reactions, the constant must be equal to zero, and furthermore, that in the case of reactions involving gases the chemical constant is additively composed of the constants for the different substances taking part in the reaction, as determined from their vapor tension curves. Thus, the chemical constant of the reaction,

$$2H_2 + O_2 = 2H_2O,$$

all the substances involved being considered in the gaseous state, can be calculated from the constants of reactions similar to the following:

Solid (or Liquid) Hydrogen $\rightarrow H_2$ (gas).

It is therefore possible to calculate the "chemical" constant of any reaction from tables of constants of the reagents involved.

### Relation of Quantum Theory to Nernst's Heat Theorem

The assumption that the specific heat decreases to zero as the absolute zero is approached is evidently in accord with the experimental data that have been obtained since the Nernst heat theorem was enunciated. Moreover, the quantum theory enables us to calculate the actual values of the specific heats down to the absolute zero, not only for the case of solids, as shown above, but also in the case of gases.[10]

The second part of Nernst's assumption, that $dA/dT$ tends also to decrease to zero as the absolute zero is approached, is justified by Debye's and Keesom's deductions that near the absolute zero the specific heats vary as $T^3$. Otherwise $\frac{Q}{T^2}$ would become infinite as $T$ diminishes.

### Calculation of Chemical Constants

It has been pointed out by Tetrode[11] and more recently by Sackur[12] and Keesom[13] that the chemical constants, as well as the specific heats, may be deduced by considerations similar to those used by Planck in developing his radiation formula. Both Sackur and Keesom conclude that it is possible to express $C$ in terms of the number of atoms in the molecule and the molecular weight (M). Thus

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[9] This may be readily deduced as follows: Consider a reaction in which $A$ changes into $B$. Allow the reaction to occur at temperature $T_1$ and let $Q_1$ be the heat absorbed. Then heat the product, $B$, to temperature $T_2$. If $C_B$ denotes the specific heat of $B$ the total amount of energy absorbed in changing from $A$ at $T_1$ to $B$ at $T_2$ is equal to $Q_1 + C_B(T_2 - T_1)$. On the other hand, the same final state can be obtained by heating $A$ to $T_2$ and allowing the reaction to occur at this temperature. Denoting the heat of reaction at $T_2$ by $Q_2$ and the specific heat of $A$ by $C_A$, it follows from the law of conservation of energy, that:

$$Q_2 + C_A(T_2 - T_1) = Q_1 + C_B(T_2 - T_1)$$

or

$$\frac{Q_2 - Q_1}{T_2 - T^1} = (C_B - C_A)$$

In the limit

$$\frac{dQ}{dT} = \Sigma C_v$$

where $\Sigma$ indicates that the algebraic sum is to be taken of all the specific heats involved.

[10] W. H. Keesom, Phys. Zeit. *14*, 665, 1913.

[11] Ann. Phys. *38*, 434, (1912).

[12] Ann. Phys. *40*, 67–106 (1913).

[13] Phys. Zeit. *15*, 695, (1914).

for monatomic gases, the latter obtains the relation (in C.G.S. units),

$$C=3.67+1.5 \log M \qquad (13)$$

For diatomic and triatomic gases, Sackur obtains similar expressions. In these cases, however, the agreement between the observed and calculated values is not quite as good, but the very fact that these speculations lead to results that are in fair accord with experimental data in even a fraction of the cases goes far to justify the application of the method. As Sackur points out, *it is possible by making use of deductions from the quantum theory to calculate the free energy of a chemical reaction at any temperature from thermochemical data obtained at any other temperature.* In enabling us to determine the free energy of any reaction from calorimetric data, the quantum theory becomes, therefore, of extreme utility to the physical chemist.

There is one more point that is worth while emphasizing in this connection, viz.: That while the classical thermodynamics necessarily leaves the question as to the relation between free and total energy only partly answered, the application of the quantum theory taken in conjunction with the laws of thermodynamics leads to a complete solution. Let us consider what this means. The first law of thermodynamics states that in all transformations of energy in an isolated system, the total energy of the system remains constant. The second law states something about the conditions under which heat energy can be transformed into mechanical energy or its equivalent in any other form of energy. The Nernst heat theorem and quantum theory give us additional information as to the inner mechanism of this energy transfer. In this respect the quantum theory holds the same position with regard to ordinary thermodynamics as the kinetic theory holds with regard to the laws of equilibrium, and we believe that for a complete comprehension of natural phenomena both aspects, that is the kinetic as well as static are absolutely essential.

### C) Emission of Electrons by Light and X-Rays. Photo-Chemical Reactions

The atomistic view of the structure of energy has also led to surprisingly simple relations in the consideration of such apparently different fields as the photo-electric effect, emission of electrons by X-rays and photo chemistry.

#### Photo-Electric Effect

The fact that a surface illuminated by ultra-violet light becomes positively charged, and thus facilitates the passage of electricity in such a direction as to charge the surface positively, has been known for a number of years as the Hallwachs or photo-electric effect. The phenomenon has received its simplest explanation in terms of the electron theory, as being due to an emission of electrons under the influence of ultra-violet light. Accurate measurements have shown that the maximum velocity of the emitted electrons is independent of the intensity of illumination and depends only on the frequency of the incident (monochromatic) radiation.

The number of electrons emitted increases, however, with the intensity of the illuminating source. In the case of highly electro-positive metals like sodium and potassium, light of even lower frequency than ultra-violet causes the emission of electrons.

On the basis of the quantum theory it is possible to deduce a relation between the frequency of the incident light and the velocity of the ejected electron.

Denote the initial velocity of the electron leaving the surface by $v$ and let $m$ be its mass. Let $P$ denote the work required to carry an electron through the surface of the metal. The energy for this emission must be obtained from the incident light, and on the basis of the quantum theory this must be equal to $h\nu$. Consequently,

$$\tfrac{1}{2}\, mv^2 = h\nu - P \qquad (14)$$

Denoting by $V$ the potential difference through which the electron must pass to acquire a velocity $v$, and combining (14) with the relation,

$$Ve = \tfrac{1}{2}\, mv^2 \qquad (15)$$

where $e$ denotes the charge on an electron, we obtain the relation,

$$V = \frac{h\nu}{e} - \frac{P}{e} \qquad (16)$$

By measuring $V$ for different values of $\nu$, it is evidently possible to test this conclusion. In the actual experiments it is more convenient to determine the minimum positive potential which it is necessary to apply to the illuminated surface in order to cut down the electron emission to zero. Such measurements are difficult to obtain with any degree of accuracy, and it is only within the past year that excellent experimental confirmation of equation (16) has been obtained. At the meeting of the American Physical Society held in Chicago, November 29, 1913, Prof. Millikan announced that he had obtained such confirmation over a large range of frequencies, the observed value of $h/e$ being within five per cent of that calculated from other data.[14]

### Photo-Chemical Reactions

Einstein has also extended the above arguments to the case of photo-chemical reactions.[15] Assuming that the energy absorbed per gram-molecule in any photo-chemical reaction is $\delta$ then it follows directly from the concept of energy quanta, that

$$\delta = nh\nu$$

where $\nu$ is the frequency of the monochromatic, radiation that supplies the energy of the reaction and $n$ is some integer. This is known as Einstein's law of photo-chemical equivalency.

The proportionality between amount of photo-chemical action and intensity of illumination follows as a direct consequence of this relation.

According to Boll and Victor Henri[16] the actual value of the ratio $h\nu/e$ as determined in most cases is far from unity, varying all the way from $10^6$ to $10^{-3}$. To account for this discrepancy, Baly assumes a disturbing influence of the medium, while Bodenstein[17] assumes the existence of intermediary reactions involving electrons.

The latter theory is extremely interesting and suggestive. Bodenstein makes the assumption along with Stark that in all photo-chemical reactions the first stage is the liberation of an electron as in the ordinary photo-electric effect. Consequently, the energy absorbed must be $h\nu$ per electron emitted. Bodenstein then draws a distinction between what he designates as primary and secondary reactions respectively. In primary reactions, the molecules that have been deprived of electrons react directly; so that for these reactions the ratio between the number of molecules reacting and the amount of energy absorbed $(h\nu/\epsilon)$ ought to be equal to unity.

On the other hand, in the case of secondary reactions, the electron attaches itself to a molecule, renders it active, and becomes free again after the reaction. It is therefore conceivable that the quotient $h\nu/\epsilon$ can become greater than unity.

### Emission of Electrons by X-Rays

A phenomenon closely related to the photo-electric effect is the ejection of electrons from surfaces bombarded by X-rays, and it has been shown that in this case also the velocity of the emitted electrons is proportional to the potential difference between the electrodes of the tube which produces the rays, that is, the "harder" the X-rays, the greater the velocity of the emitted electrons. Assuming, therefore, that the X-ray transfers a quantum of energy from the electron bombarding the anode to the electron emitted from the surface upon which the X-ray impinges, it is possible to calculate the frequency of the latter.

The calculation is similar to that of the emission velocities of photo-electrons. We have

$$Ve = h\nu = \frac{hc}{\lambda} \qquad (16a)$$

as in equation (16). If $V = 40{,}000$ volts,

$$\lambda = \frac{hc}{Ve} = \frac{6.62 \times 10^{-27} \times 3 \times 10^{10}}{4.774 \times 10^{-10} \times \frac{40{,}000}{300}} = 3 \times 10^{-9}\ \text{cm.}$$[18]

This is the order of magnitude of the wave-lengths which have been obtained by measuring the diffraction patterns produced by letting X-rays pass through crystals.

There is a still further similarity between the emission of electrons by X-rays and ultra-violet light. Besides the normal photo-electric effects mentioned above, there exists a selective photo-electric effect which is characterized by the fact that at a certain frequency of the incident illumination there is emitted an abnormal number of electrons. The frequency at which this maximum emission occurs is characteristic of the substance illuminated and decreases with decrease in atomic weight. Similarly there exists a selective X-ray effect, so that at a certain definite voltage in the exciting tube, corresponding to rays of a definite hardness, there occurs an abnormal emission of electrons from the surface upon which the X-rays impinge, and here also the frequency of X-rays required to produce this abnormal emission is nearly proportional to the atomic weight of the excited substance.

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[14] See also Phys. Rev. *4*, 73, (1914). Prof. Millikan's experimentally determined value of $h$ is $6.561 \times 10^{-27}$.

[15] Journal de Physique, *3*, 277 (1913).

[16] Compt. rend. 158, 32, 1914.

[17] Z. physikal. chem. *85*, 329, 1913.

[18] $e = 4.774 \times 10^{-10}$ electrostatic units; $h = 6.62 \times 10^{-27}$ erg. sec. and $c = 3 \times 10^{10}$ cm. To convert volts to electrostatic units it is necessary to divide by 300.

We find therefore a complete parallelism between the phenomena exhibited by X-rays and ultra-violet light.[19] But while the lowest wave-length so far measured in the ultra-violet is about $10^{-5}$ cm., the above measurements show that hard X-rays are electromagnetic waves with wave-lengths of the order of magnitude of $3\times10^{-9}$ cm. To produce X-rays with a wave-length of $3\times10^{-6}$ cm. would require potentials of about 40 volts, and recent work[20] has shown that even with voltages as low as 17 it is possible to obtain qualitative indication of the production of X-rays. At this voltage the wave lengths of X-rays emitted is 74.55 $\mu\ \mu$. It is interesting to note that the shortest wave-lengths so far detected in the ultra-violet portion of the spectrum is 90 $\mu\ \mu$, so that it would appear as if the gap between X-rays and ordinary visible light has been filled in.[21]

The fact that the emission of electrons by light and X-rays occurs instantaneously has led to the conclusion that the electrons possess a latent store of energy whose average value for each frequency is $\frac{h\nu}{2}$. Consequently the immediate effect of a beam of light or X-rays is to cause the emission of those electrons whose energy content is just below $h\nu$, while the remainder of the incident energy is distributed among the other electrons. It has already been stated in a previous section[22] that Planck has arrived at the same conclusion for the average energy of a linear oscillator, and this conclusion is quite in accord with a large number of recent observations on the behavior of substances at temperatures which are near the absolute zero.

There is still another point to be observed in this connection. While the application of the quantum theory to radiation and specific heats suggests emission and absorption of energy that is discontinuous with respect *to time*, the observations on emission of electrons by X-rays and ultra-violet light lead to the conclusion that the discontinuity exists here with respect to space. In other words, in order to account for the fact that the X-ray carries over undiminished the energy of the electron that produced it to another electron that is emitted by it, it is necessary to assume that the amount of energy represented by it keeps together as an entity or quantum throughout the different transformations. A corpuscular theory of X-rays such as originally suggested by Prof. Bragg accounts for this fact very well; but such a theory is obviously not in accord with the diffraction experiments of Laue and the analogies exhibited by ultra-violet light and X-rays. To reconcile these apparently conflicting facts, it is necessary to assume for X-rays some form of "spotted-wave" theory—but as yet no physicist has dared to propose such a theory.

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# PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

## PART II (NOS. 6 TO 12 INC.)

By E. C. Parham

Construction Department, General Electric Company

### (6) ALTERNATOR PARALLELING KINK

Most operating station engineers are familiar with the fact that the proportional sharing of load between two alternators operating in parallel is a matter of the proportional supply of energy from their respective prime movers; and that the adjustments of load are effected by adjustments of speed and not by field rheostat adjustments, as in the case of direct current generators.

Two certain alternators, driven by a water-wheel shaft, though not required to operate continuously in parallel, were intended to alternate in 12-hour shifts. On trying to transfer the load from one to the other at the end of a shift, it was found to be impracticable, because the instant they were thrown together their individual breakers would open.

An inspector called in to diagnose the case attributed the trouble to unequal speeds of the generators. The driving pulleys on the water-wheel shaft proved to be of exactly the same size. One generator had an iron pulley and the other a wooden one, the latter one being about $\frac{1}{4}$ in. larger in diameter. The wooden pulley was removed and placed on a lathe and turned down until it was only a trifle larger than the measured difference called for. On again putting the machines into service and throwing them together they would run in parallel for a few seconds, but then the current would begin to climb and finally blow the breakers. The diameter of the wooden pulley was then gradually reduced by applying sandpaper; and the length of time that the machines would parallel without blowing the breakers gradually increased, as the diameters of the two pulleys became more nearly the same. In this manner satisfactory permanent parallel operation was finally obtained, which proved that the breaker blowing had been due to unequal speeds.

### (7) ARMATURE BANDS BREAKING

Armature bands may fail for any of several reasons, for example, (1) foreign object in the air gap, (2) defective banding, (3) armature grounded or otherwise short circuited and bandwire thereby burned, (4) low bearings permitting bands to rub the pole-pieces, and (5) excessive armature speeds. Whatever the cause, the usual result is the grinding of the broken or burned band between the armature and the pole-pieces in such a manner as to destroy all conclusive evidence as to the original cause of trouble. Of the causes named, only No. (5) will be considered here.

Bandwires are designed to stand reasonable over-speeds; but in special cases, as for instance, racing turbines or series motors running comparatively free, the stresses must be reduced otherwise than by increased bandwire strength.

In the instance which is of interest, the bridge of a coal unloading crane was operated by a series motor. The bridge runway was about 600 feet long. The motor armature had burned out several times and in each case a broken band seemed to be involved. An increase in the size of wire and in the number of bands did not seem to help matters appreciably. Finally the services of a competent inspector were engaged. One day he noted that the bridge ran much faster in one direction than in the other, but after measurement found the runway to be level. To check the possibility of a wrongly set or shifted brush-holder, or of there being a field so grounded as to cut out more turns in one direction than in the other, he jacked up the bridge and took motor speeds in both directions; they were approximately the same. He then became convinced that the high winds, which came down the valley directly in line with the runway, were responsible. This proved to be the case. A brake on the bridge stopped all trouble.

### (8) AN EFFECT OF LOW FREQUENCY

A motor designed to operate at a certain frequency will take a certain amount of current when rated voltage is applied to it under a given load condition. With the same voltage and the same load but with higher frequency, the current will be less than at normal frequency; and with lower frequency, the current will be greater. The reason is that in the first case the duration of each period is less and the current has therefore less time in which to reach its maximum value in either direction and, in the second case, each current impulse in either direction has more time in which to increase against the restraint of self induction. In other words, the impedance of a motor is greater for high frequency than for low.

Once an inspector was asked to determine the cause for overheating of a three-phase induction motor which operated a very busy transfer table. The motor received its energy from a hydro-electric station, which also supplied current to an electric railway; the heavy loads of the railway and of the table occurring at about the same time of day. As the water supply was not liberal, the heavier loads would bring down the speed of the alternator, decreasing the supply frequency to the extent of 20 to 25 per cent. To aggravate matters, the voltage was maintained almost constant during the periods of low frequency.

The net result was an increase in the motor current, hence excessive heating. The increase of current in the case described was due to the combination of three reasons: (1) low frequency; (2) voltage higher than should have been applied at the reduced frequency; (3) impaired power-factor, owing to the lowering of the frequency simultaneously with the raising of the voltage. An indirect effect of the low power-factor was to increase the current corresponding to a given effort; this condition prompting the table operator to abuse the motor by advancing its controller more rapidly than would ordinarily have been required.

### (9) ROTOR RESISTOR HEATING

The speed and torque of a slip-ring induction motor are controlled by means of an adjustable external resistance connected to the rotor and to an external controller. These regulating devices have no electrical connection with the stator.

We know that open-circuits or short-circuits in the starting resistance of a direct current motor will prevent smooth acceleration and will cause certain resistance sections to overheat; because the resistance will not then be cut out in smoothly graduated steps and irregularity in one part of a rheostat is likely to overload another part. Similar causes produce similar effects in the case of irregularities in the connections of the resistor of an induction motor.

The resistor of a certain three-phase induction motor, operating a turn-table, was continually causing trouble because of broken resistance grids. The cause of the grids becoming damaged was first attributed to the blow which the table sometimes received when a heavy locomotive passed onto it. The fact, however, that similarly equipped turn-tables in other parts of the system gave no such trouble rendered that assumption very questionable. Closer investigation disclosed the fact that all of the trouble was due to improper contact between the controller fingers of the resistor and their corresponding cylinder segments. Some of the resistor sections that should have been cut out on the more advanced positions of the controller were still remaining in circuit, because their respective fingers failed to make the short-circuit contact. As a result these sections heated, softened, and broke; furthermore, the opening of one section by breakage threw additional load on the other sections which in time also heated and gave way. After cleaning the controller, replacing the fingers and the segments where required, and adjusting the contacts, normal operation was secured and maintained.

### (10) MOTOR STARTING BLEW CIRCUIT-BREAKER

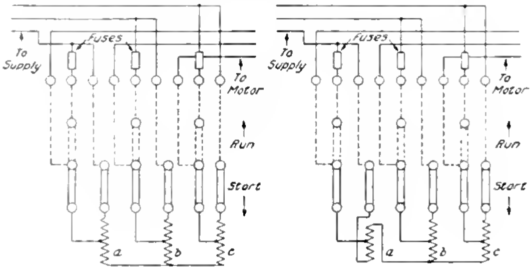
Unless a special resistance is used to reduce the current at the time of moving a controller to the "off" position (this in order to decrease flashing with the attendant blistering of fingers and cylinder tips), the value of the starting resistance sometimes used with direct-current motors is made such as to promptly start the motor on the first controller notch with the maximum load to be started under regular working conditions. This often means that the total starting coil resistance will permit of an initial current flow greatly exceeding the rated full-load current of the motor. This initial current will maintain only for a moment, since at the instant the armature begins to revolve, its counter e.m.f. reduces the current very rapidly.

Considerable annoyance was experienced by the peculiar action of a motor, the circuit-breaker of which would operate as soon as the controller was placed upon the first notch. Tests and inspection proved all internal and external connections to be according to the manufacturer's instructions, and all parts of the circuit to be free from grounds and short-circuits. The motor had normal field strength, the commutating poles were properly connected, and there was no flashing at the brushes when voltage was applied. The current rating of the motor was 13 amperes at 500 volts, and the maximum for which the circuit-breaker could be set was 30 amperes. Upon tying in the circuit-breaker, relying on two 30-ampere fuses for protection, and closing the switch, the motor started and came up to speed in a normal manner. The insertion of an ammeter showed a starting current of about 40 amperes.

The cause of the trouble was that the amount of the current admitted by the starting resistance exceeded that for which the breaker could be set.

### (11) REVERSED COMPENSATOR COIL

Sometimes a standard piece of apparatus will contain a defect even after being most carefully designed, manufactured, tested, and installed; and will then fail under perfectly normal conditions. On the other hand, it is almost unbelievable how such defective apparatus oftentimes will continue to operate with apparent satisfaction.



Figs. 1 and 2

In one instance, a railway motor armature was connected three commutator bars from the correct ones; but it was not discovered until a month later when the car was run into the repair shop because the armature had failed on the opposite end. In another case, one motor of a four-motor car ran for several weeks with a field coil reversed, thereby making three poles of like polarity.

Of interest here, is the case of a starting compensator that was in use two years and then failed. It was repaired and ran for more than a year before failing again. On the occasion of the second repair, some one noticed that the coils were heating more than were the coils of similar compensators doing similar work. Investigation disclosed the fact that one of the coils was reversed, as indicated in Fig. 2 (Fig. 1 indicates normal connections of such a compensator). The original compensator probably had a reversed coil and the error had retained through all repairs. The starting duty of the compensator was comparatively light, otherwise failure would have occurred much sooner, for insertion of ammeters in the starting leads showed greatly unbalanced currents.

### (12) GRADUATING RESISTANCE STEPS

Commutating poles greatly increased the possibilities of motor speed regulation by means of a controller-operated variable resistance in the motor field circuit: the commutating poles oppose the tendency of the armature current to distort the commutating field when the field due to the field magnets is weakened by the introduction of resistance in the field circuit. Variable-speed motor equipments include two rheostats: One, the starting rheostat, is connected in series with the armature and is cut out in graduated steps as the controller is advanced; the other, the field control rheostat, is normally short-circuited but is placed in series with the field step by step. Ordinarily, no part of the field control resistance is connected in series with the field until all of the starting resistance has been removed from the armature circuit, because when a motor is accelerating it requires all of the field available in order to limit the amount of the starting current.

In a particular case of commutator roughening there was no bad cutting, but it was impossible to get the surface to take on a polish. It was soon noted that operation on the starting notches was normal and that on all running positions continuous operation was satisfactory, but that, in passing from one field-control position to the next, the brushes started to spark and spit; this was what was preventing a polished surface. An examination of the field-control rheostat disclosed excessively heated parts, and suggested that perhaps the wrong rheostat was being used. This was confirmed by a checking of the armature speeds, which were found to be too high. On substituting the proper controller with its attached rheostat, the commutator soon took the desired polish.

# SOME RECENT DEVELOPMENTS IN LEVER AND DISCONNECTING SWITCHES

By H. G. French

Switchboard Engineering Department, General Electric Company

Although it is usually to the advantage of all concerned to employ standard or existing types of apparatus in electrical installations, it often happens that some of the conditions of operation are such that this apparatus will not properly fill the requirements. It is then necessary to develop special devices for the purpose, unless those of standard form can be adapted, modified or combined with others to accomplish the desired result. The manner in which this has been done in several cases is illustrated in this article. Special means of interlocking to safeguard service, protect machinery or life, prevent a wrong sequence of operation, or to enable the attendant to operate lever switches of large size with comparative ease, are described in detail.—Editor.

Lever switches are ordinarily the simplest of electrical devices, and of no particular interest from a mechanical point of view; but when it becomes necessary to accomplish more or less intricate circuit connections by such means and provide safeguards against improper operation, some of the developments in this line of apparatus are of more than passing interest. Such contrivances are generally known as mechanical or electrical interlocks, and there are three principal points to be observed in their design; viz., simplicity of construction, so as to avoid undue cost; strength and durability; and convenience of manipulation. In some other cases the unusual features are needed to ensure ease of operation, or semi-automatic action.

The automatic lever switch, Fig. 1, is virtually an interlock between two sources of supply for lights in a station or other location where failure of the normal source must not cause the building to be thrown into darkness. This, of course, is on the assumption that another source of supply is available, such as a storage battery. In main or substations an auxiliary source is generally available, and much inconvenience and sometimes delay may be avoided by this simple device, which ensures a continuous supply for the lights. There is also a field for this switch in the lighting systems of large buildings, such as hospitals, office buildings and apartment houses, in which the installation of a storage battery is not likely to be an unjustified expense.

The operation of this switch is as follows: When failure of normal voltage occurs, the low voltage release drops its armature, which trips the latch from the crossbar above it, and the springs on the hinges of the switch throw it quickly to the upper contacts, which are connected to a storage battery or other emergency source. At the same time an auxiliary switch at the top is thrown into contact, causing a bell or other indicator to operate to attract the station attendant's notice. When the normal source is again in operation, the switch is thrown down by hand and latched: Fig. 1. shows a switch for 100 amperes capacity, 250 volts. Similar switches have been made for 200 and 300 amperes, and they can be made triple-pole as well as double-pole.

Fig. 1. An Interlocking Lever Switch for Automatically Connecting a Reserve Source of Current to the Mains on failure of the Normal Supply

Large direct current motors in industrial service are frequently located at isolated points, and where frequent starting or stopping is not necessary the problem arises of providing a starting switch and circuit breaker arrangement that can be operated with safety by unskilled attendants, and without the possibility of damage to the motor. A large motor panel designed to meet these conditions is shown in Fig. 2. The interlocked starting switch and circuit breaker are so arranged as to make an improper sequence of operations impossible when starting the motor. A mechanical interlock between one pole of the circuit breaker and the lower, or off position of the starting switch, makes it necessary to have the latter in its full "off" position before the left-hand pole of the circuit breaker can be closed. An auxiliary switch, also opened by this movement of the starting switch, allows the coil of the low voltage release to be energized. The starting of the motor can then begin with the step by step operation of the switch, during which the operator must keep depressed a button in the end of the handle, thereby holding open the auxiliary switch until the starting switch has been brought to the full running position. The auxiliary switch is then automatically held open, and the operator may remove his hand. However, should he attempt to leave the starting switch on any intermediate contact, the removal of his hand allows the auxiliary switch to short-circuit the low voltage release coil, tripping the breaker. This in turn cannot be closed again without throwing the starting switch to the full off position again. The motor field switch also controls an auxiliary switch connected in parallel with the low voltage coil, so that the motor field circuit must be closed before the circuit breaker, and if the field switch is opened while the motor is running the circuit breaker is tripped.

The auxiliary switch actuated by the button in the end of the starting switch handle has been specially designed for this service, being entirely enclosed so that dust cannot interfere with the contacts, which also have a rubbing motion when opening or closing. The most reliable auxiliary switch is necessary here, and this design fully meets the requirements.

Another valuable feature of the starting switch used is its definite step by step operation. It is impossible to carry the blade past more than one starting clip (representing a rheostat connection) at one movement of the lever. Moreover, the blade always stops fully in contact with the starting clip. These clips are strongly reinforced so that they are very substantial and reliable and will not become sprung out of good contact. The lever controlling the movement of the blade is in practically an upright position during all of the starting operation, and has a positive stop, allowing exactly the same movement of the blade at each step. In opening the switch a single throw of 180 degrees carries the blade and lever to the full off position.

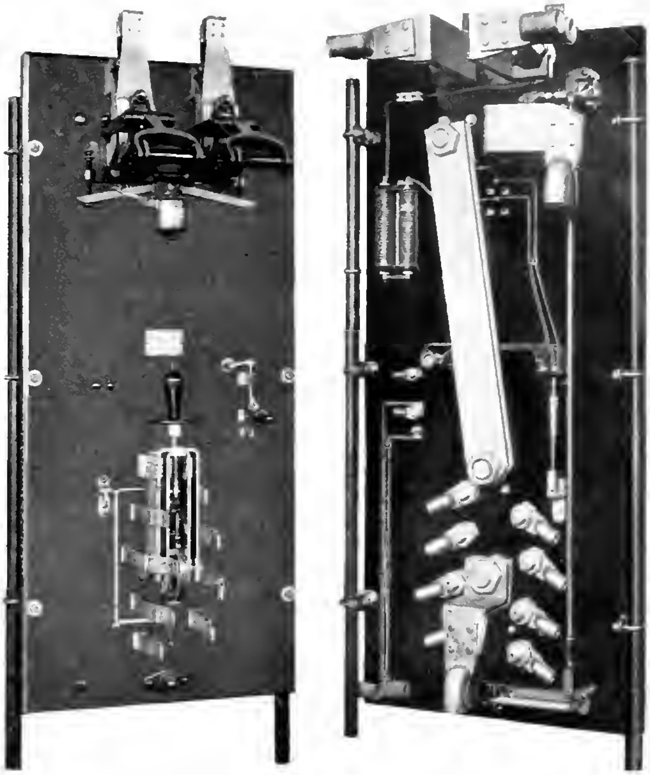


Fig. 2. Motor Panel provided with Interlocks to Prevent Improper Sequence in Operation

From the foregoing it is seen that any mistake in manipulation of this starting panel merely causes the circuit breaker to open, thus protecting the motor. On the other hand, complication is avoided, and it is easy for anyone to operate this apparatus in the proper sequence. Starting panels of this description are in use with large motors for pumps, etc., in isolated locations, and unskilled attendants operate them with entire safety. Panels of 800 to 3000 amperes capacity are available.

A set of six single-pole, single-throw, 15,000-volt disconnecting switches, in two interlocked groups, is shown in Figs. 3 and 4. The poles of each group are located alternately and the hinge blocks connected so as to form three single-pole, double-throw switches, occupying a minimum of vertical space. This set of switches was designed for use in a high tension bus compartment where vertical dimensions were not sufficient for the ordinary triple-pole double-throw set. Were it possible to use such a double-throw set, it would be necessary to join the blades by crossbars, which are undesirable on high tension disconnecting switches. The use of single-throw switches also facilitated their connection to the circuits. There are two three-phases busses, connection to only one of which can be made at a time. The blades are linked near the hinges to insulating rods passing through the central holes of the lower insulators and acting upon a single interlock bar behind the switch panel. A spring with a positive stop for its travel automatically returns the bar to mid-position when the switches are opened, so that the operator does not have to shift the interlock in order to close any set of switches at any time. The interlock mechanism controls a set of auxiliary contacts for the indicating lamp circuits, by which visual indication is provided at the desired place as to the position of the disconnecting switches, thereby showing which bus is connected. The mechanism is also arranged so that it can be fastened with a padlock to prevent the switches of either group being closed, and it may be locked in neutral position so that no unauthorized person can close any switch.

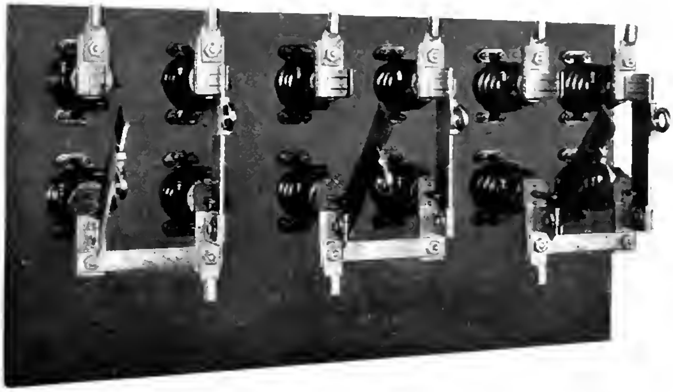


Fig. 3. Six Single-Pole, Single-Throw Disconnecting Switches Connected to Form Three Single-Pole, Double-Throw Switches

The latter feature may be invaluable at times in safeguarding the lives of persons engaged in repair or inspection of other apparatus in series with these switches, and forms a distinct advance in the application of the safety-first idea to high tension station apparatus.

An interlock of extremely rugged construction is shown in Fig. 5. This was designed for the battleship Oklahoma, and its use obviated the employment of various additional switches of large size and a complicated arrangement of connections, thereby avoiding the use of an additional panel where space is at a premium. The switches shown are of 250 volts, 3500 amperes capacity, and are interlocked in two pairs, each pair being entirely independent of the other mechanically. The lower double-throw switch is interlocked, with respect to its right-hand contact, with the single-throw switch in the upper right-hand corner; and the upper double-throw switch is interlocked, with respect to its left-hand contact, with the single-throw switch in the upper left-hand corner. All switches can be closed in the positions shown in the front view, but only one switch of a pair can be closed when in

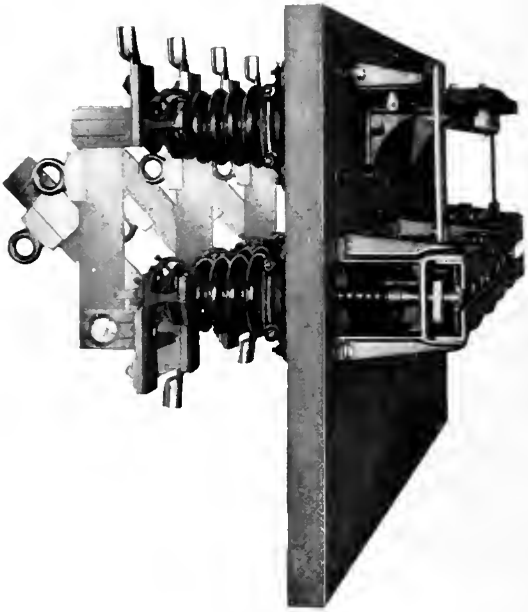


Fig. 4. Side View of Switch Shown in Fig. 3

the positions shown in the side view of the set. The interlocking elements consist of very rigid U-shaped castings, each having two substantial stops extending outward on one side to prevent, when in the proper position, the closing of a switch into a contact beyond. These castings are mounted on heavy bronze rods supported close to the face of the panel and connected to shifting levers, so that when both switches of a pair are open a slight movement of one of the small handles shifts the interlock as desired. Parts of opposite polarity in the mechanism are connected by insulating shafts.

The friction of the contact clips against the blades requires considerable effort on the part of the operator when opening or closing lever switches of high ampere capacity, and these are, therefore, generally limited to single-pole construction. The largest of these are regularly made of the split lever construction, the blades being arranged in two groups, each of which is joined to a handle so that one-half of the switch can be thrown at a time.

Triple-pole lever switches of large capacity would be extremely difficult to operate, if of the usual construction, and especially inconvenient when used for starting large rotary converters from the a-c. side, where it is desirable to throw the larger switch of the pair from two-thirds to full tap without loss of time during the operation. Fig. 6 shows an a-c. six-phase rotary starting lever switch combination, the larger switch being of 4000 amperes capacity. It is of the split lever construction and has two crossbars with separate handles, one-half of the blade of each pole being fastened to one crossbar and the remainder to the other. As the upper contacts are connected to the transformer two-thirds tap for only a short time during starting, they are arranged to make contact only with that half of the switch which must be thrown first to the lower or running side. Half of the blades readily carry the load until the operator can throw over the second section. Large triple-pole switches such as this are easily operated, whereas the alternative would be a considerably more expensive set of large solenoid-operated circuit breakers. Rotary starting switches of this construction of 5000 amperes capacity are in use and are operated without difficulty.

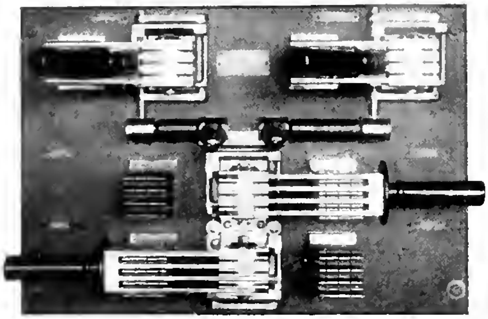


Fig. 5. Interlocked Switch of Special Construction

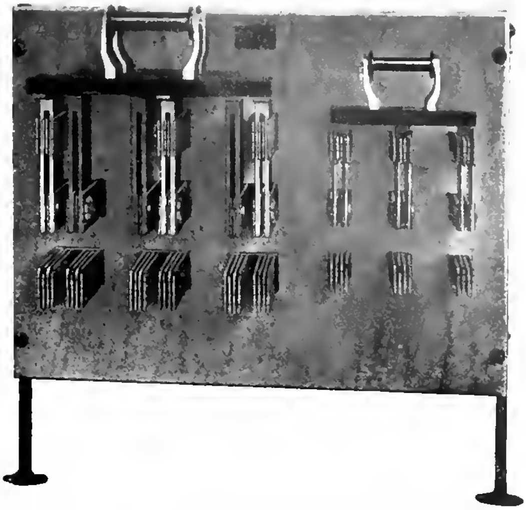


Fig. 6. 4000-Ampere Switch for Starting Synchronous Converter from A-C. Side

In another case, that of a single-pole lever switch for 12,000 amperes, the split lever construction was not considered desirable for the purpose for which the switch was intended, and it was necessary to provide for ease of operation in some other way. This was accomplished by providing a pair of heavy clamps, as shown in Fig. 7, supported from the blade so that the contact clips could be clamped tightly to the blade sections. Spacing pieces between adjoining pairs of clips were provided. The contact clips are not given any "set," or adjustment for pressure, as in the case of the lever switch of standard design, but are left parallel and cause practically no frictional resistance to the movement of the blades when the switch is opened or closed. As this switch is used in a place where it need seldom be operated, the adjustment of the clamps by means of a wrench presents no serious inconvenience.

Pole changing lever switch sets for three-speed induction motors of voltages up to 550 volts consist of two double-throw switches, each usually of four poles mounted side by side, thus resembling a starting switch combination for six-phase rotary converters. They are, however, used only for changing the motor connections, the switching on and off of the current being done by means of the compensator switch. If it were possible for the operator to close the pole changing switches into certain sets of contacts it would allow an induced current to flow in one of the motor windings, and to avoid this the switches must be interlocked in certain positions. In order to avoid a wrong sequence of operations, the adjoining ends of the cross-bars are beveled and overlapped, constituting the simplest conceivable form of interlock, which is at the same time entirely adequate. These pole changing switch sets have been developed in such a way that for motors of different internal connections the order of operation is the same in changing from low speed to medium, and from medium to high speed. The switches are sometimes mounted on a slate base supported on the side of the motor stator, just above the motor connection board, so that the motor and pole changing switch set are a unit. This is of considerable advantage where the available space for switching apparatus is limited.

Fig. 7. 12,000-Ampere Lever Switch of Special Construction

Fig. 8. Single-Pole Pivot Switch with Guiding Clips

A single-pole pivot lever switch is shown in Fig. 8, the feature of interest being the slotted guide for the blade which guards the contact clips against undue lateral strain when the blade is thrown in. The guide brings the

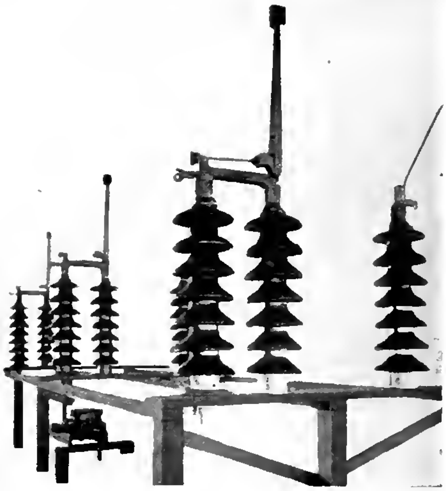


Fig. 9. Motor Operated Mechanism Attached to 110,000-Volt Disconnecting Switch

blade properly into line before it can begin to enter any contact. Such switches are used for changing transformer tap connections to a circuit.

Occasionally, when developing a switching arrangement for unusual conditions, there appears to be a need for some such interlocking device or special construction as has been described; but in a considerable number of such cases it is found to be possible to avoid its use by means of a different arrangement or interrelation of standard apparatus. It may be of interest to mention that sometimes as much thought is required to accomplish this as to develop a complicated interlock to suit the condition.

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# THE APPLICATION OF DIRECT-CURRENT MOTORS TO VARIABLE SPEED DRIVE

By R. S. Sage

Power and Mining Engineering Department, General Electric Company

The forepart of this article is devoted to a brief discussion of the elementary principles involved in producing variation of speed in d-c. motors, and shows why the commutating pole is a requisite in the design of motors to be used for wide speed ranges by the field control method. After a short statement as to the general classes of power requirements some space is given to a more detailed description of the three control systems and a discussion of their adaptability to the three general classes of power requirements; the third method (field control) receiving special consideration. The concluding paragraphs deal with the subject of compound windings for motors of this class, and close with the statement that the application of the commutating pole adjustable speed motor should prove of advantage in the majority of drives for variable speed apparatus.—Editor.

With the general appreciation of the advantages of electrical drive in the factory, mill and shop, there has come a continued demand for motor drives to suit the numerous varieties of service conditions that obtain in these fields. Nearly every type of machine has operating characteristics, distinctly its own, and a careful study of these is desirable and often essential before the selection of a drive is made.

Electrical manufacturers have developed standard lines of motors covering a wide range of capacities and speeds, but notwithstanding, on account of the development of new types of machinery and the almost unlimited capacity and speed combinations which are possible, it is often necessary to meet the demand with special designs of motor drives.

The advantages to be gained in the driving of many types of apparatus at variable speeds, without the usual inefficient and more or less unsatisfactory mechanical devices for this purpose, has opened up an extensive field for the electric drive, and at the same time has furnished an incentive for developing the direct current adjustable speed motor to its present degree of perfection.

It is the purpose of this article to outline some of the considerations incident to the application of electric motor drive to variable speed machinery.

As for the induction type of alternating current motor, it does not find extensive application in this field, which often requires continuous service at wide ranges in speed, for up to the present time no method has been devised whereby these operating conditions can be met with a degree of success comparable to that of the best direct current system. Its use, however, on one of the various systems now employed may be advisable under certain circumstances; for instance, if d-c. power is not available and the demand for adjustable speed drive does not warrant the installation of a d-c. generating set.

The subject matter following will therefore apply to the consideration of the direct or continuous current motor only.

The term "adjustable speed" as applied to motors is understood to mean variation of the operating speed, which is under control and capable of adjustment as by some means external to the motor. This is in distinction from variations in speed due to the inherent characteristics of the machine itself, such as the change of speed due to load change in series motors. Under adjustable speed motors are classed shunt motors and compound motors with light series fields.

The advantages reserved to the d-c. motor for many industrial motor applications may be said to be due to the advent of the commutating pole into the design of d-c. apparatus. Indeed, the benefits gained by the use of commutation poles are so many and positive that it is now common practice to supply them with practically all direct current machines, including motors even for constant speed service. Increased overload capacity, better commutating ability under all loads with consequent increased commutator and brush life, reversible operation with one brush setting, decreased bulk per horse-power and speed adjustment possibilities, all declare for real advantages by the use of commutating poles in motors.

### Methods of Motor Speed Control

The fundamental equation of the d-c. motor may be written $V_L - V_R = V_B = K \times \phi \times N$, (1)

where $V_L$ is the line voltage, $V_R$ the voltage drop due to internal and external resistance of the armature circuit, $V_B =$ the back or counter e.m.f., $K$, a constant for a given machine; $\phi$, the armature flux and $N$ the motor speed. Assuming $K$ constant, the only way of changing the speed $N$ is to change the values either of $\phi$, the flux through the armature, or of $V_B$. To change the value $V_B$ requires the variation of the value of $V_R$, if $V_L$ is constant, or of the value of $V_L$, if $V_R$ is constant.

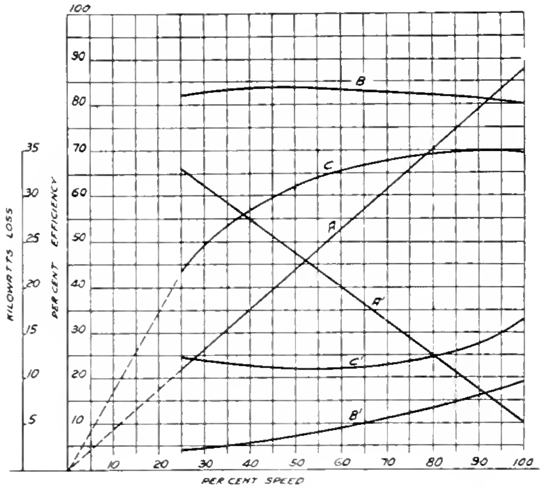

Fig. 1. Comparison of efficiencies and losses of a 50-h.p. motor for 4 to 1 speed range on three systems of control. Curves *A*, *B*, and *C* and $A^1$, $B^1$, and $C^1$, represent efficiencies and losses respectively for armature resistance, field weakening, and variable voltage systems

The manipulation of any one of these three elements therefore constitutes the three general methods of obtaining speed variation in d-c. motors. As a matter of fact, the quantity $K$ may also be variable and produce speed changes, as for example, with a motor having a double armature winding and two commutators. However, this method, as well as a few others, are eliminated from discussion as being comparatively uncommon and limited in their application.

These three general methods as put into practice consist of the following:

(a) *Variation of* $V_R$, by means of a variable external resistance in the armature circuit, the field being excited by a constant line voltage producing constant value of flux through the armature. The internal voltage drop at full load current being only about 5 per cent of the line voltage, the speed is, for a given armature current, practically inversely proportional to the external resistance. Since the entire armature current passes through the external resistance, the energy absorbed by the system is proportioned between the motor and the resistance in the ratio of the voltage across them so that the efficiency for a given current varies nearly directly as the speed, as shown in Fig. 1 (A).

(b) *Variation of* $V_L$, or supply voltage. In this method $V_R$ becomes simply the internal voltage drop and is constant for a given current; also as the field is excited at a constant value from an outside source, the speed varies directly as the line voltage. The usual method is to vary the voltage of a motor-driven generator by means of an adjustable rheostat in its separately excited field, one such generating set being required for each motor controlled. The only losses incurred (external to the motor itself) in thus reducing the speed of the motor are those of the generating set and generator field rheostat. The efficiency of this method is in general considerably higher than for the previous system, especially at reduced speeds. An adaptation of this system, known as the multiple voltage system, is also used, in which two or more supply circuits are provided at different constant potentials, with switching arrangements for throwing the motor from one to the other. Intermediate speeds may be obtained either by means of resistance in the armature circuit or by field weakening, which method will next be described. In the multiple voltage system there is necessary either several individual generators for each circuit, a single generator with balancer set, or a three-wire generator or rotary converter with auto-transformer.

(c) *Variation of $\phi$*, the flux passing through the armature, gives the third general method of speed adjustment. This may be accomplished in a somewhat indirect way by changing the reluctance of the magnetic path, as by varying the air gap, removing iron from the magnetic circuit, or by decreasing its effective area. The simplest and most practical method is, however, to change the value of the field current by inserting an adjustable resistance into its circuit, a single constant voltage circuit being applied to the armature. From equation (1) it follows that the speed is inversely proportional to the flux, $V_R$ being the internal voltage drop only. The currents handled and losses involved in this system are comparatively small, resulting in high efficiency and ease of manipulation.

The difficulty which until recent years rendered this system impractical for any considerable speed range was that due to the decreased commutating ability at weak field strengths. A brief review of the chief causes of this condition may be of advantage at this point.

Consider the ordinary non-commutating pole motor: The distribution of the magnetic flux around the periphery of the armature may be represented by plotting a curve showing volts as ordinates and commutator bars as abscissæ. Such a curve is shown in Fig. 2. Curve $F$ represents the shape at no load, which is due to the field alone, and $A$ the flux due to the magnetization of the armature under load, this being displaced 90 degrees from the field flux. The resultant flux distribution at full load would then be as shown by curve $r$, in which it is seen that the neutral position is shifted back to the point "$n$," at which point the brushes must be placed for good commutation; i.e., at this point the voltage is zero. Now, if the main field strength is weakened, it will readily be seen that the distortional effect of the armature strength shown in the curve $r$ will become very much aggravated and the neutral position still further shifted from the geometrical neutral. Furthermore, the field strength necessary for the reversal of the short circuit current during commutation is greatly weakened. The result is that commutation is accomplished with a great deal of sparking and operation rendered impractical. This shifting of the neutral, even in motors with slight field weakening, makes the ordinary motor unfit for reversing duty.

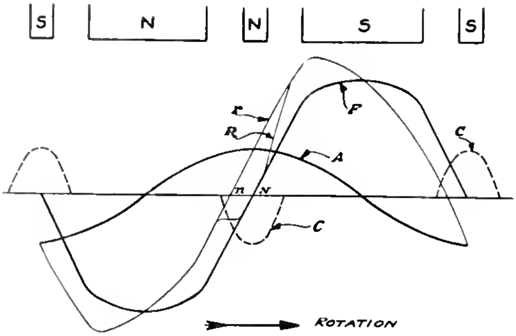

Fig. 2. Flux Distribution

$F$—Field form of shunt field alone—no load.
$A$—Field form produced by armature magnetization—full load.
$r$—Resultant of $F$ and $A$—full load.
$C$—Commutating field—at full load.
$R$—Resultant of $F$, $A$ and $C$—full load.
$N$—Geometrical neutral point.
$n$—Neutral point displaced by field of $A$.

In practice, where commutating poles are not used, it is necessary that the field strength have about double the armature strength for good commutation. For this reason it is found that the limit of speed increase by field weakening for such motors is ordinarily 15 to 30 per cent.

The use of the commutating pole, however, has overcome these difficulties to a large extent and the large number of this type of motor now in successful operation, through speed range ratios of three to one and four to one, and even higher, demonstrate its practicability for this system of speed control.

From the foregoing it is seen that the function of the commutating pole, or interpole, is to provide a flux which will neutralize the neutral shifting effect of the armature cross magnetization, and also to furnish sufficient commutating flux for the reversal of the current in the short circuited coils under the brushes.

The poles are placed midway between the main pole pieces and are magnetized by a winding which is in series with the armature, thereby producing a flux which is proportional to the distorting flux of the armature.

The curve $C$ represents the field produced by the interpole and $R$ the resultant field. Its effect is seen in keeping the neutral point stationary, under which condition a motor of otherwise good design is capable of having its speed increased by field weakening to a point where the armature strength exceeds the field strength by a large percentage.

### Power Requirements

The power requirements of variable speed apparatus can be divided into three general classes as follows:

1st: Loads requiring constant power; i.e., torque inversely proportional to the speed.

2nd: Loads requiring constant torque; i.e., power directly proportional to the speed.

3rd: Loads with power increasing faster than the speed; i.e., torque increasing directly in some proportion to the speed.

These statements follow from the fact that rotative power is the product of the torque and speed.

The service may be continuous or may be intermittent for any of these load conditions.

The torque developed by a motor is directly proportional to the armature current and the field flux, and for a given machine the torque in foot pounds is given by

$$T = 0.00196 \times Ca \times q \qquad (2)$$

where $Ca$ is the armature current in amperes, and $q$ is the volts per r.p.m. in terms of terminal voltage. (The torque available at the motor shaft is this value multiplied by the efficiency.) By referring to equation (1) it is seen that the quantity $q$ is proportional to the flux $\phi$, being the product of the design constant $K$ and flux $\phi$. From the equation (2) the current and speed relations are readily observed for any of the power conditions mentioned above and with any of the different systems of control.

### Most Suitable Method of Control

While the determination of the system which can be most advantageously employed in obtaining speed adjustment in d-c. motors is dependent upon a number of factors, and a study of each individual application is advisable before a selection is made, the nature of the operating conditions is the first great consideration and in many cases eliminates at least one system from further consideration. For example, the speed range may be so large that the field control method alone is impractical; or the adjustment required may be so fine and at the same time the range so great as to eleminate all but the generator field control method. Again the speed regulation at any particular setting may be of great import, thus prohibiting the use of armature resistance control.

Among other factors which have an important bearing on the system used are operating efficiency, cost of energy, first cost of apparatus, ease of control, reliability, etc.

### Speed Control by Armature Resistance

Speed control by the armature resistance method may be said to be permissible under quite a number of conditions, but as a means of obtaining even a moderate range in speed with either constant power or constant torque for continuous service, it is entirely inapplicable from a standpoint of economical operation. Aside from its low efficiency, bulky and expensive rheostats are required, which obviously constitute disadvantages.

Another serious objection to its use is the series characteristics which obtain at varying torques. At low speeds, changes in torque (i.e., armature current) are accompanied by nearly proportional inverse changes in speed. Hence it is not adaptable to those drives which are subject to load fluctuations and which require nearly constant speed irrespective of load.

Applications which may admit of its use are those which require greatly reduced power at the low speeds; viz.: Service of the third class mentioned above, or constant torque intermittent service. Thus it is used for driving fans in which the power required varies nearly as the cube of the speed. Or again, its use is often satisfactory in combination with field control to obtain extreme low speeds, especially if the output is low at this speed or if for short running periods. For example, it is used with printing press motors (usually in combination with field control) to secure low speed running for short periods.

Were it not for the indirect advantages secured by commutating poles, their use in motors on the simple armature resistance system, to obtain perfect commutation, would perhaps not be necessary, since those conditions which render good commutation difficult are particularly lacking in this system.

The chief concern from a design standpoint is for the radiation of the losses at the low speed without undue temperature rise. The ventilation, being appreciably restricted at low speeds, the heat radiating ability is considerably poorer, so that for a given loss the temperature rise of the motor, both armature and field, is greater the lower the speed. Since in equation (2) the quantity $q$ is constant for this system of control, it follows that the torque is directly proportional to the armature current; therefore for constant torque service the current taken by the motor is constant at all speeds and the $I^2R$ losses constant. (Actually the current must increase at low speeds on account of the lower efficiency.) The capacity of the motor is therefore determined by the power output at the maximum speed with margin sufficient to enable the motor to run cool under the low speed conditions.

### Adjustable Supply Voltage

As previously stated, this system provides a very flexible and rather efficient method of speed control, and. moreover it is not subject to the objection in the foregoing system regarding instability of speed on fluctuating torques, since the motor is directly across the supply circuit and the speed change under various loads is that due to the inherent regulation only. Curve *C*, Fig. 1, shows the efficiency of a 50-h.p. constant torque motor on this system. Its use, however, is limited on account of the cost of auxiliary generating apparatus. The generating set usually consists of a motor-driven generator which operates the working motor directly off its terminals; or the generator may be connected in series with the motor and the line circuit and deliver variable voltage to the motor by a "boost and buck" action. The multiple voltage system also requires a considerable outlay in generating machinery and also in a suitable distributing system requiring the use of three or more wires. The chief disadvantage is therefore that of high cost.

This system is applicable particularly to constant torque service or that of the third class above, and provides a very efficient means of starting heavy loads. It is used for motors driving the rolls of paper calenders, cold rolls in steel mills, and also for mine hoists, etc.

The remarks made above regarding the capacity and commutation conditions for motors with armature resistance control apply also to this system of control.

### Variation of Field Current

This system affords a simple and efficient means of speed adjustment in motors on a single constant voltage circuit without the use of auxiliary apparatus other than a field rheostat. By reason of its simplicity of operation, comparatively low first cost and high efficiency, it finds more extensive application than either of the foregoing systems, for industrial service.

The efficiency of this type of adjustable speed motor falls off comparatively little at high speeds, the tendency being for the decreased field losses to offset the increased friction and windage loss. Fig. 1 (*B*) shows this characteristic for a 50-h.p., 4 to 1 speed motor for constant torque. For constant rated power output the curve would be little changed, being slightly higher at the 50 per cent speed point. At low speeds the efficiency is apt to be high at light loads and at high speeds high at overloads.

The change in speed from no load to full load of shunt wound adjustable speed motors is but a small percentage of the full load speed, usually not exceeding 5 or 6 per cent, and the regulation tends to be lower at weakened field, due to the weakening effect of the commutating field on the main field. Thus the undesirable series characteristics encountered with armature resistance control do not obtain.

### Limitations (Field Control)

A reference to equation (2) will show that in this system the torque is inversely proportional to the speed and that the output is constant throughout the speed range. It is therefore primarily a constant output system. However, at the high speeds, on account of the increased radiating ability, it is possible to increase the armature current and thereby the torque and output. The amount the current can be increased depends upon the speed range, and for speed ranges approximating 3 to 1, it is ordinarily limited by commutation rather than heating.

Motors obtaining increased speed by field weakening are being built to successfully operate through ranges of 4 to 1, and in small capacities even 5 or 6 to 1, and the limitation is, in a great many cases, a mechanical consideration. Thus it is impractical to run commutators at much above 5500 feet per minute peripheral speed because of the difficulty experienced in obtaining perfect brush contact at these speeds. Again, in the larger sizes the commutator construction necessary to withstand the high strains is costly, involving as it does the use of shrink rings, possibly more expensive brush rigging, and in some cases forcing the design out of the bearing bracket type into the pedestal bearing class, which again means increased cost.

These difficulties especially attend motors designed for voltages of 230 volts and less. Adjustable speed motors for field control to operate on voltages above 230 volts, e.g., 500 to 600 volts, are subject to closer limitations in capacity and speed range than on the lower voltages, so that a finer electrical design is often necessary with a resulting higher cost. It is therefore advisable, if possible, to operate on the lower voltages, particularly on wide speed ranges.

If the field weakening system is applied where constant torque only is required, then generally speaking, there will be available at low speeds a capacity in excess of that required. This, of course, means higher first cost of motor, since the size of the motor is determined by the maximum output required and the minimum speed at which it is necessary to run.

Fig. 3. Standard Type of Planer Motor. Rated 35 h.p., 250/1000 r.p.m., 230 volts. The planer is one of the more recent to which the adjustable speed motor has found application

This fact is sometimes overlooked, and when a motor is wanted, for example to deliver 25 h.p. at 400 r.p.m. and 50 h.p. at 800 r.p.m., it is often not appreciated that this machine will be very close to the size of a 50 h.p. at 400 r.p.m.

If it is known, however, that the output necessary at the low speed is less than at high, i.e., constant torque or class 3 service, it is often possible, especially in the case of wide speed ranges, to apply a motor in a smaller frame than would be required for constant horse-power throughout the range. This is also often the case even in constant horsepower service when it may be necessary to operate at full output at low speeds for short periods only.

It is seen, therefore, that although theoretically an adjustable speed motor for constant torque service by the field weakening method would be larger than one for the same service by the armature rheostatic method by the ratio of the speed ranges, practically it may be made smaller than this.

### Applications (Field Control)

In the field of application requiring constant output to which this system is adapted, is included all machine tool drives, comprising lathes, boring mills, shapers, drill presses, cold saws, milling machines, etc. The driving of rubber calenders and cold rolls in steel mills are also notable examples of this application.

Examples of those applications which require constant torque and for which the field control method is very often used are centrifugal pumps, plunger pumps, positive blowers, air compressors, conveyers of various sorts, hoists, rotary printing presses, etc.

The recent application of the d-c. motor to reversing planer drive affords a good example of the capability of the commutating pole motor to successfully operate under rapidly varying power and speed conditions. These motors ordinarily have a speed range of 250 to 1000 r.p.m., with their rated output based on a two-hour run at 500 r.p.m. On the cutting stroke the speed is from 250 to 500 and at the end of the cut the speed is brought to zero, the motor reversed and the speed increased to 1000 r.p.m. in the opposite direction in the course of a few seconds. The return stroke is made at 1000 r.p.m. and the motor is again brought to a standstill and reversed for another cut at low speed. The control equipment is such as to allow the return and cut to be made at any desired speed within the speed range.

The question as to whether armature control should be combined with field control, thus giving a lower first cost motor, is dependent upon the total range, the output desired at low speeds and its duration, cost of energy, etc., and consideration of these factors should determine the advisability of its adoption.

Thus in service of the nature of class 3, in which the range is wide and the power drops off greatly with the speed, as in centrifugal fans and some types of blowers, there is a possibility of greater efficiency at low speed, besides a lower cost motor, by adopting armature control in part.

The General Electric Company has standardized sizes as large as 50 h.p. for 4 to 1 speed range at 230 volts for constant output, continuous duty, and 3 to 1 at 550 volts; and have built for continuous service 4 to 1 motors in 75-h.p. to 125-h.p. capacities, with reduced torque at the extreme low speeds. There are also in successful operation numerous adjustable speed motors of larger horse-power capacities, among which are duplicate 300-h.p. 230-volt motors with a speed range of 400 to 800 r.p.m. by field control, for constant output continuous service, for driving cold rolls, in a steel mill. These are also capable of carrying two-hour overloads of 25 per cent at either speed and maximum momentary loads of 200 per cent and 175 per cent respectively at 400 r.p.m. and 800 r.p.m. For similar service the same company has furnished a 225-h.p. 500-volt motor for operation through a speed range of 225 to 675 r.p.m.

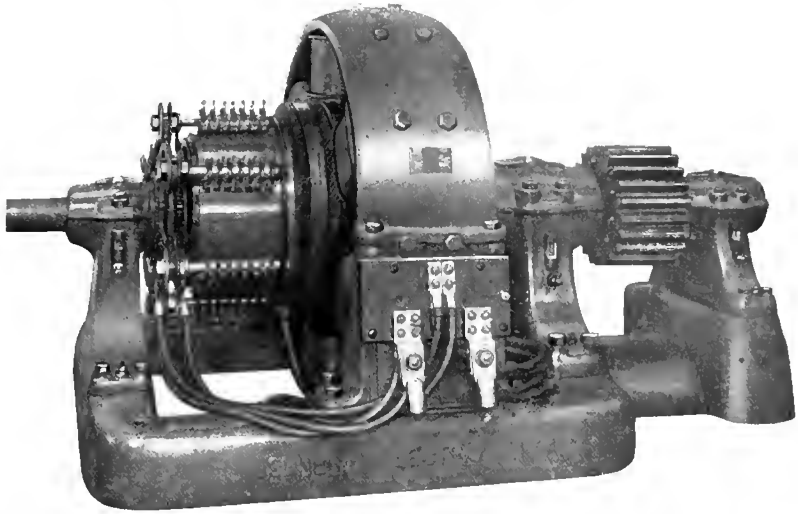

Fig. 4. One of a Pair of 300 H.P., 400 800-R.P.M., 230-Volt Motors for Gearing to Cold Rolls of Sheet Steel Mill

### Compound Wound Motors

For most adjustable speed applications using field control shunt wound motors are satisfactory, having good regulation and in reversing service allowing of simpler connections. However, compound wound motors are sometimes desirable usually on account of the higher starting torque afforded with the same armature current, as for example with reciprocating air compressor drive or apparatus having a high static friction to overcome.

Often a machine requires a strong torque at starting, but when up to speed requires better regulation than afforded by a compound motor. For this service the motor is supplied with its usual strength of shunt field winding and in addition is wound with a series winding which is in service only at starting and is automatically cut out by the starting rheostat when the machine has reached its running speed. The use of motors for printing press drive affords an example of the application of this type of winding.

When for any reason an adjustable speed motor with any considerable speed range is made compound wound and the series winding left in service at the maximum speed, it is important to make sure that the motor will at all times be positively connected to a load sufficient to hold its speed below the maximum for which the armature has been mechanically designed to run. For at extreme weakened shunt field, the field produced by the current in the series winding may be a large proportion of the total field strength and the loss of this series field by losing the load would leave the machine with such a low field flux that the speed might attain a sufficiently high value to cause an arc-over or mechanical rupture of the armature.

Since motors for wide speed ranges are generally designed with high flux densities at the low speed it is questionable if the addition of a series winding for starting purposes would produce an additional torque of any practical magnitude.

In concluding it may be said of the electric drive for variable speed machinery that its problems admit of simpler solution and its application finds greater scope, through the adoption of the commutating pole type of motor with field control on a single voltage circuit, and there are comparatively few instances in which it is not of advantage to either wholly or partially apply this system.

# THE ECONOMIC SIGNIFICANCE OF THE RELATION BETWEEN LINE VOLTAGE AND LAMP VOLTAGE

By M. D. Cooper

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Long continued study and investigation, in which the author has taken a large part, has shown that the rated voltage of incandescent lamps is on many occasions not the most economical value of electric pressure to apply. After a detailed discussion of the many factors influencing the quality and cost of electric power and light, the author describes several cases in which all persons concerned were benefited by lamp operation at slightly over-voltage, or at least not below rated voltage. To substantiate the arguments presented in favor of an over-voltage operation the author concludes with facts taken from electric census reports, which show that the tendency of practice has been in this direction for a number of years.—Editor.

In earlier days electric light was considered a luxury, to be afforded only by the family whose income was above the average. Electrical development has been so fast that now-a-days electric light is considered by a majority of its users to be a necessity and it could be classed as a luxury only in the humblest of homes. Except in those places where cheap gas is available, electric light is fully as cheap, if not cheaper, than any other form of artificial illuminant. This cheapness may be due to the fact that small customers are served at a loss, yet if *full* exploitation of the possible field were made, such relative economies could be made that the service would become profitable. The future promises early developments which will materially aid in the realization of the full possibilities in the lighting field. When this condition comes about, electric light will be no longer classed as a luxury by anyone, but will become an economic necessity for any and all who use artificial light.

The marvelous commercial development that has taken place in the electric lighting industry is in no small degree attributable to the fact, which is the boast of the industry, that while other elements of the cost of living have continually increased, the cost of light has continually decreased. This decrease in the cost of light is due mainly to the continual increase in the efficiency of the apparatus for generating and distributing electric energy and for translating this energy into light. As the cost of operation has decreased, corresponding decreases in the rates of charge for electricity have been made.

That decreasing the price of a commodity will increase its consumption is an economic axiom which no one will deny. The relation between the decrease in price and the increase in consumption will depend largely upon the nature of the commodity. The Massachusetts Board of Gas and Electric Light Commissioners has furnished some interesting figures on this relation as applied to electrical energy. Data compiled from their report show the sales of current in various cities and towns as depending upon the average selling price per kilowatt-hour. During the period of time covered by the data, it is reasonable to assume that no marked changes transpired in selling methods, amount of sales effort, etc., and that therefore the figures show the true economic significance of the effect of selling price on sales. The figures given show that the consumption varies inversely as the square of the price approximately, indicating, for example, that a 10 per cent reduction in price would result, not in a loss in gross income, but actually in a gain of 10 per cent. The latest census of the electric light industry also gives interesting figures on this subject:

| Year | Million Kw-Hr. Sold | Population (1900 and 1910) | Sales—Kw-Hr. per Capita | Income from Sale of Current | Average Price per Kw-Hr. |
|---|---|---|---|---|---|
| 1902 | 1880 | 76,303,387 | 24.6 (=100%) | $ 84,000,000 | 4.48c. (=100%) |
| 1912 | 8628 | 89,912,353 | 96.0 (=390%) | 287,000,000 | 3.33c. (= 74%) |

Thus for a decrease in price of 26 per cent, there followed an increase in sales per capita of 290 per cent. These figures would indicate that the sale of current varies inversely as the 4.6 power of the average selling price. The change in price is in this case not the only cause of increased sales, since during the ten year period there was a vast increase in the amount of sales effort expended.

If it were possible to obtain figures on electric *light*, instead of electric *energy*, it would probably be found that a similar conclusion would result—namely, that a decrease in cost of light of any given percentage would result, not in a proportionate reduction in the amount spent per capita for light, but in an increase in this expenditure of at least as great a percentage.

At the time of the introduction of the tungsten filament lamp it was greatly feared that its use would make heavy inroads upon the income of the central stations. Sufficient time has now elapsed to fully dispel this fallacy, for it has been found that the resultant decrease in the cost of light has so extended the use of light and the possibilities of electric service, that the balance is entirely on the other side of the ledger. To quote a statement of a prominent central station manager, "The mazda lamp and the flatiron are the sheet anchors of the electric lighting industry."

To illustrate the general economic or commercial aspect of the relative cost of light and the relative satisfaction derived from its use, may be cited the case of two small middle-western cities. One is a town of 2500 inhabitants and the other of 300 inhabitants. They are located near together and are both supplied from the same station, under the same management and under like policies.

The larger town has 150 electric customers or 30 per cent of the total possibilities and the smaller town has 50 customers or 80 per cent of the total possibilities. In casting about for a reason for this difference it was found that the lamps in the larger town were operating under such voltage conditions that they failed by about 30 per cent to give their full rated candle-power, while the lamps in the smaller town were burned up to voltage and thus were giving their full rated candle-power. It was stated that in the larger town complaints of dim light were numerous. As nearly as could be ascertained, the difference in quantity of light obtained was the sole reason for the great difference in the realization of the possibilities of electric service in these two towns.

The term "electric service" has in recent years come to mean much more than the mere supply of electric energy. Many stations are supplying free renewals of incandescent lamps and free renewals of arc electrodes, many offer inducements of financial assistance in the installation of wiring, many maintain periodical inspection of current consuming devices to see that they are operating properly, many render assistance in the design of lighting or power installations, and many supply current consuming devices free or at reduced rates. These and many other items are included under the general term "electric service."

That these items of service are profitably given shows it is a good commercial policy to increase the use and satisfaction that the customer derives from his electricity supply.

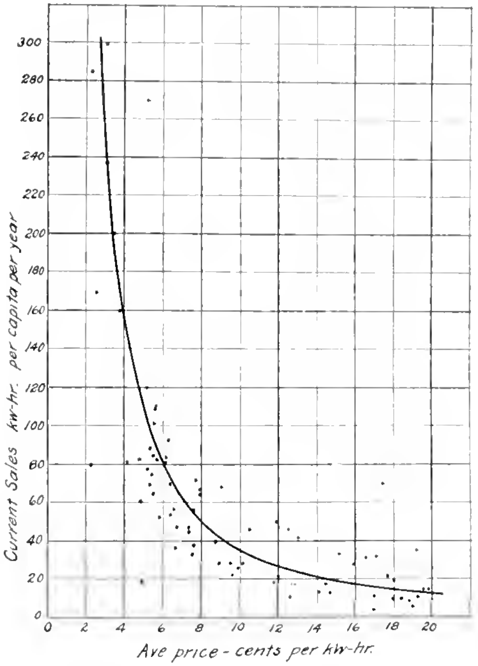

Fig. 1

Except in the case of power consumers, it is *light* that constitutes the main item of electric service, and by the degree of satisfaction and the economy in its use is the customer's opinion of the service gauged. Any increase in the economy of light production that it is possible to make will therefore result in distinct gain to the station.

The production of light by means of incandescent lamps involves the consumption of two things—current and lamps. For any given type and size of lamp, the amount of light it will give or the amount of energy it will consume is merely a question of the length of life it is desired to obtain, and conversely, the length of life obtained is merely a question of the light production or current consumption desired. Light and life are mutually exclusive—either is obtained at the sacrifice of the other, hence the satisfactory operation of incandescent lamps depends upon getting a proper balance between these two items.

The cost of light is made up of the same two items, the cost of energy and the cost of renewals. As the electric pressure supplied to a lamp is increased, the cost of energy per candle-power decreases and the cost of renewals per candle-power increases. Since the increase in one and the decrease in the other are ordinarily not of the same magnitude, it therefore follows that a change in the impressed voltage will affect the economy of light production. As the voltage is increased up to a certain point, the decrease in energy cost per candle-power is greater than the increase in renewal cost per candle-power; therefore, with this point as a limit, an increase in the voltage supplied to a lamp will result in an increase in the economy of light production.

The controlling factor in determining at what voltage or at what efficiency a lamp should be operated has in the past been the length of the lamp life which the public deemed to be satisfactory. In the early days of the carbon lamp, a life of about 500 hours was considered satisfactory, and as the quality of the lamps improved the life became longer and longer, till the public became accustomed to the use of lamps which were very long lived. When the tungsten filament lamp first appeared on the market, it was relatively expensive, and in order to keep the proper balance between energy cost and renewal cost, it was rated at such an efficiency that it gave a very long life. This still further increased the public idea as to the life which a lamp should give. As the quality of the lamps has been improved and as the price has been reduced, the life has been held at the same figure, when economically and logically it should have been reduced. The net result today therefore is that in the opinion of the public the quality of a lamp is a matter largely of the length of its life, and not, as it might better be, a matter of its economy in the production of light.

In actual point of fact, the energy element in the cost of light is of far greater importance than the lamp renewal element. Take for example a 40-watt lamp; during its rated life of 1000 hours it will consume 40 kilowatt-hours, which at ordinary lighting rates would cost from \$3.00 to \$4.00. The lamp cost is only \$0.30, or less than one-tenth of the total cost of operating the lamp. The renewal cost being relatively so small, it is apparent that it is not economical to conserve the \$0.30 item at the expense of efficiency of utilization of the \$3.00 or \$4.00 item.

An increase of one per cent in the voltage supplied at the terminals of a mazda lamp will result in the following characteristic changes: An increase in candle-power of 3½ per cent; an increase in energy consumption of 1½ per cent; and an increase in renewal expense of 15 per cent. Since the renewal expense is generally less than one-tenth of the total expense, a 15 per cent increase in this item is equivalent to not more than 1½ per cent on the total; therefore, an increase of one per cent in voltage will cause an increase of about 1½ per cent in the total cost of operation, and since the corresponding increase in candle-power is 3½ per cent, it follows that each per cent of increase in the voltage supplied will result in a net gain to the customer of ½ per cent in the economy of light production. Since the renewal expense increases relatively faster than the energy expense, there is a limit to the voltage increase which will result in a gain in the economy of light production. For ordinary cost of current, this limit is from 4 to 8 volts above the rated voltage of the lamps. Within this limit, and particularly if lamps are being burned at a pressure less than their rated voltage, an increase in line voltage will be a distinct benefit to the central station's customers in amount of light and in economy of its production, and to the central station in amount of revenue.

Increasing the voltage on the circuits of a central station results in a paradoxical condition whereby everybody gains—the customer gets more light, better light, and cheaper light, the central station sells more current, and the lamp manufacturer sells more lamps. It is true that the expenditure the customer makes is not decreased, but he gets an amount of light proportionately greater than the increased expenditure, therefore the change is a net gain for him.

The fallacy of the fear that increasing the efficiency and candle-power of lamps will cause a proportionate reduction in the income of the central station has now become fully demonstrated. On the introduction of the tungsten filament lamp such fears were expressed. The introduction of the lamps has been very gradual, and although the average income per socket may have, in general, been slightly decreased, yet the extension of the electric lighting field and the lengthening of the hours' use of light, due to the lesser cost, have maintained the income not only above the point which would be representative of a decrease proportional to the increase in efficiency of the lamps but actually have lead to an increase in income. Such increases in candle-power as are brought about by slight increases in voltage would not be of as great a magnitude as the change from carbon to mazda lamps, hence should not occasion any fear of decreased income due to customers using smaller lamps.

It is interesting to note in this connection the marked increase in the general standard of illumination that has come about during the last few years. Records show that the average candle-power of all incandescent lamps sold in this country has increased from 26.0 in 1911 to 28.3 in 1912, and to 32.5 in 1913. These figures, in connection with those previously given as to the decrease in rates and increase in central station income, conclusively show that the best way to develop the lighting industry is to give the customer full advantage of every increase in efficiency and economy and every decrease in cost of light that can possibly be made.

By reason of its control over the voltage delivered to incandescent lamps on its circuits, and in comparison with the significance of the rated candle-power, wattage and life of the lamps, the central station has entire command over the quantity and quality of the light received by its customers, over the economy of the production of this light, and over the revenue obtained therefrom. The following table shows the effect of various impressed voltages on the candle-power of a 110-volt mazda lamp:

| Voltage Supplied to a 110-Volt Mazda Lamp | 106 | 108 | 110 | 112 | 114 | 116 | 118 |
|---|---|---|---|---|---|---|---|
| Effect on candle-power | Loss 12.1% | Loss 6.2% | Normal | Gain 6.5% | Gain 13.3% | Gain 20.3% | Gain 27.7% |

**Similarly, the following table shows the effect of voltage on wattage:**

| Voltage Supplied to a 110-Volt Mazda Lamp | 106 | 108 | 110 | 112 | 114 | 116 | 118 |
|---|---|---|---|---|---|---|---|
| Effect on wattage | Loss 5.69% | Loss 2.85% | Normal | Gain 2.89% | Gain 5.81% | Gain 8.75% | Gain 11.73% |

Under a straight meter rate, the effect on income will be proportional to the effect on wattage.

These figures point out the fact that it is advisable for a central station to maintain on its lines a voltage which is no lower than the rated voltage of the lamps used. It is of course impossible to maintain exactly the same voltage at all parts of the distributing system—the many possible causes of voltage variation preclude the possibility of such an ideal state of affairs. The figure which should be thought of as the "voltage of the lines" is the average voltage at *customers' lamp sockets* during the *time when the lamps are in use.* As far as a lighting customer is concerned, it makes no difference to him what the voltage may be at noon, provided, of course, that he is not using his lamps at that time—but it is an extremely important consideration with him that the voltage should not be too low in the evening or at any other time when he wants to use his lamps.

The maintenance of a uniform voltage on its lines by the central station does not always lead to a solution of the "proper voltage" question, since it has often been found that quite a number of different voltages of lamps are found upon the circuits. Unless enough variation in voltage is experienced to warrant the central station in supplying more than one voltage of lamp, it is generally found that the lamps of voltages other than the standard supplied by the central station have been secured from some local dealer. If these lamps are of a higher rated voltage, their use entails a loss of revenue to the central station, a loss of light to the users, and a loss of renewal business to the dealer who sells them. In the great majority of cases where dealers follow such a practice, the reason generally is that the central station is selling lamps at a price the small dealer cannot meet and therefore, in order to make any lamp sales at all, the small dealer feels compelled to use as a selling argument the greater length of life which the lamps will give when they are of a rating a few volts higher than the voltage of the circuit. Where such conditions exist, a positive injury is being done—not only to the parties directly concerned, the customer, the central station and the dealer, but also to the entire electrical development of the city, since the attention of the light-using public is being directed to an element in the cost of light which is of relatively small importance, and opinions are being formed in their minds which will be detrimental to the highest development of lighting service.

In those places where electrical dealers are not supplying the correct voltage of lamps for use on the central station circuits, the station has an admirable opportunity for increasing its revenue and improving its lighting service by taking steps to secure the use of lamps of the proper voltage. In many cases a dealer is supplying an improper voltage of lamp merely because he does not know what the right voltage is or perhaps because the voltage of the circuits has been changed and he has not been informed of the change. In such cases a letter or a phone call will suffice to improve conditions. With respect to the voltage of lamps sold there lies one of the most easily arranged and executed, the most far-reaching, and mutually most profitable lines of cooperation between central station and dealer.

The expectation of the public in regard to the life of incandescent lamps is largely a matter of habit. In places where the lamps have been burned under voltage, with consequent loss of light to the customer, loss of revenue to the station and loss of lamp renewal business to the lamp distributers, the public has come to expect a long life from its lamps; but on the other hand, where the voltage has been kept up to or above the lamp voltage, the customers have become used to a shorter lived lamp and are willing to thus sacrifice a little on life for the sake of the greater and better illumination.

Even where a considerable increase in line voltage is made, the customers are not slow to appreciate the greater illumination secured even though they soon find out that it is obtained at the expense of an increased outlay for lamps. A case in point was encountered recently in the investigation of the voltage conditions upon the circuits of a middle-western city. In this city were two central stations—a private plant and a municipal plant. There was very close competition between the two stations and each one was doing everything possible to improve and extend its service. In a number of places, particularly commercial lighting installations, it was found that both companies had a service entrance and that the customer was provided with a throw-over switch so that he could burn his lamps upon either circuit. Measurement of voltage in such places showed that the pressure on the municipal lines was about 5 volts higher than on the lines of the private company. A number of these customers drew comparison between the amount of light delivered when the lamps were on the private lines and when they were connected to the municipal lines. In all such cases, sufficient experience had been had with operation on both of the lines so that the resulting costs were fully known and appreciated, yet the sentiment of the customers was that they very much preferred burning the lamps on the circuit having the higher voltage.

The comment of a central station manager along similar lines is pertinent to the subject under discussion. He stated, "I do and always have belonged to the 'plenty-of-voltage' class and find that after giving a customer plenty of voltage at his lamps he will not go back to a high voltage lamp for a low voltage circuit. You cannot get light without juice and plenty of it and the average consumer falls in line with this practice very easily unless somebody comes along and says, 'The voltage is too high; the station is all wrong; you ought to go down and see those fellows and find out what they are giving you.' Down he comes and says, 'What kind of voltage are you giving me? My lamps won't stand it. There has got to be something done.' 'Well,' I say, 'you can increase your particular voltage to suit yourself, then kick for lack of illumination, but please keep your nose out of the plant's voltage if you want illumination!'"

The fact that improving the voltage conditions upon the circuits of the central station is a profitable business procedure is fully borne out by the results of many tests which have been made by the organization with which the writer is connected. Two years ago, a series of voltage tests on the circuits of central stations in various parts of the country showed that as a general average the lamps were burning four volts below their rated voltage. Similar tests of a year ago showed an average of two volts under voltage, while a much more extended series of tests very recently conducted shows that upon all circuits investigated the average voltage corresponded almost exactly with the voltage of the lamps.

The advantages to the customer from the standpoint of increased illumination, illumination of a better quantity at increased economy, the advantages to the central station from the standpoint of increased revenue and improved service, and the advantages to the electrical dealers who supply lamps, all point to the fact that lamps should be operated at a voltage certainly not less than their rated voltage.

# NOTES ON THE USE OF THERMO-ELECTRIC APPARATUS IN HIGH FREQUENCY SYSTEMS

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This paper deals with thermo-electric phenomena and shows their application to technical apparatus. The scope of the paper is to show the use of certain apparatus which may be built very readily for laboratory purposes and which are very convenient for measuring currents up to the highest frequencies independently of the shape and length of wave.—Editor.

Most of the instruments used for the lower commercial frequencies cannot be employed for similar measurements in high frequency systems unless special precautions are taken in their design. This is due to the effects of capacity, resistance, and self and mutual inductance. The magnitudes of these quantities are dependent on the frequency and wave-shape. It is therefore readily understood that high frequency apparatus based on the dynamometric principle cannot be considered, and that electrostatic instruments are only applicable where the voltage is rather high. Since many wireless stations are operating with spark systems which produce more or less damped waves it is desirable to be able to design an instrument whose indications are independent of the wave shape or frequency.

All the above requirements are satisfied by a meter which operates on the principle of heat production due to resistance, since the indication is a result of integrated effect and is therefore independent of wave form or frequency. It is due to this fact that the hot wire type of meter has been largely adopted for this class of service. However, this type of meter inherently requires a rather large consumption of energy and is not available for small currents. In the latest type of high frequency meter the resistance is used to heat up one or more thermo-couples and the indications of the instrument are proportional to the e.m.f. of the thermo-couple.

## Heat Evolution Due to Currents of Various Wave-Shapes

In the following section a mathematical treatment is given, in order that the reader may gain a thorough insight into just what happens when the $I^2R$ loss is dissipated. Consider the simplest case, a continuous current $i$ flowing through a conductor of ohmic resistance $r$. We obtain for the quantity of Joule's heat $q$, produced in one second:

$$q = \frac{1}{4189} \cdot r \cdot i^2 \; Cal\ sec \qquad (1)$$

In case of an undamped oscillatory current which obeys the sine law, the heat produced per second is

$$q = \frac{1}{4189} \cdot \frac{1}{T} \int_0^T i^2 \cdot r \cdot dt \; Cal\ sec \qquad (2)$$

where $T$ is the period of a complete cycle. The instantaneous value $i$ is given by the equation

$$i = I\ max. \sin 2\pi f t$$

in which $f$ denotes the frequency. By substituting the effective value of the current,

$$I\ eff = \sqrt{\frac{1}{T} \int_0^T i^2\, dt}$$

in equation (2) we obtain the relation

$$q = \frac{1}{4189} \cdot r \cdot I^2 eff \; Cal\ sec$$

$$= \frac{1}{4189} \cdot r \cdot \frac{I^2 max.}{2} Cal\ sec \qquad (3)$$

Now let us consider the case of damped oscillations. In this case the amplitude of each oscillation gradually diminishes and finally reaches zero; then the oscillations start again with the same original amplitude and continue to diminish as before. That is, wave trains of oscillations are produced, and at any instant the value of the current may be represented by

$$i = I_0 . \epsilon^{-\delta t} \sin (2\pi f) t$$

where $I_0$ denotes the maximum amplitude of the current, that is, the initial value of the discharge, and $\delta$ the damping factor of the oscillation, which is equal to $\frac{r}{2L}$, where $r$ is the ohmic resistance and $L$ the effective self-inductance of the circuit in question. Hence the expression for the energy converted into heat per second may be written

$$q=\frac{1}{4189}N.r\int_0^\infty I_0^2\epsilon^{-2\delta t}\,sin^2\,(2\,\pi\,f)t.dt$$
$$=\frac{N.r.I_0^2}{4189.4\,\delta\left(1+\frac{\delta^2}{(2\,\pi\,f)^2}\right)} \qquad (4)$$
$$\cong\frac{N.r.I_0^2}{4189.4\,\delta}Cal\ sec$$

where $N$ is the number of damped wave trains per second. The logarithmic decrement, $\Delta$, is very often used by present day writers. If it were introduced, equation 4 would become

$$q\cong\frac{N.r.I_0^2}{4189.4.\Delta.f}Cal\ sec \qquad (4a)$$

Hence the effective value of the current of a damped oscillation is expressed by

$$I\ eff\cong I_0\sqrt{\frac{N}{4.\Delta.f}} \qquad (5)$$

since by definition the effective value of any current is that value which a continuous current must have, in order to produce the same Joule's heat with a given resistance.

### Thermo-Electricity—Peltier Effect—Thomson Effect

In 1822, Seebeck found that by heating two dissimilar metals at the contact where they touch one another, a thermo-electric force is produced. For instance if a thermo-couple consisting of two different metals, such as bismuth and antimony, has its junction point heated, a thermo-electromotive force is produced and if the terminals are connected, a thermo-electric current will flow from *Bi* to *Sb*.

In 1834, Peltier discovered that a direct current flowing through a junction of two different metals will heat or cool the point of contact of the two metals according to the direction of flow. Thus if the positive terminal of the applied electromotive force is connected to the bismuth terminal and the negative terminal to the antimony, the junction of the thermo-couple will be cooled, since the latter is absorbing heat; and if the current be caused to flow in the opposite direction there will be an evolution of heat, or in other words the junction point will heat up. Hence we learn that the Peltier effect is reversible and not like the Joule's heat effect, where there is always an evolution of heat regardless of the direction of current flow. It can therefore be seen that the thermo-electric current $i_g$, which is made to flow through a galvanometer, will obey the following equation

$$i_g=k_1\,i_0^2\pm k_2\,i_0 \qquad (6)$$

where $i_0$ is the direct current which is exciting the thermo-couple, and $k_1$ and $k_2$ are constants. The law of heat generation in such a circuit is expressed by

$$q=\frac{1}{4189}\,(i_0^2r\pm V.i_0)\,t \qquad (7)$$

where $V$ stands for the thermo-electric potential difference due to the heating of the junction.

Lord Kelvin discovered a phenomenon similar to the Peltier effect. It is observed in metal conductors where there exists a difference of temperature at different points. For instance, if the direction of the current through a copper wire is the same as that of the heat flow, we obtain an evolution of heat, while if the current flows from a place of low to one of higher temperature an absorption of heat will occur. This effect (Thomson effect) is zero for lead, and therefore it is customary to tabulate the thermo-electric power of different metals with respect to lead. It was later discovered that iron when used with another metal has an inversion of its thermo-electric force at high temperatures. Cummings has experimentally demonstrated that a thermo-couple consisting of iron and copper reaches a neutral point at 275 deg. Centigrade; above this temperature iron is positive and below it negative with respect to the copper. This inversion of the thermo-electric effect was also observed by the writer to be present in crystal detectors, such as are used in wireless telegraphy. For instance when a Marconi wave meter carries too large a current in virtue to its being too closely coupled to the circuit whose wave length is to be measured, the polarity of the crystal changes and the deflection of the galvanometer will be reversed. This is due to the fine contact point becoming overheated on account of the excessive incoming high frequency current. This phenomenon indicated that the rectification by means of such a crystal detector (usually some metal against lead sulphide) is very probably due to a thermo-electric effect, since we observe what is evidently a case of thermo-electric inversion.

### The Thermo-Electric Diagram

In order to better illustrate the thermo-electric relations, the thermo-electric diagram is given, see Fig. 1. This diagram was first suggested by Lord Kelvin, and is very convenient, since from it we are able to read the thermo-electric power of any metal at any temperature. The thermo-electric powers in micro-volts per degree Centigrade are plotted as ordinates, while the abscissae give the absolute temperature of the junctions in degrees Centigrade. Thus for instance at 250 deg. the iron corresponds to −5 micro-volts, for if the iron is heated up to 249½ deg. and the lead to 250½ deg., so that the difference of temperature between the metals is one degree, the voltage of such a thermo-couple will be 5 micro-volts and the current will flow from lead to iron. On the other hand, if a platinum-lead couple be at the same temperature there will only be a voltage of 2 micro-volts and the current will flow from platinum to lead. It therefore follows that the thermo-electric force of a couple consisting of platinum and iron is 7 micro-volts at 250 deg., the platinum being positive.

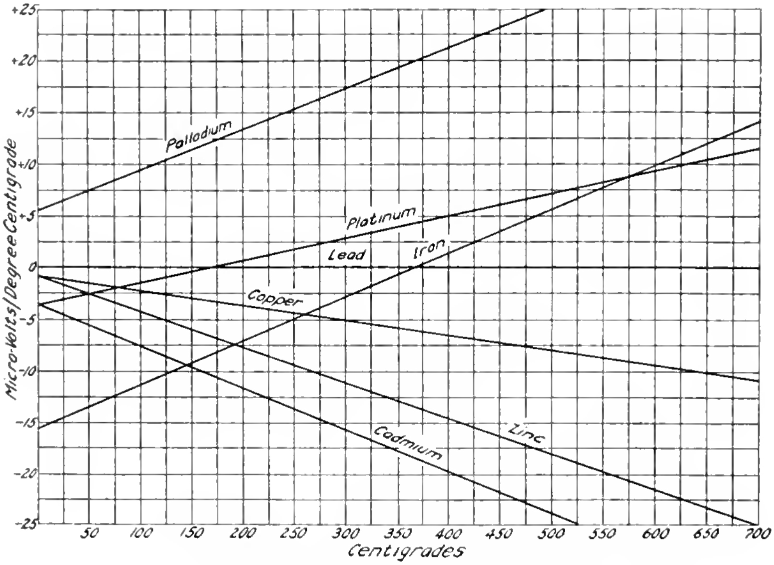

Fig. 1. The Thermo-Electric Diagram for various Metals based on Micro-Volts per Absolute Degree Centigrade

Furthermore, we can study the "electric heat convection" which is known as the Thomson effect. In the case of metals whose characteristics in Fig. 1 slant downward, such as, for instance, cadmium, the heat convection is in the direction of the flow of the current, while in the case of metals whose thermo-electric force increases with temperature, such as iron, the heat travels in the opposite direction to the current. According to the numerous investigations of Le Roux and others, lead does not show any Thomson effect, accordingly there will be no heat convection owing to current flow in this metal, and therefore its characteristic is taken as the axis of abscissae.

### Explanation of the Thermo-Electric Phenomena

According to the electron theory of conduction an electric current in a metal is due to a connection of negatively charged corpuscles or electrons, under the influence of the potential gradient acting at every point in the metal. These electrons are present in all substances as essential constituents of the atoms. Owing, however, to vibrations of the atoms some of the electrons are being continually set free while others are re-entering into combination with the charged residues of the atoms. There are therefore always present a certain number of free electrons, and it has been shown by Richardson that the emission of electrons by heated bodies leads to the assumption that the number of these free electrons increases with the temperature according to a law which is similar to that of the rate of evaporation of a substance. These free electrons are in most cases held back by forces on the surface of the conductor. But when such a material is heated up, the kinetic energy of the electrons becomes sufficiently great to allow some of them to overcome this surface retardation and escape.

On the basis of this theory it is possible to obtain at least a qualitative explanation of the thermo-electric force and the Peltier and Thomson effects. The derivation of the relations involved are all given in Richardson's original paper,* but it has been thought that an illustration of the manner in which the theory may be applied might be of interest in this connection.

Assume a constantan and manganin wire to be soldered together and the junction to be heated to a definite temperature. As soon as this temperature is applied to the junction of the two metals, electrons will be emitted and

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*A paper on Electric Conduction presented at the twenty-first general meeting of the American Electro-Chemical Society, Boston, Mass., April 19, 1912.

therefore a current will flow from the metal which has emitted the greatest number of electrons to the metal which has lost the fewer electrons since it will be the least positively charged of the two. A field will be built up due to this current flow, which will tend to stop further emission of electrons. The current flow will increase until a stable condition occurs in which the constantan and manganin will each be receiving as many electrons as they are giving off. Under this steady condition the manganin wire will have the potential $V_{Mn}$ and the constantan wire the potential $V_{Co}$, we therefore can write the expression for the difference of potential between the manganin and the constantan wires which is the electromotive force at the terminals of this couple

$$V_{Co}-V_{Mn}=\frac{1}{e}\left(w'_{Co}-w'_{Mn}\right)+{}_{Co}P_{Mn} \quad (8)$$

where $e$ is the electric charge of an electron and $w'_{Co}$ and $w'_{Mn}$ the internal latent heat of evaporation of the constantan and manganin wire respectively. The second term of this equation gives the part due to the Peltier effect; it is very small in comparison with the contact potential, that is, the term, $\frac{1}{e}(w'_{Co}-w'_{Mn})$. Considering the Thomson effect we remember that the two elements of the couple are of the same material but their temperatures are different. The intrinsic potentials of the two elements are not equal, due to this temperature difference and therefore the electric potentials of the electrons are different. Richardson has also introduced a formula for the specific heat of electricity, based on this assumption. The formula shows that the Thomson coefficient (specific heat of electricity) is dependent on the temperature coefficient of the latent heat of evaporation of the electrons from the metal.

### The Application of Thermo-Electricity to Measuring Instruments

As was previously pointed out, hot wire meters are not appropriate for the measurement of very small currents, and have a relatively high consumption of energy. For instance the most sensitive hot wire instrument of Hartmann & Braun has a resistance of 9.37 ohms and an energy dissipation of 333 × $10^{-4}$ watts for a 100-mm. deflection, while an ordinary thermo-couple has a consumption of about 50 × $10^{-4}$ watts for a 100-mm. deflection. If such a thermo-couple be placed in a vacuum, the dissipation of energy will be reduced about tenfold. For this reason Flemming, Hausrath, and others have used such thermo-electric instruments with galvanometers of low resistance. †

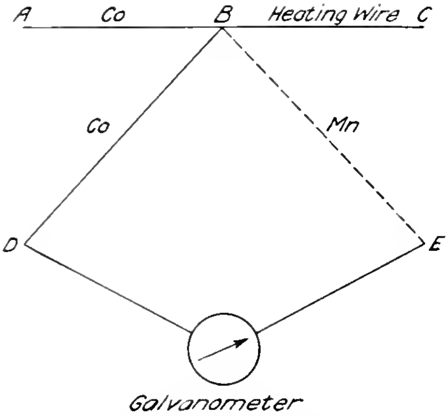

Fig. 2. A Thermo-Electric Current-Measuring Apparatus Employing One Thermo-Couple

Since this apparatus also renders invaluable aid in the measurement of minute direct currents or of small currents of lower frequencies, it seems worth while to give a brief description of those types which can be made up for laboratory purposes.

We shall first consider a thermo-couple, as shown in Fig. 2. $ABC$ is a very short heating wire of constantan, $BD$ and $BE$ are short pieces of constantan and manganin wire respectively. These wires have a diameter of about 2 mils. $BD$ and $BE$ are welded together with the heating wire by means of a very small joint as shown. As soon as a current passes through $ABC$ the junction point $B$ will become heated up and a thermo-electric current will flow through the galvanometer. The condition for maximum sensibility is attained when the resistance of the galvanometer is equal to the internal resistance of the thermo-couple. When using a Deprez-D'Arsonval galvanometer one is able to measure currents as low as 50 × $10^{-6}$ amperes with an ordinary thermo-couple in air. If the effective value of the current to be measured is $I_{eff}$ and the resistance of the short heating wire $ABC$ is $r$, the direct current

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† Flemming, the principles of electric wave telegraphy and telephony, page 470.
W. Dudell, Phil. Mag. (6) 8, 91, 1904, Electrician 55,260, 1905.
H. Brandes, Phys. Z., 467, 1905.
W. Voege, E.T.Z., 467, 1906.
L. W. Austin, Phys. Z. 12, 1135, 1226 1912.
A. Hund, Arbeiten aus dem Elektrotech, Institut Carlsruhe, Vol. III.

passing through the galvanometer may be expressed by the equation

$$i_g = k \, . \, r \, . \, I^2 \, eff \qquad (9)$$

and the deflection $\alpha$ of the galvanometer is given by the expression

$$\alpha = k^1 \, . \, I^2 \, eff \qquad (10)$$

where $k$ and $k^1$ are constants. If $n$ such thermo-couples are connected in series, the deflection $\alpha_n$ of the galvanometer will be

$$\alpha_n = k^1 \, . \, n \, . \, I^2 \, eff \qquad (11)$$

The arrangement of such a system of thermo-elements is shown in Fig. 3. The incoming oscillatory current must pass through the block condenser $C$, which should be of sufficient capacity (about 2 micro-farads) to be approximately a short circuit for the high frequency current being measured, and be of infinite resistance to the thermo-electric current produced in the couples. The galvanometer current is made to pass through a choke coil with an inductance of approximately 0.1 henry, in order to prevent the high frequency current flowing through the galvanometer. In most cases the inductance of the galvanometer itself is sufficient. The design must be so arranged that the points $B_1B_2B_3$, etc., are very fine spots, while the joints at $A_1A_2A_3$, etc., are thoroughly soldered to copper rods which support the thermo-couple and are set perpendicular to its plane. These relatively massive copper rods which support the thermo-net also serve the purpose of conducting the heat away from the joints. Hence, if a current be made to pass through the thermo-elements the $B$ junctions will be heated up, while the $A$ junctions will remain at practically the temperature of the surrounding air. In this way we can obtain a relatively high thermo-electric force at the expense of a somewhat increased dissipation of energy; nevertheless the energy consumption is always far less than that of an equivalent hot wire instrument. The disturbances due to air circulation may be effectively overcome by putting the whole thermo-electric system under a cover. Table I is given in order that the reader may gain some conception of the magnitude of the quantities involved. The couples as used by the writer are shown in Fig. 3 and were made up of about four mm. lengths of constantan and manganin wires. The constantan wire had a diameter of 3 mils, and the manganin wire a diameter of 2 mils.

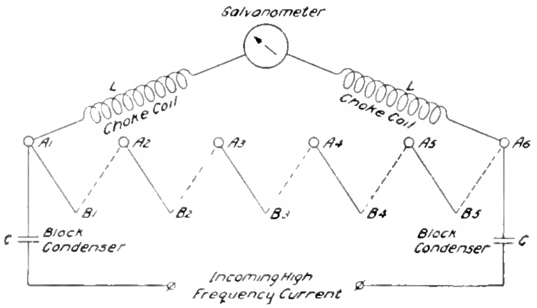

**Fig. 3.** A System of Thermo-Couples and Galvanometer which will give a large Deflection in measuring a small Current and which requires but a small Expenditure of Energy. Its use is limited to Alternating-Currrent Measurements

TABLE I

| High Frequency Milli-amps. | Milli-volts | High Frequency Milli-amps. | Milli-volts |
|---|---|---|---|
| 31 | .55 | 94 | 5.30 |
| 37 | .95 | 99 | 5.95 |
| 43 | 1.25 | 104 | 6.70 |
| 48 | 1.40 | 108 | 7.30 |
| 54 | 1.75 | 113 | 8.05 |
| 60 | 2.15 | 118 | 8.50 |
| 66 | 2.55 | 122 | 9.05 |
| 72 | 2.95 | 126 | 9.70 |
| 77 | 3.45 | 130 | 10.40 |
| 83 | 4.10 | 136 | 11.20 |
| 88 | 4.80 | | |

TABLE II

| High Frequency Milli-amps. | Divisions on the Scale of the D-C. Instrument | High Frequency Milli-amps. | Divisions on the Scale of the D-C. Instrument |
|---|---|---|---|
| 20 | 3.5 | 54 | 43.5 |
| 25 | 4.0 | 60 | 50.5 |
| 31 | 7.0 | 66 | 58.0 |
| 37 | 14.5 | 72 | 70.0 |
| 43 | 29.5 | 77 | 82.0 |
| 48 | 35.0 | 83 | 91.5 |

The indicating instrument was a Hartmann & Braun milli-voltmeter having an internal resistance of 160 ohms, with an 18 milli-volt scale. This combination will of course not give the condition for maximum sensitiveness since the internal resistance of the thermo-couples was only about one-ninth that of the resistance of the milli-voltmeter which replaced the galvanometer of Fig. 3. For this reason Table II is also given. Here a Paul instrument with an internal resistance of only 53.5 ohms was used. All readings are for high frequency currents taken from an Alexanderson machine at 40,000 and 65,000 cycles per second. The indications for these two frequencies did not show any appreciable discrepancy.

For very accurate measurements the arrangement as shown in Fig. 4 is suggested, since here a separate heating wire *AB* is provided, which is located very near to the joints $C_1$, $C_2$, $C_3$, etc. This system can be calibrated by means of continuous current. In order to insure the proper relative location of the joints with respect to the heating wire it is well to fasten it to the thermo-net at different places by means of an insulating material. This arrangement is not quite as sensitive as that shown in Fig. 3, but has the great added advantage that it can be used for direct or alternating currents up to the highest frequencies. This system cannot be used under a vacuum since there would be practically no thermo-electromotive force because the heat conductivity in a vacuum is almost zero. When only two couples are to be connected in series the writer has always used the scheme shown in Fig. 5. In this case the current in any couple cannot flow from the constantan to the manganin and therefore the Peltier effect will not be present, but the thermo-electric forces will nevertheless be added. If large currents are to be measured a shunt must be used, since a thick heating wire of low resistance would change its resistance with changes in frequency, due to skin effect. Even at the lower frequencies errors are liable to be introduced by such parallel paths; we will therefore analyze the conditions and study the means for overcoming these errors. Assume that the heating wire whose resistance is $r_h$ and self-inductance $L_h$ has a current of $I_h$ flowing through it and that $r_s$, $L_s$ and $I_s$ are the corresponding quantities of the circuit in parallel with it. The vector addition of these two currents gives the current in the external circuit. Fig. 6 shows the wiring diagram for this scheme. For the case of sine wave currents the ratio of the magnitudes of the currents in the parallel branches is given by the equation

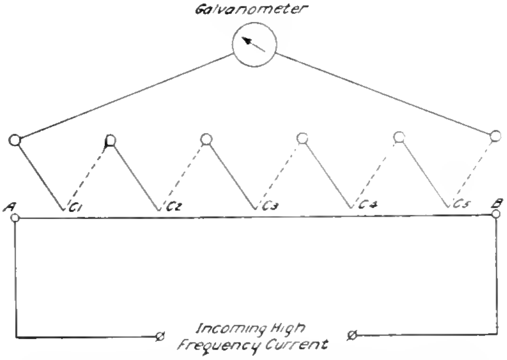

Fig. 4. A System that is more accurate than that of Fig. 3 but not quite as sensitive. It is equally Applicable to both Alternating-Current and Continuous-Current Measurements

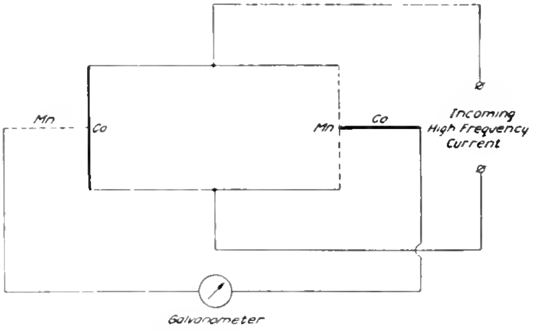

Fig. 5. A Good Scheme of Connections when but two Thermo-Couples are to be used

$$\frac{I_h}{I_s} = \sqrt{\frac{r_s^2+(2\,\pi f\,L_s)^2}{r_h^2+(2\,\pi f\,L_h)^2}} \qquad (12)$$

It is evident from this expression that even if the ohmic resistance and self-inductance did not alter with changes of frequency, the current ratio would not remain constant, since it is dependent on the wave length of the high frequency current in question. This means that such an instrument is not suitable for measurements in high frequency systems except at only the one definite frequency at which it has been calibrated. On closer consideration of equation (12) it becomes apparent that it is possible to keep the ratio, $\frac{I_h}{I_s}$, con-

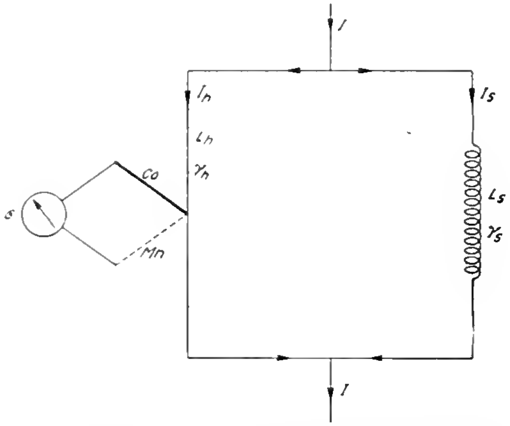

Fig. 6. The Thermo-Couple System shown in Fig 2 shunted to measure heavy Currents. As shown, can be used only at the frequency at which it is calibrated

stant, if the self-inductances are sufficiently large so that the effect of the ohmic resistance becomes practically negligible in comparison with the influence of the inductive reactance.

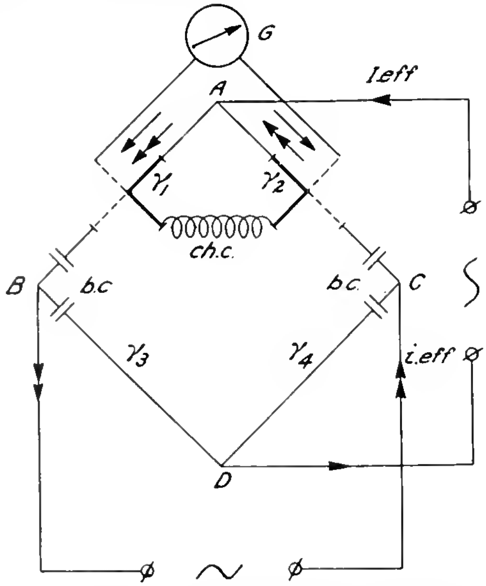

Fig. 7. Scheme of Connections for a Thermo-Cross Bridge, an Arrangement giving Deflections directly proportional to the amount of Current

Then equation (12) becomes

$$\frac{I_h}{I_s} \cong \frac{L_s}{L_h} \tag{13}$$

Therefore if additional self-inductances are inserted in the two branches, providing of course that there is no mutual inductance between the two branches, we obtain an apparatus which can be applied to any frequency. If for instance, the instrument is to be used with frequencies of from 5000 to 100,000 cycles per second, the value of the self-inductance should be so chosen that the resistance will be negligible as compared to $2\pi.5000L$. In general if the error of the combination is not to exceed $\mu$ per cent the self-inductance of the branch is given by the equation

$$\frac{1}{L_h} \leqq \frac{2\,\pi f}{r_h}\sqrt{\frac{1}{(1-\mu)^2}-1} \tag{14}$$

Since it is practically impossible to avoid entirely the effects of mutual inductance, when working with such high frequencies, it has accordingly been found advantageous to use capacities instead of inductances for reactances. Then the general expression of the current ratio is

$$\frac{I_h}{I_s} = \frac{\sqrt{r_s^2+\left(2\,\pi f\,L_s-\frac{1}{2\,\pi f\,C_s}\right)^2}}{\sqrt{r_h^2+\left(2\,\pi f\,L_h-\frac{1}{2\,\pi f\,C_h}\right)^2}} \tag{15}$$

If the values of the capacities are so chosen that the effects of the resistance and self-inductance are negligible, the equation becomes

$$\frac{I_h}{I_s} \cong \frac{C_h}{C_s} \tag{16}$$

which is likewise constant at all frequencies. The value of the capacity then is of course to be so chosen that the effect of ohmic resistance and inductive reactance becomes negligible in comparison with the capacity reactance at the highest frequency at which measurements have to be made, that means, for the above example, $r_h$ has to become negligible in comparison with $\frac{1}{2\pi\,.\,100{,}000\,.\,C_h}$.

If the error of the combination shall not exceed $\mu$ per cent the capacity is given by the expression

$$C_h \leqq \frac{1}{2\,\pi f\,.\,r_h}\sqrt{\frac{1}{(1-\mu^2)}-1} \tag{17}$$

All the thermo-electric apparatus above described have a sensibility proportional to the square of the current being measured. We naturally desire an apparatus which will have indications directly proportional to the current, so that the divisions of the scale may be uniform. This requirement has been satisfied by using the thermo-cross bridge, as shown in Fig. 7. This arrangement is based on the superposition of two currents one of which is constant and known. Suppose two equal thermo-crosses are inserted in the branches *AB* and *AC* of the bridge. There are then in each branch two thermo-elements soldered together at one point. The heavy lines represent constantan wire and the dotted lines, manganin wires. The bridge is so balanced that the resistances of all the branches have neither inductive nor capacity effects. Let the current which flows through *AD* be *Ieff*, and that through *BC* be *ieff*, and assume them to be in synchronism. For any instant we have in *AB* the current

$$\frac{I+i}{2}$$

and in *AC*

$$\frac{I-i}{2}$$

where $I$ and $i$ represent the instantaneous values. The heat produced in the branch $AB$ is

$$q_{AB} = \frac{1}{4189}\left(\frac{I+i}{2}\right)^2 . r\ Cal\ sec \qquad (18)$$

and in $AC$

$$q_{AC} = \frac{1}{4189}\left(\frac{I-i}{2}\right)^2 . r\ Cal/sec \qquad (19)$$

$q_{AB}$ and $q_{AC}$ produce electromotive forces in the thermo-elements, being at right angles to the branches of the bridge. The elements are in series, with polarity opposed to one another. A choke coil (*ch. c.* Fig. 7) keeps back the high frequency current from flowing through the galvanometer. The block condensers (*b.c.* Fig. 7) limit the thermo-electric current to the bridge. The direct current $i_g$ which flows through the galvanometer may be expressed by the equation

$$i_g = i_{g_{AB}} - i_{g_{AC}} \qquad (20)$$

The relations for the currents $i_{g_{AB}}$ and $i_{g_{AC}}$ are

$$\begin{aligned} i_{g_{AB}} &= k\,.\,r\,.\left(\frac{I+i}{2}\right)^2 \\ i_{g_{AC}} &= k\,.\,r\left(\frac{I-i}{2}\right)^2 \end{aligned} \qquad (21)$$

where $k$ is a constant. At any instant the current flowing through the galvanometer under the above conditions is

$$\begin{aligned} i_g &= 2\,.\,k\,.\,r\,.\,I\,.\,i \\ &= k^1\,.\,I\,.\,i \end{aligned} \qquad (22)$$

Assuming the current $I$ to be the constant, the equation 22 then becomes

$$i_g = \text{Const}\ i \qquad (23)$$

This term shows that the direct current $i_g$ is directly proportional to the current $i$ for a constant value of $I$. As the deflection of the ordinary galvanometer is also proportional to the current flowing through it, it follows that the indicator of the thermo-cross bridge will deflect directly proportional to the current. By utilizing the above method we are able to measure very small currents.

Assuming that the current $I$ and the current to be measured $i$, are not in phase with one another, we can then write for pure sine waves

$$\begin{aligned} I &= I\ max.\ sin\ (2\,\pi f)t \\ i &= i\ max.\ sin\ (2\,\pi f\,t + \Psi) \end{aligned} \qquad (24)$$

At any instant we get for the current flowing through the galvanometer

$$i_g = k^1 . I_{max}\, sin\ 2\,\pi f\,t\,.\,i_{max}\, sin\ (2\,\pi\, ft + \Psi)$$

where $\Psi$ is the displacement of phase between $I$ and $i$. For the average value we obtain

$$i_{g_{AB}-g_{AC}} = k^1 . \frac{1}{T}\int_0^T I\ max\,.\,i\ max\,.\,sin\left(\frac{2\,\pi}{T}t\right) \times sin\left(\frac{2\,\pi}{T}t + \Psi\right)dt \qquad (25)$$

Solving, equation 25 gives the expression

$$i_{g_{AB}-g_{AC}} = k^1 I\ eff\,.\,i\ eff\ cos\ \Psi \qquad (26)$$

which shows that for a constant current *Ieff* the deflection of the galvanometer is proportional to the effective value of the current. The displacement $\Psi$ only diminishes the sensibility, but can be kept constant, and thus does not affect the proportionality of the thermo-cross bridge. Furthermore, we learn that the above arrangement can be used as phaseometer.

In order to prove the proportionality of the thermo-cross bridge Tables III and IV are given here. Both tables show that the deflections $\alpha$ of the galvanometer increase linearly with the currents to be measured. The results in Table III satisfy the equation

$$\alpha = 300\,.\,I\ eff$$

and those of Table IV are represented by

$$\alpha = 265\,.\,I\ eff$$

TABLE III

| *I eff* in Amperes | Deflection $\alpha$ in mm | $\frac{\alpha}{I\ eff}$ | Constant Quantities |
|---|---|---|---|
| 0.04 | 12.0 | 300 | *i eff* = const. (very small) |
| 0.06 | 17.5 | 292 | |
| 0.08 | 24.0 | 300 | |
| 0.10 | 29.5 | 295 | $r_3 = 36.4\Omega$ |
| 0.12 | 36.5 | 304 | |
| 0.14 | 42.5 | 304 | $r_4 = 36.7\Omega$ |
| 0.16 | 49.0 | 306 | |
| 0.18 | 54.0 | 300 | $f = 50$ cycles/sec |
| 0.20 | 59.5 | 297 | |
| 0.22 | 67.5 | 306 | *I eff* in phase with *i eff* |
| 0.25 | 75.0 | 300 | |

TABLE IV

| *I eff* in Amperes | Deflection $\alpha$ in mm | $\frac{\alpha}{I\ eff}$ | Constant Quantities |
|---|---|---|---|
| 0.04 | 10.5 | 263 | *i eff* = const. (very small and same value as in Table III) |
| 0.06 | 16.0 | 267 | |
| 0.08 | 21.0 | 263 | |
| 0.10 | 26.5 | 265 | |
| 0.12 | 32.0 | 267 | |
| 0.14 | 38.0 | 271 | $r_3 = 36.4\Omega$ |
| 0.16 | 42.5 | 265 | |
| 0.18 | 47.5 | 264 | $r_4 = 36.7\Omega$ |
| 0.20 | 52.0 | 260 | $f = 50$ cycles/sec |
| 0.22 | 58.5 | 266 | *I eff* not in phase with *i eff* |
| 0.25 | 66.0 | 264 | |

As the data in both tables were obtained under the same conditions, we have $cos\ \Psi = \frac{265}{300} = 0.8825$ as an expression for the displacement between *I eff* and *i eff*. This corresponds to an angle $\Psi = 28°3'20''$.

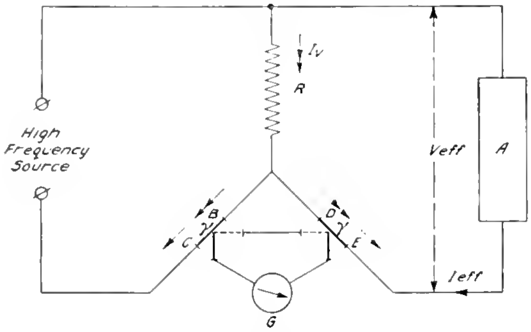

Fig. 8. A Variation of the Thermo-Cross Bridge shown in Fig. 7. Both Current and Energy can be measured on this Bridge

A modification of this thermo-cross bridge is shown in Fig. 8. This arrangement not only enables us to measure the current but also the energy of a high frequency system and therefore we have a high frequency wattmeter operating by the action of thermocouples. In Fig. 8, *A* represents the device which consumes the energy, *BC* and *DE* are small heating wires for the two thermocouples, which are indirectly heated. *V eff* denotes the drop in potential across the energy consuming apparatus and *I eff* the corresponding current. *R* is a resistance which is so large that the current flowing through it is proportional to the voltage drop over the energy consuming apparatus. Then at any instant the current $\left(\frac{I_v}{2}+I\right)$ will flow through the heating wire *BC*, and the current $\left(\frac{I_v}{2}-I\right)$ will flow through the wire *DE*, where

$$I_v = k . V \tag{27}$$

That is, the current $I_v$ is proportional to the voltage $V$. Hence if the instantaneous values of the voltage and the current carried by the load at *A* are expressed by the relations

$$V = V\ max. sin\ (2\pi\ ft + \phi)$$
$$I\ = I\ max\ \ sin\ (2\pi\ ft)$$

the galvanometer deflection $\alpha$ is given by

$$\alpha = K . \frac{1}{T} \int_0^T V max. I max. sin\left(\left(\frac{2\ \pi}{T}\right)t + \phi\right) \times sin\left(\frac{2\ \pi}{T}\right)t\ dt = K . V\ eff . I\ eff\ cos\ \phi \tag{28}$$

where $K$ is a constant and $\phi$ the phase displacement between the voltage and the current. Equation 28 indicates that we are thus able to measure the energy of a high frequency system. It is yet to be noted that in equation 27 it was assumed that $I$ is proportional to the voltage across the apparatus which is consuming energy. This assumption is not quite true since there is also a drop in the heating wire, *DE*, which has the resistance *r*, therefore the actual expression for the value of $I_v$ becomes

$$I_v = k(V + V_1) \tag{28a}$$

where $V_1$ is the drop across the heating wire. This correction factor is derived in the following section, and a diagram of connections given in Fig. 9, which shows an arrangement that eliminates this error. The derivation is given for the case of a direct current, since the correction factor will be the same for both alternating and direct current, as *R* and *r* are assumed to be non-inductive. According to Kirchhoff's law the algebraic sum of the incoming and outgoing currents at a point is zero. Hence for the junction point, *O*, we obtain

$$I_1 = I_2 + I_v \tag{29}$$

and by solving for $I_1$ and $I_2$, we get

$$\left.\begin{aligned} I_1 &= I + \frac{I_v}{2} \\ I_2 &= I - \frac{I_v}{2} \end{aligned}\right\} \tag{30}$$

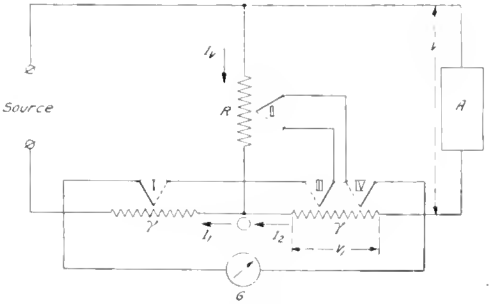

Fig. 9. A Scheme of Connections which is an Improvement over that shown in Fig. 8

The actual dissipation of energy in *A* is

$$W = V . I_2 \tag{31}$$

If only the thermo-couples *I* and *III* are used, the deflection of the galvanometer will be

# APPLICATION OF POWER APPARATUS TO RAILWAY SIGNALING

By H. M. Jacobs

Signal Accessories Department, General Electric Company

This article is the second of a series of three on the subject of railway signals that the author has contributed to the Review. It deals with automatic block and interlocking signals; the former being located along the right-of-way, while the latter are placed at terminals, cross-overs, etc., and are controlled from towers. The automatic block signals are built for operation on a-c. and d-c. circuits; the d-c. signals receiving their current in most cases from storage batteries located at convenient points along the route, while the a-c. signals are supplied with energy from transmission lines. The interlocking signals are either manually operated or are controlled through electric-pneumatic or all-electric devices. The final article of the series will consist of descriptions of some of the larger installations, and will appear in the December issue.—Editor.

In an article in the December, 1913, issue of the General Electric Review, there was given, in a most elementary way, a short historical sketch of the general development of railway signaling and an interpretation of the various day and night indications of the semaphore signal in most common use. It will be remembered that railway signals are divided roughly into two general classes; viz, automatic block signals and interlocking signals, the difference being that the latter are located where there are switches, junctions or cross-overs, and are controlled by an operator located in a tower, while the former are located along the stretches of track outside the interlocking zones and are automatic. This article will give a short description of the various systems of each class of signals, showing in each case the application of the various kinds of power apparatus.

## Automatic Block Signals

Automatic block signals may be divided into two general classes, d-c. operated and a-c. operated. As all d-c. signals are operated by batteries, this class may be further subdivided according to the various battery systems used; viz., primary batteries, portable storage batteries, and stationary storage batteries.

It is well for us to consider the d-c. systems first, for actual automatic block signals did not come into existence until after the invention of the d-c. track circuit; and it was quite natural that, inasmuch as the track circuit was fed from a battery, the signal mechanism should be operated from a like source of power.

Primary batteries were first used, the renewals being made on the ground. Following this came the portable storage battery, the discharged batteries being exchanged for batteries newly charged and taken to convenient charging stations. Some roads now employing this system have battery trains which periodically exchange charged sets for those discharged, the charging being done at one or more large plants conveniently located along the system. Some of these plants have generating apparatus as large as 50 to 300 or 400 kw. capacity. Other charging stations are located at the railroad shops, the power for charging being taken from the main d-c. busbars, as in this way the necessity of special generating apparatus is avoided. Still other roads establish charging stations at several convenient pumping plants to take care of the batteries on each particular division. In this case the charging equipment may consist of a small generator capable of charging from three to five groups of batteries, and driven by either a steam turbine, marine engine, or gasolene engine, and controlled by a simple switchboard. By designing the apparatus so that its operation is exceedingly simple, the pump man always on duty may look after the charging and in this way effect a great saving in labor.

The third class, or stationary battery scheme, employs at each signal location duplicate sets of batteries so connected to a battery charging switch that they may be interchanged without interrupting the discharge line or opening the series charging line. The switch is also arranged so that when a battery is sufficiently charged it may be cut off from the series line and allowed to stand idle until required. Fig. 1 illustrates such a switch in the position of transferring batteries. It has two interlocked motions; namely, a transverse motion, to interchange the batteries on the discharge circuit, and a vertical motion to cut off the one battery from the charging circuit and cut the series line through the switch without interruption by first inserting a resistance at the moment of cutting off the battery and then inserting a short-circuiting strip. The motions are so interlocked that the battery cannot be cut off from charge until it has first been cut free from the charging line. At no time is it possible to interrupt the discharge circuit. On account of the varying rates of discharge of the track batteries and signal batteries, these are grouped on separate switches. The line side of these switches is connected in series with the line side of the switches at the adjacent locations, until several consecutive locations (the number of which depends on the total number of cells of batteries possible to have on charge at any one time and the voltage drop in line wire) are connected in series to one feeder from a small power station. These charging stations usually feed out at a maximum of 600 volts on each of two lines running in opposite directions along the right-of-way. If the track has a branch line at this point, or a junction, more feeders are added to accommodate it.

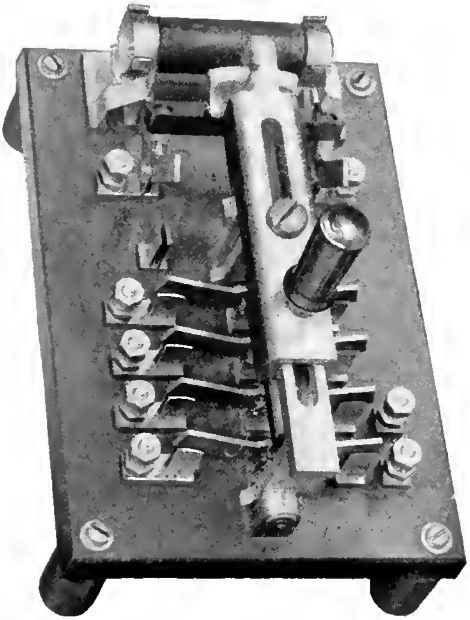

Fig. 1. **Battery Charging Switch and Diagram of Connections**

The power apparatus usually consists of a two unit motor-generator set, the generator delivering power at 350 to 600 volts to the switchboard. In each feeder there is located a line rheostat to independently maintain the proper charging current. Fig. 2 illustrates a two-way switchboard built for the New York Central & Hudson River R. R., and Fig. 3 a motor-generator set similar to the one controlled from this board. The line rheostats are mounted on the wall of the station.

One other system more or less special should be mentioned; that employing both d-c. and a-c. Batteries are used for the operation of the signals and a-c. for the track circuits in order to overcome the effect of heavy foreign current. Instances of this kind are very rare and usually are a reconstructed d-c. system arranged to overcome increased foreign current. When it is necessary to install a-c. track circuits, the whole system is usually changed to a-c. operation.

The reader may have wondered where the batteries at the various signal locations are housed. Figs. 4 and 5 illustrate respectively a typical battery well and chute, and it will be noted that every precaution is taken to protect the batteries from frost.

For the systems described above, the power apparatus required is as follows:

(*A*) *Primary battery systems.*
- Track circuit resistances (except where used with gravity cells or high internal resistance batteries).
- Low voltage lightning arresters.

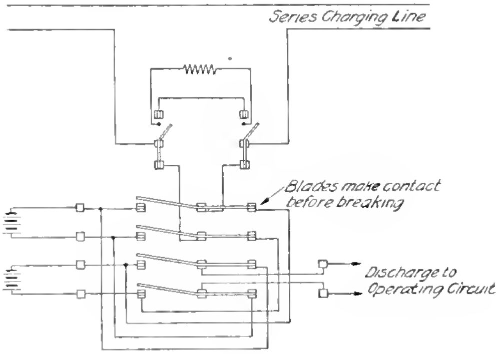

**Fig. 1-A**

(*B*) *Portable storage battery systems.*
- Complete charging equipment: Prime movers, generators, switchboards and rheostats.
- Track circuit resistances.
- Low voltage lightning arresters.

(*C*) *Stationary storage battery systems.*
- Complete charging equipment: Prime movers, generators, switchboards and rheostats.
- Choke coils, 600 volt lightning arresters.
- Battery charging switches.
- Track circuit resistances.
- Low voltage lightning arresters.

On account of the impossibility of static conversion and the impracticability of rotary conversion of direct current, and the excessive losses at low voltage transmission, no extensive d-c. system without the use of batteries has been devised. Alternating current, of course, will permit of transmission at high voltages and transformations to the proper working voltages by means of static transformers at various locations, thus effecting a very great saving in transmission line losses.

Fig. 2. Switchboard for Series Line Charging, New York Central & Hudson River Railroad

As noted in the previous article, a-c. systems came into use as a remedy for the disturbing effects of propulsion current on electrically operated roads. Its adoption on steam railroads is largely a question of reduced maintenance, elimination of foreign current troubles due to proximity of interurban trolley lines, power economy over battery systems, ability to run longer track sections, or anticipation of future electrification. It is not our purpose to discuss the relative merits of the two systems, a-c. and d-c., or of the various subdivisions.

The continuity of service of an a-c. system depends almost entirely on the reliability of the generation and transmission system. Only in the third mentioned class of d-c. signals is there a transmission line, and should this fail for a few minutes or even a few hours the system would continue to operate because the batteries connected thereto are not the ones in operation at the time being. But the continuity of operation of a-c. signals is a direct function of the transmission line service; and for this reason the generating apparatus, controlling and switching devices, and the transmission, transformation and protection systems must be of the very best. The majority of roads using a-c. signals have the customary aerial line paralleling the tracks.

Some roads generate and transmit single-phase; others generate three-phase and transmit single-phase, using the other two phases locally for lighting and power; while still other roads generate and transmit three-phase. A single-phase secondary distribution system may be supplied from a single-phase line, or from one phase of a three-phase transmission line; but a two-phase secondary distribution system must be supplied from a polyphase transmission line—three-phase with T-connected transformers or two-phase with two transformers per location. But the writer knows of no instance where an extensive two-phase transmission system is in operation, probably because of the greater economy of the three-phase transmission.

The usual transmission voltages are 4400, 3300 and 2200, and at each location this is stepped down to 110 or 220 volts for operating the signal mechanism, and further to 6, 8, 10, 12 or 15 volts for the track circuits and lights. The lowest voltages are obtained sometimes by taps or extra coils on the main transformers and sometimes by separate trans-

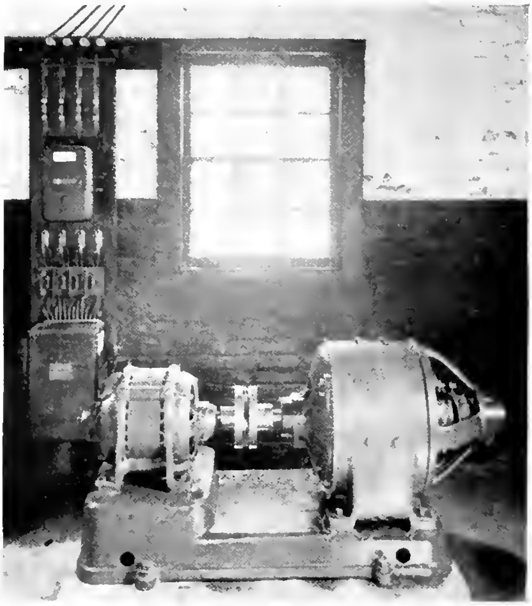

Fig. 3. Motor-Generator Set Controlled from Switchboard shown in Fig. 2

formers connected to the 110-volt circuits. Frequencies are either 25 or 60 cycles, and when a choice may be made for steam or d-c. roads, 25 cycles is the more preferable, as power at this frequency is more efficiently transmitted through the rails, thus making possible longer track sections. But if there is a possibility of a-c. electrification of part or all of the road, 60 cycle will be chosen, since the propulsion current will undoubtedly be 25 cycles and the frequency of the signal circuit must not be a low harmonic of the propulsion current on account of interference and false indications resulting therefrom.

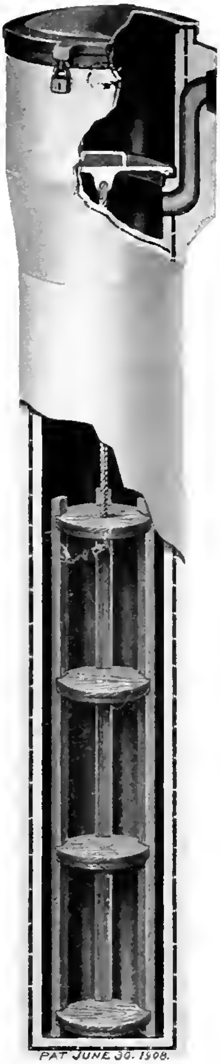

Fig. 5. Concrete Battery Chute

The Chicago, Milwaukee and St. Paul Railroad will soon place in service the last 40 miles of a 458-mile installation of automatic signals on which work was started the latter part of 1912. The complete installation is operated from a single-phase, 4400-volt, 60-cycle transmission line supplied at intervals exclusively from 2200-volt, 60-cycle commercial sources. In only one instance is the supply considered unreliable and to provide against interruption a synchronous motor-generator set with storage battery reserve has been installed.

Fig. 4. Concrete Battery Wall

In three-phase transmission various means are resorted to, to balance the load. In some instances, the signal load is carried entirely on one-phase, and the station and building lighting, which is connected at night only, on the other two. Inasmuch as the power factor of the signal system is usually from 50 to 65 per cent, it has been found advisable to carry the signal load and the lighting load balanced on all three phases as nearly as possible. In one instance on the Southern Railway this has been nicely accomplished

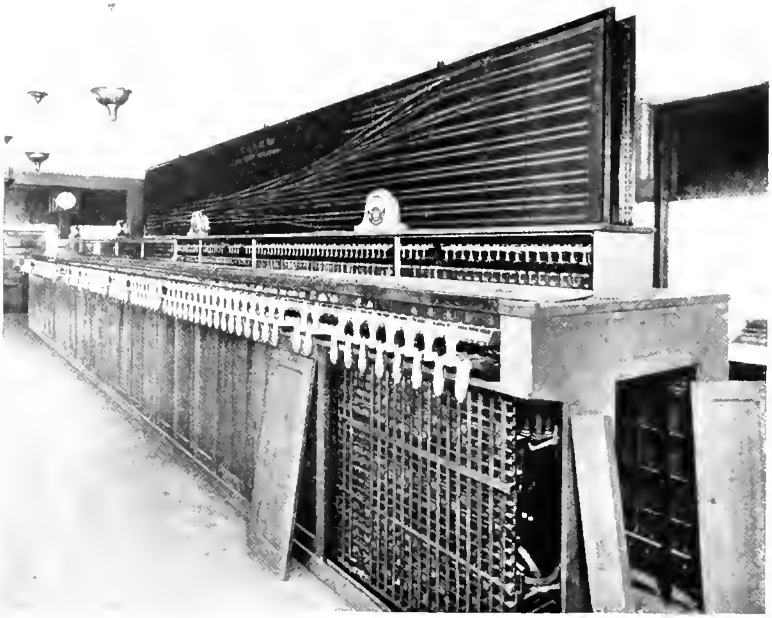

Fig. 6. Electrodynamic Interlocking Machine, Chicago & Northwestern Railway, Chicago, Ill.

by transposing the line wires at such intervals as to divide the particular installation into approximately three equal parts, the two lower wires being used throughout for signal purposes and the top wire and alternately one of the lower wires for the station lighting. The signal load is thus equally distributed and the lighting load so distributed as to obtain practically an equally balanced load at all times. Because of the inherent characteristics of T-connected transformers, a practically balanced two-phase load will give a similarly balanced three-phase load; but to guard against the unbalancing effect of heavy traffic on one track and light traffic on the other, the two phases supplying the two tracks are interchanged at intervals. This system has been adopted as standard by the Atchison, Topeka & Santa Fe R. R.

All of the above mentioned systems have been of the aerial transmission line construction. The Pennsylvania R. R. has done, and is doing, much in underground transmission with single-phase, 3300 volt, 60 cycle power. The wires are laid in asphaltum pitch in wooden trunking about two feet under the surface. This system is extremely expensive, but it eliminates the troubles due to wind and sleet storms, lightning, and kindred aerial line troubles. It also introduces by its capacity quite a correcting influence for low power-factor.

The power apparatus required for the various a-c. systems comprises in whole or in part the following power apparatus:

Generators: Steam, gasolene or motor driven.
Switchboards.
Transformers and fuses.
Lightning arresters, choke coils and line material.
Line sectionalizing equipment: Oil switches, line (power) relays.
Resistance units and reactance coils.

### Interlocking Signals

The second general class of railway signals, interlocking signals, are those located at switches, junctions or crossovers, and are controlled by one or more operators located in a tower. They are so termed because their movements are controlled by a mechanism the parts of which are so interlocked as to

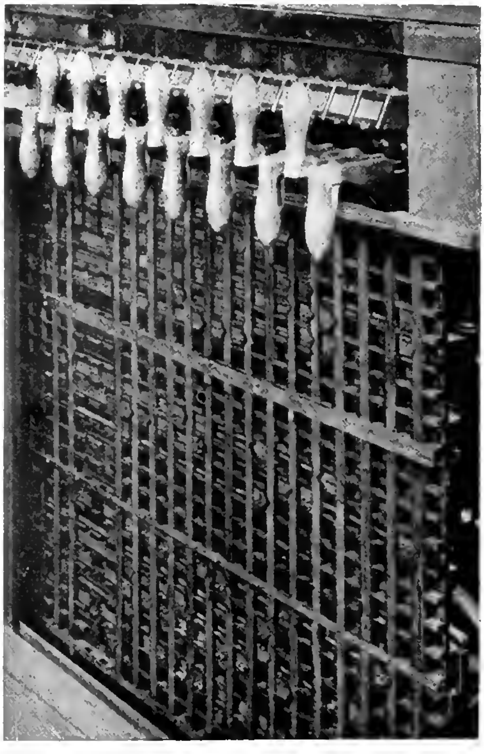

Fig. 7. Detail of Locking Bed of Machine shown in Fig. 6

prevent the movement of the switches and signals that would give conflicting information for the movement of trains. Each separate switch, signal or derail is operated by a separate lever, except in certain cases where they are operated always in conjunction. The levers are all concentrated in a single frame. The interlocking is accomplished in a so called "locking bed" placed in either a horizontal plane back of the levers or in a vertical position in front of the machine. Fig. 6 illustrates a machine of the latter type. By a combination of horizontal or locking bars, and vertical or tappet bars, with locking dogs, certain levers are locked against movement by the movement of others. Such a combination of levers and interlocking rods with their accessories forms what is called an interlocking machine. A section of a machine of this kind showing the interlocking rods, is illustrated in Fig. 7. The locking bars carry V shaped dogs which fit into similarly shaped notches in the tappet bars in such a manner that when one tappet bar is moved vertically by its lever one or more locking bars are moved by the dogs which engage them, and the dogs on them slip into the notches on various tappet bars, thus locking and preventing the movement of their corresponding levers by the operator. In this principle of locking all types of machines are the same.


Fig. 8. Mechanical Interlocking Machine with A-C. Electric Locks. A-C. Indicator on Wall

There are today in common use three general types of interlocking; viz.: The mechanical, the electro-pneumatic, and the all-electric.

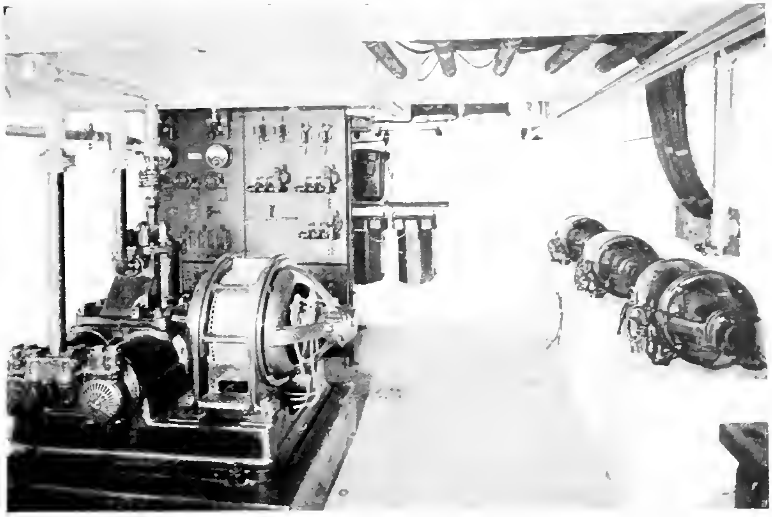
Fig. 9. Power Equipment in Basement of Tower at Montclair, N J., Delaware, Lackawanna & Western Railroad

While passing through some railroad yards the reader has doubtless noticed rows of one-inch iron pipe parallel to the tracks on pipe carriers extending from a signal tower to the various switches and signals. These pipes are the medium by which the signal devices are mechanically controlled by the operator in the tower, and the plant is of the "mechanical" type. Such a plant is illustrated in Fig. 8, and shows clearly the locking bed where the levers are interlocked against movements as described above. Mechanical plants are restricted to small territory owing to the limited physical strength of the operator; power-operated interlocking plants, electro-pneumatic and "all-electric," therefore afford more extensive control.

In electro-pneumatic plants the signal devices are operated by compressed air under low voltage electro-magnet control from the machine in the tower. Fig. 9 shows the power equipment in the basement of the Montclair, N. J., Delaware, Lackawanna & Western Railroad tower. Relay racks occupy the entire ground floor and the interlocking machine is on the second floor. Compressed air at 90 to 100 lb. per sq. in. is supplied from either one of the two duplicate motor-driven

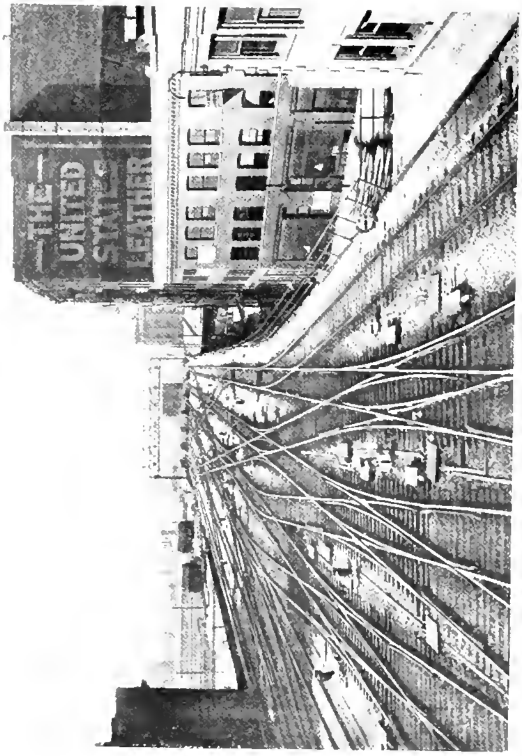

Fig. 10. Track Layout of Switches and Signals Controlled from Machine shown in Fig. 6

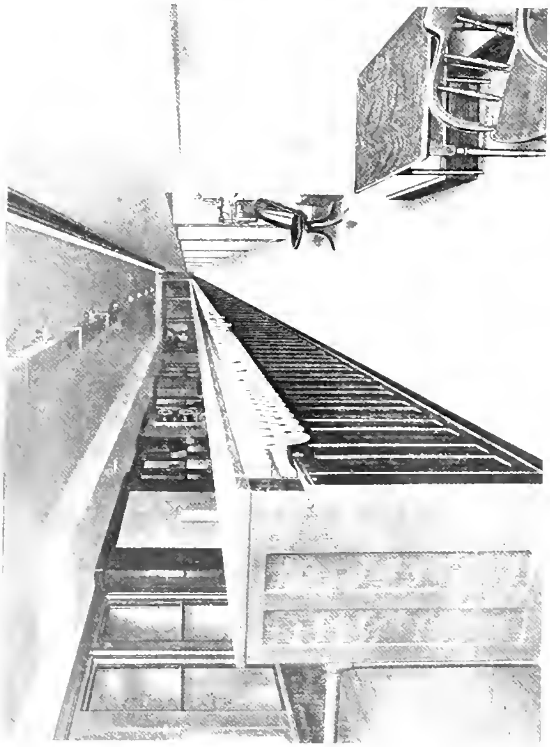

Fig. 11. Electrodynamic Interlocking Machine, Grand Central Terminal, New York City

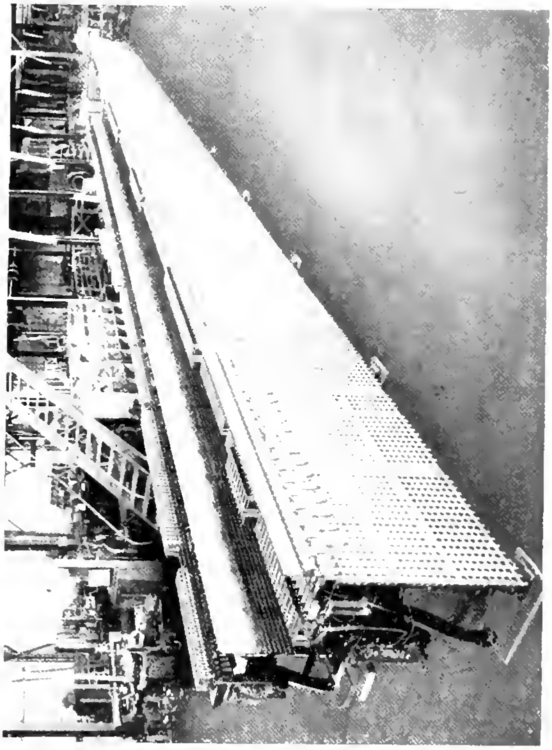

Fig. 12. Two Electrodynamic Machines for Grand Central Terminal, Partly Assembled in Factory

Fig. 13. All-Electric Interlocking Machine, New York, Westchester & Boston Railroad, Columbus Avenue Tower

compressors. Power for operating the magnet valves on the signals and switches is supplied through the machine controlling mechanism from a 20-volt storage battery, and the track circuits are fed from two 5-volt groups of storage batteries in multiple. All batteries are in duplicate and the switchboard is so arranged that the idle batteries may be charged from the motor-generator sets in various combinations. This installation will be described more fully in a succeeding article.

"All-electric" machines require quite an extensive power plant equipment, as independent circuits of three different voltages are necessary, each supplied from a single or duplicate set of batteries. The signal and switch motors operate from a 110-volt main battery, the machine locks, lights, and indicators from a 15- to 20-volt battery and the track circuits from an 8- to 10-volt battery. For this a charging equipment is required, the choice of which is governed by commercial power conditions; for instance, steam or gasolene engine-driven generators in isolated plants or where the commercial power is unsatisfactory, and motor generator sets or mercury arc rectifiers where dependable commercial power is available.

The application of alternating current for machine locks, lights, indicators and track circuits has simplified the battery charging problem, making necessary only the 110-volt battery for operating the signal and switch motors. The charging apparatus then consists either of a mercury arc rectifier equipment or switchboard with motor-generator set. The battery is usually of sufficient capacity to operate the interlocking several days on a charge. To guard against interruption in service, auxiliary alternating current generating apparatus consisting of gasolene- or steam-driven units are frequently used, but at many interlockings the traffic conditions are such that the time required to put such auxiliary units into service would cause very serious delays. In some cases to overcome this the storage battery has been made extra large, and the motor-generator set normally used for charging it arranged for reverse operation; that is, the d-c. generator may operate as a motor driving the a-c. motor (which in such a case must be of the synchronous type) as an a-c. generator. This arrangement is used at Jamaica, N. Y., on the Long Island Railroad. In case the a-c. source of power is not of the same frequency as the signal circuit, the motor is made of the induction type, of sufficient capacity to drive both the a-c. generator and a d-c. generator for charging the battery. Should the a-c. source fail, the d-c. machine will act as a motor driving the a-c. machine loaded as before. In some instances more than one supply is available and automatic switching equipments are oftentimes provided to shift the operation from one to the other.

The accompanying illustrations show several interesting views of interlocking machines and installations. Fig. 6 previously referred to shows the General Railway Signal Company's electro-dynamic machine at the Lake Street tower, Chicago & Northwestern terminal, Chicago, and Fig. 10 the track layout of switches and signals controlled therefrom. The iron boxes located between the tracks enclose the switch motor machanisms. The dwarf signals to govern slow speed and back-up movements, located between the tracks and the semaphore signals on the structural steel towers across the tracks, are clearly shown. Fig. 11 illustrates a similar type of machine built by the same company and installed in the Grand Central terminal of the New York Central & Hudson River Railroad, New York City. To handle the immense amount of traffic, a second similar machine is required, one having 360 and the

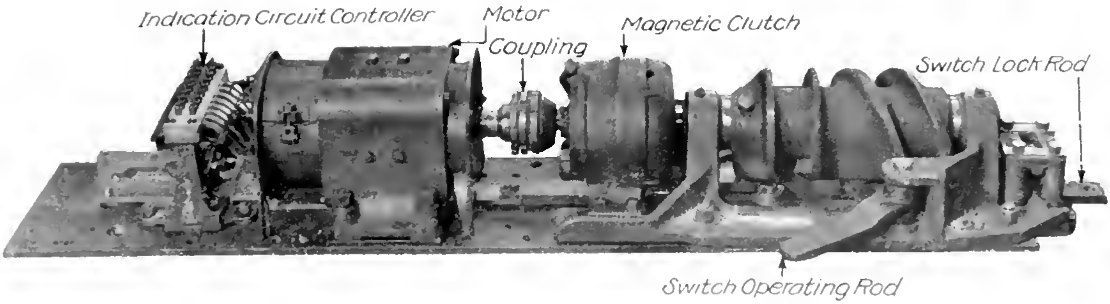

Fig. 14. Electrically Operated Track Switch

other 400 operating levers, both of which are shown in Fig. 7, as assembled in the factory. A small machine installed in the Columbus Avenue tower of the New York, Westchester & Boston Railway Company, built by the Union Switch and Signal Company, is illustrated in Fig. 8. Directly above the machine is a track diagram which shows at a glance just which tracks are occupied and which are clear.

In a succeeding article several installations of power apparatus for signal use will be described in detail and the application of various kinds of equipment shown.

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# THE HEATING AND TEMPERATURE SECTION OF THE A.I.E.E. STANDARDIZATION RULES

By H. M. Hobart

Chairman of Subcommittee on Rating, 1914, A.I.E.E. Standardization Rules

Consulting Engineer, General Electric Company

The basis of this article is a table (supplemented by references and explanatory notes) which has been prepared by the author to furnish, in a clear and compact form, a record of the limits of "observable" temperature rise as prescribed by the 1914 A. I. E. E. Standardization Rules. The simplicity of presentation and convenience of application to which the rules have been reduced in this table should be appreciated by all interested in the heating of electrical machinery.—Editor.

In sections numbered from 149 to 200 inclusive of the 1914 Standardization Rules of the A.I.E.E. are set forth the new requirements as regards heating and temperature. On most occasions the data which is really needed relates to the permissible temperature rise. In the Table presented in this article, the endeavor has been made to give in definite form the permissible values of the observable temperature rise for various occasions. Three methods numbered I, II and III have been given, to which resort may be made in determining the temperature of electrical machinery. A hasty study of the rules might lead to the conclusion that these are *alternative* methods, and that any one of the three may be used in any case. A closer study of the rules will show that this is not the intention. Irrespective of the order in which these methods are numbered, the most general method is that numbered II. In the Table in section 192 of the rules, this is designated as the "resistance method;" but there is a parenthetic statement reading: "With Thermometer Check when Practicable." Method I is designated: "Thermometer Only." Close study of the rules shows that the purpose is, that of these two methods, number II is the fundamental method and number I is a special case to which resort is permitted under certain circumstances. With the exception of machines for which the limits are definitely stated and for which Method III is exclusively employed, the general case will require Method II. The spirit of Method II (which is that adopted by the I.E.C.) is that both resistance and thermometer measurements shall be made, and the highest temperature obtained by either method shall be regarded as the observable temperature.

With the present attitude entertained in many quarters toward resistance measurements, however, it was felt that it would be premature to make the use of resistance measurements mandatory for all cases. Furthermore, the expense of the resistance as compared with the thermometer method would make it unreasonable to employ it in the case of small machinery made in large quantities. Consequently, Method I was provided, and under certain circumstances (set forth in the text of the Standardization Rules), the supplier of the machine can elect to employ exclusively thermometer methods. But when this prerogative is exercised, the permissible limit of observable temperature is lower than when he employs Method II and makes both thermometer and resistance measurements. If the supplier of the machine elects to employ exclusively thermometric measurements, he has no option but to accept the penalty of keeping within the lower observable temperature rise. There is another group of cases where resistance measurements would not be desirable, as in the case of series windings, where the contacts and connections constitute a considerable percentage of the total resistance. In such instances, the rules state (see section 179) that the resistance measurements need not be made. This does not throw the case amongst those to which Method I applies, since it is not a case of

## TABLE SHOWING, FOR VARIOUS KINDS OF MACHINES, THE LIMITS FOR THE "OBSERVABLE" TEMPERATURE RISE, PRESCRIBED IN THE A.I.E.E., 1914, STANDARDIZATION RULES

| | Description of the Winding or Parts | Prescribed Methods for Determining the "Observable" Temperature Rise | | LIMITING RISE OF "OBSERVABLE" TEMPERATURE A1 | A2 | B | Corresponding Ambient Temperature of Reference* | Remarks |
|---|---|---|---|---|---|---|---|---|
| I | All windings in which the conductors have bare surfaces, (such as edgewise-wound strip conductor, or copper castings), against which thermometers may be directly applied. | Use Method I, qualified by Section 176. [See also the first footnote on Page 26.] | | 50 | 60 | 80 | 40 | † |
| II | Stator field windings (with conductors covered by insulation) whose proportions and design do not preclude reasonably accurate commercial determinations of the temperature by the resistance method. Also rotor field windings of these proportions and design when the speed is not too high to permit of making satisfactory estimates from thermometer readings taken at intervals after shutdown. | Method II is prescribed. But the party supplying the machine has the option to employ exclusively Method I, if he accepts the penalty of keeping within the lower limits. | When Method II is Employed (See Section 177) | 45 | 55 | 75 | 40 | |
| | | | When Method I is Employed (See Section 175) | 40 | 50 | 70 | 40 | ‡ |
| III | Field windings on rotors of turbo-generators and other extra-high-speed machines. (See last footnote on Page 26.) | Method II, with exemption from requirement to make check reading by thermometer. | | 45 | 55 | 75 | 40 | |
| IV | Stator and rotor field windings (with conductors covered by insulation) where the joints and connections form a considerable part of the total resistance. (See Section 179.) | Method II, but employing only thermometers. (This is *not* Method I, since that relates to the *arbitrary* exclusion of resistance measurements when they could approximately be made.) | | 45 | 55 | 75 | 40 | § |
| V | Armature windings on all rotors. Also armature windings on all stators of machines with cores of less than 50 centimeters length (if of not over 500 kv-a.), irrespective of voltage. Also armature windings of all stators of machines of less than 50 centimeters width (if for less than 5000 volts), irrespective of rating. (See Section 185.) | Method II is prescribed. But the party supplying the machine has the option of employing exclusively Method I, if he accepts the penalty of keeping within the lower limits. | When Method II is Employed (See Section 177) | 45 | 55 | 75 | 40 | |
| | | | When Method I is Employed (See Section 175) | 40 | 50 | 70 | 40 | |
| VI | Armature winding on all stators of machines with cores of 50 centimeters length and greater. Also armature windings of all stators for 5000 volts and over, if of over 500 kv-a. rating, regardless of core length. (See Section 185.) | Method III is prescribed | For double-layer windings. (See Section 186.) | 50 | 60 | 80 | 40 | |
| | | | For single-layer windings for a pressure of 5000 volts or less. (See Section 186.) | 45 | 55 | 75 | 40 | |
| | | | For single-layer windings above 5000 volts. [E represents rated pressure between terminals in kilovolts.] (See Section 186.) | 45-(E-5) | 55-(E-5) | 75-(E-5) | 40 | |
| VII | Transformers in which the windings are surrounded by air. (See Section 180.) | Method II is prescribed for all cases. (See also Section 180.) | | 45 | 55 | 75 | 40 | |
| VIII | Transformers in which the windings are immersed in oil and in which the oil is cooled by the circulation of water through a coil of pipes immersed in the oil. (See Section 194.) | Method II is prescribed for all cases. (See also Section 194.) | | 50 | 50 | 50 | Temperature of Inlet Water 25° | |
| IX | Transformers immersed in oil but without water cooling. (See Section 193.) | Method II is prescribed for all cases. (The stated rises are permitted only in so far as they do not occasion a temperature in excess of 90 degrees in any part of the oil, as required by Section 193 of the rules.) | | 45 | 55 | 75 | 40 | ¶ |

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* When the machinery is to be employed in locations with an ambient temperature exceeding that of reference, the approved rise must be reduced by the amount of the excess. But in the absence of special information the standard ambient temperatures of reference set forth in Sections 153 and 157 are to be assumed.

† When conductors of copper castings are supported by Class C insulation, no temperature limits are specified.

‡ When the temperatures are obtained after a shut-down, the methods of bringing the rotor to rest should be such as to influence these temperatures as little as possible.

§ In this case, the results from resistance measurements would be too low and it would be futile to make them.

¶ The 90-degree limit for the oil will usually control the rating.

(Continued on following page)

**TABLE—Continued**

| | Description of the Winding or Parts | | Prescribed Methods for Determining the "Observable" Temperature Rise | Amperes per Brush Arm | Limiting Rise of "Observable" Temperature | Corresponding Ambient Temperature of Reference* | Remarks |
|---|---|---|---|---|---|---|---|
| X | Railway Motors | Nominal Rating Rises after 1 hour. (See Section 415.) | Commutator. | | 90 by thermometer | | |
| | | | Any other part. | | 75 by thermometer<br>100 by resistance | | |
| | | Continuous Rating Rises on stand test. (See Section 420.) | Windings with A2 insulation. | | 65 by thermometer<br>85 by resistance | | † |
| | | | Windings with B insulation. | | 80 by thermometer<br>105 by resistance | | |
| XI | Commutators. (See Section 198.) | | Method I is prescribed. The stated rise is only permitted when it does not occasion transgression of other limits stated in Section 198. | 200 and less | 90 | 40 | |
| | | | | 300 | 85 | | |
| | | | | 400 | 80 | | |
| | | | | 500 | 75 | | |
| | | | | 600 | 70 | | |
| | | | | 700 | 65 | | |
| | | | | 800 | 60 | | |
| | | | | 900 or more | 55 | | |
| XII | Collector rings. (See Section 197.) | | Method I is prescribed. See also Section 197 for limitations coming before the value given here. | | 90 | 40 | |
| XIII | Squirrel Cage and Amortisseur Windings | | See Section 196. | | | | |
| XIV | Cores | | See Section 199. | | | | |
| XV | Other parts, (such as brush-holders, bearings, pole-tips, etc.) | | See Section 200. | | | | |

* When the machinery is to be employed in locations with an ambient temperature exceeding that of reference, the approved rise must be reduced by the amount of the excess. But in the absence of special information the standard ambient temperatures of reference set forth in Sections 153 and 157 are to be assumed.

† For temperature rise in service, see Section 440.

electing to employ only thermometer measurements, when resistance measurements could reasonably be employed. In such a case as this, the supplier of the machine is not compelled to keep within the observable temperature corresponding to Method I, since he does not arbitrarily select the alternative of making thermometer measurements only, and hence there is no reason why he should pay the penalty of keeping within the lower limits of temperature rise.

Other instances which come within Method II and in which only one kind of measurement need be made are those where it would be impracticable, or unreasonable, to require the thermometer check. Amongst such cases is that of rotors of turbo-generators. It takes a long time to bring such rotors to rest, and by the time it is practicable to take thermometer measurements of the temperature of the rotor, so long an interval has elapsed that such measurements would be of no value. The endeavor has been made to bring together in the accompanying table, in the briefest practicable form, the most important data relating to the observable temperature rise permitted by the rules. It would be desirable however, that in addition to consulting the values set forth in the table, the accompanying sections of the rules to which reference is made should be consulted with a view to understanding their real intent.

The designations $A_1$, $A_2$, B and C, in the table, relate to the classes of insulation and may be interpreted by referring to Sections 188 and 190 of the rules.

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## OSCILLATING CURRENT TRANSFORMER

The Consulting Engineering Laboratory has recently developed a portable oscillating current transformer, designed for the purpose of testing insulators and bushings with high frequency high potential.

The advantages of testing with high frequency high potential are, that the corona spreads more evenly and clings more closely to the surface of the porcelain, and thus searches out more thoroughly for flaws in the porcelain than the 60-cycle high potential. The high frequency test approximates more nearly to the conditions under which insulators fail in service, namely, surges due to lightning and arcing grounds. The testing outfit is more compact and easier to handle than the corresponding 60-cycle outfit. The high frequency testing outfit for testing insulators up to 150,000 volts is shown in the illustration.

The oscillating current transformer consists of two concentric windings arranged vertically in a stoneware jar and immersed in transil oil. The two windings are connected together at one end and grounded, the outer coil consisting of a few turns of copper strip wound on a form of treated wood. The ends of the coil are brought out through the stoneware jar under the oil and are connected to a condenser and spark gap. The condenser is charged by a 13,200-volt 2½-kw. transformer. When the voltage across the condenser reaches a sufficient value to break down the spark gap, an oscillatory discharge takes place through the oscillation transformer, the frequency being equal to $\frac{1}{L\pi\sqrt{LC}}$ This oscillation is communicated to the high tension coil wound in a single layer on a hard rubber form. The voltage induced in the high tension winding depends on how nearly the natural frequency of the two circuits coincide. By making the frequency of the high tension winding considerably higher than the low tension winding, it is possible to obtain good regulation, as the addition of more insulators decreases the frequency of the high tension circuit, and this brings it more nearly into resonance with the low tension circuit. With the outfit shown in the illustration the addition of 16 suspension type insulators tested in multiple in strings of two, gives a voltage drop of 20 per cent.

A reactance divided into two coils is connected in series with the secondary of the 60-cycle transformer, so as to limit the current through the transformer when the spark gap breaks down and to prevent a power arc forming across the spark-gap.

Oscillating Current Transformer

The high frequency high potential is controlled by varying the length of the spark gap in series with the condensers. Voltages ranging from practically zero to 170,000 volts can be readily obtained.

The apparatus is supported on an angle iron frame mounted on casters and enclosed on all sides with perforated iron. A wooden cover encloses the top and supports a sphere gap, which is used for measuring the high frequency high potential; a graduated scale enables the gap to read off directly in volts.

The supply voltage is 110 volts 60-cycle; fuses and disconnecting switches are mounted inside the frame, the main switch being connected with a rod to a handle shown in the near corner of the illustration. The handle immediately below this is connected through a rod to the spark gap. These handles represent the entire control of the apparatus.

The frequency of the low tension circuit of the oscillating current transformer is 220,000 cycles.

P. E. Hosegood.

## QUESTION AND ANSWER SECTION

The purpose of this department of the REVIEW is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the REVIEW.

Second, it publishes for the benefit of all REVIEW readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting suject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

### CROSS-ARM BRACES: CHOICE OF POSITION

**(115) Why are the cross-arm braces used in pole-line construction sometimes attached to the pole side of the cross-arm while at other times they are fastened to the other, or outer side, of the cross-arm?**

**What are the merits of each method of fastening?**

There is only one real argument, and that dictates that the braces shall be placed on the outer side of the cross arm. By bolting them to this face, they assist the arm in resisting the twisting action to which it is subjected when an abnormal line strain developes due to a wire or cable breaking. When this unbalanced pull is in the direction away from the side of the pole to which the arm is attached, the braces are placed under compression; and, correspondingly, when the pull is in the other direction, the braces are placed in tension.

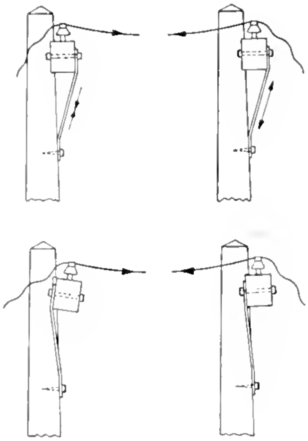


Fig. 1

If the braces are attached to the inner face of the arm, they can only provide support for an unbalanced vertical load on the arm. By accomplishing this only, they do not fulfill their complete function.

Fig. 1 will assist in making this explanation clear.

T.A.W.

### AUTOMATIC VOLTAGE REGULATORS: PARALLEL OPERATION

**(116) Will you please publish a detailed diagram of the connections which were briefly described in the answer to Question No. 107 (GENERAL ELECTRIC REVIEW, July, p. 771). It is desired that the diagram be applicable to the operation of two alternators controlled individually by separate automatic voltage regulators. The system which the units feed in parallel is three-phase delta connected.**

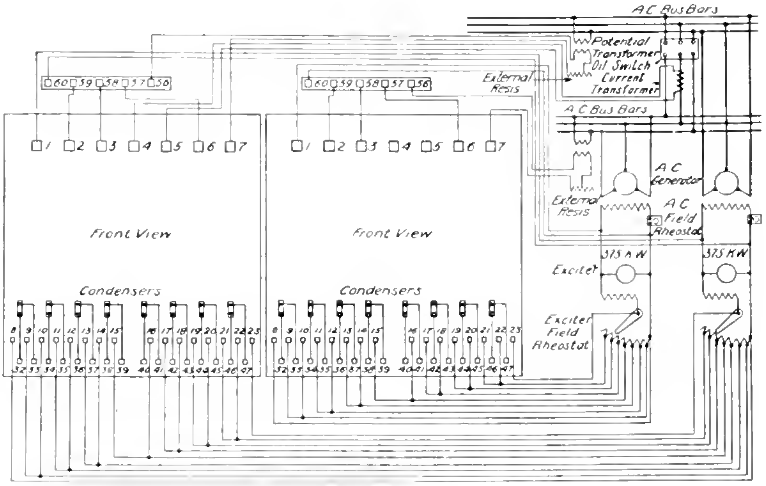


Fig. 1

Fig. 1, illustrates the automatic voltage regulator connections to be made for the control of the equipment specified.

O. C. R.

### AUTOMATIC VOLTAGE REGULATOR: CHANGE FROM A-C. TO D-C.

**(117) Can a standard alternating-current automatic voltage regulator be altered so as to operate on a direct-current circuit?**

No, certain inherent features in the design of an automatic voltage regulator for use on alternating current preclude any changes being made in it which will enable it to operate satisfactorily on direct current.

H. A. L.

### POLYPHASE SYNCHRONOUS CONVERTER: OPERATION ON SINGLE-PHASE

**(118) What would be the result if a synchronous converter was started up from the d-c. end and synchronized on the a-c. end, only one phase however being closed, the other two remaining open? The system is 25 cycle, three-phase, with generator neutral grounded. The transformer at the converter is delta double-star connected. The converter supplies an Edison three-wire system with grounded neutral. Also, what would be the result if an attempt were made to pick up load on the converter under these conditions?**

A synchronous converter connected as specified in the question, and supplying the neutral of the Edison three-wire system, would have a greater tendency to pulsate due to increased line drop, which is the result of operating single-phase instead of three-phase. The severity of the pulsation would be fixed by the characteristics of the particular machine and its supply line. It is altogether likely, however, that the converter would run satisfactorily at no-load on single-phase.

The amount of load that the converter would be capable of carrying is determined by this tendency to pulsate. If its operating characteristics were such that the machine would run stably at no-load and under load, the amount of d-c. power which could be drawn from it would be in the neighborhood of one-third normal capacity at unity power-factor with normal heating. This is based upon a value of heating between the maximum and average temperatures of the windings.

The d-c. voltage, of course, would be lower on account of the increased line drop and the change in the ratio of conversion within the machine. At no-load the decrease would be slight and under load probably somewhat more than 3 or 4 per cent. With normal field excitation of the converter, the d-c. voltage would also be decreased due to the reaction of the magnetizing current of the idle transformers which would be supplied by the converter. This 3 or 4 per cent is approximate and is accounted for by the change in ratio and drop in the secondary connections of the transformer, the surplus being due to the high-tension line drop, the amount of which cannot be predicted, of course, without knowing the dimensions of the line and the amount of energy being converted.

J. L. B.

### FEEDERS: TROLLEY CIRCUITS

**(119) What are the general considerations involved in the layout of trolley-wire feeders, particularly those for a line fed from one end?**

Feeders on railway systems have two functions; first, to increase the conductivity or carrying capacity of the trolley circuit, second, to permit sectionalizing the trolley wire.

Those sections of the trolley wire, which of themselves would be of insufficient capacity to carry the load, have taps spaced at frequent intervals (say 1000 ft. or oftener) at which additional current is brought in from feeders. For those other sections, which have a greater proportional current-carrying capacity, one or two taps are sufficient.

In the case of a stub-end feed with a number of cars operating over the entire section, it is frequently desirable to taper the feeders in order to get sufficient carrying capacity near the substation. That is, two or more feeders will go out from the substation and end in the trolley wire, one at a short distance, another at a farther point, and so on.

For the most economical use of the copper, the trolley should be fed at frequent intervals from every feeder where there are multiple feeders, but in practice the feeders are sometimes kept isolated from each other for special reasons. As an example of this, one feeder may be "boosted" to a higher voltage than normal and fed into the extreme end of the trolley wire so as to raise the potential at that point.

As regards uniform or tapered feeders it can be said that, for *approximately* the same maximum voltage drops, the weight of copper will be the same in either case.

It is customary to install switches across the section insulators in the trolley wire, in order to tie the whole system together and to get the greatest benefit from the copper installed by permitting one section to help those adjacent. In this case the section switches must be opened in order to isolate a section.

G.H.H.

### MINING LOCOMOTIVES: DETERIORATION

**(120) Will low voltage, due to very poor rail bonding, cause overheating and a rapid rate of deterioration of the mining locomotive motors to which it is applied?**

Overheating and a greater than normal deterioration of mining locomotive equipment (and in fact of any direct-current series-motor tractive apparatus) may well be expected when the condition of the rail bonding is bad.

Practically all mining locomotives use direct-current series motors. The speed of this type of motor is directly proportional to the counter e.m.f. at the motor terminals; and, therefore, when the applied voltage is low (for instance, due to poor rail bonding) the motor speed and consequently that of the locomotive is low. This lowered speed will not appreciably change the value of the current drawn from the line by the motor if the load on the locomotive (equivalent of torque) is to be maintained the same at the decreased voltage; because it is a fundamental law of the series motor that the value of the current required is dependent only upon (and directly proportional to) its torque output. Since the armature or field current of the motor will not be less at the lower voltage and constant load, the number of heat units liberated in the motor will remain the same as at full voltage, neglecting core losses (these will decrease slightly but are a small percentage of the total heat loss); and consequently the *rate* of increase of temperature with continuous operation will remain nearly the same for either condition of voltage. If, as under ordinary conditions, the locomotive would be required to perform the same amount of work per day, it would become hotter at low voltage than at normal, because it would take a longer time to accomplish the work at the lower speed. Although not a commercial probability, if the motor is to be run only for the same length of time at low voltage as at normal, and in doing so perform a less amount of work (proportional to the reduction of the voltage) it will operate at normal temperature.

G. H. S.

### PHASING-OUT: PECULIAR VOLTAGE MEASUREMENTS

(121) Fig. 1 is a diagram illustrating the transformer connections at both the power-station and the substation end of a certain distributing system at the time of phasing-out a new transformer *D*.

Transformer *C* was in service, feeding the overhead and the underground lines that supply small motor and lighting customers. The customer's transformers on these lines transform the voltage to 230 volts. The middle points of the low-tension side of these transformers are grounded and the customers receive power at 115 volts (obtained between these grounded middle points and either of the outside lines). The 2300-volt lines are non-grounded.

Peculiar conditions were found when the phasing tests were made between the new transformer *D* and the 2300-volt bus. In operation a regulator similar to the one connected to transformer *C* was used with this transformer, *D*. However, at the time of this particular test, it had been taken out of the circuit altogether because of trouble which had developed within it.

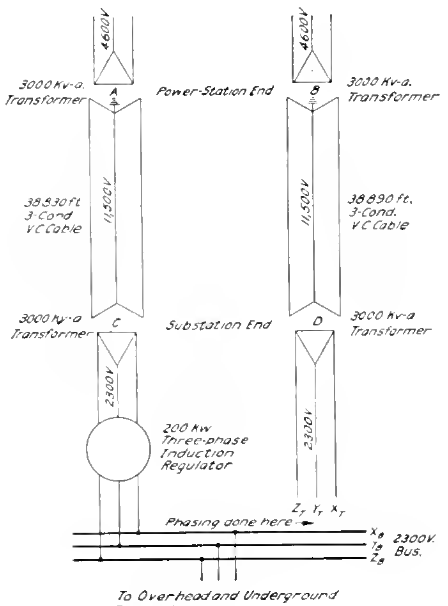


Fig. 1

| Voltmeter and potential transformers connected between | Volts | Voltmeter and potential transformers connected between | Volts |
|---|---|---|---|
| $X_T$ and $X_B$ | 0 | $Y_B$ and $Z_B$ | 2280 |
| $Y_T$ and $Y_B$ | 0 | $X_B$ and $Z_B$ | 2280 |
| $Z_T$ and $Z_B$ | 0 | $X_T$ and gr. | 1100 |
| $X_T$ and $Y_B$ | 3880 | $Y_T$ and gr. | 1060 |
| $Y_T$ and $Z_B$ | 3840 | $Z_T$ and gr. | 1100 |
| $Y_T$ and $X_B$ | 2800 | $X_B$ and gr. | 1180 |
| $Z_T$ and $Y_B$ | 3520 | $Y_B$ and gr. | 1310 |
| $X_B$ and $Y_B$ | 2200 | $Z_B$ and gr. | 1416 |

Denoting the lines coming from the new transformer *D* as $X_T$, $Y_T$, and $Z_T$, and the bus as $X_B$, $Y_B$, and $Z_B$, the tabulated data were obtained.

It can be seen that apparently $X_T$, $Y_T$, $Z_T$ and $X_B$, $Y_B$, $Z_B$ can be thrown in parallel, that is, the deltas representing the voltages of the two circuits seem to coincide.

How is it possible to get such high values of voltage when taking the cross voltage readings, $X_T - Y_B$, $Y_T - Z_B$, and $Z_T - Y_B$? Why are the voltages to ground considerably different for the transformer and the bus? The voltages for the transformer are too small to locate a neutral in the center of the delta, while for the bus they are too large. What is the cause of this? There is no electrical connection between the transformer and the bus.

Considering the bus voltages first, it will be found that by plotting a triangle the sides of which respectively represent the values of the voltages between the buses and then laying off the corresponding voltages to ground these three latter meet in a common point. This shows the neutral to be a definitely fixed point which may be explained by the fact that the capacity of the network, to which the bus is connected, is appreciable and that the neutral is held so by the capacity current to ground.

Turning to the readings obtained on the new transformer, it naturally would be supposed that each voltage to ground would be the same, and be of a value approximately 57.7 per cent of the line voltage. The actual readings obtained are near enough alike to assume that, since each was taken separately, the neutral point shifted in each case with respect to the line. Because the new transformer is not connected to the buses or to any system of appreciable electrostatic capacity, there is only a very small capacity current and the neutral, therefore, is unstable. When a potential transformer is connected from one line to ground, it appears only natural that the voltage across it should drop to some value below the actual value existing before the potential transformer was connected. If three potential transformers and three voltmeters had been connected in Y, the voltage reading from each line to neutral would have been equal and of a value approximately 57.7 per cent of the line voltage.

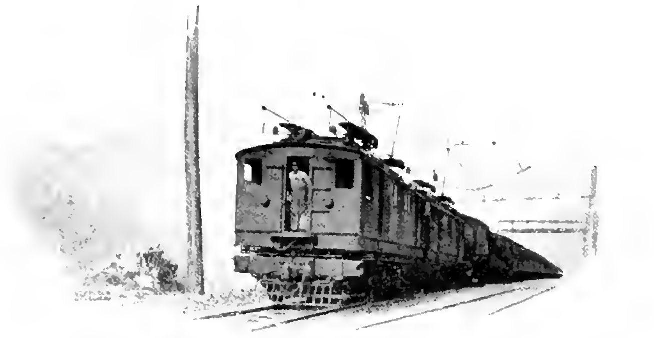
The fact that zero voltage was read between $X_T$ and $X_B$ and between the corresponding *Y* and *Z* lines would seem to indicate that the proper lines were about to be connected together, but this is not positive proof as the bus and the new transformer secondary are stated as being entirely insulated from each other. The higher voltages obtained on the cross readings, however, make it appear that in this instance, at least, two points, (for instance $X_B$ and $Z_T$) were connected together when the other readings were taken.

The most pertinent comment drawn forth by such a test (and the one whose importance should be emphasized) is that, *if no connections other than those of the potential transformer were made between the two three-phase lines, none of the readings taken between the bus and the new transformer terminals can be assumed as positively indicating anything in particular.*

R.K.W.

# GENERAL ELECTRIC
# REVIEW

NOVEMBER, 1914



## A Special Number
## on
## Electric Traction

# GENERAL ELECTRIC REVIEW

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GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

Our last November issue was devoted to "Electric Railways" and at that time we stated that we hoped some day to issue a special number on "Electric Traction" covering some of those problems involved in the electrification of steam railroads. So the present issue is devoted to "Electric Traction," and we hope that the contributions will be read with interest and profit by those concerned with our heavy traction problems. The articles cover a wide field, and we believe much valuable operating data are contained in the articles written specially for this issue by those responsible for the operation of the various steam roads that have been electrified. We wish to express our appreciation of the generous help given us by these contributors.

It is gratifying to find that in all cases where a direct comparison of the operating expenses before and after electrification can be made, that marked economies can be traced to the change in motive power. A most striking example of the results that may be expected from the electrification of many of our steam railroads can be found by studying the figures found elsewhere in this issue relative to the first year's operation of the Butte, Anaconda & Pacific Railway. The service on this road is of an unusually severe nature and the unparalleled results obtained as set forth in the detailed statements of the economies effected, speak most eloquently for the 2400-volt equipment. In fact there is little doubt but what the success of this particular installation will have a far-reaching effect on determining the choice of equipment for many other installations.

The Canadian Northern electrification at Montreal has adopted apparatus and equipment similar to that of the Butte, Anaconda & Pacific Railway, and we have every reason to believe that their judgment in this matter was influenced by the success achieved by the higher voltage direct-current system under the severest kind of operating conditions. As is well known, the Chicago, Milwaukee & St. Paul Railroad is contemplating the electrification of a whole steam road division, and here again we expect to see the direct-current system used, with a trolley potential as high as 3000 volts. When this last named electrification is completed we confidently expect to see operating economies effected of a nature which will determine the trend of much future work.

We believe that is it becoming very thoroughly recognized that the adoption of electric traction, even for the severest kind of railroad service, involves today nothing in the nature of an experiment. Electric motors and locomotives and all the incident apparatus and equipment have been designed and tested beyond the point where there is any room left for discussion as to their capabilities. Electric equipment is available today for all classes of service, ranging from the ordinary city street car service, both light and heavy interurban service (the latter often closely approximating steam road conditions), right up to the severest steam road requirements, whether these are to be considered for slow or moderate speed freight service or high speed passenger service of the most exacting nature.

There are articles in this issue dealing with both the design of motors and the design of locomotives for heavy traction service which we believe will be read with considerable interest. The article describing the Illinois Traction System is of special value as showing how some interurban roads are approximating steam road conditions and how thoroughly all the equipments and appurtenances of some of these roads have been developed to meet the severe conditions and give the highest class of service with safety, economy and satisfaction to the public in general.

Many of the most notable examples of steam road electrification up to the present time have been the electrification of large city terminals. In these instances the change from steam to electric operation has been primarily made to eliminate the smoke nuisance and the change had been rather a matter of compulsion than choice. The same law of necessity has dictated the electrification of the various tunnels now operated electrically. In the case of most terminal electrifications the change in the mode of operation has been accompanied by the building of most elaborate terminal buildings, and the entire rearrangement of tracks. Some of our modern steam road terminal buildings are the most elaborate and pretentious buildings erected in modern times, and the cost has run into many millions of dollars. The benefits derived from electrification have been varied and most pronounced; but as such tremendous sums of money have been expended at the same time, which, while providing improvements, were not necessitated by the change in the form of motive power, it is hard in most instances to arrive at anything like a correct figure for the economies secured by electrification. For instance, the property holders in the immediate neighborhood and the city itself must make enormous gains by the improvement in real estate values. If the railroad is one of the property holders, and in many instances this is the case, they also make large financial gains in this direction. Is this profit taken into consideration in computing the benefit conferred by electrification? Most new electrified terminals operate on two levels, thus saving enormously in the ground area covered, and this in a locality where real estate is enormously valuable. Is this gain considered? It has been proved many times that any improvement in service will stimulate traffic and therefore electrification will increase traffic returns. This in common with many other points should be taken into consideration.

In all cases that we know electrification has shown operating economies sufficient to justify the expenditure; but when millions upon millions have been spent on other improvements at the same time, it is difficult to differentiate what proportion of the outlay can correctly be charged against electrification as distinguished from all the other improvements that have been effected at the same time.

It is most unfortunate that the calamity of the great European war should have broken out at a time when the finance of the country was going through such a trying period. The period immediately preceding the war practically amounted to a second reconstruction period, but there is little doubt that the potential and basic wealth of the country can overcome the effects of these trying times and meet successfully the strained financial conditions imposed by so large a section of the world being thrown into confusion by war.

It is during a reconstruction period of any kind that we look for ways and means of effecting economies, so it is natural that if economies can be obtained by electrification, and we maintain that they can, a study of the operating conditions of many steam roads would be profitable at the present time.

We fully recognize that the technical considerations are not the paramount issues, but that the problem has resolved itself into one of finance. The engineers and manufacturing concerns have eliminated any technical difficulties that existed. The main hindrance to many schemes of electrification at the present time is to be found in the difficulties encountered in raising money and especially in raising money for railroad purposes, but we believe that when those who can dictate the "doing" or "not doing" of things, realize that a tendency to construct rather than destroy has started they will stimulate in every available way, to the utmost limits of their power, any efforts put forward by the railroads to secure economies. Should pessimism give way to confidence, a great impulse will be given to the electrification of steam railroads, and we shall then proceed along the paths of progress, in spite of all obstacles, with greater energy in the future than in the past.

# DEVELOPMENTS IN ELECTRIC TRACTION

By W. B. Potter

Chief Engineer, Railway and Traction Department, General Electric Company

After mentioning briefly some of the more important features of development in electric railways, the author passes on to a consideration of some of the problems of steam road electrification. The requirements of design in both electric motors and locomotives are reviewed and some of the factors governing the choice of higher direct current voltage for heavy traction work are set forth.—Editor.

W. B. Potter

THE electrification of railways has naturally been extended in the classes of traffic where the substitution of electric power has afforded advantages not obtainable with power of some other character. Electric motor cars, as compared with the horse or cable car, were immediately recognized as a more efficient method of transportation, and the extraordinary development of the trolley car service was a natural result.

During the early development of electric equipment for transportation purposes the individual motor car and the electric locomotive received about equal attention. Because of the greater opportunities in urban service the motor car soon became more prominent, and for a number of years the motor car equipment received almost exclusive attention.

Results obtained in trolley car service demonstrated beyond question the success of electric power and did much to establish confidence in the reliability of electrical equipment. For the heavier service of handling trains the use of a motor car as an electric locomotive was but a natural development. The entrance of electric power into the domain of the steam locomotive really began in the early nineties with small trains in passenger service. The Intra Mural Railway at Chicago in 1893, where motor cars were used as electric locomotives, initiated in this country the permanent invasion of the extensive steam service on elevated lines.

The further development of multiple unit control, permitting any number of motor cars in a train to operate in unison, made possible a schedule performance which even the largest of steam locomotives would be incapable of handling, quite apart from the objectionable features incident to the use of steam.

The earlier applications of electric power to regular steam railway service were in most cases for service in tunnels and railway terminals, with the object of eliminating the smoke and gases common to the use of steam locomotives. The Baltimore & Ohio Tunnel which commenced operation in 1895 was the first instance of electrification as applied to heavy traffic, and the first electric locomotives to successfully initiate the struggle for supremacy with steam locomotives under main line requirements.

The electrification of main line service is no longer an experiment. The heaviest traffic can be successfully handled, and therefore there remains only the question of whether it will pay. As a rule, excepting the expense incident to the initial investment, the cost of operation with electric power will be less than with steam, and often this saving will show a handsome return on the investment. There are many instances, such as tunnels and terminals, where other considerations than the financial showing are of paramount importance. Even in such instances there are often local conditions where the value of property will be enhanced, or where territory necessary to steam service can be made available for other purposes and therefore remunerative.

The possibility of handling heavier, or even equal trains at higher speeds is becoming better recognized as a means of increasing the tonnage over a given route, and so provide for an increasing traffic more economically than by the construction of additional lines under steam operation.

Electric locomotives for heavy traffic must be so constructed as to withstand the severe shocks and strains which occur in the handling of trains, and to facilitate inspection and maintenance the electrical and other equipment should be conveniently located. Much attention has been given to the development of different general types, and many varieties of electric locomotives differing both in mechanical design and electrical equipment have been built and tested.

Variations in the mechanical construction are influenced largely by different methods of transmitting the power from the electric motor to the driving wheels. The motor car and steam locomotive have both served as models, with innumerable variations in which their characteristics have been differently combined and in many cases with indifferent success. Geared or gearless motors mounted on the driving axle, or in special cases a combination of gearing and parallel rods, each with reference to its fitness for the particular purpose, are the most promising methods of drive. Guiding trucks will undoubtedly be used in high speed service and doubtless at slower speeds with very heavy locomotives where the weight distribution on the track may be of importance.

The character of electrical equipment, considering the larger power required in main line service, is influenced by the problem of electric transmission to the locomotive and the collection of current from the conduction circuit. As the amount of current varies inversly as the voltage, the transmission and collection are therefore made easier at higher potentials. The development of equipment suitable for higher voltages has received much attention, and there are at present a number of important railway electrifications of this character on which alternating or direct current is used. The respective merits of alternating or direct current involve many details of which only a few are of general interest as influencing the trend of commercial development.

The equipment for alternating current, whether three-phase, single-phase or split phase, does not at present appear susceptible of many improvements by which the cost may be reduced, and there is further an uncertain investment for counteracting the influence of the alternating current on telegraph and telephone lines.

Direct current operation at potentials higher than 600 volts is no longer in the experimental class; the most important electrification being the Butte, Anaconda & Pacific, where successful operation at 2400 volts has been fully demonstrated

A vital question affecting the use of direct current in heavy service is the amount of current which can be successfully collected from the conducting circuit, particularly from an overhead construction, as with the third rail there is ample margin even at 600 volts.

As a device for collecting current the ordinary trolley wheel has proven successful in handling far heavier equipment than originally contemplated. The roller pantograph, which is in effect an elongated trolley wheel, has proven very successful in service for which the ordinary trolley wheel would not be suitable. The sliding pantographs, of which there are many in service, when fitted with copper faces have a collecting capacity even exceeding that of the roller, and there is no doubt a pantograph equipped with a suitable sliding collector will successfully collect current to the full capacity of the overhead conductor.

An improvement in the overhead catenary construction, accomplishing the double purpose of securing greater flexibility and an increased conductivity, is obtained by the use of two conductors lying close together in the same plane, with the supporting hangers located alternately so that the mid-span of each conductor is opposite the supporting hanger of the other. Within practical limits 1000 amperes may easily be collected from a single 0000 conductor and 2000 amperes from two 0000 conductors. With a copper conductor and copper faced sliding collector having grease lubrication, the tests and obtainable records indicate a life of the conducting wire fully comparable with that commonly obtained with a trolley wheel or roller pantograph.

It is a reasonable statement that with a potential not exceeding 3000 volts, no difficulty will be experienced in collecting from an overhead construction the current required by locomotives in the heaviest passenger or freight service. The choice of a higher direct current voltage is, therefore, a question of economics—whether the saving in copper or further spacing of substations will justify the greater cost of rolling stock equipment at a higher voltage. Careful estimates, comparing 3000 volts with higher voltages up to 6000 as applied to main line operation, show practically no advantage in favor of the higher voltage. In the majority of cases in this class of service the investment for locomotives is by far the larger item as affecting the selection of the voltage.

As between the different systems the indications point strongly toward the more general adoption of direct current for main line electrification and heavy railway service generally.

# THE POSSIBILITIES OF AN ELECTRICAL COMMISSION

By Frank J. Sprague

Consulting Engineer, New York

The author makes a strong plea for all manufacturing and engineering interests to subordinate all discussions of non-essentials, in order to view the general problem of steam road electrification in its broadest aspects and to co-operate for the common good. He points out the financial and economic aspects of the problems and reviews some of the most important technical considerations.—Editor.

Frank J. Sprague

"STAGNATION of export freight traffic, dwindling domestic and passenger revenues, piling up of unpaid obligations, passing of interest payments of railroad securities aggregating nearly $600,000,000, and early maturity of as much more in fixed charges and short term notes,"—such are the conditions, tersely described, confronting trunk line railways at a time of unparalleled harvests, because of unwise or dishonest financing, overmuch regulation by Public Service Commissions and a war convulsing half the civilized world.

To those hoping for, and believing in the ultimate operation of railways by electricity, the situation seems fraught with tremendous consequences, for the results of the financial paralysis brought about will be felt throughout the life of the present generation.

Must we, therefore, give up the hope of advance in electrification, or is there some means of mitigating its enormous cost to such an extent as will in some measure remove the incubus now resting upon railway financing? If so, then it behooves all manufacturing and engineering interests to lay aside or subordinate the discussion of non-essentials, view the general problem in its broadest aspects and co-operate for the common good.

What I have often pointed out, that electrification is primarily a financial problem, and will ordinarily only be adopted when the results to be attained will accomplish something that steam cannot, or will return a larger net dividend on capital than when the latter is expended in some other way, must be accepted as true. Therefore the first requisite for any hope of success is to reduce the capital charges of electrification, this in spite of the repeated claims that differences of opinion as to systems, or the necessity of the acceptability of some single standard, has been the greatest barrier to advance.

That the latter has an influence is undeniable, but as I stated at the recent meeting of the National Electric Light Association in Philadelphia, the matter of power supply is more important than the question of system, for everyone who looks forward to the future of our country sees a specter arise, the failure of our coal and timber supply. With an ever increasing demand for power we must then fall back upon hydraulic supply, but meanwhile we should conserve our natural resources by making use of the diversity factor possible to large commercial stations properly located and interconnected, for such can not only relieve the railways of the cost of large stations with ample reserve, operated at a low load factor, but supply the power at a reasonable cost.

Referring, however, to the matter of systems, it is undoubtedly wise to see if it is not possible to remove the discordant note which has been so dominant, or at least soften its character; and the question arises, to what extent and by what means can railway electrification be now standardized and its probable development be determined?

It is a subject to which I have given much thought, and to its solution no small amount of energy. For many years after the advent of the a-c.—d-c. substation, higher potentials for the direct current secondary distribution was generally discouraged and deferred, at first because of difficulties in motor construction, some real and others assumed, and later because of the advent of a new system which promised to remove the limitations of potential on the working conductor and the objection of moving apparatus in substations, and sometimes even of the substations themselves.

The so-called "Battle of the Systems," limited for trunk line consideration in the

United States, was at first defined by those who committed themselves to advocacy of a single system, as a choice between single-phase trolley operation to 11,000 volts or over, at either 15 or 25 cycles, and 600 volts d-c., third-rail operation from substations supplied from a high tension prime station, as typified in the New York, New Haven and the New York Central installations. In Europe, on the other hand, the disputants divided themselves into three camps, the English in practice principally advocating direct current, the Swiss, German and Swedish engineers single-phase, and the Italians polyphase operation.

It was unfortunate that the comparison between systems, and especially between direct current and single-phase, was based on an over enthusiastic belief in, and acceptance of the merits and accomplishments of the new system, and an unwarranted disregard of the possibilities of the development of the older one along the lines which I had for many years advocated.

It had long seemed to me that in each of the systems there were certain normal maxima of operating potentials, at which there would be established a balance of advantages for that system; that there was nothing in the art which prevented successful operation at the working conductor at 6,000 volts for polyphase operation, 11,000 to 15,000 volts for single-phase, 1200 to 1500 volts for direct current with a protected third rail and from 2500 to 3000 volts with direct current trolley; that there were inherent differences in the weights and costs of single-phase and direct current motor equipments, when built and operated under like conditions of reliability, which were irremedial, and which were likely in a large measure to offset whatever advantages might be achieved in efficiency of the secondary transmission; that in view of the coming necessary interconnection of power supplies, in which railroad use would be but one of many, an arbitrary adoption of a specific cycle for trunk line operation was of questionable advisability; and, finally, that only after the inevitable development of each of the systems to its natural limits could any final determination be made whether, on the one hand, conditions were so varied and the application of electricity so catholic that no one system could be accepted for general application to the exclusion of all others, or, on the other hand, that there was a definite trend in the favor of some one system towards which the activities of engineers, manufacturers and railway officials should be bent.

This general position and contention was not an advocacy of any one system, but a prophecy of development, and a plea for conservative action and judgment. Time, I think, has vindicated the correctness of this attitude, and while perhaps it has not lessened individual solidarity of belief and zeal, there has been some mitigation of asperity in the advocacy of systems, and a tendency to unite, to some extent at least, on a more general advocacy of electric operation as a substitute for steam, wherever proper, on broader grounds and for more cogent reasons than sentiment and minor differences in transmission efficiencies.

The art has steadily advanced. Polyphase equipment seems best at about 6000 volts and 15 cycles; single-phase remains generally at about 11,000 volts at both 15 and 25 cycles; and direct current has already arrived at 2400 volts, and even a much higher voltage is proposed for the overhead trolley, with any required initial voltage for transmission.

Polyphase operation is still limited to concatenated speed variations; single-phase, when carried out with commutated motors, permits variation with a variable tap transformer; and with direct current speed variation to any essential degree is attained by grouping of motors, and, thanks to the interpole construction, by variations of field strength.

We have, therefore, practically arrived at, or certainly are in sight of the limiting potentials and practices which I have indicated, and for which, so far as applicable to direct current practice I have, oftentimes to some discomfort as a prophet, been the advocate. But with these various goals reached, it is but fair to say that there is still no general agreement as to many fundamentals, and professional and manufacturing rivalries the world over are unduly manifest.

Urban and interurban transportation, surface, elevated and subway, and terminal and subway problems have all been successfully solved, the aggregation of any required amount of power has been made possible by the multiple unit system, the reliability of electric operation has been established, and of late the attention of the transportation world is being directed anew and with keener interest to the possible inauguration of electricity in place of steam on trunk line divisions. With the possibilities and dangers of far-reaching and costly mistakes, shall the settlement of the problems involved be left to the necessarily slow and independent solution of individual trials?

I may be pardoned if I express the belief that no railway official however broad his experience, no manufacturing company whatever its resources, no electrical engineer however experienced, confident or self-assertive, can alone settle this question. The problem is too big, it involves too many financial, techincal and operating problems, it comprises too great an assemblage of advantages and disadvantages viewed at different angles, for any single mind. Even if such a one should be entirely correct in final analysis and prophecy, his dicta cannot carry the necessary measure of authority for general acceptance, nor should it do so. Of course, I do not mean that this or that railway problem cannot be met and successfully solved, operatively, by one or more methods, and by many able men, but varied as such solutions are and will continue to be under existing conditions, manifestly they cannot have broad national acceptance.

In the various electrical fields in which I have been more or less active I have always been a firm believer in meeting a condition of stagnation by some commensurate risk, and then to secure standardization by effective co-operation. Risks in an unknown field, with problematical results, are naturally undertaken by the enthusiast whose prophetic vision ignores ordinary financial restrictions, in the hope of laying a foundation of development which in the end promises commensurate reward; but once the way has been blazed in a new field of endeavor, then the attrition of mind against mind in co-operative effort is needed to formulate the grounds for the most stable and satisfactory advance.

It was with this idea in mind that, some two years ago, I addressed myself to the problem of trying to find some means of breaking through the wall of inertia which, buttressed by ignorance, disbelief and sometimes even by misrepresentation with regard to the possibilities of electrification, was interposed between accomplished facts and the hoped-for wider application. I sought to find some way of meeting existing conditions, financial and other, in the trunk line situation, and while demonstrating the financial advantages of electric operation to suggest some plan to relieve the railways in a large measure of the financial burden of electric equipment.

It seemed that the time had come when steps could be taken to remove the unnecessary asperities and soften the differences which had characterized the advocacy of systems, and to determine in some authoritative way the lines along which the future development should or should not take place. If engineers and manufacturers were sincere in their belief as to the economic advantages of electric operation in the place of steam, something surely could be done to manifest that belief in a substantial financial way, either singly or in co-operation; and the best interests of the art would be subserved if the great manufacturing companies could come to a common basis of understanding, and unitedly bend their energies toward common lines of development. It also seemed that, in connection with the future and inevitable concentration of small into great power stations, and their interconnection of supply of electric energy for a thousand and one purposes, there was an opportunity for the development of a financial organization outside of the manufacturing and railway companies which could play an important part in railway electrification,—in short, in general power stations would be found a great leveller of industrial class demands.

Various phases of the question were discussed with many manufacturing officials and a number of consulting engineers. Progress was slow, and still is, although some encouraging advance has been made towards a better understanding. At first it was thought by some that the American Railway Association, or possibly the American Institute of Electrical Engineers, through suitable committees, could be instrumental in arriving at the necessary conclusions. But it is almost unnecessary to point out that every committee of such an organization is made up of men absorbed in their individual businesses, that these committees can meet but infrequently, are more or less unwieldly, and are generally dominated by one or two members. As a rule, their conclusions cannot well indicate more than a general review of what has been accomplished, and voice with some measure of authority facts already self-evident. Nor could any uncompensated group of men of the necessary ability and experience afford to give the time for adequate study, or assume the great responsibility of decisions of far-reaching importance.

Then, too, the American Railway Association represents what I may term the defensive organization, that is, a conservative group of railway men whose methods of operation the believers in electricity hope to change. If, of course, this association held anywhere near equal beliefs in the new motive power, it could be most effective. but I believe through agencies which, although under its direction, would be external to itself.

The fact must be accepted that electricity is playing an increasingly important part in the evolution of steam railroading, and with the already successful handling of terminal problems the public is demanding with growing force that the smoke nuisance shall be abated in large centers of population.

Congestion at terminals is requiring a solution that can seldom be met with lateral enlargement, but must rather be solved through changed methods of operation which will reduce switching and "dead" movements, and permit utilization of space on more than one level.

Greater earnings must be looked for in a larger use of the capital already tied up in investment, as by the increase of frequency of service and capacity permissible by the use of electricity.

Increase in efficiency and economy also, as well as in capacity, may be expected under suitable conditions of freight traffic.

At terminals, important returns may be anticipated from the results of electrification, such as the reclamation of air rights for commercial development, and the use of cheap power for heat, light and improved methods for mechanically handling freight.

I believe that the application of electricity to problems of transportation by various systems has now sufficiently advanced to give entire confidence in the hope that correct solutions may be arrived at, no matter whether there is indicated a definite trend towards a particular development, or on the other hand a catholicity of application.

Yet we must recognize the fact that one of the great barriers to the consideration of the electrification of trunk lines is the radical differences in opinion between engineers and manufacturers as to what shall be the preferred future system or systems, as well as ignorance of the facts as to equipment and operative cost. In short, because the doctors do not agree, or are not entirely frank in their diagnoses.

Consider for a moment what the bewildered railway official and financier must view, and is asked to digest: Steam and water power central stations operated at 15, 25, 40 and 60 cycles, either limited to special use or seeking the advantages of co-operation and diversified supply; polyphase systems operated at constant or concatenated speeds, but with high weight factor of motive power, with double overhead lines at 6000 volts at 15 and 25 cycles, and with regenerative braking on descending grades; single-phase operation at 11,000 to 15,000 volts, at 15 and 25 cycles, with or without step-up and step-down transformers, with comparatively high efficiency of local transmission, but with the disadvantages of low weight factor and high equipment cost for rolling stock; direct current operation with third-rail at 600, 1200 actual, and 1800, 2400 volts proposed, and with overhead trolley at 600, 1200, 1500, 1800, 2400 actual and 3500 volts proposed, from rotary or mercury rectifiers, or motor-generator substations; top contact third rails with or without protection of various kinds, and under contact rails protected by sheathing; trolley lines, flexible and rigid, with simple or catenary suspension, and cross span and bridge supports; geared and gearless locomotives, solid and quilled armature suspensions, symmetrical and unsymmetrical arrangement of trucks and motors, solid and articulated cab constructions, direct and side rod drives; high and low centers of gravity; variable bridge and tunnel clearances; and so on to the end of the chapter.

If a representative technical society could arrive at some common conclusions, not only as to the present state of the art but the probable trend of development, such would probably be accepted by the manufacturing companies and engineers in general, and would go a long way toward relieving steam railway officials of at least one serious problem.

But the members of a technical society can not give, uncompensated, the time necessary for the comprehensive study necessary; and if similar conclusions could be arrived at by the manufacturing companies' engineers, in consultation with the officials of representative railroad companies, probably the same result would be achieved. But the engineers of these companies, however able, are concerned in the designing, manufacturing and sale of apparatus, and hence possibly and naturally biased to some extent in favor of their own creations. If, therefore, this general problem could be referred to representative engineers selected by, and occupying a confidential relation to the manufacturers, their engineers and the railroad companies, and who could be made the repository of the technical advances and facts individual to the companies, as well as the construction and operative facts on the railway installations already made, similar effective conclusions might be hoped for.

If we assume this latter procedure, the practical question is, can there in any manner be organized a group of consulting engineers of sufficient judgment and experience, technical training, independence of judgment and knowledge of railway and electrical conditions, men big enough to subordinate their preconceived opinions in the face of facts, to whom such momentous questions could be submitted for at least advisory conclusions.

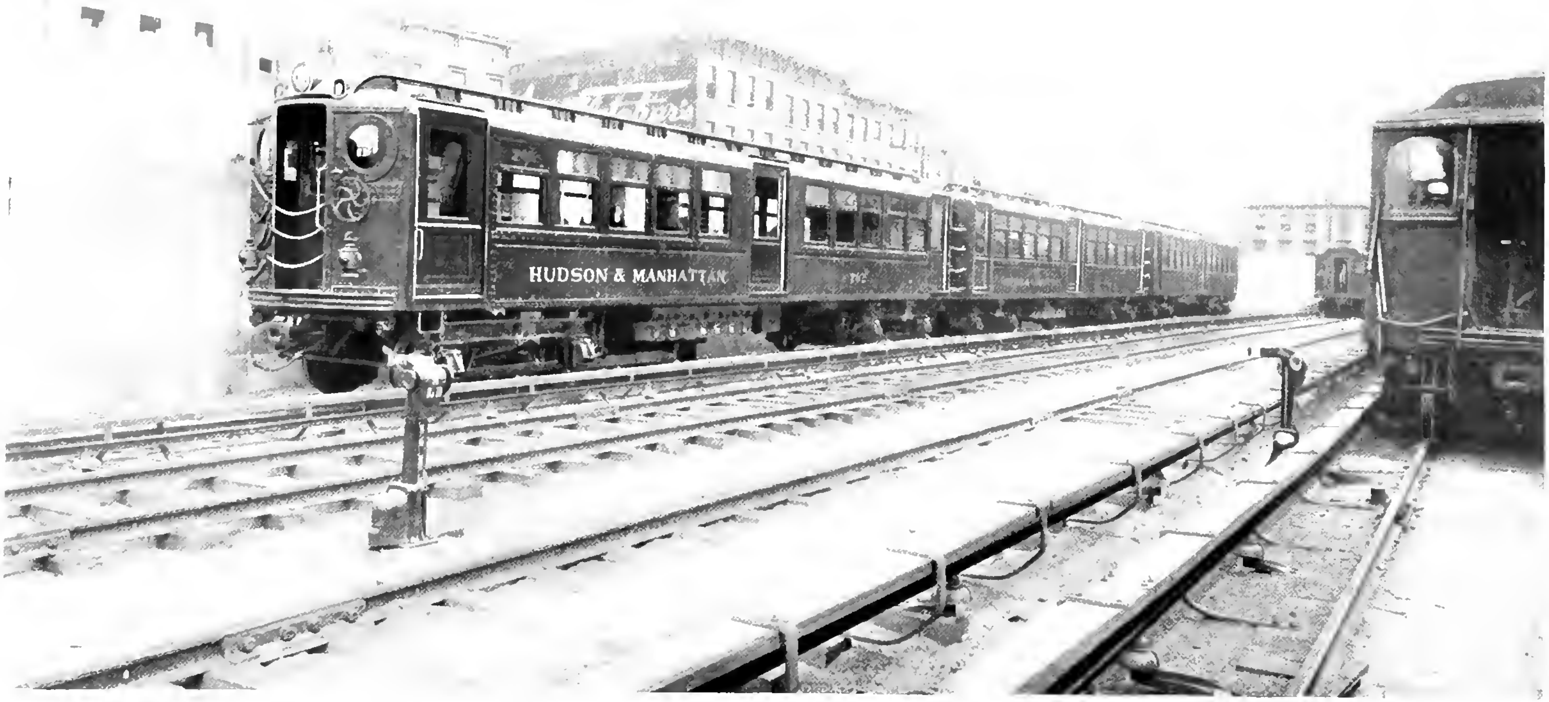
It seems to me that one of the troubles which has confronted electrical engineers, when dealing with the trunk line problem, has been a lack of a common ground of understanding, that they should be in more intimate touch with the actual facts with regard to steam operation, its possibilities and economies, as well as the limitations of increase of capacity to provide for future needs. If so, then much greater headway could be made by such a body of engineers, fitly representing various phases of opinion and experience, persona grata not only to each other and manufacturing companies, but to the railway companies as well, if instead of attempting to arrive at conclusions from theoretical discussions, or application of known facts to assumed conditions, they should apply their studies to some concrete case or cases which should embrace in extent and variety all the principal problems of trunk line electrification.

Most of the electrification projects in connection with trunk lines which have been carried out in this country have been dictated by local terminal necessities which could not be met by steam operation, but for the more extensive projects other reasons must prevail. Even with a settlement of system and demonstrated ultimate economy of operation and increase of capacity denied to steam operation, the financial problem facing the railroad man is a most serious one, for it is certainly true that the assumption of the actual cost of power supply, as well as that of rolling stock, the provision of reserve, and the individuality of installation and development constitute a serious burden which, if it could be in a large measure eliminated, would tend to accelerate electrification.

Assuming, therefore, some general agreement as to standards and the best methods of electrification, would not such be materially advanced if, as I have already indicated, the burden of reliable power supply at a reasonable rate and with ample reserve, and the possible provision of rolling stock on a basis of usage, could be undertaken through the agency of outside capital, leaving the railroads only the minor burden of supplying fixtures along the right of way, and co-operating with the power companies in the erection of general power supply lines upon their own property?

To effectively carry out the ideas above crudely set forth, I may state that at least one of the principal manufacturing companies has expressed itself as being favorably inclined to co-operate in the creation of a technical commission, to be composed of disinterested engineers of wide and varied experience, who shall make a thorough study of the various systems of electrification as applied to such situation or situations as may be taken up; that it is prepared to bear any required part of the expenses of such a commission incident to the making of a comprehensive study of trunk line problems; that it is in favor of some scheme of financial development which shall relieve the railroads of a part of the burden of raising capital; and, finally, that it only awaits the necessary co-operation of railroad officials to make effective this joint effort to avoid the heavy costs of mistakes due to individual judgment, on the threshold of a possible great electrical development in transportation whenever the financial skies make such practicable.

Despite this promising advance, the proposal has met with sufficient obstruction to thus far prevent its adoption in the form which promises the greatest effectiveness, but need that be the final result?



Three-Car Train on the Hudson and Manhattan Railroad. Mr. L. B. Stillwell deals with the operation and maintenance of these cars and their equipments in his article entitled, "Co-ordination in Railway Equipment"

# CO-ORDINATION IN RAILWAY EQUIPMENT

By L. B. Stillwell

The author dwells on the fact that it is not only the goodness of the individual elements of equipment that determines the success of a railroad, but that the ultimate results must depend upon the proper co-ordination of all the constituent practice. The equipment of the Hudson and Manhattan Railroad is analyzed to support the authors contentions, and many valuable tables of statistics are given showing the operating costs, detentions, etc.—Editor.

The gross earnings of a transportation system will largely depend on its traffic winning characteristics. Primarily traffic is influenced by the frequency and reliability of service and by the comfort and security afforded to passengers by the rolling stock and equipment.

Reliability of service depends not only upon the proper design and construction of car bodies, trucks, motors, control, air brakes and brake rigging, but also, and especially, upon the proper assembling of these constituent factors and their effective co-ordination.

Transportation service may be broadly considered as a commodity, with the rolling stock and power equipment as the production plant and the right-of-way as the distributing plant. Obviously, the commercial success of a transportation system, as with any other enterprise, will depend on its ability to meet the specific requirements of the territory involved, and upon the efficient co-ordination of the many integral parts of the complete transportation production machine, consisting of the power generating plant, the transmission system, the rolling stock, the car maintenance shops, and all the auxiliary equipment of signals, telephone system, etc.

The large sums involved in the construction, equipment and subsequent operation of electric railway properties warrant the most thorough investigation of such a project to determine its true economic character "before the fact." The subsequent analysis of the actual operating expenses of a property is often in the form of an inquest.

In the selection of equipment or right-of-way, for a transportation system, the first cost and fixed charges should always be considered in reference to the cost of operation, upkeep and amortization. Investigation will frequently show that a relatively higher first cost of equipment will be fully warranted by attendant reduction in operating expenses.

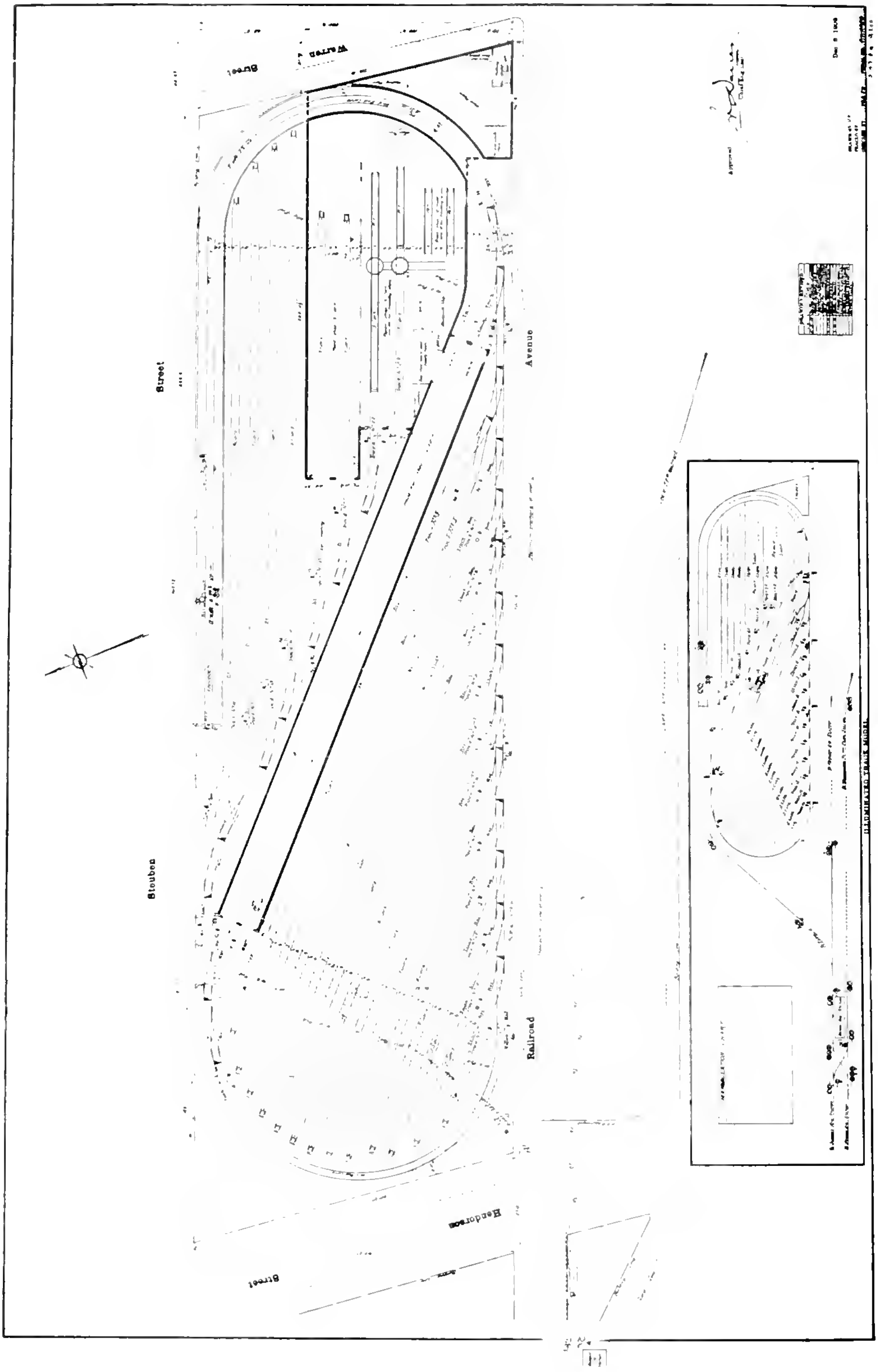
The competent consulting engineer, experienced in railway equipment and operation, is best fitted to make a comprehensive study of the operating conditions of a proposed system, and to thoroughly co-ordinate all the many necessary details so as to insure the greatest traffic winning service, with the minimum expense for operation and maintenance.

The proof of the pudding is in the eating thereof. Likewise, the test of a railroad is the analysis of its operating expenses. Though the pudding be of the best of materials, but only half-cooked, indigestion may be confidently expected; likewise, the railroad material may be the finest of its kind, but if the amalgamation of the whole be not skillfully accomplished, disappointment will be experienced with the financial returns.

In equipping the Hudson & Manhattan Railroad, the executive officers of the company placed upon the consulting engineers direct and full responsibility, not only for the selection and installation of motors, control equipment, air brake work, and wiring, but also for the actual design of car bodies, trucks and brake rigging, as well as for the plans and equipment of the inspection and repair shops. As a result of this policy, provision was made in the design of the cars for the convenient and effective support of motive power and brake equipment, and the completely equipped motor car is characterized by unity of design in a very exceptional degree.

The accompanying costs of maintenance of the rolling stock of the Hudson & Manhattan Railroad have been carefully compiled from the records of the railroad company in order to analyze as thoroughly as possible the detail expense of operation involved in the specific service in which the cars are used. A short description of the equipment is given to illustrate to what extent careful car design and selection of equipment can be made to contribute to reliability of service and to low cost of operation.

In selecting the motive power equipment for the Hudson & Manhattan Railroad cars, due consideration was given to the peculiar conditions of service imposed by the fact that the cars were to operate entirely in



Railroad Avenue Car Yard, General Plan of Interlocking Plant tunnel service under the Hudson River, and that the bulk of the traffic would consist of carrying passengers to and from suburban and through line steam railroad trains operating on definite schedule. It is obvious that a satisfactory service under these conditions would require absolute reliability and regularity of train operation, in order that close connections may be assured, and the further realization that delay of trains in the tunnel service would soon cause the traveling public to lose confidence in the system, effecting a consequent loss of traffic. As the profile of the tunnel system includes several grades of approximately 5 per cent, it was necessary to provide ample motive power per car to meet the possible contingency of the presence of a "dead" motor car in a two-car train, on the maximum grade. That this liberal motive power equipment per ton of car weight is a good investment, aside from its necessary purpose of accelerating the dead car in case of stopping at a signal on a grade, is evidenced by the remarkably low maintenance cost of the motors, and the almost entire freedom from commutator and kindred troubles.

As reliability of service depends primarily on the adequate upkeep of motive power apparatus by thorough inspection and repair, particular attention was given to the facilities afforded for this work.

Thus, in the car design, careful provision was made for the application of control apparatus, so that every contact surface and working part of the apparatus can be thoroughly and readily inspected and maintained by the repair men. This was done with full regard to the human element and with a realization that what is easy to do will be done and what is hard to do will be neglected.

In the design of the inspection shop, particular attention was given to the arrangement of inspection pits, so that abundance of daylight is admitted to the underside of the car by the use of an elevated track for the car and low windows in the side walls of the building. Further a permanent hanging gallery is provided to give access to the car body at its floor level, and thus make it possible for window cleaners and car body inspectors to proceed steadily with their work and in no way interrupt the equipment inspectors at work on the trucks and control apparatus beneath the car body. The work thus proceeds in an orderly and expeditious manner and the capacity of the inspection pit is greatly increased thereby. Many expedients have been devised by the operating force to assist in the dispatch of their work and every operation has been studied with a view to its efficient and economical accomplishment.

The arrangement for switching cars to and from the inspection pit is such that no interference occurs with other yard movements. No back-up movements on the inspection pit are necessary and there is no "dead" mileage for bringing in cars for inspection.

In the design of the repair shop, provision was made for adequate natural lighting, and the machine tool equipment was carefully selected to meet not only the routine repairs of car equipment, but to furnish facilities for repairs of power house and elevator machinery and incidental light repairs required by other departments of the road. Power operated hoisting apparatus was installed so that the physical energies of the shop men are reserved for productive effort. This in itself greatly assists in the securing of the best class of workmen, as well as greatly advancing the rapidity of repair work. The arrangement of the shop is such that all the members of the working force are under the constant and unobstructed observation of the foreman, as no intervening walls are permitted. Any delay to the progress of the work of an individual or gang can be instantly noticed in this way and remedied, without the constant patrolling of the shop by foremen.

As the item of labor is the largest in the cost of maintenance of equipment, it is obvious that the facilities for accomplishing necessary work should be carefully considered in the original design and equipment of the shop, as in many cases no additional cost will be involved.

The development of railroad motive power equipment has been greatly promoted by the interchange of information between various operating men, engineers and manufacturers, through the medium of conventions, committee work and trade journal enterprise, as well as by direct contact between the various interested parties. It is reasonable to expect that the hearty co-operation of all concerned, in patient, constructive analysis and criticism of existing systems, designs, shop methods and methods of manufacture will lead to still further reduction in operating costs and improvement in reliability of service.

The desirability of publishing operating costs and records of reliability of service should be apparent to all, as it unquestionably has a stimulating effect in encouraging operating men to sustained efforts in these directions.

The railroad repair and maintenance shop is a fruitful field for the designing engineer. A careful analysis of the design of parts of apparatus finding their way to the scrap heap will often enable a designing engineer to accomplish radical reductions in the cost of maintenance, with a possible trifling expenditure of effort, by arranging for a change of design or of material in faulty apparatus.

Much has been written about the education of employees in the special work on which they are engaged, and no question can be raised as to the desirability of careful selection and training of those connected with the operation and maintenance of equipment. It cannot be too strongly impressed upon the operating force that *constant proper maintenance is far better than occasional heavy repairs*. It is obviously cheaper to keep out of trouble than to get out of trouble.

Table 1

### DELAY RECORD HUDSON & MANHATTAN RAILROAD

| | 1910 | | | | | 1911 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Detentions | Minutes Detention | Per Cent Trains on Time | Miles per Detention | Miles per Minute Detention | No. of Detentions | Minutes Detention | Per Cent Trains on Time | Miles per Detention | Miles per Minute Detention |
| January | | 30½ | | | 17,150 | 15 | 49½ | | 37,200 | 11,300 |
| February | | 21 | | | 22,300 | 2 | 3½ | | 282,000 | 161,500 |
| March | | 35½ | 99.18 | | 15,050 | 2 | 7 | 99.87 | 312,000 | 89,300 |
| April | | 7 | 99.47 | | 72,100 | 2 | 3½ | 99.79 | 297,000 | 169,500 |
| May | 11 | 45½ | 99.52 | 46,400 | 11,220 | 3 | 21 | 99.87 | 196,500 | 28,100 |
| June | 12 | 42½ | 99.40 | 39,400 | 11,130 | 2 | 8 | 99.73 | 269,100 | 67,300 |
| July | 4 | 19½ | 99.73 | 112,000 | 23,000 | 4 | 21 | 99.45 | 123,500 | 23,600 |
| August | 6 | 20 | 99.67 | 75,400 | 22,600 | 4 | 14½ | 99.75 | 127,800 | 35,200 |
| September | 7 | 18 | 99.60 | 74,900 | 29,100 | 7½ | 26½ | 99.55 | 74,700 | 21,100 |
| October | 8 | 19½ | 99.65 | 68,700 | 28,200 | 12 | 45 | 99.81 | 53,600 | 15,630 |
| November | 21 | 69½ | 99.34 | 29,300 | 8,860 | 8 | 57 | 99.49 | 87,600 | 12,280 |
| December | 41 | 151 | 99.37 | 16,650 | 4,520 | 6½ | 12½ | 99.61 | 65,800 | 44,750 |
| Average per month | 14 | 40 | 99.493 | 57,843 | 22,102 | 5.75 | 22.6 | 99.69 * | 160,558 | 56,630 |

* Average for ten months.

| | 1912 | | | | | 1913 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Detentions | Minutes Detention | Per Cent Trains on Time | Miles per Detention | Miles per Minute Detention | No. of Detentions | Minutes Detention | Per Cent Trains on Time | Miles per Detention | Miles per Minute Detention |
| January | 8 | 24½ | 99.47 | 77,800 | 25,400 | 10 | 40 | 99.65 | 58,500 | 14,620 |
| February | 5 | 23½ | 99.65 | 111,000 | 23,600 | 8½ | 43 | 99.51 | 61,600 | 12,160 |
| March | 5 | 10 | 99.67 | 120,000 | 59,755 | 13½ | 20½ | 99.87 | 43,100 | 28,400 |
| April | 4 | 12 | 99.40 | 145,000 | 48,300 | 16 | 26 | 99.57 | 35,500 | 21,800 |
| May | 8 | 17½ | 99.44 | 73,500 | 33,600 | 10½ | 20½ | 99.85 | 54,800 | 28,100 |
| June | 14 | 46 | 99.72 | 37,400 | 11,400 | 12½ | 37 | 99.74 | 42,000 | 14,200 |
| July | 13 | 32½ | 99.73 | 34,800 | 13,850 | 9½ | 22½ | 99.81 | 53,300 | 22,500 |
| August | 10 | 24 | 99.71 | 50,300 | 20,950 | 13½ | 46½ | 99.71 | 37,400 | 10,850 |
| September | 14 | 44½ | 99.16 | 36,100 | 11,120 | 6 | 12½ | 99.80 | 85,200 | 41,400 |
| October | 13 | 38½ | 99.00 | 43,300 | 14,620 | 9¼ | 26 | 99.57 | 60,400 | 21,500 |
| November | 12 | 29½ | 99.50 | 45,600 | 18,520 | 6 | 22 | . | 87,700 | 43,900 |
| December | 11 | 57 | 99.61 | 54,500 | 10,520 | 14½ | 59 | . . . | 40,900 | 10,080 |
| Average per month | 9.75 | 30 | 99.505 | 69,108 | 22,311 | 10.8 | 31.3 | 99.708 * | 55,033 | 23,293 |

* Average for ten months.

The arousing and sustaining of the interest of every employee connected with the service is always a potent factor in any industry. This is particularly true in transportation systems, where reliability of service largely depends upon the intelligent and faithful efforts of many individual workers.

The Hudson & Manhattan cars are all motor cars, each equipped with G-E Type M control and two G-E 76 motors. The line voltage is 650. The commutation was a matter of special consideration in the selection and design of these motors, and their low cost of maintenance and freedom from commutator troubles is noteworthy. Flash-overs are practically unknown on the road.

Tables 2 and 3 and Fig. 1 are arranged to illustrate the distribution of expense of maintaining the rolling stock of the Hudson & Manhattan Railroad:

Fig. 1 shows the cost of maintenance of rolling stock from January 1st, 1910, to December 31st, 1913. It will be noted that the average for the four years is 1.48 cents

### Table 2

## MAINTENANCE COSTS OF CAR EQUIPMENT ON HUDSON & MANHATTAN RAILROAD

### Subdivided in Accordance With I.C.C. Standard Classification of Accounts

| Number | Name of Account | 1910 | 1911 | 1912 | 1913 |
|---|---|---|---|---|---|
| 29 | Superintendence | 0.1112 | 0.1128 | 0.1386 | 0.1166 |
| 30 | Car Bodies.... | 0.3501 | 0.6420 | 0.3917 | 0.7472 |
| 34 | Electrical Equipment | 0.1173 | 0.1941 | 0.1163 | 0.1141 |
| 35 | Shop Machinery.. | 0.0217 | 0.0374 | 0.0181 | 0.0438 |
| 36 | Shop Expenses..... | 0.0841 | 0.1714 | 0.1635 | 0.1977 |
| 69 | Carhouse Employees | 0.5101 | 0.5071 | 0.4339 | 0.5171 |
| 70 | Carhouse Expenses. | 0.0083 | 0.0067 | 0.0363 | 0.0387 |
| | Total.. | 1.2028 | 1.6715 | 1.2984 | 1.7752 |
| | Mileage | 6,288,778 | 6,705,780 | 6,675,777 | 6,571,942 |

Average cost for four years, 1.487 cents per car mile.

### Table 3

## SUBDIVISION OF MAINTENANCE COSTS IN CENTS PER CAR MILE ON HUDSON & MANHATTAN RAILROAD

### Repair, Material and Supervision

| 1913 | Motors | Pumps and Governors | Control | Car Bodies | Trucks | Air Brakes | Wheels and Axles | Painting | Miscellaneous | Material | Supervision | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.0050 | 0.0243 | 0.0132 | 0.0444 | 0.0687 | 0.0391 | 0.0007 | 0.0433 | 0.1388 | 0.7621 | 0.0134 | 1.1530 |
| February | 0.0030 | 0.0225 | 0.0194 | 0.0324 | 0.0564 | 0.0288 | 0.0004 | 0.0600 | 0.1816 | 0.7344 | 0.0142 | 1.1531 |
| March | 0.0008 | 0.0179 | 0.0287 | 0.0489 | 0.0564 | 0.0202 | 0.0045 | 0.1276 | 0.1789 | 0.6297 | 0.0129 | 1.1265 |
| April | 0.0078 | 0.0138 | 0.0266 | 0.0834 | 0.0372 | 0.0248 | 0.0012 | 0.1350 | 0.1376 | 0.9384 | 0.0092 | 1.4150 |
| May. | 0.0054 | 0.0189 | 0.0117 | 0.0788 | 0.0268 | 0.0365 | 0.0028 | ..... | 0.1450 | 0.0699 | 0.0092 | 1.4050 |
| June. | 0.0026 | 0.0212 | 0.0241 | 0.0950 | 0.0256 | 0.0852 | 0.0029 | ...... | 0.1428 | 1.1287 | 0.0099 | 1.5380 |

### Inspection

| 1913 | Motors | Pumps and Governors | Control | Car Bodies | Trucks | Air Brakes | Brake Shoes | Oilers | Car Cleaning | Miscellaneous | Total | Total Inspection and Repairs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.0055 | 0.0063 | 0.0507 | 0.0691 | 0.0359 | 0.0526 | 0.0116 | 0.0157 | 0.1838 | 0.0953 | 0.5265 | 1.6795 |
| February | 0.0067 | 0.0040 | 0.0553 | 0.0702 | 0.0353 | 0.0585 | 0.0114 | 0.0154 | 0.1948 | 0.0984 | 0.5480 | 1.7011 |
| March | 0.0056 | 0.0055 | 0.0672 | 0.0561 | 0.0337 | 0.0587 | 0.0117 | 0.0166 | 0.1852 | 0.0942 | 0.5345 | 1.6610 |
| April | 0.0044 | 0.0026 | 0.0541 | 0.0762 | 0.0320 | 0.0617 | 0.0125 | 0.0129 | 0.1870 | 0.0891 | 0.5325 | 1.9475 |
| May. | 0.0047 | 0.0010 | 0.0605 | 0.0767 | 0.0335 | 0.0541 | 0.0106 | 0.0148 | 0.1781 | 0.0985 | 0.5325 | 1.9375 |
| June. | 0.0060 | 0.0057 | 0.0740 | 0.0745 | 0.0387 | 0.0679 | 0.0116 | 0.0190 | 0.1971 | 0.1090 | 0.6035 | 2.1415 |

per car mile. The high peaks in the early part of 1911 and in 1913 are due to extensive painting and car body repairs. This low cost of maintenance is not due to neglect of apparatus, as is evidenced by Table 1, which illustrates the reliability of service by recording the percentage of trains on time during the same four years, and the average miles per minute of delay over the same period. It is worthy of note that the average reliability of service for the four years has been 99.599 per cent of trains on time, while the average miles per delay was 59,654, and the average length of delay was three minutes.

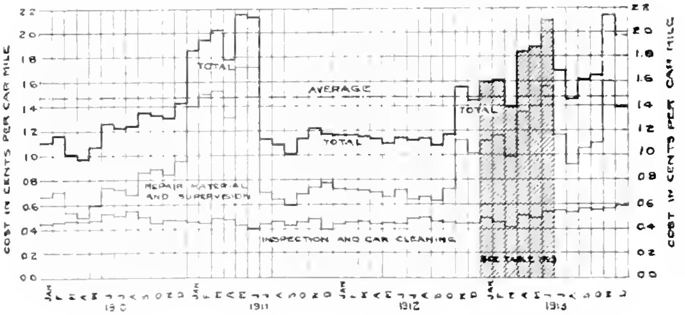


Fig. 1. Curves Showing Costs of Maintenance of Car Equipment During a Four Year Period

Table 2 shows the costs of maintenance of car equipment arranged in accordance with the Interstate Commerce Commission's standard classification of accounts, from which it will be seen that the average cost of maintenance of electrical equipment for the four years was about 0.1354 cents per car mile, being less than 10 per cent of the total cost of car maintenance.

Table 3 is compiled to illustrate the relative costs of maintenance of various portions of the equipment during the period of six months in 1913, indicated by the cross-sectioning on Fig. 1. It is noteworthy that the average total cost of labor for repairs and inspection for motors during these months was about 0.005 cents per car mile and for control about 0.04 cents per car mile.

The low maintenance costs of the motor and control equipment illustrate the result of close co-operation between the manufacturers and the operating and engineering representatives of the railroad, special attention being given to the accessibility of the apparatus for inspection and repair, the low cost of the parts to be replaced on account of wear and tear of service, and the liberality of design of working and current carrying parts.

Car cleaning on the Hudson & Manhattan road forms a considerable item of the total cost of the maintenance. Specific conditions of tunnel service require that the interior of the cars be kept free from dust or loose material of any nature, as the strong drafts occasioned by the movement of the car would, if dust laden, be a considerable annoyance to passengers. Traffic winning service, therefore requires frequent sweeping out of the cars at terminals, and as particular provision was made for this work in the design of the car, it will be of interest to record that cars are regularly swept at terminals while on service tracks, the time allowed for this work being 45 seconds. The interior of the cars was specially

Fig. 2. View of Underbody of Car, Showing Ease with which Resistance Grids and Contactor Box can be Inspected

designed to avoid ledges or crevices capable of retaining dust or dirt. Such features materially aid in the accomplishing of the necessary work. The average cost of car cleaning for four years is $5.01 per car per month.

The Hudson & Manhattan maintenance costs are used as an illustration of the saving to be secured by careful selection and design of equipment for a system operating under special conditions. The same engineering methods were employed in the case of the New York, Westchester & Boston Railway, where a high speed suburban service is furnished; the rolling stock being maintained at a cost of about 2.36 cents per car mile.

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# THE FINANCIAL ASPECT OF STEAM RAILROAD ELECTRIFICATION

By William J. Clark

Manager Traction Department, General Electric Company

American railroads are not able at the present time to take advantage of the recognized economies to be secured by electrification, owing to the political and economic conditions which prevail in railway finance. But the present conditions will not be permanent, and the author makes a strong appeal to America to take every available advantage of the general situation to create a new set of conditions which will benefit the trade of the country as a whole. This would stimulate railroad finance and put the railroads of America in a position where they could take advantage of the recognized economies to be secured by electric operation.—Editor.

William J. Clark

At the present, when the very foundations of world finance are shaken by the most terrific of all wars, it is difficult to write comprehensively upon any of its specific phases, and obviously the financial aspect of steam railroad electrification is one of these.

The advancement of the electric traction art and its great economic advantages over steam in the operation of railroads have been generally conceded for several years. Yet, the great majority of American railroads have not been able to consistently favor its introduction, in view of their difficulties in raising the necessary capital to make this possible, or even to care for their more pressing immediate requirements. This is because of America's own political and economic conditions which have most seriously handicapped railroad finance.

The great objective and desire of American railroad management is to furnish the best transportation facilities which political, governmental and financial conditions will permit, the last of which are virtually determined by the other two; as is exemplified in the European situation of today, the far reaching effects of which unfavorably affect the financial aspect of steam railroad electrification here for the time being.

All economic truths are recognized however, and taken practical advantage of so soon as incidental factors permit; consequently full realization of the fact that electric operation increases the net earnings of railroads will eventually, in itself, so shape the financial aspect of their electrification that electric traction will then "come into its own."

When the adjustment of the pressing and most important questions of universal finance which have ever arisen will be accomplished cannot now be determined, but in connection therewith almost inconceivable opportunities are presented to America, which if taken full advantage of cannot fail to bring to it unprecedented permanent progress and prosperity of every character; and the extensive electrification of American railroads should be an important element in the creation and maintenance of such conditions.

Most essential to this country, in its attempt to secure the greatest possible advantages from the present general situation, is immediate realization by its entire people that great financial, industrial and commercial policies and enterprises, which yesterday were considered by some as of individual interest only to others more favored than they, now stand out as that which alone can and will, if unobstructed in their legitimate spheres and logical development, bring the maximum of personal benefits to all.

Illustrative of this, as very recently intimated by the President of the United States, a reversal of our present public policy toward the railroads has become an absolute necessity; for we cannot have immediate and unbroken progress and prosperity without increased and improved railroad facilities that are already needed to meet the present transportation requirements of the country. It is impossible to promptly secure these unless the investment of private capital in our railroads is at once made more attractive than it now is, and delay in their acquirement would well nigh prevent the complete realization of present hopes and opportunities.

Even though America should eventually secure adequate railroad facilities through the adoption of the most costly and continuing uneconomic course possible, viz., government ownership and operation, it would be at far too late a date to meet the demands of the present situation; for, as is well known, the estimate of the Interstate Commerce Commission as to the time required to make a physical valuation of the railroads is five years.

The possible future return upon, and the reliability of investments in American railroads has also an important and immediate bearing upon the reshaping and adjustment of the world's financial conditions to the advantage of this country for the most serious problem which confronts it, in such regard, is presented by European holdings of American securities, which principally consist of its railway issues. Unquestionably, many of these will soon be marketed here, which means gold exportation or its practical equivalent, the establishment of temporary European credits on this side of the ocean.

The extent of these transactions will depend upon the actual necessity for sale, plus the possibility of Europeans being able to make what they may consider to be more reliable and attractive investments elsewhere; in which connection it should be remembered that rates of interest throughout the world will doubtless be higher in the future than during the recent past.

Obviously, the smaller the total of these sales, the greater will be the amount of American capital available for internal requirements and the expansion of its commercial and similar interests abroad, which will in time create fundamental lasting betterments at home.

Therefore, if the earning power of American securities is increased and European faith in their solidity is upheld by a favorable attitude on the part of our public and government, their amount, which must be absorbed here, will be kept down to the lowest possible minimum,—probably to a much smaller total than is now expected,—for these securities held abroad are almost entirely in the possession of actual investors, who, unless forced to dispose thereof, would be content with a fair return upon these investments, providing their future is well assured.

A growing mistrust of our securities exists in Europe, so there is immediate necessity for its removal. Otherwise, a wholesale unloading in this country may occur, with the serious results already indicated; viz., that when we most need capital to meet our internal requirements and to take full advantage of our unequalled opportunities abroad, it will be extensively absorbed by purchases of what Europe will sell in our stock exchanges, at whatever prices can be realized. If these are slaughtered, then possibilities of financial panic and disaster, with resultant depression and stagnation in everything, would confront the United States instead of its gigantic advancement toward all that any nation could possibly wish.

It is not reasonable to suppose, however, that the American people, who have successfully met every great crisis and emergency of the past, will now be so lacking in patriotism and intelligence as not to meet all the requirements of the present extraordinary situation, and thus secure every possible advantage for the United States and its citizens, both collectively and individually.

Therefore, we can at last reasonably look for long deferred justice being done to our railroads, and the resultant improvement in the financial aspect of American railroad electrification.

# MULTIPLE UNIT TRAIN SERVICE ON THE NEW YORK CENTRAL AND HUDSON RIVER RAILROAD

By Edwin B. Katte

Chief Engineer, Electric Traction, New York Central and Hudson River Railroad Company

The electrification of the New York Central Terminal led to many changes in the operation of suburban service. The author discusses some of these and compares the old steam with the new electric schedules. The multiple unit cars and their equipment are described at length and the tests made on the multiple unit trains are given.—Editor.

The suburban service of the New York Central and Hudson River Railroad Company was electrified primarily to eliminate the smoke nuisance in the Park Avenue tunnel and was mandatory by State Law. Early in the electrification studies of the Grand Central Terminal and the lines leading thereto, it was apparent that the suburban service could be best handled by multiple unit cars, and the through service, that is trains operating beyond the suburban zone, by electric locomotives.

The advent of electricity materially changed the methods of operating the Grand Central Terminal as well as the two divisions of the railroad adjacent thereto, and it is for this reason that a direct comparison between steam and electric operation cannot readily be made. The principal operating changes which were effected are as follows:

The jurisdiction of the Grand Central Terminal Manager formerly extended to 57th Street, New York City. From this point, the operation of suburban trains on the main line was under the Superintendent of the Hudson Division, and Harlem Division trains were under the Superintendent of that division. At the present time, the Grand Central Terminal Manager is also the General Superintendent of the Electric Division and his jurisdiction extends over the suburban zone from Grand Central Terminal to North White Plains on the Harlem Division, a distance of 24 miles, and from Grand Central Terminal to Croton, on the main line, a distance of 34 miles. This includes the entire suburban service, with the exception of trains on the Putnam Division, which do not enter the Grand Central Terminal, and Peekskill trains, which latter service is handled by multiple unit cars drawn by steam locomotives between Croton and Peekskill, a distance of 6 miles. For these reasons it is difficult to compare the former steam service with the existing electric operation. It is accepted that the service is better because of the quicker acceleration and affords a greater cleanliness in operation, but the relative cost has not been determined.

A direct comparison of train schedules in steam and electric operation is given in the table below:

### COMPARISON OF SUBURBAN TRAIN SERVICE

| Items | Hudson Division | | Harlem Division | |
|---|---|---|---|---|
| | Steam | Electric | Steam | Electric |
| Date of time table | Dec. 1906 | Dec. 1913 | Dec. 1906 | Dec. 1913 |
| Number of trains per 24 hours | 54 | 44 | 59 | 64 |
| Number of trains per max. hour | 5 | 7 | 8 | 10 |
| Fastest schedule time between terminals, min. | 65 | 68 | 51 | 46 |
| Average schedule time for local express min. | 72.4 | 72.0 | 56.6 | 51.2 |
| Average schedule time for locals min. | 79.2 | 76.6 | 64.5 | 59.1 |

Electric operation in the case of the New York Central and Hudson River Railroad Company was not a choice, it was a necessity and was not installed with the hope of effecting any economy in operation, but to permit trains to enter New York City under Park Avenue without smoke and to make possible the new Grand Central Terminal. The property owners along Park Avenue have benefited financially more by the change in motive power than has the railroad company, and if the railroad company were permitted to enjoy a portion of the revenue derived by the city in taxes on the increased

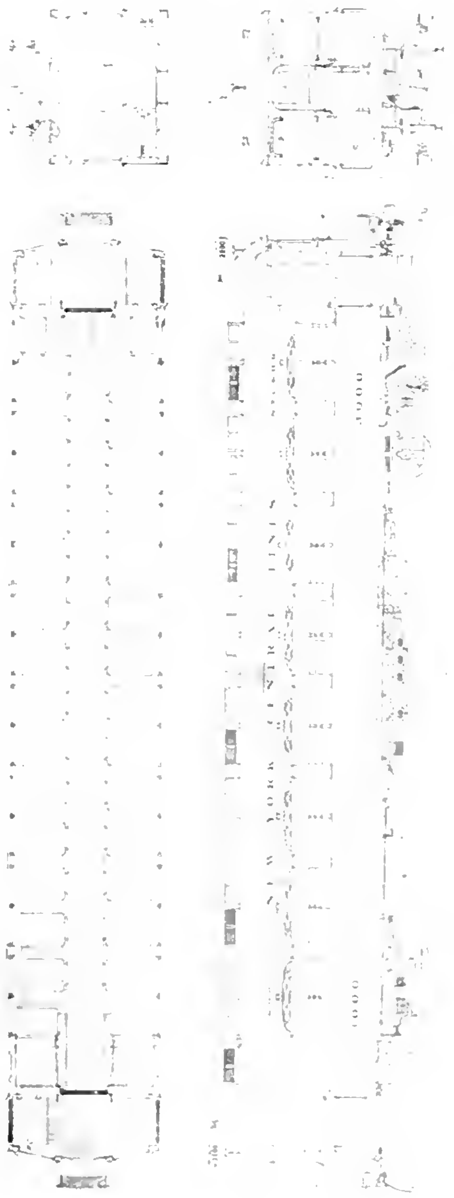


Fig. 1. Drawing of one of the Earliest All-Steel Passenger Motor Cars

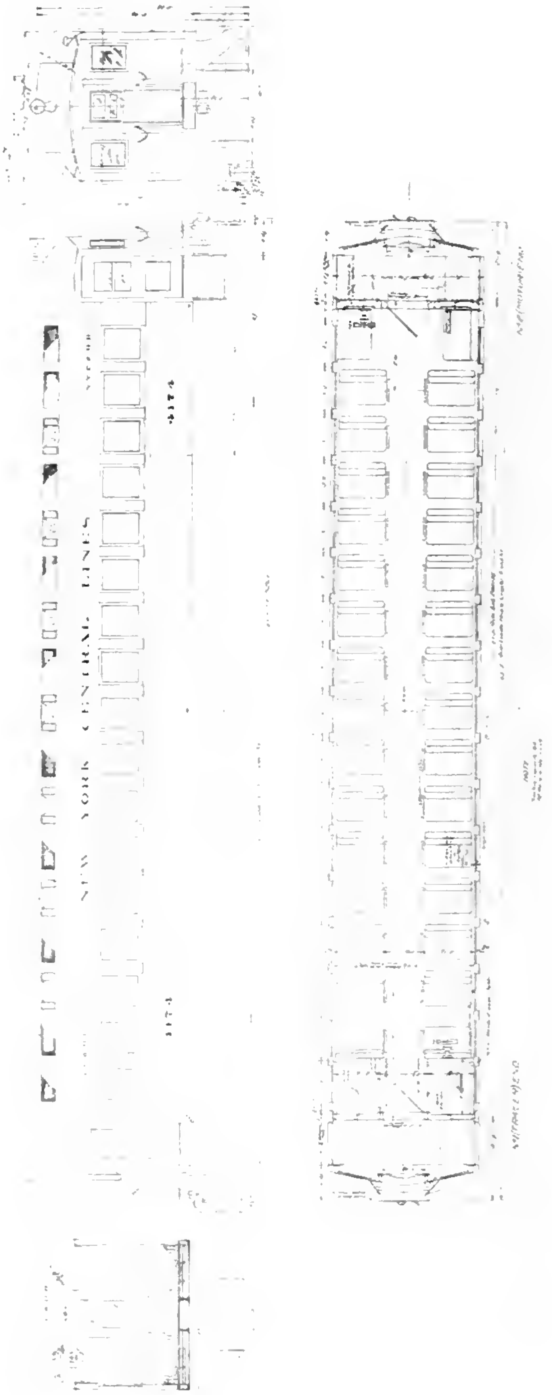


Fig. 2. Drawing of the Latest Type of All-Steel Passenger Motor Car

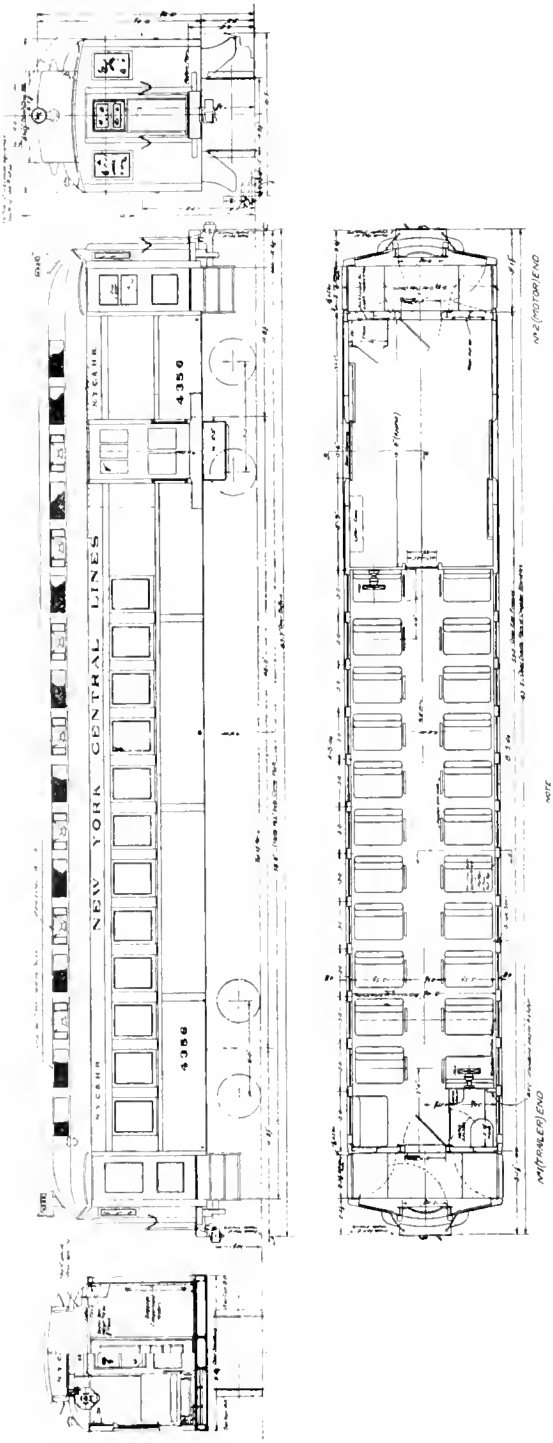


Fig. 3. Drawing of the Latest Type of All-Steel Combination Smoker and Baggage Motor Car

valuations of Park Avenue property, the heavy fixed charges on the cost of electrification could more easily be carried and electric operation would assume a more favorable commercial aspect.

### Multiple Unit Motor Cars

The multiple unit cars of the New York Central and Hudson River Railroad Company are of all-steel construction and consist of an original lot of 125 motor cars built by the American Car & Foundry Company, 55 trailer cars built by the St. Louis Car Company and 6 combination baggage, mail and express motor cars built by the latter company. A subsequent order of 19 motor cars and 6 combination baggage and smoking motor cars has been filled by the Pressed Steel Car Company. The original cars were the first all-steel passenger cars used on a trunk line railroad and the design was necessarily crude in the light of the present steel cars, since they were made up almost wholly of structural steel shapes and plates commonly rolled by the steel mills and of other stock parts.

The original motor car general drawings are reproduced in Fig. 1. This car weighs 105,800 pounds, of which 26,900 is in the trucks, 12,200 in the motors, 48,300 in the body, and 18,400 in the body equipment which includes the electric, gas, steam and brake apparatus, also seats, basket racks, cooler, tool box, etc. The body is 50 ft. long and 9 ft. $8\frac{5}{8}$ in. wide over sheathing, and the height from track over roof is 13 ft. $9\frac{1}{2}$ in. The length between coupler knuckles is 62 feet. The seating capacity is 64 passengers. The framing is of the side girder type with a 6-in. angle side sill, a bulb angle below the windows and the side sheathing $\frac{3}{16}$ in. thick forming a plate girder on each side of the car, carried by the cast steel bolsters and supporting the floor system by means of built-up cross members at the ends of the body and at three points between the trucks. The center sills are shallow "I" beams, transmitting the buffing and draft forces, and acting as cantilevers beyond the end sills to carry the platforms. The floor is of fireproof composition laid on galvanized steel sheets with keystone shaped corrugations and wooden floor strips.

The outside of the car above the window sills is covered with steel sheets $\frac{1}{8}$ in thick, and the inside with sheets and moldings $\frac{1}{16}$ in. thick. The ceiling and roof are of composite board. The doors except the vestibule end doors are of the sliding type, a feature which however, has been abandoned on the later cars. The vestibule is completely enclosed and is used as a motorman's cab. The master controller and brake valve are so located that when the vestibule end door is open, as it normally is except at the front of trains, it conceals and protects them. Two saloons at the same end of each car are provided. The seats are reversible, of the "Walkover" type, and are rattan covered.

Both steam and electric heat are provided; also gas and electric light, thus permitting the cars to be operated outside of the electric zone. Electric fans are placed at each end. The switches and fuses for light, heat, fans and air compressor are placed on a slate switchboard in one of the body end bulkheads. Control, circuit breaker and headlight switches are placed overhead in each vestibule. The main motor fuse and the main auxiliary fuse are under the car. The cars are connected by a bus line on each car for supplying current to a car while crossing gaps in the third rail. Resistance is inserted in the bus line on each car, to keep down the rush of current. All wiring is in iron pipe conduit, excepting wiring for heat, light and fans, which is in Sprague flexible conduit.

The draft gear is of a type developed especially for these cars. The coupler is 8 ft. 9 in. long, pivoted at a point three feet ahead of the bolster, and designed for curves of 135 feet radius. Connections are made from the coupler shank to the forward corners of the truck, to guide the coupler to the center of the truck when rounding curves. The buffer is mounted to swing with the coupler. The brake and signal pipes are carried on the sides of the coupler shank and connected at the pivot, by lengths of hose, to the pipes on the body.

The cars built by the St. Louis Car Company are of essentially the same design as those built by the American Car & Foundry Company. They were originally used as trailer cars but were designed to be later equipped with motors and this has now been accomplished on 36 of the 55 trailer cars.

The cars furnished by the Pressed Steel Car Company during the year 1913 represent the latest practice in steel car construction. They are almost an exact reproduction of the New York Central main line all steel coaches, though shorter in length. The appearance is illustrated in the reproduced general drawings given in Figs. 2 and 3.

They follow the earlier cars in arrangement and equipment, the principal differences being as follows:

Body length increased 3 ft. 2 in. to accommodate larger seats.

Seat spacing increased from 34½ in. to 36 in. to accord with main line practice.

Doors hinged instead of sliding, to accord with main line practice.

Doors steel instead of wood.

Roofing steel instead of composite board.

Wooden floor strips omitted.

Gas omitted, as cars do not operate beyond the electric zone.

Steam heat omitted for the same reason as the gas.

Electric heaters along side of car instead of under seats, this being possible since the steam pipes are omitted.

Window arrangement changed to accord with main line practice.

Wood furring eliminated.

Greater use of heat insulation and sound deadening material.

Use of cast steel combined body bolster and platform.

Space between cars reduced by forward extension from vestibule end door posts.

Two switchboards instead of one to facilitate handling.

The side girder type construction of the original motor cars is retained and this is the principal difference between these and the main line coach. The Commonwealth Company's cast steel combined bolster and platform is used in the underframe from the end of the car to a point back of the bolster, where the sills are attached to it. The center sills are of the same size as in the earlier cars but reinforced by a ¼ in. top cover plate. The floor arrangement follows closely that of the main line coach, viz., galvanized "Chanarch" sheets covered with composition flooring and a sub-flooring of light flat flanged sheets carrying insulating material. The two switchboards are on opposite sides of the car in the end bulkhead. One carries the switches and fuses for lights, heaters and fans, handled by the trainmen; the other back of the motorman contains the compressor switch and main switch, and the control apparatus. The weight of this car is slightly greater than that of the earlier design. The wheel spacing and loading are shown in the diagrams and tables.

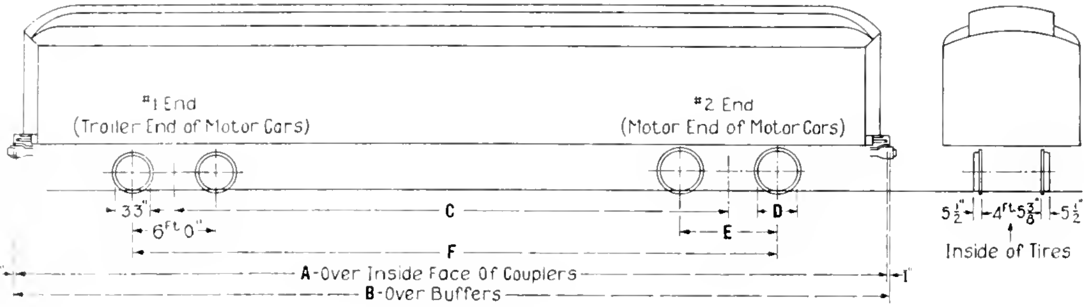
**Trucks**

The original motor and trailer trucks are of special design and were built by the American Locomotive Company. They are illustrated in the group of drawings in Figs. 4 and 5. The principal dimensions of the trucks are as follows:

| | Motor Truck | Trailer Truck |
|---|---|---|
| Wheel base . . | 7 ft. 0 in. | 6 ft. 0 in. |
| Frame centers . | 6 ft. 8 in. | 6 ft. 4 in. |
| Wheel diameter . | 36 in. | 33 in. |
| Journals . . . . | 5½ in. by 10 in. | 5 in. by 9 in. |
| Weight equipped without motors . . | 15,300 lb. | 11,600 lb. |

The motor truck has cast steel side frames of the locomotive type, suspended directly without equalization from the ends of elliptic springs above the journal boxes. The trailer truck has 8-in. "I" beam side frames, which later have been reinforced by ½-in. plates. The pedestals are of cast iron with single equalizers. Both trucks have cast steel transoms of channel section, spread at the ends for a broad connection to the side frames and formed to receive the spring plank hangers, the brake hangers, and on the motor trucks the brake levers. The bolsters are of cast steel with center bearings cast integral. The journal boxes are of the Symington type, with pivot lids, and have stirrups cast on the bottom to carry the third rail shoe beam. The wheels are of the cast center, steel tired type. On the motor truck one wheel on each axle has its hub extended to a length of 14 ⅜ in. and has a seat of 15½ in. in diameter on which the motor gear is shrunk. The ends of the motor axle bearings are directly against the finished surfaces of the wheel hubs.

The motor trucks under the last lot of motor cars and under the converted trailer cars were of a special design built by the Standard Motor Truck Company.



## MOTOR CARS

| Type of Car | DIMENSIONS A | B | C | D | With A. L. E | With A. L. F | With S. M. T E | With S. M. T F | WEIGHTS No. 1 End | No. 2 End | Total | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | | | | |
| St. Louis pass. cars. | 62-0 | 62-2 | 38-6 | 36 | 7-0 | 45-0 | 6-11½ | 44-11¾ | 48,000 | 63,400 | 112,200 | 1 |
| St. L. comb. Sm. & Bagg. cars | 62-0 | 62-2 | 38-6 | 36 | 7-0 | 45-0 | 6-11½ | 44-11¾ | 48,100 | 63,200 | 111,300 | 1 |
| St. L. comb. B., M. & Exp. cars. | 61-0 | 61-2 | 38-6 | 36 | 7-0 | 45-0 | 6-11½ | 44-11¾ | 52,200 | 68,800 | 121,000 | 1 |
| P. S. C. pass., lot 822. | 63-5 | 63-7 | 40-0 | 36 | 7-0 | 46-6 | 6-11½ | 46- 5¾ | 50,300 | 64,600 | 114,900 | 2 |
| P. S. C. comb. S. & B., lot 823 | 63-5 | 63-7 | 40-0 | 36 | 7-0 | 46-6 | 6-11½ | 46- 5¾ | 50,200 | 65,800 | 116,000 | 2 |
| St. Louis conv. trailer. | 62-0 | 62-2 | 38-6 | 36 | 7-0 | 45-0 | 6-11½ | 44-11¾ | 48,800 | 62,700 | 111,500 | 2 |
| A. C. & F. pass. car . . | 62-0 | 62-2 | 38-6 | 36 | 7-0 | 45-0 | 6-11½ | 44-11¾ | 45,600 | 60,200 | 105,800 | 1 |

## TRAILER CARS

| Type of Car | DIMENSIONS A | B | C | D | E | F | WEIGHTS No. 1 End | No. 2 End | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | | | |
| A. C. & F. cars . . . . . . . . . . . . . . . . | 62-0 | 62-2 | 38-6 | 33 | 6-0 | 44-6 | 41,850 | 39,650 | 81,500 |
| St. L. cars. . . . . . . . . . . . . | 62-0 | 62-2 | 38-6 | 33 | 6-0 | 44-6 | 45,200 | 43,000 | 88,200 |

Note 1—.Weights shown for No. 2 end and total are with A. L. Co. motor truck. For S. M. T. Co. motor truck deduct 450 lb.
Note 2—.Weights shown for No. 2 end and total are with S. M. T. Co. motor truck. For A. L. Co. motor truck add 450 lb.

The dimensions, etc., given for the earlier motor trucks apply approximately to these also, except that the weight is 14,700 lb., being 600 lb. less. The center and side bearings, brake connection and drawbar connections are so arranged that the truck as a whole will interchange with the earlier truck. Most of the features standard on the trucks of the manufacturer are included in these trucks. All the principal frame members are pressed steel, of channel section. There is the usual pedestal jaw on the outer side of each journal box, but the inner pedestal jaw is omitted and the boxes tied together rigidly by the equalizers. The elliptic springs are of unusual design, the leaves in each band being divided into two groups, each group tapering separately. The bolster is of cast steel. Its side swing is dampened by a friction device consisting of two sets of steel leaves, one attached to the bolster and the other to the transom, which are interlaced and pressed together by adjustable springs. The brakes are supported from the non-spring-borne parts of the truck. The third rail shoe beam is shorter than on the earlier trucks and is carried by the equalizers instead of by the journal boxes. On these trucks the wheels are solid forged steel and the gears are mounted directly on the axles.

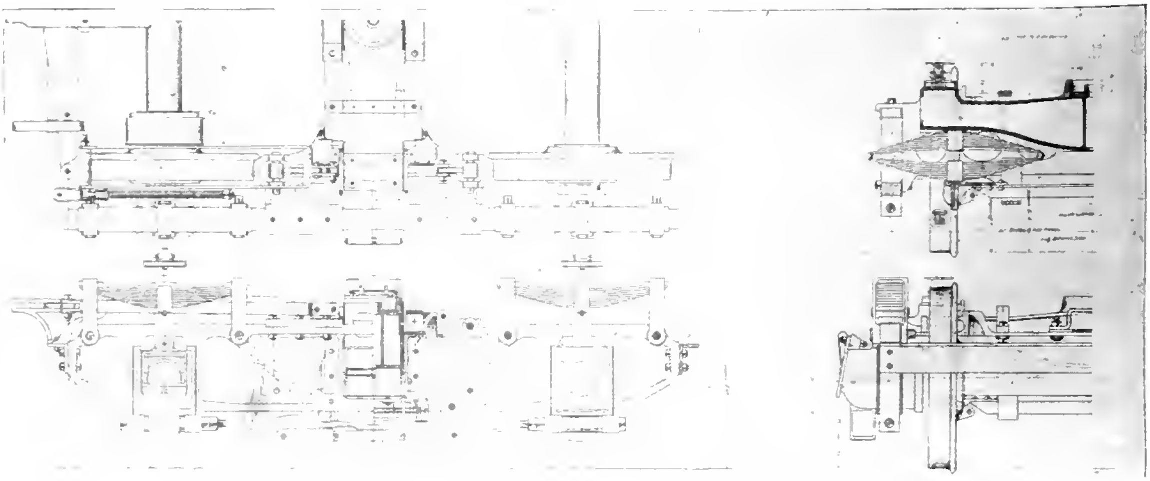


Fig. 4. Drawing of one of the Original Motor Trucks. The Motor is not shown here

### Motor Equipment

The motors for all of the motor cars have been furnished by the General Electric Company and are known as GE-69-C which may be briefly described as follows:

Their one-hour rating at 600 volts is 200 h.p. at the axle. They are of the box frame type and are run closed without ventilation. The frame and gearcase occupy all the space between the wheel rims, with only sufficient clearance to permit the use of flanged brake shoes. To economize space the armature bearings are set entirely within the general outline of the frame and extend inside the armature core head and the commutator shell. The motor is journaled directly on the axle, and supported at the opposite side by a nose resting on the truck transom without springs. The motor not being of a recent type, further description seems unnecessary.

### Multiple Unit Control Equipment

The control equipment on all of the motor cars is of the Sprague-General Electric type, consisting essentially of solenoid-operated contactors which make the different electric connections of motors and regulate the resistance in series with them, a solenoid-operated reverser, and master controllers for controlling the current supply to the solenoids of the contactors and reversers. The contactors (15 on the earlier cars and 11 on the latest), the reverser and a circuit breaker are mounted in boxes under the cars, with convenient removable covers for inspection. There are four forward positions of the controller handle: 1st, motors in series, all resistance in circuit; 2nd, same, resistance cut out; 3rd, motors in parallel and resistance in circuit; 4th, same, resistance cut out. The second and fourth are running positions; the first is used for low speed switching. In the reverse direction, only the first two positions are available. The motorman places the controller handle in any one of the above positions, and the connections are automatically advanced, resistance being cut out step by step, and the motor connections changed from series to parallel, under control of a current relay which permits each successive step to be taken only after the increase of speed and counter e.m.f. has reduced the current to a given value. A system of interlocks prevents any further advance of the control steps in case the reverser fails to throw or any contactor fails to open or close when it should. The master controller has a "dead man's handle," a device consisting of a button on the handle, connected with a small valve inside the controller, whereby, if the motorman relaxes his hold on the handle, an emergency valve is caused to open and allow air to escape from the brake pipe, causing an emergency application of the brakes.

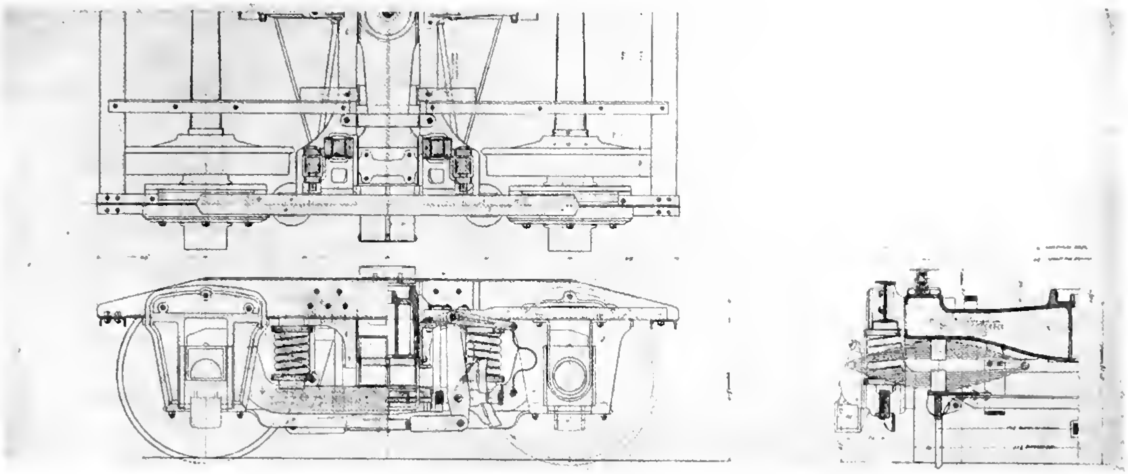


Fig. 5. Drawing of one of the Original Trailer Trucks

### Air Brake Equipment

The air brake and train signal equipments were furnished by the Westinghouse Traction Brake Company. Both are arranged for operation in connection with standard coaches and with steam locomotives. The brakes are known as Schedule AML, and have the modern features of graduated release, quick recharge, high emergency pressure, etc., which greatly facilitate suburban operation by increasing the flexibility of the brakes and the accuracy of stops. The compressor, known as D-2-EGX, has a capacity of 25 cubic feet of free air per minute and supplies air to two 16-in. by 60-in. main reservoirs. Air is supplied through a feed valve set at 90 lb. to a line running through the train known as the "control pipe" from which air passes to the engineer's valve and the triple valves. This is in addition to the usual brake pipe through which the action of the triple valves is controlled. The brake cylinder is 14-in. by 12-in. The levers are arranged to give shoe pressures equal to 90 per cent of the weight at the trailer end of the car and 100 per cent at the motor end, the excess at the motor end being an allowance to compensate for the rotative inertia of the armatures. The air signal equipment on each car is a combination of the usual car equipment and locomotive equipment with signal valve and whistle at each end of the car.

### Multiple Unit Train Service

Express multiple unit trains consist of from two to ten motor cars, a photograph of a six-car train is given in Fig. 6; local trains are usually from three to twelve cars in length and are made up in the proportion of two motor cars to one trailer.

From typical service tests made in January, 1908, with multiple unit trains, the following statistics have been selected:

### MULTIPLE UNIT TRAIN TESTS

| Items | Test No. 1 | Test No. 2 | Test No. 3 | Test No. 4 |
|---|---|---|---|---|
| Location of tests | Harlem Div. | Harlem Div. | Hudson Div. | Hudson Div. |
| Total wt. of train | 365T | 330T | 200T | 165T |
| No. of motor cars | 6 | 6 | 3 | 3 |
| No. of trailer cars | 1 | 0 | 1 | 0 |
| Total miles run | 12.5 | 12.5 | 6.3 | 6.3 |
| Av'ge speed m.p.h. | 31.4 | 29 | 23.6 | 21.3 |
| Number of steps | 3 | 3 | 2 | 1 |
| Watthours per ton mile | 35 | 37 | 35 | 31 |

A direct comparison, on the New York Central Railroad, of the cost of steam and electric operation for suburban service is not possible because of the changed operating conditions previously described; nor can any accurate statement be made of the complete cost per car mile for the reason that the multiple unit cars are not equipped with wattmeters, and the current generated at the power stations is used for so great a variety of service that the amount of current delivered to the cars cannot be segregated with any degree of accuracy. It is, however, generally conceded that the cost of operating and maintaining multiple unit trains is less than the cost for a similar service with steam trains. Nevertheless, the saving is not sufficient to cover the first cost of the electric installation.

The benefits which have accrued from electric operation are enjoyed more by the public than by the railroad. It is obvious that adjacent property owners and municipalities through which electric trains pass are more benefited than the railroad, and it has not been demonstrated that the railroad has yet received adequate return on the investment.

Fig 6. A Six-Car, Multiple Unit Express Train

# ECONOMIES OF STEAM ROAD ELECTRIFICATION

By A. H. Armstrong

Assistant Engineer Railway and Traction Engineering Department,
General Electric Company

The author calls attention to the fact that the electric locomotive has demonstrated conclusively that it can obtain operating results in any class of service that will compare favorably with steam operation. Many of the operating features in steam road service in which economies could be secured by substituting electric for steam locomotives are cited, and the sources of the probable economies to be secured with the extensive introduction of electric locomotives on main line steam roads are summarized.—Editor.


A. H. Armstrong

THE success attending the operation of electric locomotives has furnished ample proof of the fitness of this type of motive power to replace the steam engine in any class of service. It is natural that in the early days of electric locomotive construction there should be a wide diversity in types and systems of operation. Uniformity of design will be obtained only after the weaker forms of construction have succumbed to the test of continued commercial operation. It is fair to state that in no class of railroading is there so much attention paid to detailed operating figures as obtains in the several electrical installations. While such figures reflect in a great measure the special conditions surrounding each particular installation, there are nevertheless general records of reliability, economy in operation and cost of maintenance that are doing a great deal to settle the much discussed questions of forms of locomotive construction and systems of distribution.

In every installation, with perhaps no exception, electrical operating results have disclosed a favorable comparison with previous steam operation. Indeed it becomes more apparent that main line railroading today is *steam* railroading governed, in a large measure, by the limitations of the steam engine itself. The length of engine division facilities provided at terminal points, coal and water facilities, the length of a crew run, the tonnage and speed of trains and even the profile of the road itself are all governed by the possible performance of the steam engine and are all subject to radical change with the substitution of the electric locomotive.

In this connection, it must be remembered that the attractive results so far obtained with electric locomotives of considerable capacity have been largely secured in city terminal and tunnel installations with but the two exceptions of the New York, New Haven & Hartford and the Butte, Anaconda & Pacific. Through service to New Haven has been of such recent date that operating figures are not yet obtainable, but the details of operation published in this issue, as given by Mr. Cox in his A. I. E. E. paper at Spokane, covering the first six months of operation of the Butte, Anaconda & Pacific are of special interest as indicating the savings effected over previous steam operation. The Butte, Anaconda & Pacific Railway handles trains of the heaviest freight class and its success in regard to both reliability of service and economies effected contributed in no small measure to the decision to electrify a considerable part of the main line of the Chicago, Milwaukee & St. Paul Railway lying in the same territory.

Many of our electric interurban railways, in magnitude of tonnage hauled and mileage of track, approach some of the smaller steam railway lines, but the mind of the steam railroad operator has been rather slow to accept interurban operating figures as applying in equal degree to his larger problem of transportation. To the electrical engineer, however, the electrification of the main steam line differs from the interurban problem only in the size of the electric locomotives involved, as turbo-generator units and step down substations are already in operation of a capacity considerably in excess of the needs of the average main line steam service. Interest therefore centers particularly in the electric locomotive, not only as regards its design and cost, but because this new type of motive power which can be built of unlimited capacity and speed bids fair to break through many traditions surrounding the operation of steam railways, with resultant benefits of a far-reaching nature. The usual length of a steam engine division may vary from 110 miles in the mountains to 150 miles on the plains, but with the electric locomotive requiring inspection only after 2500 miles run (the present practice in the New York Central and Pennsylvania electrical zones) there is no reason why engine divisions should not be much longer than this. The longer electric locomotive run is entirely possible, as this type of motive power is not dependent upon coal and water facilities, has no need to reach a round house to have its fires cleaned, boiler washed, etc.; in fact, has no operating base, and furthermore can be kept in operation twenty-four hours a day up to the limit of what good practice determines as a reasonable mileage to run between inspections. The flexibility of such a type of motive power can hardly be overestimated and the fact that it is ready for instant service at any time it is reported for duty should effect certain economies in operation and eliminate much lost time in present steam railroading, which is directly chargeable to the limitations of the steam engine itself.

Carefully compiled statistics indicate that certain western railroads purchase in the neighborhood of 12 lb. of coal for each horsepower-hour of actual work expended at the driver rims in hauling trains of all classes. Whether the electrified steam railroad depends for its source of power upon coal or water power, there will be considerable fuel economy effected. If coal is the best source of power then the modern turbo-generator power house is so economical as to use considerably less than half the coal now demanded by the steam engine when effecting the same tonnage movement, even after including all losses of transmission and conversion of power necessary to reach the electric locomotive.

The recent contract closed with the Montana Power Company by the Chicago, Milwaukee & St. Paul Railway is an example of the advantage of purchased power in localities favored with abundant and reliable water power. If the results obtained in the electrification of the Butte, Anaconda & Pacific Railway, operating under a similar contract, should be duplicated in the coming Chicago, Milwaukee & St. Paul installation, the saving of possibly half the previous coal expense should in itself constitute largely to the economic success of the undertaking. The coal required for the present movement of its trains constitutes roughly four percent of the entire gross ton mileage, the saving of which is not to be overlooked when considering the change to electric locomotives.

During the past decade of increasing costs, electricity is one of the few commodities that has steadily decreased in price, and this lower cost of power has been attended with improvements in electrical apparatus tending to even greater reliability and efficiency in operation. Looking forward to the further developments which the future should promise, the fuel advantages of the electric locomotive appear to be on a permanent basis.

Steam locomotives of great weight on drivers and capable of giving a tremendous drawbar pull are in general use, but such steam units deliver their maximum pull at very moderate speeds and in consequence their ton mileage capacity per hour is limited. It was left to the coming of the electric locomotive to provide a hauling unit capable of giving the greatest drawbar pull which the draft gear will permit and at a speed that may be as high as desired. In other words, one electric locomotive can be built to haul just as heavy a train as the steam engine, and at a much higher speed. Furthermore, this very powerful unit can be operated by a single crew. This means that the congestion of single track mountain divisions will be greatly relieved as full tonnage trains can be hauled at speeds as high as permitted by the alignment of the road with no restriction due to the profile. Or to put the matter differently, the introduction of the electric locomotive bids fair to greatly diminish if not eliminate the handicap of "the ruling grade."

From the operating records of the several electric railways employing very heavy locomotives, the fact becomes apparent that such locomotives can be maintained in good original condition at an expense considerably below that for an equivalent capacity in steam engines. Coupled with the much lower cost of maintenance is the greater reliability of the electric locomotive in service, an advantage that will leave its economic effect all along the line of operating costs. Undoubtedly one of the reasons contributing to the low cost of electric locomotive maintenance is that its wearable parts are easily replaced by spare parts in a few hours, thus permitting repairs to be made at leisure under the best shop conditions and with a force continuously employed.

The completion of the extensive electrification work now under way upon the Chicago, Milwaukee & St. Paul Railway will afford the first service data of the operation of a complete main line engine division. The conditions call for the movement of very heavy freight and passenger trains over both level track and two per cent mountain grades and great economies as well as operating advantages are anticipated. The success of this installation will demonstrate on the broadest scale whether the economics of electrification can offer an attractive return upon the initial investment required, and will prove the desirability of replacing the steam engine by the electric locomotive, at least on mountain grade divisions where the steam limitations are most keenly felt.

To summarize the sources of probable economies with the extensive introduction of the electric locomotives on main steam roads, marked savings should be effected in the following items of expense:

Fuel expense both as regards reduced cost of electric power, elimination of coal tonnage and coal facilities required with steam engines.

Reduced cost of engine maintenance, both direct shop expense and round house expense, which latter is practically eliminated. The fewer breakdowns of electric locomotives should also be reflected in lesser crew expense for overtime and other items.

The greater capacity of the electric locomotive as regards speed on heavy grades not only introduces considerable ecomomies, but may defer for a long time the heavy expense of double tracking a mountain grade division suffering from the limitations of steam engine performance.

Besides the direct advantages of electrification applying generally to all roads, the greater flexibility of electric power and its greater safety due to removing the fire risk and substituting electric for air braking, together with the many secondary advantages of the electric locomotive, will all have greater or less weight, depending upon the local conditions governing any particular instance. With such possibilities of radical changes in operation, it can be confidently expected that direct savings may be materially added to by great advantages in operation that may be somewhat difficult to express in terms of operating expense.

On the Butte, Anaconda & Pacific Railway

# RAIL SECTIONS AS ONE ELEMENT IN STEAM AND ELECTRIC TRACTION

By P. H. Dudley, C. E., Ph. D.

Consulting Engineer, New York Central Lines, New York

This article, coming from the pen of such an eminent authority on rails, should be of special interest and value to all railroad engineers. After some interesting general data and historical facts, the author gives such a wealth of valuable information on many different phases of rail and track construction, as well as operating data and tests of intrinsic value, that a short summary is impossible. The article is concluded by a few short and valuable paragraphs on the electrical resistance of steel rails, a subject on which we hope to publish later on, a more extended article from the same author.—Editor.

P. H. Dudley

The 6-inch 100-lb. steel rail section, laid first in 1892 on the New York Central & Hudson River Railroad, was designed with a broad thin head for an ample bearing surface of the wheel treads on a stiff rail, which could distribute a large portion of their loads to the wheel spacing for a smooth riding track. The fact is not generally appreciated that the wheel load spacing of the equipment controls the spans of the bending rails on the flexible crossties in the ballast, rather than their spacing under the rail. It was, as a rail section of that date, the most efficient engineering structure in use in the world and has fulfilled its complex functions with safety, precision and economy as an essential element of the means of railway transport. (See Fig. 8.)

The modern steel trains, the Empire State Express, the Twentieth Century Limited and others, each have a kinetic energy greater than the heaviest projectile of any high power guns yet fabricated. The stored energy for the speed of the train can be absorbed and rendered inert through several wheel contacts on the rails, when the engineer touches the handle of the air brakes to stop his train. The artillerist concentrates the stored energy of a projectile upon a single contact for destructive effect, while the railway engineer carries and distributes the total load of a train on many wheels, and therefore absorbs the stored energy for the speed of the train through several contacts on the rails for safety and utility. The weight of the rails on their flexible crosstie supports in the ballast and subgrade, occupied by the length of the steam railway or multiple unit train on its several wheels, may be but one-hundredth of the load which the rails can carry when subdivided, distributed and constrained through several wheel contacts. A rail of suitable stiffness on the flexible crossties in the ballast, due to the principle of efficiently subdivided, distributed and constrained loads, is better for good track, smooth riding of the equipment, and economical operation, than that of the major part of the wheel loads concentrated on each crosstie, through a weak rail section.

The 6-inch 100-lb. section is a model of efficiency through its metal to limit and distribute the reduced strains of its wheel loads to the crosstie supports, for it can withstand thousands of repetitions with marvellous exactness for similar conditions of service without failure.

### Some Interesting Historic Developments in Transportation

Schenectady being in the valley of least resistance to travel from east to west and vice versa, inherited the Indian trail and canoe, then developed transportation, by (1) the Conestoga wagon, (2) the stage coach, (3) the canal, (4) steam railroads, (5) electric traction.

The Mohawk & Hudson Railroad from Schenectady to Albany was chartered in 1826, although active work upon its construction did not commence until 1830 and 1831 for the Saratoga and Schenectady Railroad. Mr. John B. Jervis was Chief Engineer of both roads for construction. Locomotives were then in their primitive stage of evolution, of small tractive effort, and able to ascend only moderate gradients of a few feet per mile. Mr. Jervis was therefore obliged to construct for the Mohawk & Hudson Railroad an inclined plane operated by a stationary engine, for the ascent and descent of the cars at Schenectady, from the Mohawk River to the plateau on its banks. A similarly inclined plane was constructed from the Hudson River for the Albany terminal. The alignment of the track of the Mohawk & Hudson Railroad for 14 miles on the plateau was composed of three tangents connected by two curves. The one about midway of the line was 396 ft. long, and of 23,000 ft. radius; the second near Albany was 594 ft. long, and of 4200 ft. radius. The head of each inclined plane connected with the tangent at either end by a curve 528 ft. long and of 1100 ft. radius. To make the gradients and curves easy for the locomotives, the cuts and fills were heavy, and the cost of the railroad averaged $40,228 per mile, a large sum for 1831, but a small cost for the principles elucidated.

The New York Central & Hudson River Railroad now occupies the original line from Carmen to Karner, and includes the curve of 23,000 ft. radius. The total length of the railroad at first was 15.86 miles, and it did not run into the business portion of the Capital; but later a branch line for passengers was permitted in State Street. New York State had just completed its Erie Canal, and the Mohawk & Hudson Railroad Company at first was not allowed to transport freight.

We can study with profit the historic but frail structures of the track, the primitive locomotives and the strap iron rails for the principles of construction which eventually directed their evolution into types in 83 years for the present developments. This has required the application of the facts of experience and the principles of science of the preceding ages, on a more extensive scale than ever before in the history of mankind.

The superstructure of the track for the Mohawk & Hudson Railroad on the plateau between the inclined planes at Schenectady and Albany was constructed of a strap iron rail, $2\frac{1}{2}$ inches wide, and $\frac{9}{16}$ of an inch thick, with the upper corners rounded to $1\frac{7}{8}$ inches and spiked in the center of longitudinal stringers 6 by 6 inches, for their strength as a girder, Fig. 1. The author has one of the original rails and a piece of a stringer. To make an expected enduring track of rigid supports in the roadbed, pits 2 ft. square and with 3-ft. centers were prepared for each line of stringers, and in each pit were placed about nine cubic feet of broken stone which cost $2.00 per cubic yard. Near Schenectady, to support the stone blocks, the broken stone was placed in two parallel trenches. Stone blocks were placed on these foundations, each of $2\frac{1}{4}$ cubic feet, 16 inches in height, with a top surface of 15 by 16 inches, and upon these stringers were laid and attached by knees and spikes to support the strap iron rails. The iron formed the bearing surface for the wheel contacts and the guide for the flanges of the wheels of the passing locomotives and cars, and the stringer as a separate piece supplied the strength as a girder.

Mr. Jervis opened the Mohawk & Hudson Railroad Aug. 9, 1831, with the locomotive "DeWitt Clinton," which was carried upon two pairs of drivers and weighed $6758\frac{1}{2}$ pounds, and was intended to be under three gross tons, exclusive of the light four-wheel tender. The three cars were stage coach bodies with flanged wheels for the track. The length of the entire train was less than that of one of the present Pacific types of locomotives.

A locomotive named the "John Bull" was built by Robert Stephenson & Son, Newcastle-upon-Tyne, and weighed 12,742 pounds and had under the front end a pair of rigid carrying wheels, while the single pair of driving wheels carried 8745 pounds. The wheels of both locomotives were 4 feet 8 inches in diameter, and the wheel base of each, 4 feet 6 inches. The weight of the "John Bull" was too great for the superstructure, and was not subdivided and distributed by a wheel base sufficient in length to ride steadily over the track, and was seldom used as originally made.

Mr. John B. Jervis was constructing the Saratoga & Schenectady Railroad when he opened the Mohawk & Hudson. Three miles of track were finished with stone blocks set upon broken stone, which carried the stringers, the same as used for the Mohawk & Hudson Railroad. The strap rail was an angle iron spiked on the upper inner corners for the track, to provide for inch flanges on the engine drivers and wheels. Mr. Jervis built the balance of the line with crossties upon which the stringers were placed to support the small angle strap iron rails, and ballasted the track for the flexible superstructure and an elastic roadbed, the principle in use today on all steam railroad tracks. The design of the superstructure of the track of the Mohawk & Hudson Railroad on the rigid supports is shown in Fig. 1, and the Saratoga & Schenectady Railroad on elastic supports in Fig. 2, from the best information to date. Fig. 3

shows the original English locomotive "John Bull," by Robert Stephenson & Co., 1831.

Mr. Jervis found the engines were more severe upon the strap iron rails of the Mohawk & Hudson Railroad than was expected, and in 1832 he designed his leading four-wheel truck, arranged for both lateral and vertical flexibility to guide the front of the locomotive in place of the ordinary carrying pair of wheels of the English construction, see Fig. 4. This was also to extend the running gear of the engine, to subdivide and distribute the front truck load on the rail for the following driving wheels. The wheel base of the engine constructed on this important principle was found much easier upon the track and was extensively copied, and in a few years another pair of driving wheels was added for new engines, constituting the American eight-wheel or 4-4-0 type of engine.

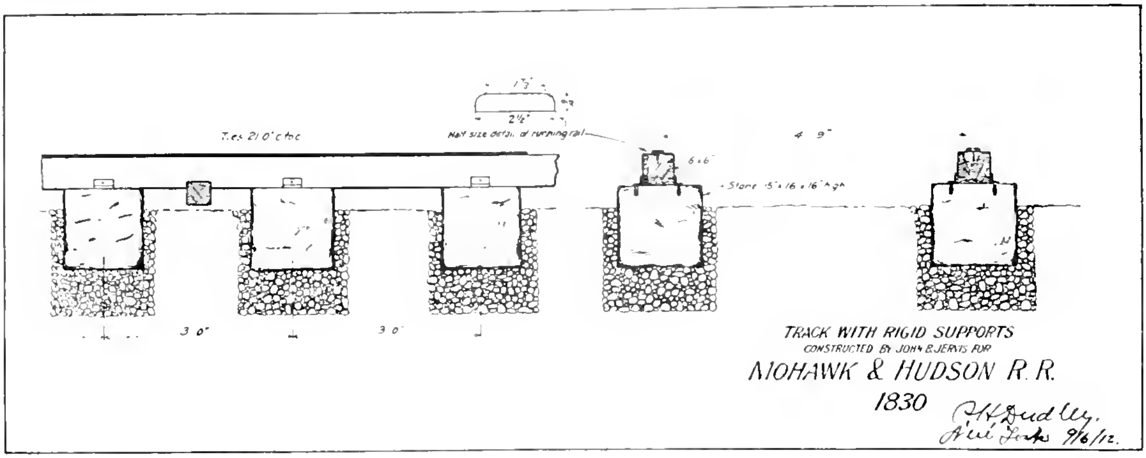


Fig. 1

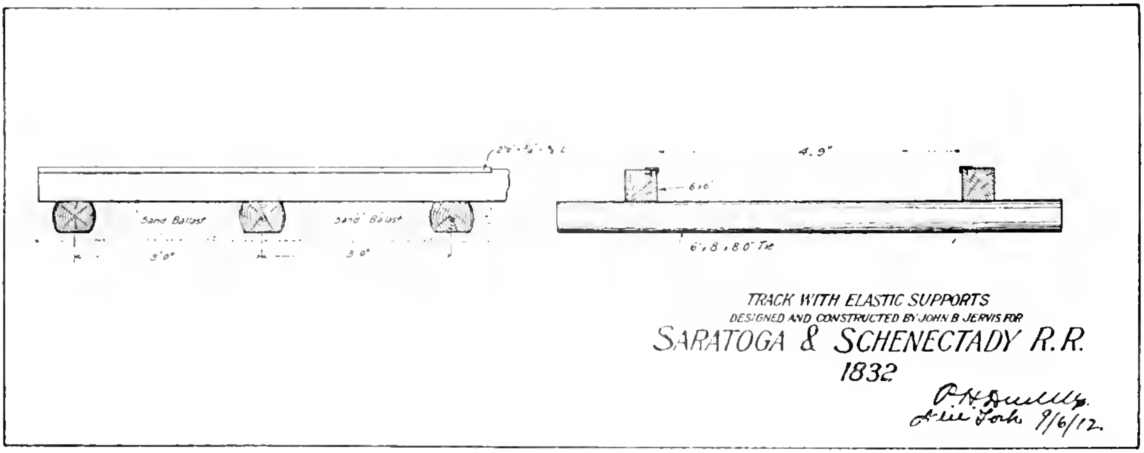


Fig. 2

The locomotive in evolution had now reached a type capable of enlargement, so flexible in the wheel base as to carry sufficient weight on the driving wheels for adhesion to pass around sharp curves and ascend gradients of 40 feet per mile, and superseded the inclined planes worked by stationary engines, used in the earlier railways.

My tribute to the enduring work of Mr. Jervis on the Mohawk & Hudson Railroad, for all coming time, is for his adoption and practice of the principle involved in the leading four-wheel truck for flexibility, and extension of the wheel base of the locomotive for subdivided, distributed and constrained wheel loads on the rails, crossties, ballast and subgrade. The practice of the principle of a flexible superstructure on an elastic roadbed, used on the Saratoga & Schenectady Railroad, is now followed by all steam railways of the world.

### Iron Tee Rail Sections

Robert Livingston Stevens in 1830 designed for the Camden & Amboy Railroad a section of rail, the principle of which combined in one piece the bearing surface for the wheel treads, the guide for the wheel flanges, and the strength for the girder, with a base to rest upon and be spiked to the crossties. This was the prototype of our present rail sections, and was rolled in 1831 by Guest & Co. of Wales. It did not come into general use on account of the expense for many years, and then the head was made more pear-shaped. The construction of the early railways with iron rails was slow, for at first all the iron used was imported from England or Wales.

There were only 23 miles of railway track in this country in 1830 composed of strap iron rails laid upon wooden or stone stringers, and only increased to 2818 miles in 1840, as the frail superstructure of the track had not taken suitable form for its development; and strap iron rails were prohibited by law in New York State in 1844. The physical properties of wrought iron were sufficient for the installation of the early railways but inadequate for their development.

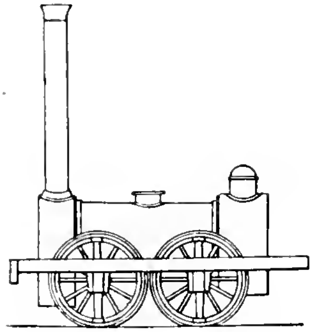


Fig. 3. "John Bull," Hudson and Mohawk Railway, 1831

### Bessemer's Invention for Making Steel

Bessemer steel replacing iron rails marks a distinct epoch in the construction of mileage, maintenance and operation of railways. Bessemer's grand conception was the application of the fact that one-half of one per cent of carbon combined with iron made a ductile steel of greater physical properties than wrought iron, and as cast iron contained from $3\frac{1}{2}$ to 4 per cent of carbon, 1.25 to 2.5 per cent of silicon, 0.50 to 1 per cent of manganese, 0.03 to 0.06 of phosphorus, a non-ductile and brittle product, he made a suitable converter and blew air through the bath of molten cast iron to burn out, first, the silicon and manganese, then the excess carbon above that desired for his grade of steel. This direct method proved only possible with the nearly pure Swedish irons. It was required in all other countries to select pig iron in which the impurities of phosphorus and sulphur would be 0.1 or under, as required for the grade of steel, and then decarburize the molten bath by blowing air through it and subsequently recarburize the blown metal with the desired carbon, manganese and silicon contents. This was a success, and, by the large product which could be made, rendered possible the present railway development by the use of steel rails of greater physical properties and more homogeneous product, to replace those of iron of inadequate physical properties.

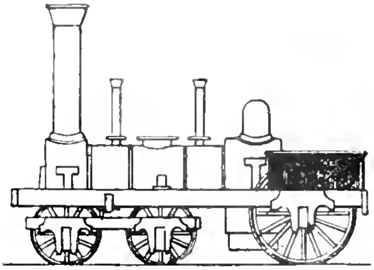


Fig 4. First Bogie Engine, Saratoga and Schenectady Railway. Jervis' Four-Wheel Front Truck Engine, Built by Robert Stephenson & Co., 1833

The use of Bessemer steel rails commenced in this country in 1863, with imported English brands of 500 to 1000 tons for trial. The early rails cost \$100 to \$120 gold per ton, which, with the premium, made the cost from \$240 to \$260 in currency during the Civil War. The early Bessemer steel rail sections were from three and one-half to four and one-quarter inches high, and the weights ranged from 56 to 60 pounds per yard.

The engineers of the New York Central & Hudson River Railroad made deflection tests and in 1870 increased the height of the rails to four and one-half inches, and the weight of the section from 60 to 65 pounds per yard. Large tonnages of the 65-lb. section were rolled in England and France, and the third and fourth tracks were laid with it about 1870 and 1871, and cost from $100 to $110 per ton. These early steel rails were so expensive that the weights of the sections were rolled as light as was considered safe for service. They were not stiff, and had small mechanical properties, and deflected to a marked extent under the wheels, and transmitted concentrated instead of distributed loads to each crosstie. A committee of the American Society of Civil Engineers, in 1873, studying the small wear of the rail under the light wheel loads, came to the conclusion that it would be desirable to design for economical reasons what was termed a residual section, and then add sufficient metal to the top of the head for several years' wear, see Fig. 5. They modified entirely the type of the section, reduced the percentage of the metal in the base and used more in the deep head, providing, as they supposed, for many more years' duration. The question of a section as an engineering structure for stiffness to reduce the train resistance and maintenance was not considered, as it was in advance of the ideas of the evolution of rail sections at that date.

The deep, heavy head, and the change from the thick to the thin base, did not make as safe a girder for heavy traffic, nor result in an equal quality of metal in the rail, as had been secured in the shallow head and thick base of the early sections, to which type we are now reverting from experience, for superior girders. The light steel rails, however, enabled the railway companies to save the cost of renewing the iron rails so often, and lessened the operating expenses, though it did not permit much increase in the wheel loads of the locomotives and cars over those

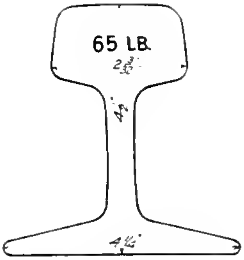


Fig. 5. New York Central & Hudson River R. R., 1870

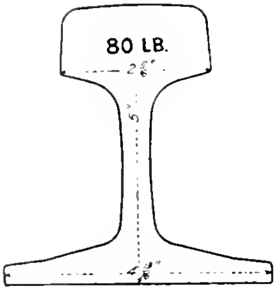


Fig. 6. New York Central & Hudson River R. R., 1884

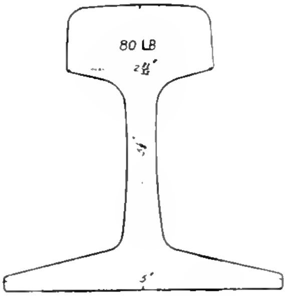


Fig. 7. New York Central & Hudson River R. R., 1892

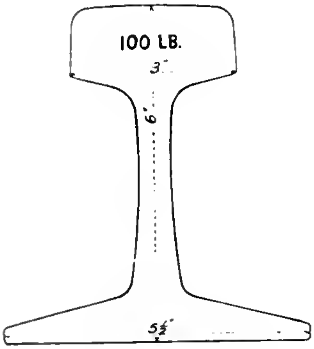


Fig. 8. New York Central & Hudson River R. R., 1892

used upon the iron rails. The railway officials were anxious to improve their tracks and increase the wheel loads of the motive power and equipment to run faster and heavier express trains, and also haul larger freight train loads. I made a track indicator, with a special 6-wheel truck, to measure and record autographically the undulations of the rails in the tracks, to determine what was necessary to improve them in an economical manner.

### Inspection of Tracks with Track Indicator

I commenced the investigation of the undulation of the rails by my track indicator in 1879. The New York Central at that time had 4½-in. 65-lb. steel rails, see Fig. 5, in general use upon the main lines, and upon some of the subsidiary lines, 56 and 60-lb., and the height was from 4 to 4½ inches. The Boston & Albany had a 4½-in. 72-lb., and the Pennsylvania, two sections of 4½-in. 67-lb.

The diagrams taken from over 10,000 miles of the Eastern lines demonstrated the fact that the rails did not have sufficient mechanical properties to distribute the loads in the wheel spacing to any marked extent, as each crosstie received nearly the major percentage of the wheel effects. The crossties cut under the rail seats with rapidity, which permitted the light equipment to cause destructive, expensive and useless injury, while the train resistance was high, as well as the cost of maintenance and operation. I added a mechanism in 1881 to sum up the undulations into feet and inches, shown on the large diagrams, of one inch in length of paper to 50 feet of track, from which the amount per mile and section was secured for tabulation, and afforded definite measures of what labor could do and what could be expected from stiff rails in the track.

The investigations by my track indicator showed on all of the lines that the rails had taken definite forms in the track, which I classified under three distinct types: First, second and third forms of permanent set.

First form: Rails which were low at the joints and high in the center.

Second form: Rails low in the joints and center, but high in the quarters.

Third form: Rails more or less wavy on the surface due to conditions of manufacture.

There were combinations of the first and second, and the second and third upon a few rails.

The forms of permanent set also indicated that the rails were not sufficiently stiff so the track could be maintained in good condition for any length of time without constant attention to surfacing by the trackmen, and the results of their labor did not become cumulative from year to year. The rails began to take a set after one or two years cutting out at the joints under the passing wheel loads, the unit fiber strains being higher than in the present stiffer sections. It was evident that the section should have sufficient metal for its elasticity to carry the wheel loads before the permanent set occurred.

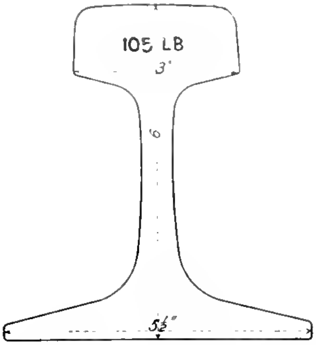


Fig. 9. New York Central & Hudson River R. R., 1912

I designed the pioneer 5-in., 80-lb. steel rail for the New York Central in 1883, Fig. 6, to furnish the superintendents of motive power and the engineers of maintenance of way a better steel rail section as an engineering structure than ever before used. It was, as a girder, 66 per cent stiffer than the 4½-in., 65-lb. section of the New York Central & Hudson River Railroad, secured by the addition of only 15 lb. or 23 per cent more metal per yard, and an increase of ½ in. in height for the section. The rail was rolled in April, 1884, and laid in July of the same year, on the four tracks from Grand Central Station to Harlem Junction, 5½ miles. The demonstration of its value in stiffness was a satisfaction to railway officials, and soon was followed by a 5-in., 80-lb. section for the Michigan Central Railway, and a 5-in., 85-lb. section for the Pennsylvania Railroad. The value of stiffness in rails as girders was so obvious that in 1883, after I had designed the 5-in., 80-lb. section already mentioned, and before it was rolled, I stated, upon the Boston & Albany diagrams for the year 1883, that it would be possible for them with new stiff rails on a well ballasted roadbed to reduce the undulations of the track to between the fifteenth and sixteenth line upon my condensed diagrams.

I distributed the area of metal for the head, web and base of the Boston & Albany 95-lb. section, which was limited to $5\frac{1}{32}$ inches in height by the railway company, owing to the curvature and heavy gradients of the line. I commenced to roll the rail in 1891, and the entire line of 200 miles of double track from Boston to Albany was completed in the summer of 1897. My inspection of the track in the autumn showed the average undulation for the entire track was 15 42/100 lines per mile upon my condensed diagrams, and confirmed the estimate of 1883, fourteen years in advance of its consummation.

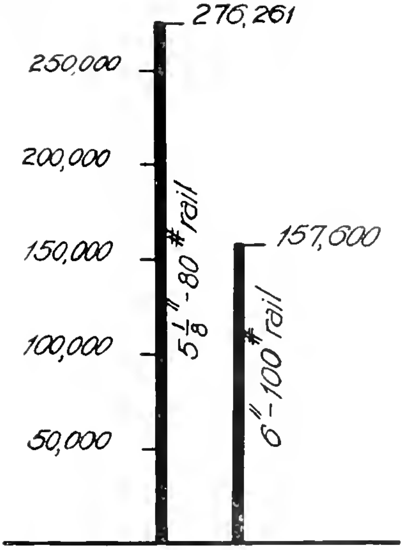


Fig. 10. Comparison of Total Stresses on Worn $5\frac{1}{8}$-in., 80 lb. and Worn 6-in., 100-lb. Rails under the same Locomotive. N.Y.C. & H.R.R.R., July, 1913

### Stiff and Heavy Rail Sections

I designed a series of stiffer and heavier rail sections, after the demonstration and experience with the first 5-in., 80-lb. by the New York Central & Hudson River Railroad, of which the 6-in., 100-lb. section, rolled March 12th, 1892, has been described. The $5\frac{1}{8}$-in., 80-lb., (Fig. 7) of which several hundred thousand tons have since been rolled, was over 10 per cent stiffer than the original 5-in., 80-lb., and some of the first made in 1892 have just been replaced by the 100-lb.

I made all my sections with broad and thin heads joined to the web with $\frac{1}{2}$-in. fillets and 12-in. radii for all sections under 70 pounds, and 14 inches for those which were heavier. The thinnest portion of the web was above the neutral axis, to form a larger junction with the base.

### Quality of Metal in the Rails

When I increased the height of the sections to augment their stiffness for smoother tracks which would check the deflections and reduce the area of contact between the wheels and rails slightly, I knew it would be necessary to increase the physical properties of the metal in the stiffer rails to avoid rapid wear and deformation. I introduced, for that reason, the low phosphorus 0.06 and 0.56 to 0.65 carbon Bessemer steel for the heavier sections. The Boston & Albany rails were rolled in 1891 out of the tougher steel, and I obtained 12 to 16 per cent ductility in the metal under the drop test, which had become obsolete for testing rails until this reinstatement. The specifications were that if 90 per cent of the butts, one from each heat, should withstand a weight of 2000 pounds falling 20 feet without fracture, and any of the remaining 10 per cent gave 4 per cent elongation per inch before breaking, the heat would be accepted. Less than 5 per cent of the heats failed under the 20-foot drop test. This high grade of steel was made for the New York Central and Boston & Albany Railroads from 1891, and continued until the low phosphorus ores were exhausted in 1898.

The metal was tough and tenacious and had so large a duration strain factor that but few breakages occurred in the zero or lower temperatures of winter, and practically none in the summer. I rolled over 500,000 tons of such metal in three-rail ingots for 30-ft. rails in the 80, 95 and 100-lb. sections. I commenced in 1893 to mark the top rail "A," the second "B," and the third or last rail of the ingot "C." The subsequent service in the track furnished the first opportunity to study the wear of the rails from the different positions of the ingots. The practice of the use of a letter to designate the position in the ingot is general for the railroad companies of the United States for rails and some wheels and tires.

The "A" rails of Bessemer steel with a trace of entrained slag and oxides wore the most rapidly under heavy traffic, but the breakages were not much in excess of either

"B" or "C" rails. It was this fact of the service tests of fourteen years that enabled me in 1907 to check the general adoption of a 20 to 25 per cent discard from the ingot. Improvements in making the steel and sound ingots to secure the full ductility of the metal due to its composition, is now the general practice and the wasteful discard is avoided.

### Reductions of Undulations in the New York Central & Hudson River Railroad Tracks, From 1881 to 1914

The undulations as summed up by the track indicator in 1881 on the New York Central and Boston & Albany Railroads averaged 8 ft. per mile, though there were some miles of 12½ ft., and others as low as 5 ft. on new rails. The New York Central & Hudson River Railroad has a chart showing the reductions of undulations in the track from 1881 to 1907, as measured by my track indicator. A curve also shows the increase in driving wheel axle loads on the engines. It is instructive and shows that, as the stiffness of the rails increased, the average undulations of the track decreased from 8 ft. per mile to 2¼ ft. in 1900, while the driving wheel axle loads increased from 30,000 to 60,000 lb. before 1907. The undulations of the track for 1914 are estimated to average about 2 feet or less per mile. The reductions in undulations of the track, by the stiffer sections as better engineering structures, have lessened the generated wheel effects and enabled heavier wheel loads and trains to be run as steam railway traction progressed.

The Empire State Express was installed Oct. 26th, 1891, with Mr. James Buchannan's 100-ton locomotive, and drew four cars of more than double its weight—the educator of the world for heavy high speed trains. The train today is three times its former weight and is composed of 8 to 10 Pullmans. Freight trains of 90 to 100 cars of about 4000 tons are now ordinary, as the train resistance is less per ton for long and heavy trains than for a single unit run by itself.

It is obvious that such progress in steam railway traction has been secured only by the utilization of important principles of construction of the equipment and the permanent way, which is apparent from observation and experience. There is, of course, difference of opinion for the reasons of the results, and the facts can be learned only by measuring the strains in the rails under the passing wheel loads.

The original 100-lb. section, to meet the progress in transportation, has been increased to a 105-lb. section, by the addition of fillets of one-inch radius to join the web and base, and the web thickened to ⅝ of an inch without other changes in dimensions. This was for additional stiffness and strength, and the rolling of basic open hearth steel from 0.63 to 0.75 carbon; see Fig. 9. The new splice bars also fit the original 100-lb. and thus join in the track the 100 and 105-lb. rail sections.

### The Equilibrium Depression Between the Track and Wheel Loads of the Passing Locomotives and Cars

The moving wheel loads of the locomotives and cars depress the rails, crossties, ballast and subgrade from the trackman's surface to the momentary equilibrium depression, and the specific deflections under the wheel contacts of the rails on the flexible crossties are limited by the strains produced in the metal of the section.

The depression is merely momentary for the rails, crossties, ballast and subgrade for they return practically to the trackman's surface after the train has passed.

## THE STREMMATOGRAPH

The stremmatograph is an instrument of precision which I designed, and completed its construction in 1897, to determine the unit fiber strains in the rails when attached to the base between the crossties under moving trains. It is the function of the stremmatograph to make autographic records of the longitudinal unit fiber strains of the elasticity in the metal of the rail section exercised in the base, due to the action of each individual moving wheel load, and its reactions on the flexible supports in the ballast and subgrade. The strains in the base are balanced in the head by those of an opposite character. The strains for a given unit length in the spans of the bending rail controlled by the wheel spacing of the equipment reverse above and below the neutral axis of the section for each passing wheel as a rule, consequently there is a series of alternating unit fiber strains to balance the stresses set up in the metal of the section to carry the wheel load effects. The unit fiber strains or balanced stresses developed in two different rail sections as simple beams of like sections on rigid supports and load are inversely proportional to their respective moments of inertia, according to the laws of mechanics.

The tests on 80 and 100-lb. rails with the stremmatograph show for the entire wheel base of the same locomotive with smooth wheels, that the above law of mechanics is equally true for the sum of all the unit fiber or balanced stresses per individual wheel, in two rail sections of different moments of inertia, on the flexible crosstie supports in the equilibrium depression of the track, until a speed is reached where the weaker section develops wheel effects in a faster ratio than the stiffer rails. The track construction and roadbed must be similar for both sections of rails; see Fig. 10.

The comparative tests were made on the New York Central & Hudson River Railroad at Coldwater, N. Y., July, 1913, upon a worn $5\frac{1}{8}$-in., 80-lb. rail rolled in 1892 and laid in track No. 3, and a worn 6-in., 100-lb. rail rolled in 1905, and laid in track No. 4, by the side of track No. 3. The worn 80-lb. rails had carried over three hundred million tons of traffic, and the worn 100-lb., one hundred and thirty-five million tons. The moment of inertia of the 80-lb. rail had been reduced from $28.5^4$ inches to $26.3^4$, according to the profile of the head, and were 30-ft. lengths spliced with 36-in. angle bars for a 3-tie supported joint. The moment of inertia of the 100-lb. had been reduced from $48.5^4$ inches to $46.77^4$, while the rails were 33 ft. long and spliced with 36-in. bars for a similar joint to the 80-lb. rail.

The ballast was gravel under each track, and the tests were made against the direction of the traffic on the 80-lb. rail owing to conditions beyond control, but with it on the 100-lb. rail.

The engine was a Mikado; the wheel base was 2-8-2; the total weight of the locomotive was 491,300 lb.; and the total length of wheel base was 68 ft., 11 in. Its tender had the usual two pairs of four-wheel trucks, a total of 10 wheel contacts upon one rail. The locomotive was nearly new; the drivers and wheels were of normal rotundity, which rendered possible speeds from $6\frac{1}{2}$ to 60 m.p.h., without the generation of large wheel effects.

The total stresses of each of eight tests upon the worn $5\frac{1}{8}$-in., 80-lb. for one rail, and six tests upon the worn 100-lb. rails for a range of speeds from $6\frac{1}{2}$ to 45 m.p.h.—140 different wheel effects for the two sections—compare within 1.52 per cent of being inversely proportional to the moments of inertia of the worn rails. Single experiments upon each section of rail for the same speed are within less than 1 per cent of the theoretical comparison. This is proof that the metal in the 80-lb. section after its 21 years of service, owing to its quality, has not deteriorated in elastic properties in the slightest degree.

These tests involve also another law of the moving locomotive, ascertained by the stremmatograph, namely, the moving locomotive as a machine on good track, distributes its total load through its center of gravity to the several but individual wheel contacts on the rail. Fig. 10 shows the comparative diagrams of the average total stresses for the eight tests on the 80-lb., and six tests on the 100-lb. rail. The mean of the total stresses per test on the 100-lb. rail was 157,600 pounds, and on the 80-lb., 276,261 pounds, and would be double in each case for both rails of the track.

The diagrams show the comparative value of the two sections as engineering structures, for the crossties, ballast and subgrade receive greater intensity of pressures, and must furnish more support for the 80-lb. than is required for the 100-lb. rails. The capacity and stability of the track of 80-lb. rails is less than that of the 100-lb., and therefore exacts more labor in maintenance, for in the practice of engineering the roadbed is strengthened by the 6-in., 100-lb. rail. The rail section on its flexible crosstie supports with its several distributed wheel loads, by the experimental proof in the track of the stremmatograph, follows the laws of mechanics for a single deflection, with the advantage of the acquired constraint per wheel, and it is one reason why, mechanically, that it has been possible to secure the present progress in steam railway traction.

Jervis's principle of subdivided and distributed loads has empowered, without injury to the rails and roadbed, the use of a heavier total load for adhesion and expended tractive effort to be distributed through several wheel contacts for locomotives and electric motors, than was formerly possible through a single pair of drivers, or the 4-4-0 class of locomotives. The wheels of the engine and tender must be included for the total stresses of the steam locomotive, therefore the tender running gear must be included for the wheel effects for each class of locomotives. The 4-4-0 would have the following designation: 4-4-0+4-4, or eight wheel contacts on one rail. This class has been superseded by the 4-4-2+4-4 for heavy passenger service, and this in turn by the 4-6-2+4-4 class. There are a number of railways with mountain gradients and rails of 90-lb. or less per yard, where the class of locomotives of 4-8-2+4-4 is used to advantage. For freight service of slower speeds and larger train loads, the Mikados of 2-8-2+4-4, are in general use, and a class of 2-10-2+4-4 are employed when a larger tractive effort is required. The loading and constraint of the rails in the equilibrium depression would be still better with a class of 4-10-2+4-4 wheel base and drivers about 57 inches in diameter.

### Basic Open Hearth Rails

The progress in transportation during the past few years has required the replacement of Bessemer rails of 0.10 phosphorus and 0.50 carbon, by basic open hearth steel of 0.04 phosphorus and 0.63 to 0.75 carbon, for 100-lb. rails or over, to secure a duration strain factor of the metal which would carry the high speed trains in temperatures of 30 deg. below zero without fracture of the rail, as so frequently occurred in Bessemer steel.

The unit fiber stresses of 18,000 to 20,000 pounds under a driver at 30 m.p.h., would be applied from zero to the full amount in about 0.04 of a second, and at 60 m.p.h. it would be 0.02 of a second from measurements by the stremmatograph. This is quick time for the application and distribution of so large unit fiber strains which are balanced by the limited stresses set up in the metal. The basic open hearth rails, from the experience with them in the track, prove to have a greater duration strain factor in the metal than it was possible to secure in all of the 0.10 Bessemer steel rails at the low temperatures. The rails are made under the specifications for the New York Central Lines elongation and ductility tests for basic open hearth steel rails which were introduced in 1910, to secure those of the maximum ductility, purity and homogeneity of the steel, due to its chemical composition for service in temperatures 40 degrees below zero F.

The drop tests are made from each melt, one from the crop of the top bar of the second, middle and last full ingot. The crop, 4 to 6 feet long, is stamped with a spacing bar of six 1-in. spaces in the center of its length on the base, head or side, as desired.

Each butt for basic open hearth rails for acceptance of the melt, must show under the drop of 18 feet for the 80 and 90-lb. sections, and 20 feet for the 100-lb. section, at least 6 per cent elongation for one inch, or 5 per cent for two consecutive inches before fracture. The elongation of each of the six spaced inches is measured by a flexible rule, divided into hundredths of an inch, therefore the increased one-hundredths after the drop give the percentage of elongation per inch of the metal. The ductility is completely exhausted in one test for each melt, and is made in rotation from the different ingots in succeeding melts. The melter has the ductility of the last melt, before he taps another from the same furnace, which has enabled a greater uniformity of the steel to be obtained than was possible before the tests. The specifications for the ductility tests have been adopted by the American Railway Engineering Association for use by the railroads in the United States.

### The Wheel Problem

The wheel consists of a tread constructed of uniform radius revolving upon its axis of lesser rolling and with less axle friction than would be produced by sliding on its support, and is the mechanical embodiment of a principle for transportation so ancient that its origin is unknown. The wheels and drivers are the only contacts on the rails to support and carry the equipment, and it is requisite that the material of their treads should be homogeneous and able to maintain their rotundity for a considerable length of service.

A 36-in. wheel makes 560.2 revolutions per mile, and for a static load of five tons the repetitions upon the metal of the tread are equivalent to 2801 tons per mile. To run from New York to Chicago, the applied static tons per mile equal 2,718,164 mile-tons per wheel for the trip, exclusive of generated wheel effects.

The New York Central Lines are giving special attention to the wheel problem by measuring the wear and deformation on thousands of sections of marked wheels to secure a metal in the wheel treads which will maintain their rotundity under the large mile tons of service and the action of the brakeshoes to control the trains.

### Electric Traction

The principles and practice elucidated by the stiff rail sections for steam railway practice apply equally to electric traction. The latter has the advantage for city traffic, for imbedded girder rails on rigid supports with welded joints can be used to carry millions of tons of traffic, before the track requires adjustment or renewal of the rails.

Electric traction has rendered possible the large underground terminals like the New York Central & Hudson River, the Pennsylvania and the Hudson & Manhattan Railroads, and the subways in New York City. The 10 and 12-car multiple unit trains with 2 to 5 minutes headway, and all the appliances for safety of control in their movements, are models of electric traction.

The trolleys in the cities and country roads are usually constructed with light T rails which could be replaced with advantage by stiffer sections.

The electrical engineers have the unique problem of developing motors on similar principles to those that determined the evolution of the steam locomotive.

### Resistance of Steel Rails as Electric Conductors

The 70-lb. contact rails for the Grand Central Terminal were made of Bessemer steel in 1905, and continue to the present time, of the following desired composition:

| | |
|---|---|
| Carbon | 0.10 |
| Manganese | 0.40 |
| Silicon | 0.05 or less |
| Phosphorus not to exceed | 0.10 and as much less as possible |
| Sulphur not to exceed | 0.08 and as much less as possible. |

The manganese was just sufficient to roll the steel which gave a resistance of 8 to 8½ times that of copper. The resistance in some of the recent Bessemer 70-lb. contact rails is from 9 to 10 times that of copper, though the higher figure is from the upper part of the ingot, and doubtless was rolled cold. The resistance of a 70-lb. New York Central & Hudson River Railroad standard section of the ordinary composition for the rail was 12.5 times that of copper; of the 100-lb. Bessemer, 11 to 12 times; while the 105-lb. section in basic open hearth steel is only about 10.6 times.

Basic open hearth 70-lb. contact rails can now be obtained of about 0.10 carbon, but with phosphorus and sulphur each under 0.04, in which the resistance is guaranteed to be not over 7 times that of copper. This needs confirmation for the steel of the entire ingot.

The strap iron rail with its 6 by 6 inch wooden stringer for the girder of the Mohawk & Hudson Railroad of 1831, and the 6-inch steel section of 1892, are historic illustrations of the progress of railway transportation as governed by the rail section.

Twentieth Century Limited

# THE ELECTRICAL OPERATION OF THE BUTTE, ANACONDA & PACIFIC RAILWAY

By J. B. Cox

Railway and Traction Engineering Department, General Electric Company

The author wishes, at the outset, to gratefully acknowledge the assistance of Mr. H. A. Gallway, General Manager of the Butte, Anaconda & Pacific Railroad Company. It is through his co-operation and effort that the operating data given herein are made available. Information of this character has seldom been published and that it is here given to the public is a tribute to the broad sighted policy of Mr. Gallway's company. This article gives a description of the work done and nature of the operating conditions. The direct comparison of the operating costs before and after electrification are of the utmost value as showing what may be expected from electrification even in such a severe character of service. This paper was read before the Pacific Coast Convention of the A.I.E.E., at Spokane, Wash., on September 10, 1914.—Editor.

J. B. Cox

The Butte, Anaconda & Pacific Railway was built in 1892 principally for the purpose of conveying the ore from the mines at Butte to the Washoe smelter, which had been located at Anaconda, twenty-six miles west of Butte, where an abundant supply of water, so necessary in the reduction of the ore, was obtainable. The tracks connecting Butte and Anaconda constitute the main line which is approximately 25.7 miles in length. As the mines are mostly around the top of Butte Hill, and the shafts through which the ore is hoisted to the surface are scattered over a considerable area, yards were built at a convenient point on Butte Hill for the concentration of the cars containing the ore from these shafts, as well as to serve as a distribution point for the supplies to the mines. A branch locally known as the Missoula Gulch line, see Fig. 2, was built from these yards to connect with the main line at Rocker where yards were also established.

Since the concentrator at the smelter is also on a hill, at an elevation of approximately 340 ft. above the main line, it was advisable to establish another yard at East Anaconda from which to distribute the ore and other supplies to the different centers on Smelter Hill. The lines from these yards at East

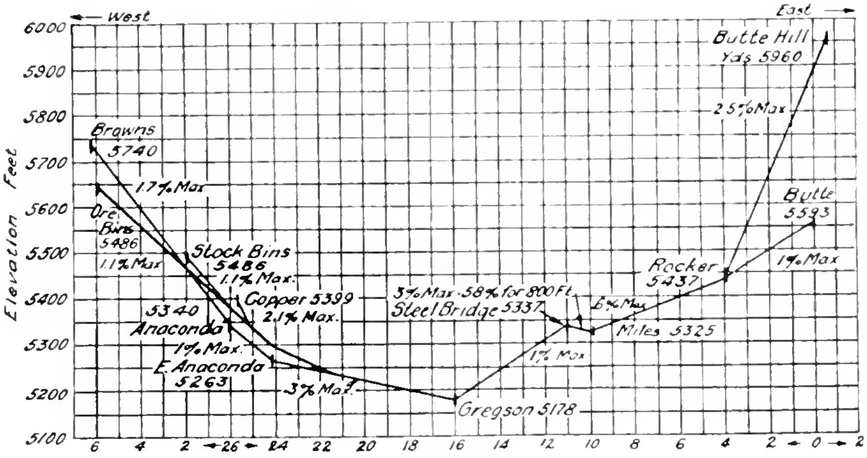


Fig 1

Anaconda to the smelter are known as the Smelter Hill lines, the longest branch of which is that leading to the concentrator which is about $7\frac{1}{4}$ miles in length. Two spurs lead off from this main track, one to the stock bin yards and the other to the copper tracks; see Fig. 4.

Fig. 2. Outline Map of Railway Lines on Butte Hill for Collection of Ore and Delivery of Supplies

From the Butte Hill yards spur tracks radiate about Butte Hill to the shafts of the various mines and to other points where supplies are to be delivered; see Fig. 1. Bins for receiving ore, as it is hoisted from the mines, are located near each shaft and from these bins the ore is loaded into hopper bottom steel ore cars of 50 tons capacity each. These loaded cars are delivered to the Butte Hill yards where they are made up into trains and taken down to the Rocker yards where they are made up into still larger trains and taken over the main line to the East Anaconda yards. Here the trains are broken up to be transported in smaller units up Smelter Hill to the concentrator yards. Thus practically all of the ore cars are handled by five different engine crews between the ore bins at the mines and the receiving bins at the concentrator.

A total of 27 steam locomotives were owned by the railway company, classified as follows:

| | |
|---|---|
| Switching | 7 |
| Consolidation | 8 |
| Mastodon | 10 |
| Passenger | 2 |

The coal used on the steam locomotives was obtained from the mines at Diamondville, Wyoming, and had to be transported approximately 395 miles for delivery to the bins of the railway company at which point its average cost was approximately $4.25 per ton.

The machinery at the mines and the smelter had mostly been electrified, and the results had been so satisfactory that the railway company had a study of their conditions made for the purpose of investigating the advantages that might be expected from the electrification of their lines. The result of this was the placing of a contract in December, 1911, with the General Electric Company for the electrical equipment of the main portion of their line consisting of the main line, spurs and yards between Butte and Anaconda, the Missoula Gulch line between Rocker and the Butte Hill yards, and the Smelter Hill lines. Owing to local conditions on the spur tracks leading to the various mines from the Butte Hill yards it was thought advisable not to electrify these until a later date.

Three of the steam switching locomotives listed above were used daily on Butte Hill for collecting ore from, and delivering supplies to the various mines from the Butte Hill yards. The Georgetown extension to Southern Cross, 22.9 miles west of Anaconda, was under way at the time; but as it was expected that only a few trains per week would take care of the traffic over this branch for some time, its electrification was not seriously considered in the original study.

It is fair to assume that a vital consideration leading to the electrification of this railroad was the rapid development and physical consolidation of a network of hydro-

**Fig. 3.** Map of Missoula Gulch Lines, Rocker to Butte Hill Yards

electric power plants in the territory tributary to the railroad.

A contract for the power for the operation of the road was made with the Great Falls Power Company, which, operating under the same management and in physical connection with the system of the Montana Power Company, was enabled to guarantee an ample supply of power at all times with exceptional freedom from interruptions to service and at a reasonably low price.

The tracks recommended to be electrified totaled approximately 90.5 miles, all of which are supplied with power from two substations, one being located in the Missouri River Power Company substation on Butte Hill and the other in the substation building on Smelter Hill, from which electrical power for operating the machinery there is distributed. At each of these substations there was vacant space for the location of the extra apparatus required for the operation of the railway, and the transformer capacity already installed at each place was sufficient to meet the extra demand required for the operation of the railway.

### Power

The Anaconda substation is connected with the Butte substation by three high tension trunk lines. The Butte substation receives power over five separate transmission lines from six hydro-electric stations of the following rated capacities:

| | | |
|---|---|---|
| Big Hole development | 3,000 kw. | 60-ft. head |
| Madison River development | 9,000 kw. | 110-ft. head |
| Canyon Ferry development | 7,500 kw. | 35-ft. head |
| Hauser Lake development | 14,000 kw. | 60-ft. head |
| Black Eagle development | 3,000 kw. | 44-ft. head |
| Rainbow development | 21,000 kw. | 110-ft. head |
| Total | 57,500 kw. | |

There is also now under construction the Great Falls development, with a capacity of 60,000 kw. and with a 155-foot head; see Fig. 7.

All of these plants are on the Missouri River water shed, and operate with a free interchange of power, and all, except the first, are located in a series below the new Hebgen reservoir, now being completed on the head waters of the Madison River, with an available capacity of 300,000 acre-feet of storage.

The individual plants are also provided with storage reservoirs aggregating 125,000 acre-feet of total available storage capacity. All of these reservoirs operating under one control are capable of developing from stored water alone, in addition to the power otherwise available from the natural flow of the river, the equivalent of about 100,000 electrical horse power for a period of 100 days.

In view of this development, the generally recognized advantages of purchasing electric power from a large operating system, instead of developing the required power independently, were readily apparent in the case of the Butte, Anaconda & Pacific Railway. The railroad was relieved of all the first cost of development and transmission of power, and of all operating expense up to the point of delivery of power to the two substations. The cost of the delivered power is less than it would have been from an independent development, because the power company is enabled to operate large generating stations at a relatively high load factor (about 75 per cent), whereas an independent plant purely for the operation of the railway would have to operate in this case at about 30 per cent load factor, with correspondingly high fixed and operating charges per kilowatt-hour actually used. The large number of generating stations and the complete network of transmission lines already developed by the power company afford ample insurance against the interruption of the railroad service due to possible failure of any part of the generating or transmitting system of the power company. The enormous inertia or flywheel effect of the motor loads connected to the power system maintain extremely steady speed and voltage under the most extreme variations of load on the railroad.

### Substation

The original equipment of each substation was practically the same, consisting of two 1000-kw., three-unit motor-generator sets with the necessary starting and operating devices. Each motor-generator set consists of a 1450-kv-a., three-phase, 60-cycle, 720-r.p.m. synchronous motor coupled direct to two 500-kw., 1200-volt direct current generators, one at either end, the two generators operating in series and supplying 2400-volt direct current to the trolley lines. The generators are compound wound and have compensating pole face windings as well as commutating poles. The series fields are connected on the grounded side of the armatures while the main fields are separately excited from a 125-volt circuit. The motor-generator sets are capable of carrying overloads up to three times normal load momentarily and 50 per cent overload for two hours. The value of this characteristic will be

Fig. 4. Map of Smelter Hill Lines

appreciated when it is noted that each electric locomotive unit has a continuous rating of approximately 900 kw., or almost equal to that of a single motor-generator set, and frequently 16 of the 17 units purchased are in service simultaneously, 11 of which are concentrated at the Anaconda end at intervals.

### Locomotives

Seventeen 80-ton electric locomotive units were purchased originally, fifteen of which are being operated in freight service and two in passenger service. These units are practically interchangeable with the exception of the gearing, the passenger locomotive being geared to operate normally at 40 to 50 m.p.h., while the freight locomotives are geared to operate at from 15 to 25 m.p.h., the maximum free running speed being approximately 35 m.p.h.

The continuous tractive effort of the freight units is 25,000 lb., at 15 m.p.h., but they are capable of exerting a maximum tractive effort of 48,000 lb., for 5-minute intervals, based on a co-efficient of adhesion of 30 per cent.

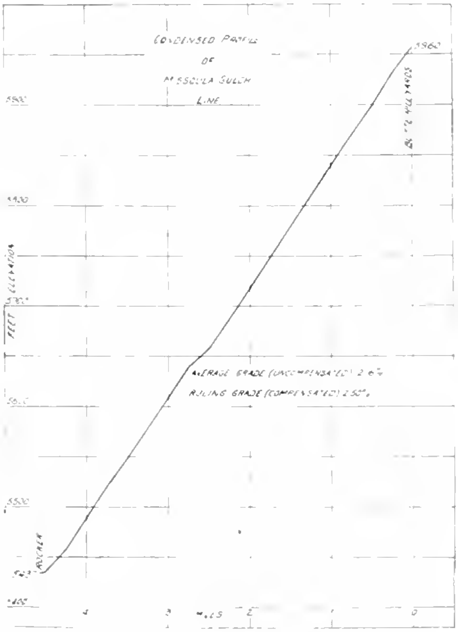


Fig. 5. Condensed Profile of Missoula Gulch Line

All the locomotive units are of the articulated double-truck type, with twin gears mounted on projections provided on the wheel centers for the purpose, and in general mechanical design are similar to the electric locomotives in operation on the Great Northern Railway, the Detroit River Tunnel Railway and the Baltimore & Ohio Railroad. Each unit is equipped with four GE-229-A commutating pole motors, wound to operate at 1200 volts each, but insulated for 2400 volts, so that two are connected permanently in series and the four are arranged in pairs, thus securing the usual two running points, with the difference that on the series position all four motors are in series and in multiple position the two pairs are connected in series-parallel.

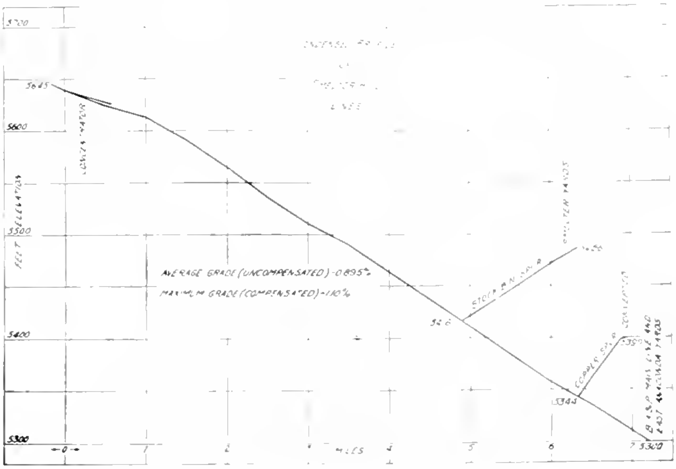


Fig. 6. Condensed Profile of Smelter Hill Lines

The horse power of each motor on the standard rating is approximately 300 h.p., making the hourly rating of each locomotive unit about 1200 h.p. The control equipment is of the multiple unit type and provides a total of 19 steps, ten of which are in series and nine in series-parallel. The 2400-volt contactors, switches, fuses, etc., are located in enclosed compartments where they can be reached only by deliberate effort. The current for the operation of the control equipment, the air compressor and the lights on the locomotive, as well as the lights on the passenger coaches, is supplied by a 2400/600-volt dynamotor located in the main compartment of each locomotive unit.

A blower which provides artificial ventilation for the main motors and the rheostats is direct connected to the armature shaft of this dynamotor. The principal data and dimensions pertaining to the electric locomotives are as follows:

| | |
|---|---|
| Length inside of knuckles | 37 ft. 4 in. |
| Length over cab | 31 ft. |
| Height over cab | 12 ft. 10 in. |
| Height with trolley down | 15 ft. 6 in. |
| Width overall | 10 ft. |
| Total wheel base | 26 ft. |
| Rigid wheel base | 8 ft. 8 in. |
| Track gauge | 4 ft. $8\frac{1}{2}$ in. |
| Total weight | 160,000 lb. |
| Weight per axle | 40,000 lb. |
| Wheels, steel tired | 46 in. |
| Journals | 6 in. by 13 in. |
| Gears, forged rims, freight locomotives | 87 teeth |
| Gears, forged rims, passenger locomotives | 80 teeth |
| Pinions, forged, passenger locomotives | 18 teeth |
| Pinions, forged, freight locomotives | 25 teeth |
| Tractive effort at 30 per cent coefficient | 48,000 lb. |
| Tractive effort at one hour rating | 30,000 lb. |
| Tractive effort at continuous rating | 25,000 lb. |

### Operation

Work on the electrification began in the spring of 1912 and the first electric locomotive was run in Anaconda on May 14th, 1913, about a year later.

On the 27th of May two ore trains were hauled up Smelter Hill with electric locomotives and on the following day, May 28th, a double-unit electric locomotive took over the regular day service of hauling the ore from the East Anaconda yards to the concentrator yards; the distance between being approximately seven miles. The ruling gradient is 1.1 per cent and is compensated. The grade is fairly uniform through the entire distance; see Fig. 6. The steam locomotives used in this service were of the Mastodon type, weighing 108 tons, 83 tons of which was on the drivers. The weight of the tender loaded was approximately 55 tons, making the total weight of locomotive and tender about 163 tons, which would average closely to the weight of the double-unit electric locomotive superseding it. The steam locomotive ordinarily made six round trips per shift, hauling 16 loaded ore cars per trip, equaling 96 cars per shift.

The average time for the trip from East Anaconda to the concentrator yards with 16 loaded cars for the steam locomotive was about 45 minutes. The double-unit electric locomotive began only 16 cars per trip but made 8 trips per shift, delivering 128 cars per shift. The average time for the uphill trip with the electric locomotives was about 22 minutes or approximately half the time required by the steam locomotive for the same number of cars. Empty cars were taken to East Anaconda on the return trip which being all down grade, gave the electric locomotive no decided advantage, as the speed in either case was limited to about 25 m.p.h. for safety on account of the curves in the line. The number of cars hauled per trip with the electric locomotives in the beginning was kept the same as it had been with the steam, for it had been decided to make the change-over by gradually replacing one steam locomotive at a time with an electric locomotive, taking the engine crew off the one and placing it on the other; thus breaking them in on the electric locomotives in regular service.

One of the regular steam engineers had been given special instructions on the electric locomotives during the trial running in order that he might become competent to act as instructor to the other engineers until they were sufficiently familiar with the electric locomotives to be left alone.

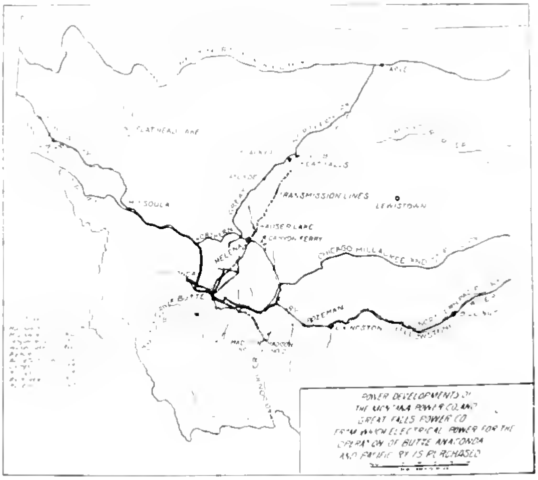


Fig. 7. Power Developments of the Montana Power Company and Great Falls Power Company from which Electrical Power for the Operation of Butte, Anaconda and Pacific Railway is purchased

The load per trip in this service was gradually increased from 16 cars to 25 cars, which is to be the standard for the present. The average time for the uphill trip with 25 cars is about 26 minutes, so that eight trips per shift is easily made, making a delivery of 200 cars possible, or an increase of slightly more than 108 per cent over what had been possible for the same crew with steam locomotives. These loaded ore cars average from 70 to 72 tons each, making the trailing load for a 25-car train from 1750 to 1800 tons.

On arrival at the concentrator yards, the ore trains are taken by a switching engine called the "spotter," which places it, one car at a time, over the weighing scales; after which they are re-arranged for placement over the concentrator bins from which the ore is fed by gravity to the crushers.

On June 20th this spotting service was taken over by a single-unit electric locomotive and on July 2nd the night service up Smelter Hill was taken over by the double-unit electric locomotive. The steam locomotive used for the spotting service was of the consolidation type and weighed 93 tons, 83 of which was on the drivers; the tender weighing loaded 62 tons, making the total weight of engine and tender, 155 tons. The steam locomotive used in the night service on Smelter Hill was similar to that used in the day service. When the electric engines were put on the night service all the handling of ore between East Anaconda and the concentrators was done electrically and the hauling capacity per crew was so much greater that it was no longer necessary to have a "spotter" crew on the night shift, so that this crew was eliminated and the night crew hauling the ore up Smelter Hill did their own spotting on arrival at the concentrator yards, it being no longer necessary to make the regular number of trips. Thus where formerly during steam operation four engine and train crews had been required, with electric locomotives three similar crews were able to do the same work and in less time, thereby reducing the number of crews required in this particular service by 25 per cent.

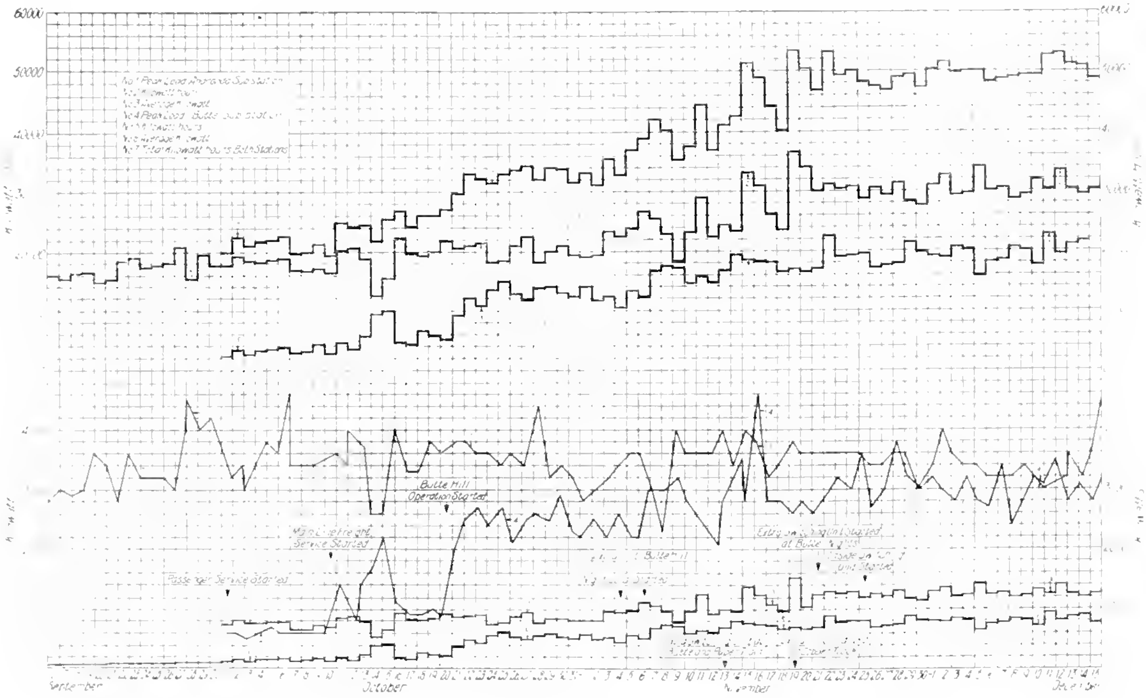


Fig. 8. Diagram of Substation Loads

On July 9th the stock bin engine was replaced by an electric unit. This engine is engaged mostly in a switching service, placing cars of coke, coal and other supplies at the smelter. The type of steam engine used here was the same as that used for the "spotter" service described above.

Another engine, locally known as the "tramp," because of the irregularity of the time or place of its service, was partially replaced on July 24th. As some of the tracks over which this engine had to operate at times had not been equipped with overhead wires, the infrequency of their use not warranting the expense, and as other conditions made it necessary to keep one or more steam locomotives in operation, the service of this electric unit was intermittent. This practically completed the electrification of the Smelter Hill service and no further extension of electrical operation was made until October, as the trolley construction on the main line was not completed until that date.

On the forenoon of September 30th an inspection trip was made over the main line from Anaconda to Butte and in the afternoon a special train carrying officials and visitors from a neighboring road was taken from Butte to Anaconda and return by one of the electric locomotives intended for the passenger service. On October 1st the regular passenger service between Butte and Anaconda was taken over for electrical operation. The steam locomotives used in the passenger service weigh approximately 80 tons, 60 tons of which is on drivers; the tender loaded weighing 52 tons, making the total weight of engine and tender 132 tons. The distance between the Anaconda and Butte stations is 25.7 miles, and the schedule time for the trip is one hour. No change has been made in this time though a reduction of 20 per cent would be possible with the electric locomotives were such desired. The standard passenger train consists of one mail and baggage coach and two to four passenger coaches, but as many as 12 passenger coaches are handled by a single electric unit on special occasions, such as excursions and on holidays.

The baggage coaches average approximately 40 tons in weight and the passenger coaches 45 tons each, making the gross weight of the three-car electric train approximately 210 tons, whereas that of a similar steam train was 262 tons—a reduction of 19 per cent in favor of the electric locomotives with approximately the same weight on drivers in each case. As had been done in the freight service the steam engineers in the passenger service, were transferred from the steam to the electric locomotives with but little previous instructions, and after the first day or so were left mostly to themselves. It may be of interest to note here that on the day shift, averaging four trips per day, during the first five months the passenger train did not come in late a single time on account of engine trouble. A comparison of the delays to the passenger trains for the month of June, 1913, with steam operation with the same month with electrical operation in 1914, is shown in Table 5. The results from Table 5 are given below.

| | | DELAYS ON ACCOUNT OF | | | | | | | | TOTAL DELAYS ALL CASES | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Trains | Meeting Points | | Power | | Engine Failure | | Lost Run Time | | | |
| | | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. |
| Steam, 1913 | 272 | 15 | 49 | | | | 44 | 4 | 13 | 20 | 46 |
| Electric, 1914 | 280 | 3 | 54 | | 27 | | 24 | | 25 | 5 | 10 |
| Decrease | 8* | 11 | 55 | | 27 * | | 20 | 3 | 48 | 15 | 36 |
| Percentage of saving due to electrical operation | 2.94* | 75.66 | | | | 45.45 | | 90.10 | | 75.12 | |

* Increase.

June was taken at random for a comparison, as that month's records were still in the office file, but the results are considered representative of general performances.

On October 10th a double-unit electric locomotive was put in the day freight service on the main line between East Anaconda and Rocker, a distance of 20.1 miles. The steam locomotive replaced in this instance was of the Mastodon type weighing 103 tons, 77 tons of which was on drivers, the tender loaded weighing 55 tons, making the total weight of locomotive with tender 158 tons. The standard train hauled on the trip west was 50 to 55 loaded ore cars weighing approximately 3500 to 4000 tons gross, and the average running time of such trains, where no stops were made, was about 1½ hours, corresponding to an average speed of approximately 13.4 miles per hour. In the beginning the electric locomotive took only the standard train but made the trip without any stop in about one hour, corresponding to an average speed of 20 m.p.h. The ruling gradient on the westward trip is 0.3 per cent and about half the distance is down grade. On the 0.3

per cent grade with a 55-car train, the steam locomotive made about 7 m.p.h. The electric locomotives with a similar train now make about 16 m.p.h. on the same grade.

The weight of the trains hauled by the electric locomotives on this run have been gradually increased up to 65 loaded ore cars averaging about 71 tons each, making the gross weight trailing about 4620 tons. Adding 160 tons for the weight of the double-unit electric locomotives and 20 tons for the caboose makes a gross train weight of approximately 4800 tons.

The remainder of this main line freight service was gradually taken on during the months of October and November, thus completing the electrification of the main line service. As many as 76 ordinary freight cars loaded with coal, coke and general merchandise have been taken in a single train on the west bound trip, and 85 empties are frequently taken from East Anaconda to Rocker east bound, the ruling grade being 1 per cent.

Table 4 gives comparative results for the month of June, 1913, with steam operation and the same month in 1914 with electrical operation of this main line service, showing that with a slight increase in the total tons of ore hauled the average tons per train was increased from 1761 to 2378 or 35 per cent, thus decreasing the average number of trains per day from 12.5 to 9.3 or 25.6 per cent.

Table 3, giving a comparison of the time per trip for these trains, is representative of the gain in this direction to be added to the decrease in the number of trains. The average time per trip during steam operation was approximately two hours, twenty-five minutes, while with the electric locomotive it was approximately one hour, forty-five minutes, showing a decrease of forty minutes or 27.5 per cent. These figures represent the time put in by the crews between Rocker and Anaconda, the distance being 21.8 miles.

The result of these improvements is indicated in Tables 1 and 2 which show that the overtime in this particular service has been decreased 73.5 per cent and the total time 42 per cent, resulting not only in greater economy to the railway company, but in shorter and easier hours for the crews.

The service on the Missoula Gulch line, running between Rocker and Butte Hill yards, was taken over for electrical operation on October 20th. This line is 4.5 miles in length and the ruling gradient is 2.5 per cent; see Fig. 5. The steam locomotives used on this line were of the Mastodon type, weighing 106 tons, 87 tons of which were on the drivers, the tender loaded weighing 56 tons, thus making the total weight of engine and tender 162 tons. Two complete crews had been required to handle this service during steam operation averaging six trips per day each. A single crew with a double-unit electric locomotive has been doing this work successfully. Thirty-five to forty-five loaded ore cars are taken down from Butte Hill yard to Rocker and about an equal number of empties taken up. In addition to the empties large quantities of timber and supplies for the mines are delivered over this line.

On November 25th the last of the electric locomotive units went into service, thus completing the electrification originally intended. The full electrical service has, therefore, now been in operation more than nine months and that on Smelter Hill more than 15 months, so that the total locomotive miles operated would be approximately close to an average year's performance.

This was the first installation of 2400-volt direct current apparatus for the operation of a railway in this country, 1500 volts being the highest heretofore installed for such purpose. The results have been more satisfactory than had been anticipated, and the development charges due to such imperfections as usually show up during the first year of operation have been perhaps smaller than is customary with an undertaking of like magnitude, even where standard apparatus is used.

Difficulties especially attributable to the higher potential have been negligible, and, while there have been occasional instances of arcing and flashing or short circuits due to ordinary causes the resulting damages have been really smaller than might be expected from a like occurence of a 600-volt installation of equal capacity.

The original brushes supplied in the motors chipped badly and before all these had been replaced it was often found, when the units were brought in for regular inspection, that some of the brushes were broken all to pieces, and while there was evidence that a flash-over might have occurred sometime no harm had resulted other than the blowing of the motor fuse. On the replacement of the fuse, the engine was continued in service until its regular time for inspection, when the cause of the fuse blowing would first be discovered.

The fact that the locomotives continued in service thus is sufficient evidence of the harmlessness of the arc-over and in no instance of the kind has any real damage been done. The locomotives have made from 25,000 to 50,000 miles each, and without exception the motors are in excellent condition. The wear on the commutators is imperceptible and the general performance of the entire equipment is quite as satisfactory and promising as that of any railway equipment with which we have had experience in similar service.

The overhead construction has been quite satisfactory and a recent examination of the trolley wire shows no indication of unusual wear. The roller pantographs are operating quite successfully, the average life being from 10,000 to 12,000 miles per roller. Where a double-unit locomotive is operated the two pantographs are connected electrically by a main bus line, and the average current collected by each when ascending the grades with a standard load is from 350 to 400 amperes. Two pantographs operating in multiple thus will collect more than double the current that can be successfully collected by a single pantograph for the reason that sparking is usually due to the momentary breaking of contact between the trolley wire and the roller, caused by hard spots on the line. When two pantographs are operated in multiple both do not encounter these hard spots at the same instant, hence one or the other always makes good contact so that the flow of current is not so frequently interrupted and consequently the sparking is greatly reduced. The double units operating on Smelter Hill were run experimentally for several days with only a single roller making contact with the wire, the operation being quite successful with the single roller collecting an average of 650 to 750 amperes while running at16 to 17 m.p.h., and 800 to 1000 amperes during the accelerating period in multiple. The sparking was not

Table 1

BUTTE, ANACONDA & PACIFIC RAILWAY

Number of Hours Engine Crews were Employed in Various Services—June, 1913, Steam Operation

| Date June | ANACONDA YARD Regular Time, Hr. | ANACONDA YARD Over Time, Hr. | BUTTE HILL YARD Regular Time, Hr. | BUTTE HILL YARD Over Time, Hr. | LOCAL Regular Time, Hr. | LOCAL Over Time, Hr. | ROAD Regular Time, Hr. | ROAD Over Time, Hr. |
|---|---|---|---|---|---|---|---|---|
| 1 | 80 | 14 | 20 | 4.50 | 20 | 3.25 | 30 | 13.75 |
| 2 | 90 | 6.50 | 20 | 6.50 | 20 | 5.75 | 40 | 17.25 |
| 3 | 50 | 5 | . . | . . . | 20 | 5.25 | 40 | 15.00 |
| 4 | 70 | 11.75 | 20 | 8.25 | 20 | 6.75 | 30 | 11.50 |
| 5 | 80 | 11.75 | 20 | 8.00 | 20 | 6.00 | 30 | 12.25 |
| 6 | 70 | 9.25 | 20 | 9.00 | 20 | 10.00 | 30 | 14.50 |
| 7 | 80 | 13.75 | 20 | 8.75 | 20 | 6.50 | 30 | 11.25 |
| 8 | 70 | 8.00 | 20 | 8.75 | 20 | 4.75 | 30 | 12.25 |
| 9 | 70 | 10.50 | 20 | 11.50 | 20 | 8.25 | 30 | 11.50 |
| 10 | 80 | 8.75 | 20 | 7.75 | 20 | 2.00 | 30 | 9.00 |
| 11 | 80 | 13 | 20 | 10.25 | 20 | 7.00 | 30 | 10.50 |
| 12 | 70 | 7.00 | 20 | 2.00 | 20 | 5.25 | 30 | 12.00 |
| 13 | 40 | 5.25 | | | 10 | 1.00 | 20 | 6.75 |
| 14 | 70 | 12.25 | 20 | 11.25 | 20 | 7.50 | 30 | 9.50 |
| 15 | 70 | 10.25 | 20 | 8.75 | 20 | 5.25 | 30 | 11.00 |
| 16 | 80 | 8.75 | 20 | 9.75 | 20 | 16.00 | 30 | 9.25 |
| 17 | 80 | 7.75 | 20 | 9.00 | 30 | 11.00 | 30 | 15.25 |
| 18 | 70 | 12.25 | 20 | 7.50 | 20 | 10.75 | 30 | 12.50 |
| 19 | 70 | 9.50 | 20 | 9.00 | 20 | 3.75 | 30 | 8.00 |
| 20 | 80 | 12.00 | 30 | 10.75 | 20 | 5.75 | 30 | 8.75 |
| 21 | 80 | 9.75 | 20 | 10.25 | 20 | 3.50 | 30 | 12.75 |
| 22 | 70 | 5.50 | 20 | 7.75 | 20 | 5.75 | 30 | 10.00 |
| 23 | 70 | 7.00 | 20 | 8.25 | 20 | 6.75 | 30 | 8.75 |
| 24 | 80 | 7.50 | 20 | 4.50 | 20 | 8.00 | 30 | 9.00 |
| 25 | 70 | 9.25 | 20 | 6.00 | 20 | 9.00 | 30 | 11.50 |
| 26 | 80 | 10.25 | 20 | 9.00 | 20 | 7.00 | 30 | 13.25 |
| 27 | 70 | 7.75 | 20 | 7.50 | 20 | 7.00 | 30 | 10.25 |
| 28 | 70 | 5.50 | 20 | 2.50 | 20 | 4.75 | 30 | 9.00 |
| 29 | 80 | 6.00 | 20 | 1.50 | 20 | 3.75 | 30 | 9.75 |
| 30 | 80 | 8.75 | 20 | | 20 | 7.00 | 30 | 9.50 |
| Total | 2200 | 274.50 | 570 | 208.50 | 600 | 194.25 | 910 | 335.50 |

Tons ore hauled during month—311,450.

serious except at hard points in the line and with two rollers in multiple there should be no difficulty in collecting 500 to 600 amperes per roller, which at 2400 volts should be equal to the requirements of any ordinary locomotive unit.

The bearings first used in the rollers were provided with ordinary bushings lubricated with oil, but when the bushings became slightly worn the oil was thrown out along the spindle and had to be replenished at comparatively frequent intervals. This was not serious in the operation of the freight locomotives but became more so when the passenger service was started, as the higher speed caused the oil to be thrown out more quickly, resulting in very short life of the bushings. Slight changes were made in the bearings and grease was substituted for the oil as a lubricant, which proved quite satis-

**Table 2**

**BUTTE, ANACONDA & PACIFIC RAILWAY**

**Number of Hours Engine Crews were Employed in Various Services—June, 1914, Electrical Operation**

| Date June | ANACONDA YARD | | BUTTE HILL YARD | | LOCAL | | ROAD | |
|---|---|---|---|---|---|---|---|---|
| | Regular Time, Hr. | Over Time, Hr. | Regular Time, Hr. | Over Time, Hr. | Regular Time, Hr. | Over Time, Hr. | Regular Time, Hr. | Over Time, Hr. |
| 1 | 70 | 7.25 | 20 | 1.25 | 20 | 2.50 | 30 | 2.25 |
| 2 | 70 | 8.25 | 20 | 4.00 | 20 | 2.50 | 30 | 5.00 |
| 3 | 70 | 9.50 | 10 | 1.00 | 20 | 4.00 | 30 | 1.25 |
| 4 | 60 | 7.25 | 10 | 2.00 | 20 | 2.75 | 30 | 4.25 |
| 5 | 60 | 12.50 | 10 | 2.00 | 20 | 2.75 | 20 | 2.50 |
| 6 | 60 | 7.25 | 10 | 2.00 | 20 | 2.50 | 20 | 2.25 |
| 7 | 70 | 8.25 | 10 | 2.00 | 20 | 2.00 | 20 | 6.25 |
| 8 | 60 | 8.75 | 10 | 1.75 | 20 | 2.75 | 20 | 3.00 |
| 9 | 60 | 10.50 | 10 | 1.50 | 20 | 4.75 | 20 | 4.75 |
| 10 | 60 | 11.25 | 10 | 1.75 | 10 | 1.00 | 20 | 1.75 |
| 11 | 60 | 5.00 | 10 | 1.50 | 20 | 3.75 | 20 | 1.25 |
| 12 | 60 | 9.00 | 10 | 1.00 | 20 | 2.00 | 20 | 1.25 |
| 13 | 30 | 1.75 | 10 | 1.00 | 10 | 1.00 | 10 | 4.00 |
| 14 | 60 | 5.50 | 10 | 1.25 | 20 | 2.25 | 20 | 1.25 |
| 15 | 60 | 6.50 | 10 | 1.00 | 20 | 2.75 | 20 | 1.50 |
| 16 | 60 | 4.00 | 10 | 1.50 | 20 | 2.50 | 20 | 2.00 |
| 17 | 60 | 7.75 | 10 | 1.00 | 20 | 3.00 | 20 | 2.75 |
| 18 | 60 | 8.75 | 10 | 1.75 | 20 | 2.25 | 20 | 1.50 |
| 19 | 60 | 7.25 | 10 | 3.00 | 20 | 2.25 | 20 | 2.25 |
| 20 | 60 | 10.75 | 10 | 1.75 | 20 | 2.25 | 20 | 5.75 |
| 21 | 60 | 8.75 | 10 | 1.75 | 20 | 2.25 | 20 | 1.25 |
| 22 | 50 | 5.50 | 10 | 1.00 | 20 | 2.75 | 20 | 2.25 |
| 23 | 60 | 6.75 | 10 | 1.00 | 10 | 1.50 | 20 | 3.50 |
| 24 | 60 | 11.25 | 10 | 1.50 | 20 | 3.00 | 20 | 3.50 |
| 25 | 60 | 7.75 | 10 | 1.50 | 20 | 2.25 | 20 | 5.25 |
| 26 | 60 | 5.75 | 10 | 1.25 | 20 | 2.50 | 20 | 1.75 |
| 27 | 60 | 8.50 | 10 | 1.25 | 20 | 2.00 | 20 | 3.75 |
| 28 | 60 | 4.25 | 10 | 3.00 | 10 | 1.75 | 20 | 2.00 |
| 29 | 60 | 6.00 | 10 | 1.00 | 10 | 1.75 | 20 | 5.50 |
| 30 | 60 | 10.50 | 10 | 1.25 | 20 | 2.25 | 20 | 3.50 |
| Total........ | 1800 | 232.00 | 320 | 48.50 | 550 | 73.50 | 630 | 89.00 |
| Decrease.... | 400 | 42.50 | 250 | 160.00 | 50 | 120.75 | 280 | 246.50 |

Tons ore hauled during month—319,700.

| | Regular | Over | Total |
|---|---|---|---|
| Total time 1913—steam.......................... | 4280.00 | 1012.75 | 5292.75 |
| Total time 1914—electric.............................. | 3300.00 | 443.00 | 3743.00 |
| Decrease............................................. | 980.00 | 569.75 | 1549.75 |
| Percentage of decrease................................ | 22.89 per cent | 56.26 per cent | 29.28 per cent |

factory. However, the vibration which results from too much play in the bearings of the roller when operating at high speeds made it desirable to increase the life of these bearings as much as possible, so that later roller bearings with grease lubrication were installed with excellent results. As yet these have not been in operation a sufficient length of time to definitely indicate how long they may be expected to last, but it would appear that the bearing will last much longer than the roller and that the attention required for the adjustment and lurbication of the bearing and the roller will be negligible.

On account of a decision of the mining company to divert to the Washoe smelter at Anaconda the shipment of approximately 3000 tons of ore per day that had previously been sent to the smelter at Great Falls, which will increase the ore traffic over the Butte, Anaconda & Pacific approximately 25 per cent, an extra motor-generator set, a duplicate of the original sets, has been installed in the Anaconda substation as a spare. Also four additional electric locomotive units were ordered and will be delivered within the next three months. These units will be duplicates of the original ones except that they are to be arranged for operating with an extra tractor truck attached when desired. This tractor truck will be a duplicate of the standard truck used under the regular units, with two standard motors mounted on it, and with the necessary arrangements for coupling both mechanically and electrically, so that the standard unit and the tractor truck may be

Table 3

### BUTTE, ANACONDA & PACIFIC RAILWAY

Comparison of Time Required per Trip of Freight Trains Between Rocker and Anaconda—First 3 Days of June, 1913, Steam Operation with Corresponding 3 Days Electrical Operation, 1914

| Train No. | | 1913 STEAM | | | | | | 1914 ELECTRIC | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Bound | | | West Bound | | | East Bound | | | West Bound | | |
| | | Tons | Time | | Tons | Time | | Tons | Time | | Tons | Time | |
| | | | Hr | Min. | | Hr. | Min. | | Hr. | Min. | | Hr. | Min. |
| 1st | 1 | 255 | 1 | 13 | 1705 | 2 | 00 | 380 | 1 | 2 | 2915 | 2 | 00 |
| | 2 | 1010 | 1 | 50 | 2848 | 2 | 5 | 314 | 1 | 15 | 3092 | 2 | 00 |
| | 3 | 1010 | 3 | 20 | 3760 | 2 | 10 | 1336 | 1 | 45 | 4088 | 1 | 20 |
| | 4 | 915 | 2 | 40 | 3420 | 2 | 30 | 1260 | 1 | 40 | 3830 | 1 | 10 |
| | 5 | 1047 | 2 | 30 | 2944 | 3 | 45 | 1240 | 1 | 40 | 4009 | 2 | 5 |
| | 6 | 1000 | 2 | 20 | 2935 | 2 | 5 | ... | .. | .. | ... | ... | ... |
| | 7 | 1010 | 4 | 00 | . | . | | .. | ... | .. | ... | ... | ... |
| 2nd | 1 | 415 | 1 | 7 | 3110 | 3 | 40 | 416 | 1 | 10 | 3100 | 2 | 00 |
| | 2 | 1010 | 2 | 10 | 3760 | 2 | 10 | 1154 | 1 | 40 | 3220 | 1 | 25 |
| | 3 | 1010 | 2 | 45 | 2884 | 2 | 00 | 1298 | 2 | 00 | 3752 | 2 | 20 |
| | 4 | 1010 | 3 | 00 | 3420 | 2 | 00 | 458 | 1 | 45 | 4029 | 2 | 10 |
| | 5 | 1104 | 2 | 20 | 3420 | 2 | 00 | 1232 | 2 | 00 | 3720 | 2 | 20 |
| | 6 | 1000 | 3 | 00 | 2910 | 2 | 50 | 1190 | 1 | 55 | 2840 | 2 | 35 |
| 3rd | 1 | 380 | 1 | 2 | 3380 | 2 | 50 | 470 | 1 | 3 | 2515 | 1 | 15 |
| | 2 | 1010 | 1 | 50 | 1630 | 2 | 45 | 1280 | 1 | 40 | 3964 | 1 | 10 |
| | 3 | 992 | 2 | 50 | 200 | 2 | 00 | 1298 | 2 | 5 | 4098 | 1 | 30 |
| | 4 | 884 | 2 | 20 | 0 | 1 | 20 | 482 | 1 | 40 | 3760 | 1 | 40 |
| | 5 | 1046 | 2 | 40 | 3150 | 2 | 30 | 1074 | 2 | 10 | 3138 | 2 | 30 |
| | 6 | 1084 | 3 | 15 | 2770 | 2 | 40 | 1200 | 2 | 15 | 0 | 1 | 10 |
| Totals | | 19–17192 | 46 | 12 | 18–48246 | 43 | 20 | 17-16082 | 28 | 45 | 17–56070 | 30 | 40 |
| Average per train | | 905 | 2 | 26 | 2680 | 2 | 24 | 946 | 1 | 41 | 3298 | 1 | 48 |

GRAND AVERAGE—1768 tons per train, time per trip, 2 hr. 25 min.—2122 tons per train, time per trip, 1 hr. 45 min.

RESULT—20 per cent increase in tonnage per train; 27.58 per cent increase in time per trip.

On June 5, 1914, one main line crew was taken off and the tonnage of the remaining trains increased so as to handle the regular business.

operated as a single unit. The motors of the tractor truck are connected with those on the standard unit in such a manner as to place all six motors in series on the series points of the controller, and with a series multiple connection with three motors in each series in the multiple position of the controller. This arrangement will make the tractive effort of the new unit 50 per cent greater than that of a standard unit for the same input with a reduction in the free running speed of about 33⅓ per cent.

This arrangement was advisable because of the increase in the weight of the trains taken up Smelter Hill, which amounted to approximately 56 per cent. A single unit when used in the "spotting "service is taxed close to the slipping point of its wheels when accelerating these heavier trains on the 0.5 per cent grades under ordinary conditions of weather, and have to be handled very carefully with the continuous use of sand when the condition of the rail is unfavorable. Connecting the additional motors in series will also result in considerable power economy, since with a single unit the controller is seldom off the series resistance points on account of the heavy trains handled and the short movements required.

Small change in the personnel of the maintenance or operating departments of the railway has been made on account of the

### Table 4

### BUTTE, ANACONDA & PACIFIC RAILWAY

**Comparison of Freight Train Movements Between Rocker and Anaconda—Steam Operation for Month of June, 1913, with Electrical Operation for Same Month, 1914**

| Date June | 1913 STEAM | | | | 1914 ELECTRIC | | | |
|---|---|---|---|---|---|---|---|---|
| | East Bound | | West Bound | | East Bound | | West Bound | |
| | No. Trains | Total Tons | No. Trains | Total Tons | No. Trains | Total Tons | No. Trains | Total Tons |
| 1 | 7 | 6,247 | 6 | 17,612 | 5 | 4,530 | 5 | 17,934 |
| 2 | 6 | 5,549 | 6 | 19,504 | 6 | 5,748 | 6 | 20,661 |
| 3 | 6 | 5,396 | 6 | 11,130 | 6 | 5,804 | 6 | 17,425 |
| 4 | 7 | 5,584 | 6 | 14,632 | 6 | 6,127 | 6 | 18,332 |
| 5 | 7 | 5,848 | 6 | 14,625 | 5 | 5,334 | 5 | 17,155 |
| 6 | 7 | 5,877 | 6 | 19,471 | 4 | 4,804 | 4 | 17,563 |
| 7 | 7 | 5,698 | 6 | 21,021 | 5 | 6,579 | 5 | 19,073 |
| 8 | 7 | 6,388 | 7 | 17,023 | 5 | 6,083 | 5 | 14,170 |
| 9 | 6 | 5,508 | 7 | 12,507 | 5 | 5,796 | 4 | 15,292 |
| 10 | 6 | 5,039 | 6 | 19,240 | 5 | 6,027 | 5 | 16,926 |
| 11 | 6 | 5,381 | 5 | 15,925 | 4 | 5,345 | 4 | 12,832 |
| 12 | 5 | 4,376 | 6 | 18,112 | 5 | 5,670 | 5 | 17,881 |
| 13 | 5 | 3,705 | 5 | 9,565 | 2 | 2,322 | 1 | 3,042 |
| 14 | 6 | 4,912 | 6 | 7,841 | 4 | 4,638 | 4 | 13,803 |
| 15 | 7 | 5,652 | 7 | 17,691 | 5 | 5,262 | 4 | 15,761 |
| 16 | 6 | 5,180 | 7 | 17,518 | 4 | 5,116 | 4 | 16,408 |
| 17 | 6 | 5,475 | 6 | 16,090 | 5 | 6,433 | 5 | 20,581 |
| 18 | 6 | 5,483 | 6 | 16,592 | 4 | 5,141 | 4 | 17,546 |
| 19 | 7 | 6,003 | 6 | 18,301 | 5 | 6,661 | 5 | 18,489 |
| 20 | 7 | 5,277 | 6 | 22,283 | 5 | 6,768 | 5 | 17,992 |
| 21 | 7 | 5,737 | 6 | 18,986 | 4 | 5,120 | 4 | 11,932 |
| 22 | 7 | 5,082 | 6 | 15,464 | 5 | 6,017 | 5 | 15,613 |
| 23 | 6 | 5,386 | 6 | 11,941 | 4 | 4,121 | 4 | 15,930 |
| 24 | 6 | 5,098 | 6 | 18,210 | 5 | 6,556 | 5 | 18,917 |
| 25 | 7 | 5,544 | 7 | 17,992 | 5 | 6,531 | 5 | 16,855 |
| 26 | 7 | 5,690 | 6 | 18,304 | 5 | 6,782 | 5 | 18,593 |
| 27 | 7 | 5,935 | 6 | 14,764 | 4 | 4,362 | 4 | 18,038 |
| 28 | 7 | 5,754 | 5 | 17,297 | 4 | 5,047 | 4 | 14,884 |
| 29 | 6 | 5,105 | 6 | 19,899 | 5 | 6,455 | 5 | 17,941 |
| 30 | 6 | 5,221 | 6 | 17,584 | 5 | 6,617 | 5 | 18,128 |
| Total | 193 | 163,130 | 182 | 497,124 | 141 | 167,796 | 138 | 495,697 |
| Average | 6.4 | 845 | 6.1 | 2,731 | 4.7 | 1,190 | 4.6 | 3,592 |

GRAND AVERAGE—12.5 trains per day, 1761 tons per train.—9.3 trains per day, 2378 tons per train.

RESULTS—25.6 per cent less trains. 35.0 per cent greater tonnage per train.

electrification and there has been no reduction in salaries or wages. An extra man with electrical experience was placed in the shops to supervise the electrical repairs to the locomotives and three linemen were retained for the maintenance of the trolley system.

The three steam switching locomotives used for concentrating the ore at and distributing supplies from Butte Hill yards are continued in this work for reasons heretofore stated. Another steam locomotive is used on the Georgetown branch and a fifth one operates at intervals over unelectrified tracks at the Anaconda end. Approximately 20 per cent of the total locomotive miles now being operated is by these five steam locomotives, the cost of which as shown in Table 6 is upwards of 40 per cent of the total cost of all locomotive performance.

The electrification of the remaining tracks on Butte Hill has been recommended and no doubt will be commenced at an early date. Table 6 referred to was made up from the regular monthly locomotive performance sheets of the railway company from which the principal saving resulting from the electrification may be noted. The saving from the partial substitution of electric power for coal is the chief item, being at the rate of $150,727.04 per year, which is remarkable when it is considered that more than 39 per cent of the total combined costs for fuel and power for the period considered was for coal and charged against electrical operation. In this instance, the saving in this item alone would undoubtedly justify the expenditure covering the entire cost of electrification. It is to be noted that with a single exception, that for depreciation of equipment, every item of expenditure in the locomotive performance sheet shows a substantial percentage of decrease in favor of electrical operation.

It is the practice of the railway company to adjust depreciation charges on all locomotives at the beginning of each half year. The amount to be charged to the depreciation of a new locomotive for the first half year it is in service is determined by taking a fixed percentage of its cost to the company, one-sixth of this amount being charged against the locomotive each month for the half year, at the end of which the amount of the depreciation for the period is deducted from the original cost of the locomotive to give a new value of which the original fixed rate of percentage is taken, in determining the amount of the depreciation for the following half year and so on.

The Interstate Commerce Commission ruling does not permit a depreciation charge until the locomotive actually becomes the property of the railway company, and as the electric locomotives were not formally taken over by the company until March, 1914, the proper monthly charge begins only with that month in the regular monthly performance sheet from which Table 6 was compiled. In fairness to the performance sheet, only the proper monthly depreciation charges were made, but as some of the locomotives had been in service eight months before these changes began an adjustment was necessary to make a proper distribution of the back depreciation, so that while Table 6 shows only the proper monthly charge for the six months compared amounting to $8471.84, in Table 7 under "Maintenance of Equipment" the total back charges were included amounting to $20,047.48. It is evident that the depreciation record on this basis for the first months of service would be comparatively high.

The total saving from locomotive performance alone, as indicated by Table 6, is at the rate of $237,581.82 per year to which should be added the credit of handling an increase of traffic at the rate of 13,938,136 ton miles per year, or 8.77 per cent more than was handled by the steam locomotives during the period compared. To this saving from locomotive performance should be added the saving from trainmen's wages which is at the rate of $31,146.30 per year, or a desrease of approximately 21 per cent, due largely to the elimination of overtime (see Tables 1 and 2) making the total saving from these two items $268,728.12 per year. From this should be deducted $10,839.12 for maintenance of the distribution system leaving $257,889 as the net operating saving per year due to electrical operation.

The roadmaster states that it is quite evident that the electric locomotives are much easier on the track at curves, but that there is no noticeable difference on tangent track; and that while sufficient time has not yet elapsed to form definite conclusions, present indications lead him to expect that any difference relative to his work will be favorable to the electric locomotives.

Arranging the items of expense appearing in Table 6 in the order of their usual appearance in the summary of a standard locomotive performance sheet and placing them on a yearly basis we have the following results:

# Table 5. BUTTE, ANACONDA & PACIFIC RAILWAY

## DELAYS TO TRAFFIC COMPARING THE MONTH OF JUNE, 1913, STEAM OPERATION WITH JUNE, 1914, ELECTRICAL OPERATION

| June | PASSENGER SERVICE | | | | | | | | | | | FREIGHT SERVICE | | | | | | | | | | | | | | | Grand Total Delays | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Trains | Delay for Meeting Points | | Delay for Power | | Delay Acc't Engine Failures | | Lost Running Time | | Total Delays | | No. of Trains | Terminal Delays and Switching | | Delay for Power | | Delay for Meeting Points | | Delay Due to Derailments and Break-in-Twos | | Delay Acc't Engine Failures | | Delay Water and Coal | | Total Delays | | | |
| | | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. | Hr. | Min. |
| 1st, 1913 | 14 | | 43 | | | | | | 18 | 1 | 1 | 14 | 12 | 15 | | | 4 | 55 | | 30 | | | | | 17 | 40 | 18 | 41 |
| 1914 | 8 | | | | | | | | | | | 12 | 10 | 5 | | | 1 | 20 | | 30 | | | | | 11 | 55 | 11 | 55 |
| 2nd, 1913 | 8 | | 42 | | | | | | 2 | | 44 | 8 | 12 | 5 | | | 2 | | | | | | | 35 | 14 | 40 | 15 | 24 |
| 1914 | 8 | | 5 | | 17 | | | | | | 22 | 12 | 11 | 10 | 3 | 20 | | 30 | | | | | | | 15 | | 15 | 22 |
| 3rd, 1913 | 8 | | 15 | | | | 14 | | 5 | | 34 | 12 | 9 | 30 | | | 4 | 30 | | | | | | 10 | 14 | 10 | 14 | 44 |
| 1914 | 8 | | | | | | | | | | | 12 | 10 | 30 | | | | 45 | | | | 30 | | | 11 | 45 | 11 | 45 |
| 4th, 1913 | 8 | | 10 | | | | | | | | 10 | 12 | 11 | 28 | | | 3 | 50 | | | | | | 19 | 15 | 37 | 15 | 47 |
| 1914 | 8 | | 5 | | | | | | | | 5 | 10 | 11 | | | | | 10 | | | | 45 | | | 11 | 55 | 12 | |
| 5th, 1913 | 8 | | 17 | | | | | | 5 | | 22 | 12 | 14 | | | | 4 | 45 | | | | | | 40 | 19 | 25 | 19 | 47 |
| 1914 | 8 | | 40 | | | | | | | | 40 | 10 | 11 | 35 | | | | 35 | | | | | | | 12 | 10 | 12 | 50 |
| 6th, 1913 | 8 | 1 | 10 | | | | | | 3 | 1 | 13 | 14 | 13 | 25 | | | 3 | 10 | 1 | 5 | | 24 | | 40 | 18 | 44 | 19 | 57 |
| 1914 | 8 | | | | | | | | | | | 8 | 7 | 37 | | | | 10 | | | | | | | 7 | 47 | 7 | 47 |
| 7th, 1913 | 13 | | 7 | | | | | | 51 | | 58 | 13 | 11 | 20 | | | 6 | 30 | | | | | | 40 | 18 | 30 | 19 | 28 |
| 1914 | 10 | | 5 | | | | | | 5 | | 10 | 10 | 7 | | | | | 20 | | | | 55 | | | 8 | 15 | 8 | 25 |
| 8th, 1913 | 13 | | 36 | | | | | | 37 | 1 | 13 | 13 | 12 | 38 | | | 5 | 20 | | | | | | 40 | 18 | 38 | 19 | 51 |
| 1914 | 8 | | | | | | | | | | | 12 | 10 | 45 | | | | 45 | | 30 | | | | | 12 | | 12 | |
| 9th, 1913 | 8 | | 24 | | | | | | 8 | | 32 | 12 | 12 | 15 | | | 2 | 5 | | | 1 | 15 | | 10 | 15 | 45 | 16 | 17 |
| 1914 | 24 | | 45 | | | | 15 | | 11 | 1 | 11 | 8 | 10 | 20 | | | | 30 | | 10 | | | | | 10 | 50 | 12 | 1 |
| 10th, 1913 | 8 | | 22 | | | | | | | | 22 | 12 | 10 | 30 | | | 3 | 35 | | | | | | 21 | 14 | 26 | 14 | 48 |
| 1914 | 8 | | | | | | | | | | | 10 | 13 | 55 | | | | 30 | 1 | 15 | | | | | 15 | 40 | 15 | 40 |
| 11th, 1913 | 8 | | 30 | | | | | | 6 | | 36 | 10 | 12 | 50 | | | 5 | 20 | 1 | 35 | | | | 5 | 19 | 50 | 20 | 26 |
| 1914 | 8 | | | | | | | | | | | 8 | 8 | | | | | 10 | | | | | | | 8 | 10 | 8 | 10 |
| 12th, 1913 | 8 | | 49 | | | | | | 12 | 1 | 1 | 12 | 10 | 50 | | | 8 | 51 | | | | | | 15 | 19 | 56 | 20 | 57 |
| 1914 | 8 | | 8 | | | | | | | | 8 | 10 | 10 | 40 | | | | 10 | | | | | | | 10 | 50 | 10 | 58 |
| 13th, 1913 | 12 | | 28 | | | | | | 34 | 1 | 2 | 10 | 11 | | | | 2 | 35 | | | 1 | 55 | | 14 | 15 | 44 | 16 | 46 |
| 1914 | 22 | | | | | | | | 9 | | 9 | 4 | 3 | 35 | | | | | | | | | | | 3 | 35 | 3 | 44 |
| 14th, 1913 | 8 | | | | | | | | | | | 12 | 12 | 40 | | | 2 | 48 | | | | | | 35 | 16 | 3 | 16 | 3 |
| 1914 | 10 | | | | | | | | | | | 8 | 7 | 40 | | | | 10 | | | | | | | 7 | 50 | 7 | 50 |
| 15th, 1913 | 14 | | 37 | | | | | | 4 | | 41 | 13 | 10 | 57 | | | 3 | 20 | | 40 | | 50 | | 4 | 15 | 51 | 16 | 32 |
| 1914 | 8 | | | | | | | | | | | 8 | 6 | 55 | | | | | | | | | | | 6 | 55 | 6 | 55 |
| 16th, 1913 | 8 | | 8 | | | | | | 11 | | 19 | 12 | 11 | 35 | | | 2 | 29 | 1 | | | | | 19 | 15 | 23 | 15 | 42 |
| 1914 | 8 | | | | | | | | | | | 8 | 7 | 50 | | | | 10 | | | | | | | 8 | | 8 | |
| 17th, 1913 | 8 | 1 | 40 | | | | | | | 1 | 40 | 12 | 12 | 51 | | | 4 | 10 | 2 | 30 | | | | 4 | 19 | 35 | 21 | 15 |
| 1914 | 8 | | 17 | | | | | | | | 17 | 10 | 9 | 50 | | | | 10 | | 20 | | | | | 10 | 20 | 10 | 37 |
| 18th, 1913 | 8 | | 37 | | | | | | | | 37 | 12 | 17 | | | | 1 | 50 | | | | | | 19 | 19 | 9 | 19 | |
| 1914 | 8 | | | | | | | | | | | 8 | 7 | 55 | | | | | | | | | | | 7 | 55 | 7 | |
| 19th, 1913 | 8 | | 10 | | | | | | | | 10 | 10 | 8 | 35 | | | 1 | 15 | | | | | | 4 | 9 | 54 | 10 | 4 |
| 1914 | 8 | | 15 | | | | | | | | 15 | 10 | 10 | 5 | | | | | | | | | | | 10 | 5 | 10 | 20 |
| 20th, 1913 | 8 | | 38 | | | | | | | | 38 | 12 | 10 | 25 | | | 2 | 40 | | | | | | 5 | 13 | 10 | 13 | 48 |
| 1914 | 10 | | 30 | | | | | | | | 30 | 10 | 10 | 30 | | | | 30 | | 45 | | | | | 11 | 15 | 12 | 15 |
| 21st, 1913 | 8 | | 5 | | | | | | | | 5 | 12 | 12 | | | | 2 | 30 | | | | | | | 14 | 30 | 14 | 35 |
| 1914 | 10 | | 22 | | | | | | | | 22 | 8 | 7 | 45 | | | | 25 | | | | | | | 8 | 10 | 8 | 32 |
| 22nd, 1913 | 12 | | 17 | | | | | | 5 | | 22 | 13 | 13 | | | | 3 | 35 | | | | | | 5 | 16 | 40 | 17 | 2 |
| 1914 | 8 | | | | | | | | | | | 10 | 10 | 40 | | | 15 | | | | | | | | 10 | 55 | 10 | 55 |
| 23rd, 1913 | 8 | | 5 | | | | | | 13 | | 18 | 12 | 10 | 25 | | | 4 | | | 40 | 1 | 41 | | 5 | 16 | 51 | 17 | 9 |
| 1914 | 8 | | | | | | | | | | | 8 | 8 | 25 | | | 20 | | | | | | | | 8 | 45 | 8 | 45 |
| 24th, 1913 | 8 | | 40 | | | | | | 16 | | 56 | 12 | 11 | 18 | | | 2 | | 2 | | | | | 35 | 15 | 53 | 16 | 49 |
| 1914 | 8 | | 10 | | 10 | | | | | | 20 | 10 | 9 | 8 | | | | 10 | | | | | | | 9 | 18 | 9 | 38 |
| 25th, 1913 | 8 | 1 | | | | | | | 2 | 1 | 2 | 12 | 12 | 35 | | | 4 | 20 | | | | 42 | | 14 | 17 | 51 | 18 | 53 |
| 1914 | 8 | | 5 | | | | | | | | 5 | 10 | 6 | 50 | | | | 22 | | 25 | | | | | 7 | 37 | 7 | 42 |
| 26th, 1913 | 8 | 1 | 6 | | | | 30 | | 3 | 1 | 39 | 12 | 13 | 25 | | | 5 | 5 | | | | | | 14 | 18 | 44 | 20 | 23 |
| 1914 | 8 | | 5 | | | | | | | | 5 | 10 | 12 | 22 | | | 1 | | | | | | | | 13 | 22 | 13 | 27 |
| 27th, 1913 | 8 | | 23 | | | | | | 11 | | 34 | 12 | 12 | 21 | | | 3 | 15 | | | | | | 14 | 15 | 50 | 16 | 24 |
| 1914 | 8 | | | | | | 9 | | | | 9 | 8 | 10 | | | | | 10 | | | | | | | 10 | 10 | 10 | 19 |
| 28th, 1913 | 8 | | 48 | | | | | | 7 | | 55 | 10 | 12 | 35 | | | 4 | 20 | | 40 | 1 | | | 10 | 18 | 45 | 19 | 40 |
| 1914 | 10 | | 15 | | | | | | | | 15 | 8 | 7 | 20 | | | | | | | | | | | 7 | 20 | 7 | 35 |
| 29th, 1913 | 10 | | 35 | | | | | | | | 35 | 13 | 13 | | | | 2 | 5 | | 15 | | 20 | | 15 | 15 | 55 | 16 | 30 |
| 1914 | 8 | | | | | | | | | | | 10 | 6 | 29 | | | 1 | 15 | | | | | | | 7 | 54 | 7 | 54 |
| 30th, 1913 | 8 | | 27 | | | | | | | | 27 | 12 | 11 | 50 | | | 1 | 40 | | | | 15 | | 30 | 14 | 15 | 14 | 42 |
| 1914 | 8 | | 7 | | | | | | | | 7 | 10 | 9 | 55 | | | | | | 20 | | | | | 10 | 15 | 10 | 22 |
| TOTAL 1913 | 272 | 15 | 49 | | | | 44 | 4 | 13 | 20 | 46 | 357 | 360 | 38 | | | 108 | 48 | 10 | 55 | 8 | 22 | 8 | 41 | 497 | 24 | 518 | 10 |
| 1914 | 280 | 3 | 54 | | 27 | | 24 | | 25 | 5 | 10 | 280 | 275 | 51 | 3 | 20 | 10 | 52 | 4 | 15 | 2 | 10 | | | 296 | 28 | 301 | 38 |
| Decrease 1914 | 8* | 11 | 55 | | 27* | | 20 | 3 | 48 | 15 | 36 | 77 | 84 | 47 | 3 | 20* | 97 | 58 | 6 | 40 | 6 | 12 | 8 | 41 | 200 | 56 | 216 | 32 |
| Percentage saving | 2.94* | 75.66 | | | | 45.45 | | 90.10 | | 75.12 | | 21.57 | 23.51 | | | | 90.04 | | 61.07 | | 74.10 | | | | 40.40 | | 41.78 | |

*Increase

**Table**

## BUTTE, ANACONDA

### EXPENDITURES IN DETAIL AND PERFORMANCE OF LOCOMOTIVES, COMPARING WITH SIX MONTHS ELECTRICAL OPERATION,

| | LOCOMOTIVE MILES | | | | | MAINTENANCE OF EQUIPMENT EXPENSES | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Freight | Passenger | Switching | Non-Revenue and Special | Total | Repairs | Depreciation | Supervision | Total |
| December, 1912, steam | 23647 | 7031 | 27307 | 2152 | 60137 | $ 9216.24 | $ 1381.68 | $ 587.79 | $11,185.71 |
| January, 1913, steam | 26018 | 6956 | 28601 | 4228 | 65803 | 8391.12 | 1340.23 | 477.68 | 10,209.03 |
| February, 1913, steam | 23514 | 6608 | 25041 | 4700 | 59863 | 9689.59 | 1340.23 | 512.77 | 11,542.59 |
| March, 1913, steam | 24948 | 7224 | 28136 | 6207 | 66515 | 8418.93 | 1340.23 | 559.97 | 10,319.13 |
| April, 1913, steam | 23649 | 6832 | 21747 | 7802 | 60030 | 8884.76 | 1340.23 | 616.86 | 10,841.85 |
| May, 1913, steam | 27167 | 7834 | 22667 | 10365 | 68033 | 6562.33 | 1340.23 | 393.08 | 8,295.64 |
| Total 6 months—Steam | 148943 | 42485 | 153499 | 35454 | 380381 | $51,162.97 | $ 8082.83 | $3148.15 | $62,393.95 |
| Cost per locomotive mile—cents | | | | | | 13.45 | 2.12 | 0.83 | 16.40 |
| Cost per ton mile—cents | | | | | | 0.0644 | 0.0102 | 0.0039 | 0.0785 |
| December, 1913, steam | 3000 | 56 | 9683 | 6946 | 19685 | $ 5567.97 | $ 769.61 | $ 431.41 | $ 6768.99 |
| electric | 35482 | 7280 | 16146 | 352 | 59260 | 1459.63 | | 226.73 | 1686.36 |
| Total | 38482 | 7336 | 25829 | 7298 | 78945 | $ 7027.60 | $ 769.61 | $ 658.14 | $8455.35 |
| January, 1914, steam | 3161 | | 9242 | 2449 | 14852 | $ 3577.93 | $ 591.95 | $ 271.27 | $ 4441.16 |
| electric | 36689 | 7264 | 15580 | 333 | 59866 | 1659.65 | | 175.18 | 1834.83 |
| Total | 39850 | 7264 | 24822 | 2782 | 74718 | $ 5237.58 | $ 591.96 | $ 446.45 | $ 6275.99 |
| February, 1914, steam | 3152 | | 9068 | 1576 | 13796 | $ 1638.43 | $ 591.96 | $ 185.13 | $ 2415.52 |
| electric | 33384 | 6608 | 15985 | 327 | 56304 | 2798.81 | 338.45 | 242.01 | 3379.27 |
| Total | 36536 | 6608 | 25053 | 1903 | 70100 | $ 4437.24 | $ 930.41 | $ 427.14 | $ 5794.79 |
| March, 1914, steam | 3012 | | 8584 | 2151 | 13747 | $ 2035.95 | $ 591.96 | $ 170.81 | $ 2798.72 |
| electric | 34664 | 7336 | 14279 | 363 | 56642 | 3064.40 | 2711.13 | 222.82 | 5998.35 |
| Total | 37676 | 7336 | 22863 | 2514 | 70389 | $ 5100.35 | $ 3303.09 | $ 393.63 | $ 8797.07 |
| April, 1914, steam | 2415 | 348 | 8001 | 2175 | 12939 | $ 1461.39 | $ 591.96 | $ 178.18 | $ 2231.53 |
| electric | 34098 | 7024 | 12883 | 768 | 54773 | 3076.05 | 2711.13 | 314.54 | 6101.72 |
| Total | 36513 | 7372 | 20884 | 2943 | 67712 | $ 4537.44 | $ 3303.09 | $ 492.72 | $ 8333.25 |
| May, 1914, steam | 1569 | 16 | 8485 | 920 | 10990 | $ 1017.37 | $ 591.96 | $ 135.67 | $ 1745.00 |
| electric | 36087 | 7658 | 13931 | 107 | 57783 | 3763.93 | 2711.13 | 262.53 | 6737.59 |
| Total | 37656 | 7674 | 22416 | 1027 | 68773 | $ 4781.30 | $ 3303.09 | $ 398.20 | $ 8482.59 |
| Total 6 months—steam | 16309 | 420 | 53063 | 16217 | 86009 | $15,299.04 | $ 3729.41 | $ 1372.47 | $20,400.92 |
| electric | 210404 | 43170 | 88804 | 2250 | 344628 | 15,822.47 | 8471.84 | 1443.81 | 25,738.12 |
| Total | 226713 | 43590 | 141867 | 18467 | 430637 | $31,121.51 | $12,201.25 | $ 2816.28 | $46,139.04 |
| Costs per locomotive mile, steam—cents | | | | | | 17.79 | 4.34 | 1.59 | 23.72 |
| Costs per locomotive mile, electric—cents | | | | | | 4.59 | 2.46 | .42 | 7.47 |
| Average costs per locomotive mile, combined steam and electric—cents | | | | | | 7.23 | 2.83 | 0.65 | 10.71 |
| Average costs per ton mile, combined steam and electric—cents | | | | | | 0.0360 | 0.0141 | 0.0033 | 0.0534 |
| Decrease shown in favor of electrical operation | 77770* | 1105* | 11632 | 16987 | 50256* | $20,041.46 | $ 4118.42* | $ 331.87 | $16,254.91 |
| Savings resulting per year on the above basis (decreased operating expenses) | | | | | | $40,082.92 | $ 8236.84* | $ 663.74 | $32,509.82 |
| Percentage of saving account of electrical operation (decreased operating expenses) | | | | | | 39.17 | 50.95* | 10.54 | 26.05 |

* Increase.

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## & PACIFIC RAILWAY

### SIX MONTHS STEAM OPERATION, DECEMBER, 1912, TO MAY, 1913, INCLUSIVE, DECEMBER, 1913, TO MAY, 1914, INCLUSIVE

| TRANSPORTATION EXPENSES | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wages of Enginemen | Eng'h'se Expenses | Fuel and Power | Water | Lubrication | Other Supplies | Total | Grand Total | Tons Coal | Kw-Hr. | Ton Miles |
| $ 8616.11 | $ 2533.91 | $26,259.02 | $ 342.51 | $ 683.21 | $ 482.88 | $38,917.64 | $50,103.35 | 6149 | | 13,182,404 |
| 9093.10 | 2814.96 | 29,085.78 | 353.15 | 761.38 | 499.84 | 42,608.21 | 52,817.24 | 6938 | | 13,167,782 |
| 8629.06 | 2530.88 | 26,150.98 | 436.89 | 864 73 | 595.36 | 39,207.90 | 50,750.49 | 6241 | | 12,014,154 |
| 8668.47 | 2637.11 | 26,893.72 | 543.34 | 851.20 | 466.73 | 40,060.57 | 50,379.70 | 6431 | | 13,406,290 |
| 8137.15 | 2184.17 | 23,690.52 | 395.55 | 790.95 | 426.20 | 35,624.54 | 46,466.39 | 5619 | | 13,371,720 |
| 9086.70 | 2252.87 | 25,537.85 | 405.39 | 924.25 | 440.75 | 38,647.81 | 46,943.45 | 6022 | 39,748 | 14,316,510 |
| $52,230.59 | $14,953.90 | $157,617.87 | $2476.83 | $4875.72 | $2911.76 | $235,066.67 | $297,460.62 | 37400 | 39,748 | 79,458,860 |
| 13.73 | 3.93 | 41.43 | 0.65 | 1.28 | 0.77 | 61.79 | 78.19 | 10.17 locomotive miles per ton of coal. | | |
| 0.0657 | 0.0188 | 0.1984 | 0.0031 | 0.0061 | 0.0037 | 0.2958 | 0.3743 | 2125 ton miles per ton of coal. | | |
| $ 2822.80<br>4163.25 | $ 780.46<br>1115.73 | $ 7529.39<br>8605.81 | $ 188.95 | $ 263.70<br>182.73 | $ 255.30<br>215.63 | $11,840.60<br>14,283.15 | $18,609.59<br>15,969.51 | 1770 | 1,558,800 | |
| $ 6986.05 | $ 1896.19 | $16,135.20 | $ 188.95 | $ 446.43 | $ 470.93 | $26,123.75 | $34,579.10 | 1770 | 1,558,800 | 14,024,005 |
| $ 2204.70<br>4040.35 | $ 674.83<br>859.76 | $ 6436.32<br>8952.53 | $ 96.00 | $ 221.14<br>184.33 | $ 189.24<br>194.51 | $ 9822.23<br>14,231.48 | $14,263.39<br>16,066.31 | 1415 | 1,670,248 | |
| $ 6245.05 | $ 1534.59 | $15,388.85 | $ 96.00 | $ 405.47 | $ 383.75 | $24,053.71 | $30,329.70 | 1415 | 1,670,248 | 15,210,014 |
| $ 2141.55<br>3760.65 | $ 479.88<br>926.75 | $ 5960.36<br>8210.53 | $ 130.41 | $ 196.98<br>166.40 | $ 122.69<br>135.88 | $ 9031.87<br>13,200.21 | $11,447.39<br>16,579.48 | 1394 | 1,487,200 | |
| $ 5902.20 | $ 1406.63 | $14,170.89 | $ 130.41 | $ 363.38 | $ 258.57 | $22,232.08 | $28,026.87 | 1394 | 1,487,200 | 13,715,904 |
| $ 2034.15<br>3753.50 | $ 369.39<br>1177.76 | $ 5571.85<br>8149.25 | $ 77.40 | $ 205.48<br>176.46 | $ 156.62<br>203.19 | $ 8414.89<br>13,460.16 | $11,213.61<br>19,458.51 | 1276 | 1,476,100 | |
| $ 5787.65 | $ 1547.15 | $13,721.10 | $ 77.40 | $ 381.94 | $ 359.81 | $21,875.05 | $30,672.12 | 1276 | 1,476,100 | 14,274,095 |
| $ 1975.72<br>3485.42 | $ 458.48<br>1183.45 | $ 2828.32<br>7918.48 | $ 89.65 | $ 198.61<br>246.87 | $ 138.05<br>221.80 | $ 5688.83<br>13,056.02 | $ 7920.36<br>19,157.74 | 608 | 1,434,300 | |
| $ 5461.14 | $ 1641.93 | $10,746.80 | $ 89.65 | $ 445.48 | $ 359.85 | $18,744.85 | $27,078.10 | 608 | 1,434,300 | 14,721,480 |
| $ 1696.10<br>3534.75 | $ 424.90<br>867.80 | $ 4162.17<br>7929.34 | $ 14.44 | $ 149.14<br>279.32 | $ 209.38<br>233.89 | $ 6656.13<br>12,845.10 | $ 8401.13<br>19,582.69 | 1898 | 1,436,270 | |
| $ 5230.85 | $ 1292.70 | $12,091.51 | $ 14 44 | $ 428.46 | $ 443.27 | $19,501.23 | $27,983.82 | 1898 | 1,436,270 | 14,482,430 |
| $12,875.02<br>22,737.92 | $ 3187.94<br>6131.25 | $32,488.41<br>49,765.94 | $ 596.85 | $ 1235.05<br>1236.11 | $ 1071.28<br>1204.90 | $51,454.55<br>81,076.12 | $71,855.47<br>106,814.24 | 8361 | 9,062,918 | |
| $35,612.94 | $ 9319.19 | $82,254.35 | $ 596.85 | $ 2471.16 | $ 2276.18 | $132,530.67 | $178,669.71 | 8361 | 9,062,918 | 86,427,928 |
| 14.97 | 3.71 | 37.78 | 0.69 | 1.44 | 1.24 | 59.83 | 83.55 | 10.29 locomotive miles per ton of coal. | | |
| 6.60 | 1.78 | 14.44 | 0.00 | 0.36 | 0.35 | 23.53 | 31.00 | 26.30 kw-hr. per locomotive mile. | | |
| 8.27 | 2.16 | 19.10 | 0.14 | 0.57 | 0.53 | 30.77 | 41.48 | | | |
| 0.0412 | 0.0108 | 0.0952 | 0.0007 | 0.0028 | 0.0026 | 0.1633 | 0.2067 | | | |
| $16,617.65 | $ 5634.71 | $75,363.52 | $ 1879.98 | $ 2404.56 | $ 635.58 | $102,536.00 | $118,790.91 | 29039 | 9,023,170* | 6,969,068* |
| $33,235.30 | $11,269.42 | $150,727.04 | $3759.96 | $ 4809.12 | $ 1271.16 | $205,072.00 | $237,581.82 | | | |
| 31.81 | 37.68 | 47.81 | 75.90 | 49.31 | 21.83 | 43.62 | 39.93 | | | |

## Table 7

## BUTTE, ANACONDA & PACIFIC RAILWAY

### Operating Expenses—Comparison of Six Month's Steam Operation—December 1912 to May 1913, inclusive with Six Month's Electrical Operation, December 1913 to May 1914

| | | December | January | February | March | April | May | Total 6-Months | AVERAGE FOR 6-MONTHS' PERIODS 1913 | 1912 | 1911 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maintenance of way and structure, | 1913 | $11,233.82 | $ 13,252.96 | $10,885.20 | $ 8072.73 | $ 9292.78 | $10,579.15 | $ 63,316.64 | $ 66,945.57 | $ 81,284.00 | $ 62,028.28 |
| | 1914 | 14,377.82 | 10,107.61 | 9607.83 | 11,509.36 | 12,505.17 | 17,749.74 | 75,857.03 | | | |
| | Decrease | $ 3143.50* | $ 3145.35 | $ 1277.37 | $ 3436.63* | $ 3212.39* | $ 7170.59* | $ 12,540.39* | | | |
| Maintenance of equipment, | 1913 | $21,824.74 | $ 24,012.20 | $26,219.97 | $18,876.43 | $23,499.93 | $19,042.16 | $133,475.43 | $132,596.33 | $109,495.65 | $103,796.27 |
| | 1914 | 23,765.83 | 18,472.16 | 17,281.41 | 23,872.53 | 26,001.79 | 24,559.16 | 133,952.88 | | | |
| | Decrease | $ 1941.09* | $ 5540.04 | $ 8938.56 | $ 4996.10* | $ 2501.86 | $ 5517.00* | $ 477.45* | | | |
| Traffic expenses, | 1913 | $ 760.84 | $ 877.49 | $ 640.02 | $ 613.85 | $ 611.27 | $ 661.06 | $ 4164.53 | $ 4224.42 | $ 4371.95 | $ 3727.60 |
| | 1914 | 703.55 | 613.98 | 548.86 | 520.85 | 631.27 | 585.71 | 3604.22 | | | |
| | Decrease | $ 57.29 | $ 263.51 | $ 91.16 | $ 93.00 | $ 20.00* | $ 75.35 | $ 560.31 | | | |
| Transportation expenses, | 1913 | $56,171.03 | $ 63,864.94 | $57,377.42 | $56,928.05 | $48,262.29 | $50,912.60 | $333,516.33 | $315,555.24 | $259,948.95 | $241,571.49 |
| | 1914 | 47,772.32 | 44,243.99 | 41,529.43 | 40,988.16 | 38,068.18 | 37,925.38 | 250,527.46 | | | |
| | Decrease | $ 8398.71 | $19,620.95 | $15,847.99 | $15,939.89 | $10,194.11 | $12,987.22 | $ 82,988.87 | | | |
| General expenses, | 1913 | $ 3218.70 | $ 2462.68 | $ 2621.97 | $ 2596.63 | $ 3434.69 | $ 2727.64 | $ 17,062.31 | $ 18,625.85 | $ 17,646.52 | $ 13,874.55 |
| | 1914 | 2963.73 | 3185.52 | 4948.42 | 5221.85 | 4655.18 | 4132.90 | 25,107.60 | | | |
| | Decrease | $ 254.97 | $ 722.84* | $ 2326.45* | $ 2625.22* | $ 1220.49* | $ 1405.26* | $ 8045.29* | | | |
| TOTAL OPERATING EXPENSES, | 1913 | $93,209.13 | $104,470.27 | $97,744.58 | $87,087.69 | $85,100.96 | $83,922.61 | $551,535.24 | $537,587.41 | $472,747.07 | $424,998.19 |
| | 1914 | 89,582.75 | 76,623.26 | 73,915.95 | 82,112.75 | 81,861.59 | 84,952.89 | 489,049.19 | | | |
| | Decrease | $ 3626.38 | $ 27,847.01 | $23,828.63 | $ 4974.94 | $ 3239.37 | $ 1030.28* | $ 62,486.05 | | | |
| Net operating revenue, | 1913 | $18,075.01 | $ 4518.47 | $ 7121.88 | $24,016.51 | $26,566.34 | $41,280.07 | $121,578.28 | $127,882.70 | $103,692.27 | $111,106.97 |
| | 1914 | 43,271.31 | 54,232.62 | 48,926.12 | 45,746.22 | 33,871.18 | 39,606.23 | 265,653.68 | | | |
| | Increase | $25,196.30 | $ 49,714.15 | $41,804.24 | $21,729.71 | $ 7304.84 | $ $1673.84† | $144,075.40 | | | |
| Taxes, | 1913 | $ 2638.58 | $ 2000.00 | $ 2000.00 | $ 2000.00 | $ 2000.00 | $ 2000.00 | $ 12,638.58 | $ 12,319.29 | $ 12,881.99 | $ 12,306.88 |
| | 1914 | 3205.50 | 2500.00 | 2500.00 | 2500.00 | 2500.00 | 2500.00 | 15,705.50 | | | |
| | Increase | $ 566.92 | $ 500.00 | $ 500.00 | $ 500.00 | $ 500.00 | $ 500.00 | $ 3066.92 | | | |
| Operating income, | 1913 | $15,436.43 | $ 2518.47 | $ 5121.88 | $22,016.51 | $24,566.34 | $39,280.07 | $108,939.70 | $115,563.42 | $ 90,810.28 | $ 98,210.09 |
| | 1914 | 40,065.81 | 51,732.62 | 46,426.12 | 43,246.22 | 31,371.18 | 37,106.23 | 249,948.18 | | | |
| | Increase | $24,629.38 | $ 49,214.15 | $41,304.24 | $21,229.71 | $ 6804.84 | $ 2173.84† | $141,008.48 | | | |

† Decrease. * Increase.

The total cost of the electrification including a change of signal system on Smelter Hill, the extra motor-generator set recently installed at Anaconda, interest during construction and all incidentals due in any way to the electrification, was in round numbers $1,201,000.00. This does not include the step-down transformers, which are the property of the power company; but on the other hand no deduction has been made for the salvage due to the elimination of 20 steam locomotives.

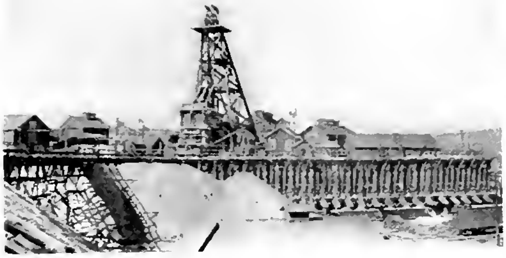
| Item of Operating Expense | Steam 1913 | Electric 1914 | Decrease 1914 | Per Cent Decrease |
|---|---|---|---|---|
| Fuel and power | $315,235.74 | $164,508.70 | $150,727.04 | 47.81 |
| Repairs | 124,787.90 | 92,278.08 | 32,509.82 | 26.05 |
| Enginemen's wages | 104,461.18 | 71,225.28 | 33,235.30 | 31.81 |
| Engine-house expenses | 29,907.80 | 18,638.38 | 11,269.42 | 37.68 |
| Water | 4,953.66 | 1,193.70 | 3,759.96 | 75.90 |
| Lubricants | 9,751.44 | 4,942.32 | 4,809.12 | 49.30 |
| Other supplies | 5,823.52 | 4,552.36 | 1,271.16 | 21.83 |
| Total locomotive performance | $594,921.24 | $357,339.42 | $237,581.82 | 39.93 |
| Trainmen's wages | $147,632.30 | $116,486.00 | $31,146.30 | 21.10 |
| Grand total | $742,553.54 | $473,825.42 | $268,728.12 | 36.19 |
| Ton-miles hauled | 158,917,720 | 172,855,856 | 13,938,136 | 8.77* |

*Increase.

If a correction be made for the item of depreciation in Table 6, charging the regular monthly amount of $2711.13 begun in March for each of the six months making the total of this item for the period $16,266.78, instead of $8,471.84 as it stands on the performance sheets, the total saving per year from locomotive performance would be reduced to $221,991.94, making the total net saving $242,299.12, which is equivalent to 20.02 per cent on the entire cost of the electrification, to say nothing of the increased capacity of the lines, the improvement in the service and more regular working hours for the crews as is indicated in Table 5 comparing the delays to traffic, and Tables 1 and 2 showing the decrease in overtime.

From Table 7 it will be seen that if taken on the basis of the increase shown in net operating revenue or operating income, this percentage is slightly greater, the rate of increase per year for these items being $288,150.80 and $282,016.96 respectively.

The estimate on which the decision to proceed with the electrification of the road was made placed the annual net saving expected at 17.5 per cent of the cost, so that the results financially have been quite as satisfactory as the general performance of the equipment.



Hoist and Storage Bins on Butte Hill

# THE CANADIAN NORTHERN TUNNEL AND TERMINAL ELECTRIFICATION

By W. C. Lancaster

Electrical and Mechanical Engineer, Montreal

A brief description is first given of the nature of the work being undertaken on this important electrification. The author then discusses why 2400-volt direct current was selected in preference to other available modes of operation. It will be noted that the successful operation of the Butte, Anaconda & Pacific Railroad had an important influence on the decision. Both the 2400-volt locomotive and multiple-unit power equipments are described in some detail. The power supply and substation equipment are also discussed.—Editor.

W. C. Lancaster

The Canadian Northern will become a transcontinental railway in June, 1915, when it is expected that the last link, the line between Edmonton and Vancouver, will be ready for operation. This newest transcontinental line will connect the Pacific Coast with Montreal and Quebec, and will operate, when completed, over 10,000 miles of track.

Its principal eastern terminus will be Montreal. To gain access to the heart of the city it was necessary to tunnel Mount Royal which forms a natural barrier between the commercial and financial sections and the country to the west. Any other route would have entailed the enormous expense of a right-of-way through thickly populated and valuable property, with numerous street crossings and other disadvantages. To the west of the mountain all the way to the Riviere des Prairies there are only farms and a few scattered villages, quite inaccessible to the city on account of the detour necessary around Mount Royal. A large section of this farm land was purchased, subdivided and incorporated as the Town of Mount Royal; more commonly known as "The Model City." Between this suburban district and Montreal a quick and frequent service will be maintained by means of multiple-unit trains.

The railroad crosses to the Island of Montreal near its western end, and follows the south bank of the Riviere des Prairies to the Cartierville yard. This yard will be used for the storage and sorting of freight; and for changing the steam and electric engines. Here also will be located the repair shops for the electric locomotives and multiple-unit cars.

From the Cartierville yard the railway runs easterly through the new town of Mount Royal, where the tracks are depressed sufficiently to allow the streets to be carried over them. The multiple-unit trains will stop about once every mile throughout this suburban district. The locomotive trains, however, will stop only at Mount Royal.

The west portal of the tunnel is located at the foot of the westerly slope of the mountain. The tunnel is 3¼ miles long and descends on a six-tenths of one per cent grade from the west portal to the terminal station. It is all tangent, except one 2-deg. curve, and is of double track construction. Each track is in a separate tube, the advantages of this being economy of construction, provision for ventilation, and safety of operation.

The east portal is at the terminal station in the city, the tracks at this point being about 45 ft. below the street surface. From this station the railway will run over a viaduct down to the St. Lawrence River to connect with the belt line operated by the Harbor Commission, thus gaining connection with the docks. As a part of the proposed viaduct across the lower level of the city there will be an elevated freight station in the center of the commercial district for the receipt and delivery of local freight.

Electrification of the tunnel was necessary both for comfort to the passengers and for reasons of safety. But, aside from these reasons, the large number of light suburban trains that are to be run at frequent intervals make electric operation more economical than steam; especially when the cheap electric power obtainable at Montreal is considered in favor of electric traction, and the expense of operating steam locomotives during the Canadian winters is fully taken into account.

The initial electrification will be carried from the terminal in the city as far as the Cartierville yard, a total of about ten route miles and thirty track miles. Later, it is expected that this will be extended a considerable distance as the country to the west of Mount Royal becomes more thickly settled.

The details of the Mount Royal tunnel and terminal are as follows:

**Tunnel**

| | |
|---|---|
| Length, feet | 17,000 |
| Rock excavation, cubic yards | 405,000 |
| Earth excavation, cubic yards | 20,000 |
| Concrete, cubic yards | 50,000 |
| Steel and iron, pounds | 4,400,000 |
| Splicing chambers, spacing in feet | 400 |
| Grade, per cent | 0.6 |

**Terminal Station**

| | |
|---|---|
| Length, feet | 1,200 |
| Width, feet | 350 |
| Maximum depth, feet | 50 |
| Rock excavation, cubic yards | 95,000 |
| Earth excavation, cubic yards | 540,000 |
| Concrete, cubic yards | 100,000 |
| Structural steel, pounds | 8,000,000 |
| Reinforcing steel, pounds | 3,500,000 |

The 2400-volt direct current system was selected after an exhaustive study had been made of all the available systems of electrification. The choice quickly narrowed down to three, namely; single-phase, 11,000-volt trolley; low voltage direct current, 600-volt trolley; and high voltage direct current, 1200 to 2400-volt trolley. A careful comparision was made between these systems as applied to the electrification under consideration both as regards first cost and operating cost.

For single-phase it would have been necessary to install frequency changers in the substation, all the available power around Montreal being at 60 cycles. Thus the chief point in favor of single-phase, the economy of transformation by means of stationary transformers instead of rotating machinery, would not have applied in this case. Another thing against this system was the necessity for a large number of multiple-unit cars. It was found that the cost of these would be extremely high compared with d-c. equipments, owing chiefly to the motors being heavier and more complicated for the same output.

As regards the use of low voltage direct current, 600-volt trolley, the main considerations were future long distance extensions and the necessity for a third-rail. If the electrification is extended for any considerable distance, as seems likely, the 600-volt system would be obviously far more expensive than one in which a higher trolley voltage is used. A third-rail was considered out of the question on account of the snow conditions prevalent in Montreal a large part of the year.

For these reasons it was thought best to use a voltage of 1200, 1500, or 2400 direct current. When future extensions were considered, 2400 volts seemed best on account of the economy in copper and substations and it therefore came down to the question of whether this high voltage which had recently been put on a commercial basis in this country would result in engineering or operating difficulties that would more than offset the economy to be gained by its use.

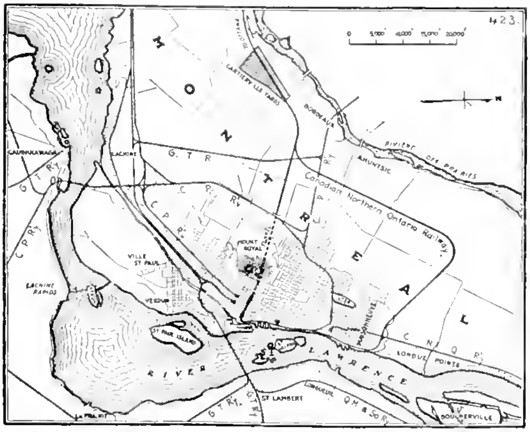


Fig. 1. Map of the Terminal Lines at Montreal showing Line through the Mt. Royal Tunnel

A little consideration shows, however, that 2400-volt direct current cannot be called experimental. When 1200-volts first came into general use, two 600-volt generators insulated for 1200 volts were operated in series to obtain the desired potential. Similarly the motors were insulated for 1200 volts but each wound for 600, and two connected permanently in series. There was little difference in the design of these machines from the old standard 600-volt generators and motors except for the extra insulation and the use of commutating poles. The matter of insulation was easily accomplished, much higher voltages having been used for a long time on alternating current machinery. Commutating poles, which are of comparatively recent developement, have done more than anything else to make high voltage direct current successful, as they overcome commutating difficulties which would be serious without them at the higher voltages.

For the first 1200-volt system, then, the generators and motors were wound for 600 volts and insulated for 1200 volts. The next step was to wind these machines for 1200 volts so that one could be used in place of two in series. This has been done successfully.

When this matter was being studied a year ago seven railroads in the United States were using motors and generators wound as well as insulated for 1200 and 1500 volts. Abroad there were at least six railroads using machines wound for 1000 volts or higher. On all these railroads this high-voltage direct current machinery had been throughly tried out and was entirely successful.

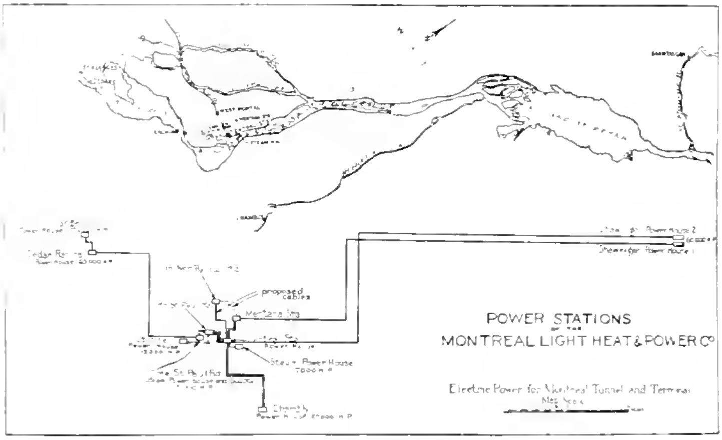


Fig. 2. Map showing the Source of Electric Power for the Montreal Tunnel and Terminal

Thus it was a comparatively simple matter to go one step further and connect two of these motors or generators wound for 1200 volts in series and insulate them for 2400 volts; this being comparable with the first simple step of connecting two 600-volt machines in series for 1200 volts.

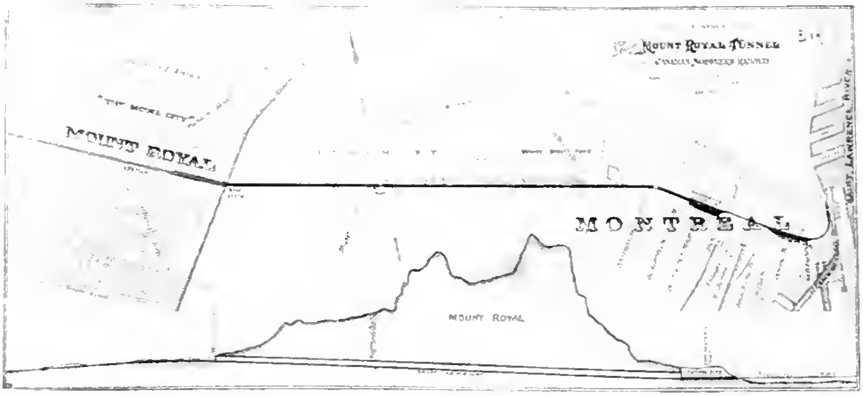


Fig. 3. Map and Profile of the Canadian Northern Montreal Tunnel and Terminal

That this can be done satisfactorily has been proven by the successful operation of the Butte, Anaconda & Pacific Railway electrification in Montana for more than a year.

The first order for equipment which will serve to start the operation of the tunnel and terminal included six locomotives, eight multiple-unit car equipments and two 1500-kw. motor-generator sets with switchboard, exciters, and other auxiliary apparatus.

The locomotives weigh 83 tons each and are geared for a free running speed of 45 miles per hour. It was not thought necessary to resort to any of the special methods of connecting the motors to the driving axles, such as are used on the rod and gearless type, as the schedule for the locomotive trains does not call for high speed. The motors will therefore be nose-supported in the usual way and geared to the axle by means of twin gears.

The locomotive has four axles with all the weight upon the eight driving wheels. The running gear consists of two four-wheel trucks articulated together by a heavy hinge. The equalization of the trucks is accomplished by a semi-elliptic leaf spring over each journal box, connected through spring hangers to the frame and to the equalizer bars. The equivalent of a three-point suspension is thus obtained. The friction draft gear is mounted in the end frame casting of the truck.

The cab, of the box type, is divided into three compartments; the center compartment for the control apparatus, and the two end compartments for the operator. Each operator's compartment is supplied with controller, control switches, ammeter, speedometer, air brake and pantograph control, air gauges, 2400-volt cab heater, bell rope, and control for the whistle and sanders; thus providing the locomotive with complete double end control.

The motor equipment consists of four commutating pole motors wound for 1200 volts and insulated for 2400 volts, two of these motors being permanently connected in series for operating on the 2400-volt trolley circuit.

The one-hour rating of each motor is 315 h.p. at 1200 volts. The motors are designed for forced ventilation which is obtained by means of a blower in the locomotive cab. Either pair of motors may be cut out in case of emergency by a special handle on the change-over switch. The locomotives are operated as two-speed machines with 10 points in series and 7 points in series-parallel. The controller is of the non-automatic type and has two handles, one to regulate the applied voltage at the motors and the other to control the direction of rotation of the motors.

The rheostats forming the external motor resistance are placed near the roof of the cab where they have ample natural ventilation.

**Fig. 4. Tunnel under Construction showing "Bottom Heading" Method**

Current at 125 volts is used for operating the contactors and for lighting the cab and headlights. This is supplied by a motor-generator set, the motor of which has two 1200-volt windings and two 1200-volt commutators in series for operation on 2400 volts. This set is mounted in the center cab and also drives the blower for providing forced ventilation to the main motors.

Two trolleys are placed on each locomotive. These are of the roller pantograph type pneumatically operated and mounted on insulated bases.

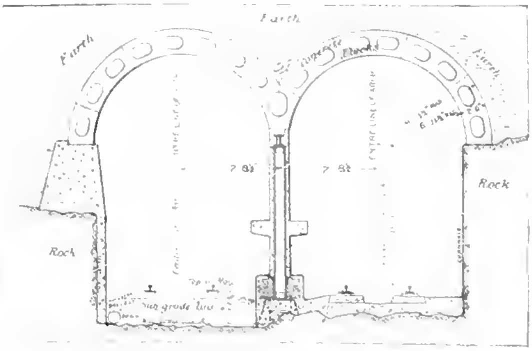


**Fig. 5. Typical Tunnel Section in Earth**

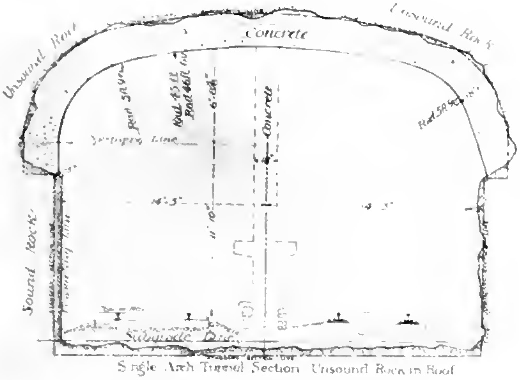


**Fig. 6. Typical Tunnel Section in Rock**

Combined straight and automatic air brake equipment is used, including a 2400-volt motor-driven air compressor, the motor having two 1200-volt windings and commutators operating in series on 2400 volts and direct

**Data on Locomotive**

| | |
|---|---|
| Length inside knuckles | 37 ft. 4 in. |
| Length over cab | 31 ft. 0 in. |
| Over-all height with pantograph down | 15 ft. 6 in. |
| Height over cab | 12 ft. 10 in. |
| Over-all width | 10 ft. 0 in. |
| Rigid wheel base | 8 ft. 8 in. |
| Total wheel base | 26 ft. 0 in. |
| Total weight on drivers | 83 tons |
| Wheel diameter | 46 in. |
| Tractive effort at 30 per cent tractive co-efficient | 49,800 lb. |
| Tractive effort at one-hour rating | 20,300 lb. |
| Tractive effort at continuous rating | 14,500 lb. |

connected to an air compressor having a piston displacement of 100 cubic feet of free air per minute. Some of the principal dimensions and characteristics of these locomotives are as given in preceding tabulation.

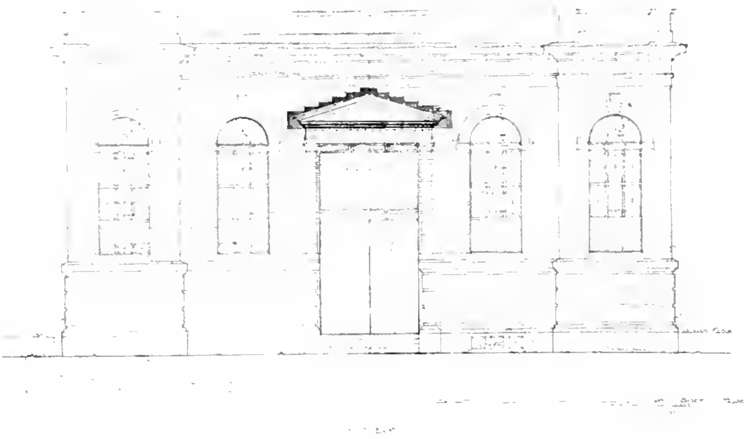


Fig. 7. Elevation of the Exterior of the Terminal Substation

**Multiple-Unit Cars**

The multiple-unit cars will be run under five-minute headway through the tunnel during the rush hours and will serve the suburban territory west of the mountain. It is expected that at first only one-car trains will be operated, but that very shortly after the terminal is put into operation longer trains will be necessary. The equipments for these cars are designed for a maximum of five cars per train. The running time between the town of Mount Royal and the main passenger station in Montreal will be 7½ minutes for a five-car train. Beyond the town of Mount Royal there will be a stop about once every mile to the end of the electrification. These cars are designed for a schedule speed of 20.6 miles per hour with a layover at each end of five minutes. They will make the round trip in one hour.

The motor equipment consists of four fully ventilated 140-h.p. 1200-volt commutating pole motors, insulated for 2400 volts. Two of these motors are permanently connected in series for 2400-volt operation. Ventilation of the motor is accomplished by drawing air into the armature at the pinion end by means of a fan on the armature shaft. The air passes longitudinally through the whole interior of the motor and is expelled through an opening in the motor frame at the commutator end.

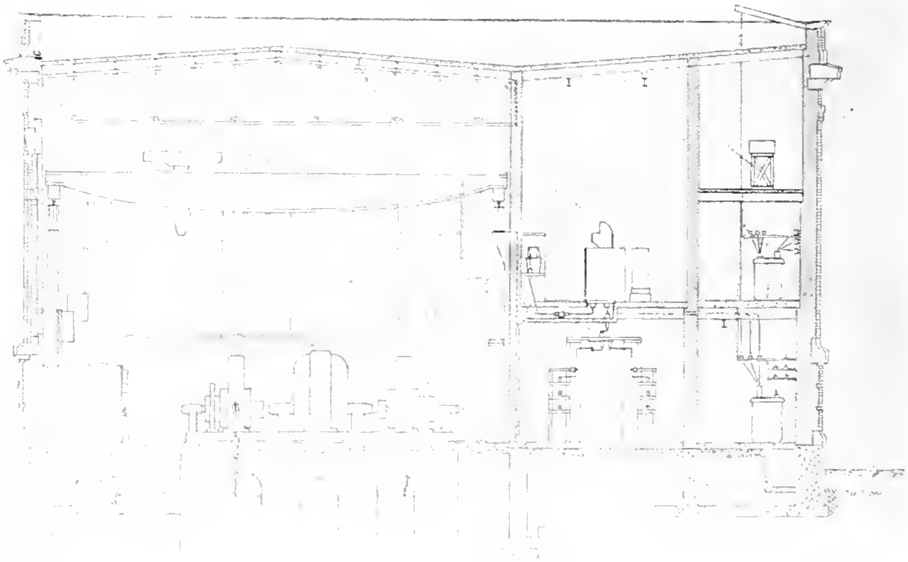


Fig. 8. Sectional Elevation through *A-A* of Fig. 9

The control is of the non-automatic type for multiple-unit operation. The equipment includes a motor-generator set for furnishing 600-volt current for the contactor circuits, air compressor and lighting circuits. This set consists of two 1200-volt motors operating in series on 2400-volts direct connected to the 600-volt generator. The master controller, contactors, switches, reverser and pantograph are all of essentially the same construction as those already described for the locomotives. The controller will have five steps in series and four steps in parallel. It differs from the locomotive controller in having the ordinary motorman's operating handle instead of a lever. This handle is provided with means for cutting off the power and applying the brakes in case the motorman removes his hand.

The electric hot-air system of car heating is used. One complete heater is placed underneath each car and receives its energy direct from the 2400-volt supply. This heater has a capacity of approximately 42 kw. and is constructed for two heat combinations so as to conveniently and economically provide for the changes in temperature. The heating equipment consists of the heating unit, the blower and the regulating mechanism; the controlling switch and thermostat of the regulating mechanism being arranged for operation from the 600-volt supply. Air is

Fig. 9. Plan of the Terminal Substation

forced through the heating unit by means of the blower and distributed to the car through air ducts along the sides. The blower is operated by a motor connected in series with the heating unit on the ground side. The capacity of the blower is 1100 cubic feet of free air per minute.

The cars are of steel construction and weigh loaded and equipped approximately 120,000 lb. Cross-seats are used near the center of the car and longitudinal seats near the ends, thus giving plenty of room near the doors where most crowding occurs when passengers are leaving or entering. The underframing of the car is entirely of steel and the car body of steel except for window frames, wainscoting and headlining, which are of wood. The heat insulation for the sides, roof and ends of the car consists of three-ply "Salamander" and is secured to the steel by means of glue and "Clinchite" nails spot welded to the sheet steel.

The outside and inside finish and all the fittings and other details conform as nearly as possible with the Canadian Northern standard practice. The principal car dimensions are as follows:

| | | |
|---|---|---|
| Length over buffers | 67 ft. | 5¾ in. |
| Length over body corner posts | 57 ft. | 6¼ in. |
| Truck centers | 42 ft. | 9 in. |
| Width over side sill angles | 9 ft. | 10½ in. |
| Width over eaves | 10 ft. | 2¾ in. |
| Height top of rail over roof | 13 ft. | 0 in. |
| Height top of rail to underside of side sill | 3 ft. | 7½ in. |
| Center to center of body side bearings | 4 ft. | 10 in. |
| Center to center of deck sills | 5 ft. | 6 in. |

### Substation

There will be only one substation required until electric traction is extended for a considerable distance. This substation is located at the west portal of the tunnel near the top of the 0.6 per cent grade. Three-phase 60-cycle

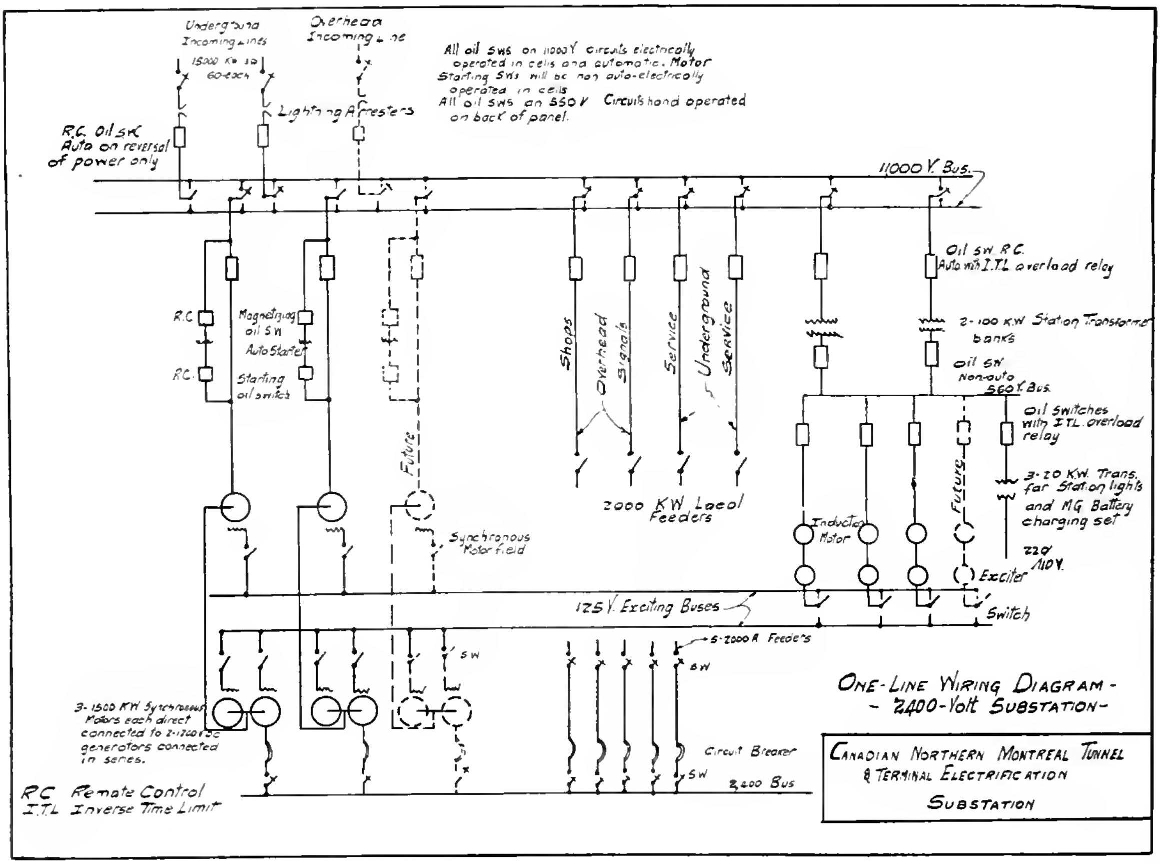


Fig. 10. One-Line Wiring Diagram of the 2400-Volt Substation

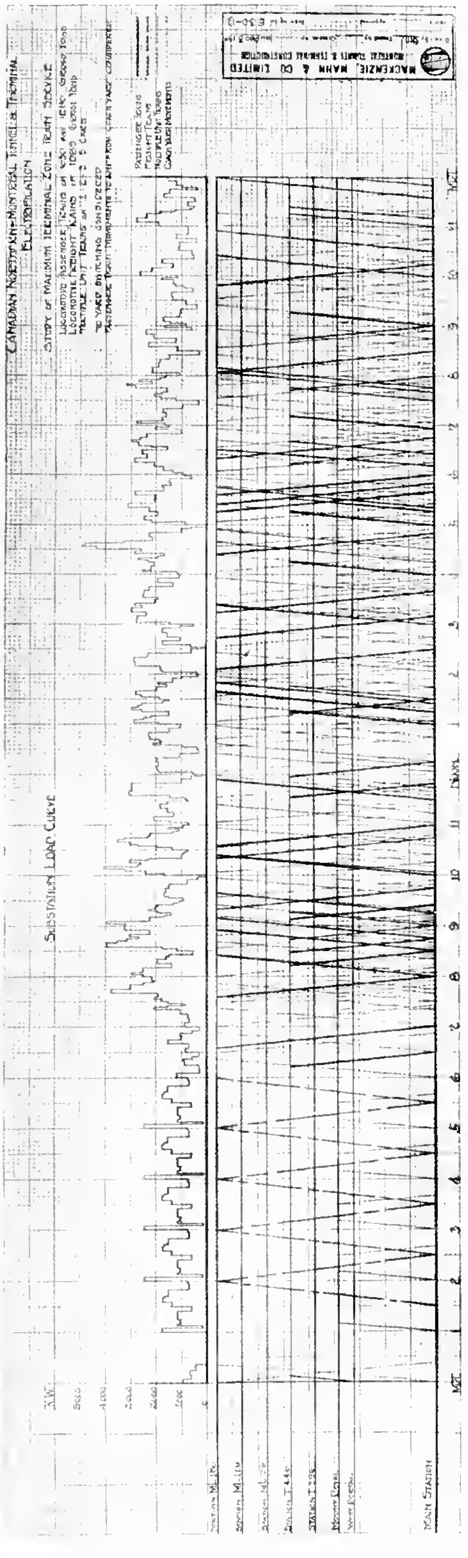


Fig. 11. Combination Curve of Substation Load and Train Service for the Terminal Zone

11,000-volt power will be purchased and delivered at this point from the Montreal Light, Heat & Power Company. This company distributes electric power from six water power stations aggregating 170,000 h.p. All of these are connected to a central distributing station, which is only a short distance from the east end of the tunnel in Montreal. Two sets of cables, one set a spare, will be installed from this central station through the tunnel in ducts and underground all the way to the substation. In addition to these underground lines, an overhead transmission line will connect the power company's Montana Street transformer station just north of Mount Royal with the substation. The switches on these incoming lines will be so arranged that the 11,000-volt busbars can be quickly changed from one to the other.

Besides the water power generating stations the power company has two steam generating stations with a total output of 32,000 h.p. These act as a reserve only and are connected to the central distributing station by underground feeders. Continuity of power supply is thus amply provided for.

The alternating current power will be converted into 2400-volt direct current power for the trolley circuits by means of 1500-kw. motor-generator sets. Two of these sets are being installed at present, one of them being a spare. There will be space provided in the station for a third motor-generator set which will be installed when the load increases beyond the capacity of one set.

Each of these sets consist of two 750-kw., compound wound, commutating pole generators wound for 1200 volts, insulated for 2400 volts, and direct connected to an 11,000-volt synchronous motor operating at a speed of 600 r.p.m. These generators are permanently connected in series. The shunt fields are separately excited. The pole face winding, series and commutating field windings are all connected on the ground side of these generators so that the armatures are the only parts subjected to the full potential of 2400 volts. Separately exciting the shunt fields would ordinarily be objectionable for the reason that if the commutator should arc over due to a short circuit on the line the generator voltage would tend to hold up and maintain the arc. To overcome this objectionable feature a limiting resistance is placed in series with each of the shunt fields. This resistance is cut into the circuit by means of a contactor operated by current coils excited from the 125-volt bus and connected in series with the auxiliary switch attached to the main direct-current circuit breaker. When this circuit breaker opens the auxiliary switch is also opened, thereby allowing the contactor to open and cut in the additional resistance, thus reducing the voltage of the generators. A speed limit device is also used. The contacts of this device are connected in series with the trip coil of the circuit breaker. In case of about 15 per cent over speed, or more, a revolving weight due to centrifugal force opens the switch, thus killing the low-voltage release coil of the circuit breaker and causing it to open.

These sets have a continuous capacity of 1500 kw. each and an overload capacity of 200 per cent for five minutes.

The switchboard is composed of thirty-two panels of natural black slate. These control various outgoing circuits for signals, tunnel lighting, and miscellaneous power as well as the substation machinery. Nine of these panels comprise the 2400-volt direct current board. The 2400-volt circuit breakers and lever switches are mounted on panels back of and above the main switchboard. They are operated by means of insulated handles on the front of the main board so as to eliminate any possibility of the operator coming in contact with the 2400-volt circuit. The breakers are enclosed between fireproof barriers. They are equipped with powerful magnetic blowouts to extinguish the arc, and are provided with a re-setting device operated from the front of the board. The field switches are mounted back of the panels with their operating handles on the front of the main board.

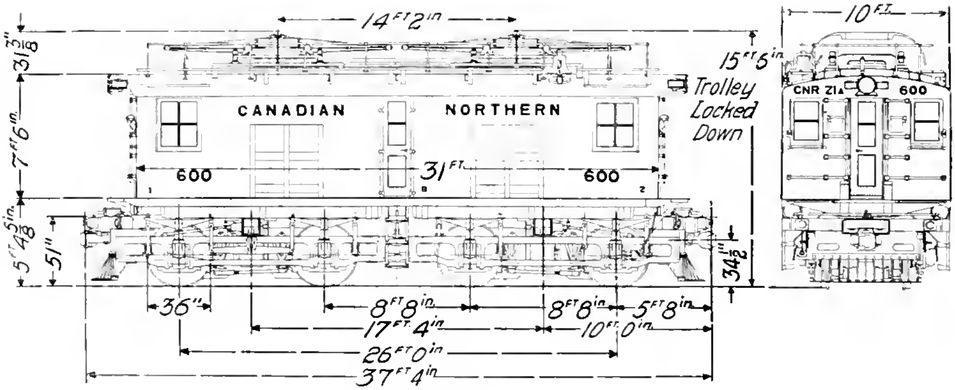


Fig. 12. Dimensioned Outline Diagram of a Canadian Northern Locomotive

There will be three motor-generator exciter sets, each consisting of a 50-kw. 125-volt generator of the commutating pole type direct connected to a 550-volt 1200-r.p.m. induction motor. Normally one exciter will furnish exciting current to the fields of the synchronous motors, and another the current to excite four generators, the third exciter being a spare.

Two banks of transformers, one a spare, each consisting of three 100-kw. 60-cycle 11,000/550-volt single-phase transformers will be installed to furnish low voltage alternating current for operating the exciters and various motors. Other small transformers will step down from 550 volts to 110 volts for lighting the station. Emergency lighting will be taken care of by means of a storage battery, which will also furnish current for operating the oil switches in case of a complete shut-down, when current from the exciter will not be available.

The substation building is 88 ft. long by 70 ft. wide by 34 ft. high and consists of a machinery section and a switching and auxiliary section. The machinery room contains the two 1500-kw. synchronous motor-generator sets with the foundation for a third set, and three exciter sets with space for a fourth. It also contains the switchboard. A 25-ton traveling crane is provided in this room. This crane will handle the heaviest piece of machinery. Under this room there is a basement where rheostats are located beneath the switchboard and where there are also storage and locker rooms.

The switching and auxiliary section is divided from the machinery section by a heavy fire wall. Underneath half of this is a basement containing rooms for oil storage and for the furnace which provides heat for the building. This section is divided into a busbar room, oil switch room, lightning arrester room, power transformer room, battery room and feeder entry room. Fire walls and doors fully guard against the possibility of any fire spreading.

The machinery room has a glazed brick dado extending 10 ft. above the floor. Above this, the room is lined with a light cream-colored brick. Ample windows are provided for light and ventilation. Revolving ventilators are located in the roof over the machinery.

The exterior of the building is finished with a dark red tapestry brick with parapet, cornice and other trimming of moulded concrete imitating dressed sandstone.

Outside the tunnel the overhead construction will be of the catenary cross-span construction supported by means of cedar poles spaced 150 ft. on tangents. The messenger cable will be of 5/8-in. steel. The height of the trolley will be 23 ft. above the rail. The hanger spacing will be 15 in. and the deflection 28 in. One 500,000-c.m. feeder will be installed from the substation to the Cartierville yard.

In the tunnel the messenger cable will be an aluminum cable one inch in diameter having a steel core as reinforcement. This cable will have a conductivity equivalent to a 400,000-c.m. copper cable. There will be no other feeder in the tunnel. The messenger supports will be spaced 80 ft. apart and the height of the trolley in the tunnel above the rail will be 16 ft.

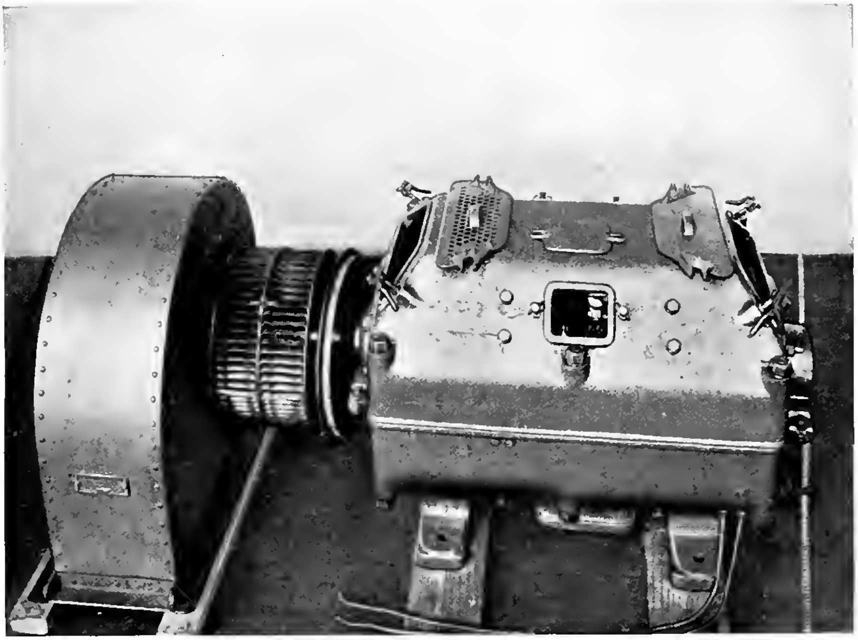


Fig. 13. Motor-Generator Set for Operating the Locomotive Control and Blowing the Main Motors

# HIGH VOLTAGE DIRECT CURRENT RAILWAYS

By G. H. Hill

Assistant Engineer, Railway and Traction Engineering Department,
General Electric Company

The writer points out that, important as is the physical success of higher voltage direct current apparatus, the economic success under industrial conditions is of still greater moment. After several references to the successful operation of the Butte, Anaconda & Pacific Railroad, the problems of transmission and distribution are discussed and illustrated with a hypothetical example. Other important problems are dealt with, and the article is concluded with a summary of the voltages for which direct current apparatus has already been designed for different fields of service.—Editor.

G. H. Hill

THE successful operation of the first extensive heavy freight electrification in this country is undoubtedly gratifying to all those who are interested in electric railway progress. The first year's operation electrically of the Butte, Anaconda & Pacific Railroad, just now ended, has demonstrated a success from every point of view. Even the most conservative must agree that electric apparatus in general and the specific apparatus employed in this instance in particular, is well adapted for the heavy, rough service involved.

The condition of the equipment throughout indicates an ample margin in capacity and freedom from any source of undue depreciation. The fact that the operation and maintenance has been in the hands of substantially the same force as under steam operation is in itself significant.

Important as is the physical success of the apparatus, of still more importance to the industry is the economic success. The very complete data of costs of operation of the Butte, Anaconda & Pacific Railroad, when a steam railroad and since being converted, which are now available, indicate a remarkable saving by electrification. This is clearly set forth in the statistics given elsewhere in this issue.

There is no special feature that makes this railroad peculiarly fitted for electric operation. The cost of coal is high and electric power reasonably low, but this is the condition throughout most of the trunk line mountain districts. Moreover, the savings shown include a material amount of traffic and switching service still being done by steam locomotives. While it may not have appeared economical at the start to electrify all of these branches and yards, it appears that a further source of saving would be opened by so doing.

Whether or not this splendid demonstration of the possibilities of electric traction could have been possible with any other system of electrification is, in a broad sense immaterial. To railroad men the fact is demonstrated that heavy grade steam railroads, freight as well as passenger, can be equipped electrically; that the apparatus can be operated by the same organization throughout; that the equipment is sturdy, capable of the hardest usage, free from weaknesses and defects and that from the very start most substantial economies can be realized.

At the same time the fact that the Butte, Anaconda & Pacific Railroad is equipped with the direct current system at 2400 volts establishes beyond question the fitness of this system for use in electrifying the mountain divisions of the great trunk railways, and is one solution of this important problem.

One of the natural questions that arise in this connection is what ultimate voltage will be found desirable to use for heavy railroad work. It is frequently assumed that the highest possible voltage is most economical and that the line potential is limited only by the possibilities of producing operative apparatus. While such limitations may have existed some time ago, the experience gained in the development and use of 1200 and 2400-volt systems, combined with the diligent study and vigorous experimenting which have been carried on, has demonstrated conclusively that both generating and motor equipments can be successfully built for at least double the voltage of the Butte, Anaconda & Pacific. This can be accepted as a reasonable and conservative statement. The application of still higher voltages is, therefore, not a matter of physical possibilities in producing apparatus but of the comparative economical results. The highest line potential is not necessarily the most economical or the best suited for all conditions of profile and traffic and it is necessary to consider all these conditions in order to determine the most suitable voltage for electrification.

It is obvious that a given amount of power can be transmitted at high voltage over longer distances with a given amount of copper, or over the same distance with less copper, than at low voltage. The problem of transformation and distribution from the high tension alternating current transmission to the rolling stock is somewhat more complex. This can best be illustrated perhaps by a crude example:

Suppose a railway were equipped with light cars consuming an average of 100 kw. each and operating on a close headway one mile apart. The load would be uniformly distributed over the system. If the line were of 500 volts, the substations of 500 kw. could be spaced about five miles apart with no feeder copper to reinforce the 4/0 trolley. A 1000-volt line would have substations of 1000 kw. spaced ten miles and a 3000-volt line potential would have substations of 3000 kw. spaced thirty miles. In each case the total substation capacity and the amount of copper would be the same.

The sole advantage of spacing substations farther apart would arise from the lower cost of apparatus and buildings per kw. At about 1000-kw. capacity per substation this cost approaches a minimum, while for a given voltage the cost of feeder copper increases rapidly with the greater spacing. At the same time the cost per kw. of generators and the weight and cost of the rolling stock increases at an accelerating ratio with the voltage. The balance in costs will be reached for the assumed railway at about a twelve mile spacing of substations and with 1200 volts line potential. On the other extreme, if the railway load consists of, say, two train units each consuming 5000 kw. spaced 50 miles apart it is obvious that substations spaced less than fifty miles will have to have substantially the same capacity each as if spaced fifty miles, so that there is a marked saving in total substation capacity by the wider spacing and the balance will arrive at about 5000 volts and 50 miles spacing. The illustration is quite crude since many other conditions enter into the problem such as varying train weights, grades and necessity for moving train fleets with a deranged schedule.

It is clear, however, that the size of train units and the density and distribution of the traffic have the determining influence upon the most economical voltage to be used as well as the substation spacing. Many local conditions will enter to modify any general conclusions. There are usually certain natural locations for substations, on account of grades, branch lines or existing stations so that each problem must be studied individually both with reference to present conditions and future growth.

The limit in weight of train units on grade sections, due to the strength of car structure and drawbars, air-brake operation and other similar considerations, makes an input of about 5000 kw. per train, not including acceleration, the maximum that will have to be dealt with.

Where traffic is dense enough to warrant electrification at all and the future growth is properly considered, it is generally found that the minimum first cost and operating cost is reached at about 3000 volts for the heaviest train service.

Many situations and many conditions indicate a lower voltage than this, for instance where multiple unit train passenger service is a considerable factor the advantages of a line voltage of about 1500 volts are quite apparent.

Motors of less than 175 or 200 h.p. increase rapidly in weight per h.p. at voltages over 700 or 800 so that four-motor equipments with series parallel control become disproportionately heavy and costly above 1500 volts. The control apparatus as well becomes rather complex and bulky for installing beneath the car floor. The lower power demand per train unit and the frequent spacing of trains which this class of service involves naturally influence the conclusion toward a lower voltage, while the size, weight and cost of the cars emphasize the economy of moderate voltage. The use of 1200 volts for suburban lines is not only most economical for the character of the traffic, but presents especial flexibility in combination with 600-volt lines, with which they usually connect. The large number and wide distribution of 1200-volt railways now in successful operation firmly establishes this voltage as standard for suburban service.

The just demands for some degree of standardization require the elimination of too great a variety of line voltages. The needs of all classes of service seem to be well met by apparatus already well developed and to a large extent in practical use. This may be summarized as follows:

600 volts for city service,
1200 volts for suburban lines connecting with 600-volt city lines,
1500 volts for moderate mixed freight and passenger traffic,
3000 volts for heavy trunk line service.

Future development will probably follow these lines, since this classification is already fairly clearly drawn in railway practice, as a result of much study and experience.

Steam railway organizations are confronted with many perplexing problems in the consideration of the inevitable electrification. It is of inestimable value to their progress, as well as to that of the electrical industry, to be able to present one satisfactory solution with respect to the electrical system and apparatus to be employed that is already developed, tested and proven. Several railways have, as a result, already adopted the 2400 and 3000-volt direct current system for important electrifications now under way.

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# THE OPERATION OF THE OREGON ELECTRIC RAILWAY

By L. B. Wickersham

Assistant General Manager, Spokane, Portland and Seattle Railway System

In last November's issue we published quite an extensive account of this 1200-volt system, and in the present article the author deals with the operation of the road since that date. The operation and maintenance of the passenger cars, an analysis of the power costs and of the substation data as regards "input," "output" and "efficiency," and a resume of the cost of maintenance for the whole electrical system, make a complete and interesting story. The tables accompanying the article are of great value.—**Editor.**

As the physical features of the 1200-volt system of the Oregon Electric were fully described in the General Electric Review, November, 1913, shortly after the 1200-volt system was put into operation, the present article is largely supplemental and is based upon operating data since that time.

It will be recalled that this line was formerly a 600-volt system operating 50 miles south to Salem, with a branch line of 19 miles to Forest Grove. An additional 72 miles south from Salem was completed in the late fall of 1912, at which time was also completed the changing over of the entire system from 600-volt to 1200-volt operation. The results contained in the table given are, therefore, the statistics on the first fiscal year of operation under the 1200-volt system.

### Cost of Operation and Maintenance

In Table I is given the operating cost for passenger service per car mile, also the monthly train mileage and car mileage over this period.

In column 1 the cost of maintenance of electrical equipment is shown in cents per car mile, while column 2 gives the maintenance cost of passenger cars themselves, exclusive of electrical equipment. Wages of motormen and trainmen are shown in column 3, and column 4 represents the power cost in cents per car mile. Common charges between freight and passenger operation are divided, as is usual, upon a car mileage basis.

It is interesting to note that the maintenance of equipment of cars, including electrical equipment averages for the year approximately 1.75 cents per car mile.

At the time the change was made from 600- to 1200-volts, two of the 600-volt GE-73 motors were retained on each car and new GE-205 600/1200 motors used on the high side. That the use of the old 600-volt motors in connection with the 1200-volt operation has not served to increase the maintenance cost of the equipment is very evident from the tabulated figures given, and justifies the investigations and conclusions of the engineers of the General Electric Company and the railway company.

The total cost of all maintenance of passenger equipment is approximately 2 cents per car mile, which is considered to be an excellent record in the maintenance of equipment at this time. The cost herein given includes the depreciation charged against the equipment.

It will be noted that the total operating expenses per passenger car mile is 22.9 cents, and that the average car mileage is 197,465, and that there is an average of 2.5 cars per train.

### Power

Power for the operation of these lines is purchased from the Portland Railway, Light & Power Company. The contract calls for $1.25 per month per kw. of maximum demand; the maximum demand being the average power during the hour giving the largest number of kilowatts delivered during any one-hour period, and is determined from the load sheets for each month separately.

The companies purchase both direct current and alternating current from the power company, the direct current being supplied in the city of Portland, while the alternating current is delivered at 60,000 volts at the railway company's substations. Printometer attachments are used for the measurement of both the direct current and the alternating current. The summation of the printometer readings at the company's two direct current substations and at their two power plants represent the daily load curve of the railway company on which the maximum demand is based.

A consumption charge of 4.75 mils per kw-hr. is charged for all power delivered to the railway company's substation and is measured on the low side of the transformer at the railway company's various substations. On the direct current readings the company pays an additional two mils for conversion. The direct current furnished amounts to approximately ten per cent of the kilowatt-hours furnished.

In Table II is shown the segregation of power costs for the fiscal year 1913–1914. The company has installed meters upon its freight equipment and in this way is able to effect an accurate segregation between passenger and freight. This enables an accurate determination to be made of passenger power costs, so that the operation of the passenger equipment can be studied and by supplementing this data with that obtained from coasting meters placed on certain equipments, motormen are instructed in the proper handling of their cars with the view of securing low power consumption. In addition to this, watthour meters have been placed on several of the passenger equipments and the actual consumption required to make certain runs determined. Motormen have learned the amount of power consumption required to make certain runs under economical handling of equipment and are encouraged to reduce this as much as possible.

Car heating tests have been made so as to properly segregate the heating and lighting from propulsion. An effort has been made to operate the freight trains as much as possible during the night hours, and careful attention is given to eliminate unusual peak load conditions.

It will be noted that the load factor has been maintained at between 40 and 50 per cent. The reason for the low load factor in July, 1914, being the heavy travel on the Fourth, which caused unusual peak conditions and necessarily lowered the load factor. The average for 14 months from June, 1913 to July, 1914, inclusive, was 46.3. The average cost per kw-hr. delivered at the

## TABLE I

### OPERATION AND MAINTENANCE OF PASSENGER CARS

| | Electrical Equipment of Cars in Cents per Car Mile | Maintenance of Passenger and Combination Cars in Cents per Car Mile | Passenger, Conductors, Motormen and Trainmen per Car Mile | Power Cents per Car Mile | Other Direct Charges Cents per Car Mile | Proportion of Common Charges per Car Mile | Total Passenger Expense per Car Mile | Train Miles | Car Miles | Average Cars per Train |
|---|---|---|---|---|---|---|---|---|---|---|
| 1913 | | | | | | | | | | |
| July | .45 | .9842 | 3.912 | 2.76 | 3.452 | 10.132 | 21.69 | 79,659 | 195,910 | 2.46 |
| August | .4725 | .956 | 3.833 | 2.878 | 3.52 | 10.652 | 22.31 | 80,351 | 201,612 | 2.506 |
| September | .4523 | .6545 | 3.5956 | 2.9823 | 3.801 | 9.84 | 21.326 | 78,489 | 215,142 | 2.741 |
| October | .528 | .996 | 3.71 | 2.84 | 4.27 | 9.566 | 21.91 | 79,985 | 210,206 | 2.63 |
| November | .405 | 1.371 | 3.865 | 2.993 | 4.80 | 11.666 | 25.1 | 77,375 | 198,173 | 2.56 |
| December | .484 | 1.444 | 3.986 | 3.31 | 4.29 | 10.476 | 23.99 | 79,360 | 196,020 | 2.47 |
| 1914 | | | | | | | | | | |
| January | .458 | 1.364 | 4.215 | 3.22 | 5.21 | 10.233 | 24.7 | 77,345 | 188,466 | 2.44 |
| February | .4556 | 1.307 | 4.116 | 3.179 | 4.042 | 9.86 | 22.96 | 72,923 | 175,305 | 2.44 |
| March | .595 | 1.452 | 4.309 | 2.993 | 4.233 | 7.318 | 20.9 | 79,493 | 188,575 | 2.37 |
| April | .6855 | 2.038 | 4.316 | 3.025 | 4.587 | 8.82 | 23.47 | 79,010 | 185,004 | 2.34 |
| May | .4189 | 1.15 | 4.208 | 2.842 | 4.23 | 10.273 | 23.122 | 83,146 | 199,773 | 2.40 |
| June | .0724 | 2.036 | 3.906 | 2.9016 | .971 | 13.967 | 23.854 | 81,780 | 215,397 | 2.63 |
| Average | .455 | 1.306 | 3.988 | 2.981 | 3.903 | 10.28 | 22.944 | 79,076 | 197,465 | 2.50 |

company's substations over this same period, including the direct current delivered, was 0.9 cents per kw-hr.

In Table II the amount of power billed includes the power supplied the United Railways, which is operated in conjunction with the Oregon Electric Railway, as they both operate under the same power contract, thereby deriving the advantages of the combined load factor. The balance of the

## TABLE II

### SEGREGATIONS OF POWER COSTS FOR FISCAL YEAR 1913-1914

| | June 1913 | July 1913 | August 1913 | September 1913 | October 1913 | November 1913 | December 1913 | Average |
|---|---|---|---|---|---|---|---|---|
| Power bill (Oregon Electric & United) | $9696.35 | $9764.02 | $10464.23 | $10687.28 | $11559.89 | $11493.20 | $10986.20 | |
| Kilowatt-hours per month | 1,115,055 | 1,148,840 | 1,221,780 | 1,255,550 | 1,392,345 | 1,375,960 | 1,299,945 | |
| Maximum demand kilowatt | 3,259 | 3,193 | 3,446 | 3,498 | 3,640 | 3,623 | 3,483 | |
| Load factor | 44.4% | 48.3% | 48.3% | 49.8% | 51.4% | 52.7% | 50.1% | 46.3% |
| Cost per kilowatt-hour | $0.00869 | $0.00849 | $0.00856 | $0.00851 | $0.0083 | $0.00834 | $0.00843 | |
| Passenger car miles | 206,715 | 195,910 | 201,612 | 215,378 | 210,224 | 198,173 | 196,020 | |
| Passenger propulsion power bill | $4585.71 | $5119.76 | $5513.30 | $6082.58 | $5597.36 | $5144.92 | $5541.70 | |
| Passenger car lighting and heating bill | $279.62 | $280.50 | $289.37 | $333.79 | $371.45 | $787.55 | $947.12 | |
| Passenger propulsion power cost per car mile | $0.02223 | $0.026133 | $0.027346 | $0.028705 | $0.026625 | $0.025962 | $0.028271 | $0.027 |
| Passenger propulsion kilowatt-hour per car mile | 2.558 | 3.078 | 3.193 | 3.375 | 3.208 | 3.102 | 3.353 | 3.113 |
| Passenger car lighting and heating cost car mile | $0.00135 | $0.001431 | $0.001434 | $0.001549 | $0.001738 | $0.003974 | $0.004831 | |
| Passenger car lighting and heating kilowatt-hours per car mile | 0.155 | 0.167 | 0.167 | 0.182 | 0.209 | 0.476 | 0.573 | |
| Revenue freight car miles | 76,729 | 83,498 | 82,164 | 90,373 | 99,887 | 85,254 | 72,538 | |
| Revenue freight power bill | $1665.02 | $1222.40 | $1370.59 | $1314.67 | $1582.93 | $1471.07 | $1087.60 | |
| Revenue car mile power cost | $0.0217 | $0.01464 | $0.01668 | $0.01454 | $0.01598 | $0.01725 | $0.01499 | $0.0166 |
| Revenue car mile kilowatt-hour | 2.497 | 1.724 | 1.938 | 1.709 | 1.923 | 2.068 | 1.778 | |
| Non-revenue freight car miles | 87,804 | 95,996 | 184,230 | 162,454 | 156,905 | 92,896 | 62 098 | |
| Non-revenue freight power bill | $936.24 | $907.30 | $927.64 | $856.71 | $1252.56 | $926.97 | $773.87 | |
| Non-revenue freight car mile power cost | | | | | | | | |
| Non-revenue freight car mile kilowatt-hour | | | | | | | | |
| Switching power bill | $115.31 | $110.80 | $120.96 | $114.82 | $317.71 | $182.21 | $86.40 | |
| Station lighting | $176.40 | $187.60 | $196.74 | $192.00 | $204.32 | $306.48 | $306.48 | |
| Shop power | $24.74 | $24.58 | $23.16 | $28.03 | $35.36 | $28.32 | $36.67 | |
| O. C. & I.,* United Railway, Ruth Realty | $1913.28 | $1911.08 | $2022.47 | $1764.68 | $2198.20 | $2645.68 | $2206.34 | |

* Other Companies and Individuals.

| | January 1914 | February 1914 | March 1914 | April 1914 | May 1914 | June 1914 | July 1914 | Average |
|---|---|---|---|---|---|---|---|---|
| Power bill (Oregon Electric & United) | $10154.98 | $9426.89 | $9179.29 | $9143.09 | $9254.41 | $9608.81 | $9602.58 | |
| Kilowatt-hours per month | 1,187,831 | 1,065,215 | 1,060,240 | 1,030,190 | 1,038,375 | 1,005,344 | 989,821 | |
| Maximum demand kilowatt | 3,296 | 3,189 | 3,079 | 3,177 | 3,239 | 3,646 | 3,703 | |
| Load factor | 46.0% | 49.7% | 46.2% | 45.0% | 42.7% | 38.3% | 35.9% | 46.3% |
| Cost per kilowatt-hour | $0.00855 | $0.00884 | $0.00862 | $0.00887 | $0.00892 | $0.00956 | $0.009702 | |
| Passenger car miles | 188,466 | 175,305 | 188,575 | 185,004 | 199,773 | 215,407 | 199,862 | |
| Passenger propulsion power bill | $5189.58 | $4906.42 | $5025.93 | $5155.69 | $5448.86 | $6072.09 | $6044.59 | |
| Passenger car lighting and heating bill | $878.59 | $663.80 | $617.80 | $440.88 | $328.57 | $177.83 | $106.88 | |
| Passenger propulsion power cost per car mile | $0.027536 | $0.027994 | $0.02652 | $0.027862 | $0.027275 | $0.028189 | $0.03024 | $0.027 |
| Passenger propulsion kilowatt-hour per car mile | 3.221 | 3.161 | 3.076 | 3.141 | 3.057 | 2.949 | 3.108 | 3.113 |
| Passenger car lighting and heating cost car mile | $0.004661 | $0.003786 | $0.003276 | $0.002388 | $0.001645 | $0.000826 | $0.000534 | |
| Passenger car lighting and heating kilowatt-hour per car mile | 0.545 | 0.428 | 0.380 | 0.269 | 0.184 | 0.086 | 0.055 | |
| Revenue freight car miles | 61,578 | 60,379 | 78,976 | 72,627 | 70,731 | 63,641 | 72,624 | |
| Revenue freight power bill | $982.23 | $1150.60 | $1232.81 | $1000.95 | $1087.85 | $1262.17 | $1298.44 | |
| Revenue car mile power cost | $0.01595 | $0.01905 | $0.01561 | $0.01378 | $0.01538 | $0.01983 | $0.01788 | $0.0166 |
| Revenue car mile kilowatt-hour | 1.865 | 2.159 | 1.811 | 1.554 | 1.746 | 2.074 | 1.863 | |
| Non-revenue freight car miles | 26,766 | 20,976 | 8,780 | 49,570 | 43,870 | 3,671 | 24,216 | |
| Non-revenue freight power bill | $610.72 | $399.69 | $236.14 | $527.08 | $447.71 | $59.61 | $132.59 | |
| Non-revenue freight car mile power cost | | | | | | | | |
| Non-revenue freight car mile kilowatt-hour | | | | | | | | |
| Switching power bill | $46.42 | $49.44 | $34.33 | $45.83 | $68.12 | $81.19 | $30.45 | |
| Station lighting | $306.48 | $306.48 | $252.57 | $252.57 | $227.35 | $159.96 | $168.17 | |
| Shop power | $33.98 | $27.08 | $40.17 | $29.10 | $29.90 | $29.16 | $24.30 | |
| O. C. & I.,* United Railway, Ruth Realty | $2099.98 | $1894.44 | $1739.54 | $1690.99 | $1616.05 | $1766.20 | $1797.16 | |

* Other Companies and Individuals.

## TABLE III

### SUBSTATION DATA

| | MULTNORMAH | | | MOFFATT | | | TONQUIN | | | WACONDA | | | ORVILLE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 Volt Rotaries Two in Series | | | 600 Volt Rotaries Two in Series | | | 600 Volt Rotaries Two in Series | | | 1200 Volt Rotaries | | | 1200 Volt Rotaries | | |
| | Input | Output | Eff. | Input | Output | Eff. | Input | Output | Eff. | Input | Output | Eff. | Input | Output | Eff. |
| July | 169000 | 142222 | 84.2 | 146000 | 116570 | 79.1 | 179200 | 148670 | 83.0 | 136200 | 109920 | 81.0 | 83500 | 73552 | 88.0 |
| Aug. | 208000 | 179758 | 86.3 | 132100 | 105100 | 79.6 | 172600 | 140180 | 81.2 | 130100 | 110900 | 85.2 | 92300 | 84341 | 89.6 |
| Sept. | 229200 | 196290 | 85.6 | 140800 | 111620 | 79.2 | 176500 | 150280 | 85.1 | 143400 | 120770 | 84.2 | 102800 | 91867 | 89.3 |
| Oct. | 279300 | 242558 | 86.8 | 162000 | 139230 | 85.8 | 191000 | 161900 | 85.0 | 149600 | 125780 | 82 | 111400 | 100329 | 90 |
| Nov. | 244900 | 201132 | 83.2 | 174600 | 137680 | 78.9 | 198700 | 169600 | 85.3 | 18300 | 94310 | 80 | 104200 | 88501 | 85.2 |
| Dec. | 197400 | 155644 | 79.9 | 171200 | 149750 | 87.0 | 201600 | 171140 | 84.8 | 119400 | 97970 | 82 | 88200 | 75850 | 86 |
| Jan. | 186800 | 156074 | 83.6 | 152600 | 124450 | 81.6 | 187900 | 159240 | 84.2 | 102900 | 84020 | 81 | 78500 | 66676 | 84.9 |
| Feb. | 156800 | 131282 | 83.7 | 135900 | 111430 | 82 | 165600 | 141000 | 85 | 87800 | 71150 | 81 | 73200 | 61282 | 85.1 |
| Mar. | 171800 | 143118 | 83.2 | 134900 | 109860 | 81 | 173600 | 149250 | 86 | 92600 | 75420 | 81.4 | 77500 | 66133 | 85.4 |
| April | 169400 | 144636 | 85 | 130800 | 102770 | 79.9 | 169600 | 146560 | 87 | 94900 | 77160 | 81.2 | 76700 | 65367 | 85.2 |
| May | 160200 | 138900 | 86.7 | 140300 | 111970 | 79.7 | 169700 | 147650 | 87.2 | 95000 | 77390 | 81.4 | 81500 | 70226 | 86.1 |
| June | 163500 | 142280 | 87 | 136900 | 111720 | 81.6 | 155300 | 136450 | 87.8 | 93100 | 76230 | 81.8 | 74200 | 64305 | 86.6 |
| Totals for fiscal year | 160400 | 138737 | 86.4 | 134600 | 108790 | 81.0 | 154600 | 138370 | 89.5 | 90500 | 71550 | 78.0 | 69300 | 59758 | 86.2 |

| | PIRTLE | | | CARTNEY | | | LASSEN | | | Totals for Month All G.E. Substations | | | HARBORTON | | | D-C. Output | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1200 Volt Rotaries | | | 1200 Volt Rotaries | | | 1200 Volt Rotaries | | | | | | 600 Volt M-G Sets Two in Series | | | | | |
| | Input | Output | Eff. | Input | Output | Eff. | Input | Output | Eff. | Input | Output | Eff. | Input | Output | Eff. | Station E | Jefferson St. | Total D-C. |
| July | 73400 | 64032 | 88.6 | 48700 | 40526 | 83.2 | 36400 | 31127 | 85 | 872400 | 726619 | 83.3 | 118550 | 83840 | 70.7 | 40040 | 117850 | 157890 |
| Aug. | 85200 | 76414 | 89.6 | 43300 | 37294 | 86.0 | 37300 | 32582 | 87.3 | 900900 | 772575 | 85.7 | 144240 | 93640 | 65.0 | 28850 | 147790 | 176640 |
| Sept. | 94400 | 82935 | 87.9 | 45600 | 39265 | 86 | 37500 | 32671 | 87 | 970200 | 825798 | 85.1 | 109890 | 70428 | 65.0 | 31280 | 144480 | 175460 |
| Oct. | 95500 | 82743 | 86.6 | 47500 | 41377 | 87 | 39300 | 33942 | 86.3 | 1085600 | 927859 | 85.4 | 118620 | 79900 | 66.3 | 40180 | 157945 | 198125 |
| Nov. | 102500 | 80124 | 79.9 | 55100 | 46143 | 83.7 | 45300 | 36730 | 81.2 | 1043600 | 854320 | 84.7 | 118040 | 77060 | 65 | 55740 | 158580 | 214320 |
| Dec. | 92300 | 78972 | 85.5 | 48000 | 39915 | 83.2 | 44300 | 36000 | 81 | 962400 | 805241 | 83.6 | 108690 | 74009 | 68 | 62710 | 166145 | 228855 |
| Jan. | 89500 | 73674 | 82.3 | 46500 | 36200 | 80 | 44800 | 35916 | 80 | 889500 | 736241 | 82.7 | 101940 | 66261 | 65 | 44601 | 151790 | 196391 |
| Feb. | 83700 | 71597 | 85.5 | 43900 | 38240 | 87 | 39100 | 32325 | 83 | 786000 | 658306 | 83.7 | 88780 | 52530 | 59 | 53085 | 137350 | 190435 |
| Mar. | 82400 | 69106 | 83.8 | 44800 | 37145 | 83 | 40900 | 33727 | 82.4 | 818500 | 683759 | 83.5 | 94540 | 53520 | 55 | 14785 | 132415 | 147200 |
| April | 79200 | 66402 | 83.9 | 41400 | 34916 | 84.3 | 39300 | 32365 | 82.4 | 801300 | 670176 | 83.6 | 89670 | 49870 | 55.5 | 26455 | 112765 | 139220 |
| May | 79200 | 68061 | 86 | 44000 | 37105 | 84.3 | 40200 | 33414 | 83 | 810100 | 684716 | 84.5 | 91580 | 52670 | 57 | 25218 | 111475 | 136693 |
| June | 77300 | 66316 | 85.8 | 43000 | 36367 | 84.5 | 39400 | 33430 | 85 | 782700 | 667098 | 85.2 | 84680 | 46590 | 55 | 26224 | 111740 | 137964 |
| Totals for fiscal year | 74500 | 63481 | 85.2 | 42500 | 35737 | 84.1 | 37800 | 31782 | 84.1 | 10723200<br>764200 | 9012708<br>648205 | 84.05<br>84.8 | 89530 | 18<br>46480 | 52.0 | 24536 | 111555 | 136091 |

## TABLE IV

### COST OF MAINTENANCE

| | Substation | Transmission System | Distribution System | Poles and Fixtures |
|---|---|---|---|---|
| 1913 | | | | |
| July | $760.52 | $275.83 | $837.87 | $399.58 |
| August | 243.04 | 320.50 | 979.42 | 452.21 |
| September | 161.57 | 161.81 | 770.70 | 576.92 |
| October | 147.42 | 218.98 | 807.12 | 878.02 |
| November | 797.21 | 273.04 | 1034.97 | 1549.02 |
| December | 636.33 | 284.13 | 1031.02 | 1515.17 |
| 1914 | | | | |
| January | 253.25 | 298.66 | 686.31 | 1489.23 |
| February | 523.69 | 291.71 | 562.43 | 1487.63 |
| March | 437.78 | 276.17 | 589.89 | 599.68 |
| April | 587.68 | 39.85 | 219.34 | 58.37 |
| May | 479.98 | 71.23 | 344.19 | 144.08 |
| June | 549.29 | 25.44 | 45.23 | 168.35 |
| Total per year | $5577.76 | $2537.35 | $7818.03 | $9318.26 |

Miles of line, 150.
Maintenance substations per mile road per year, $37.18.
Maintenance overhead lines per mile road per year, $131.10.
NOTE:—Seventy-two miles of line and four substations were new in 1912.

table is segregated and is statistical for the Oregon Electric alone.

It should be noted that the propulsion cost per car mile and the kw-hr. per car mile for propulsion alone are given separately from the car lighting and heating cost per car mile and car lighting and heating kw-hr. per car mile.

It will be noted that the approximate average propulsion kw-hr. per car mile is 3.1. This is at the meters and represents approximately 2 kw-hr. per passenger car mile at the cars, which is considered to be an economical performance, considering the weight of the equipment and the grades over which these lines operate. The average cost of propulsion measured at the meters is approximately 2.72 cents per car mile.

It will also be noted from the table that the average power cost per car mile on revenue freight is 1.66 cents per car mile, or 61 per cent of the cost per passenger car mile.

An approximate conclusion which may be drawn from this comparison between the cost per car mile in passenger and freight is the difference in tractive power per ton mile exerted to handle freight and passengers under actual running schedule.

It should be understood that these figures are averages of monthly computations, therefore approximate, but representing fairly well the average conditions of operation over the period given.

### Substation Operation

In Table III is given the output and input of each of the substations and their monthly efficiency. The average of the monthly efficiencies is also shown.

All of these substations operate rotary converters, with the exception of Harborton, on the United Railways, which operates motor-generator sets. Multnomah, Moffat and Tonquin have 600-volt rotaries in series, while the other substations have 1200-volt rotaries. Harborton has two 600-volt motor-generators in series.

The direct current output at Station E and Jefferson Street station are also shown in this table.

It will be noted that the average efficiency as averaged from the monthly efficiencies of the various substations on the Oregon Electric is 84 per cent while the efficiency of the Harborton substation averages about 62 per cent. While this difference in efficiency between the Oregon Electric and United Railways substations is partially due to the class of service which they supply, there is clearly a difference of 15 per cent in the operation of rotaries, as compared with the motor-generators.

Substations on these lines are shut down at certain intervals during the day whenever a shut-down of 30 minutes can be obtained with no trains in the zone supplied by the substations. These shutdowns are handled according to regular schedule, subject to such variations as may be given by the dispatcher in case of extra movements.

It will be noted that substations such as Orville and Pirtle, which are located on the south end of the line, show remarkably high efficiencies. These are obtained by keeping the capacity of the substations as low as is consistent with the maximum demand conditions upon them, supplementing them with a portable substation during days of unusually heavy movement, such as the Fourth of July, Rose Festival, etc.

Table IV gives the maintenance figures for substations and overhead lines for the fiscal year 1913–1914. It should be noted that 72 miles of the line, from Salem to Eugene, were constructed in 1912 and are, therefore, practically new. This is also the case with four of the substations on the south end.

On the other hand, the balance of the line has been in operation over seven years, and the pole reinforcements and renewals were begun a year ago. It is expected that the work of this kind during the fiscal year 1914–1915 and the following year will complete the reinforcement or renewal of practically all of the poles on the old part of the line.

It should be noted that the substation maintenance per mile of road per year over this period averages $37.18, and that the maintenance of overhead lines per mile of road per year averages $131.10.

# THE BALTIMORE AND OHIO ELECTRIFICATION

By J. H. Davis

Electrical Engineer, Baltimore and Ohio Railroad

The author has written an interesting account of this the first heavy electric traction undertaking in America. The physical characteristics and history of the road, the power supply, distributing system, locomotives (old and new), the operating features, and the cost of operation and maintenance are all discussed; the latter features being amplified by some valuable tables. The high maintenance charges on the Class OE-1 and OE-2 locomotives are explained by the fact that these units were much overloaded, and that for the period for which the figures are given there were no adapt facilities for re-winding armatures of this size. The high cost of third rail maintenance that has been experienced on this road is accounted for by the large amount of renewal work and the unusual local conditions.—Editor.

J. H. Davis

When it was suggested that an article on the Baltimore & Ohio electrification would be of interest in this number of the General Electric Review it was felt that, in view of the previous descriptions, very little could be said at this time with which students of heavy traction were not already familiar. However, the fact that the Baltimore & Ohio electrification was the first undertaking of this nature in the United States, and as changes have recently been made to provide for much heavier traffic conditions than originally existed, and also, as data on the cost of operation and maintenance is fairly complete over a long period of years, it was felt that a review of this subject including a statement of physical characteristics, a brief history of the reasons for electrification, together with a description of the equipment now in use, tonnage handled, sources of supply of electricity, as well as data on the cost of operation and maintenance, would prove interesting. The need of actual operating data has been felt by engineers and railroad managers who are considering the subject of trunk line electrification, and notwithstanding the fact that considerable information of this character is now available, the same has not been made public except in a few instances. Where the exact conditions of operation are stated and the data is properly used there should be no objection to its publication.

## Physical Characteristics

That portion of the Baltimore & Ohio Railroad which is electrified lies within the city limits of Baltimore, and is a part of the so-called belt line, extending from Camden Station on the west to Waverly interlocking tower on the east, a distance of 3.75 miles. There are eight tunnels in this zone, together amounting to 48 per cent of the total distance, the longest tunnel, which is between Camden Station and Mount Royal Station, being 7300 feet in length. This tunnel contains two tracks while there are four tracks between Mount Royal and Huntingdon Avenue, from which point to Waverly there are two tracks. That part of the zone through which trains are handled by electric locomotives is entirely upgrade, the difference in elevation amounting to 150 feet, which gives an average through grade of 0.9 per cent, the ruling grade being 1.52 per cent and maximum curvature, 10 deg. 16 min. Special attention is called to this fact as trains are handled electrically only in the upgrade direction, the electric locomotives returning light, which results in a unit power consumption that is in all probability larger than that for most other existing steam railroad electrifications. Fig. 1 shows map, profile and curvature diagram of the electrified zone.

## History

During the early 1890's the Baltimore & Ohio constructed the Belt Line Railroad which furnished a direct rail connection between the main line west of Baltimore and that east. Previous to this it was necessary to ferry the trains across an arm of the Patapsco River. One of the requirements of the ordinance governing the construction of the line through the city was that the trains be operated electrically. In addition the number and lengths of the tunnels necessitated special means for reducing the amount of locomotive smoke and gases, for which electrification undoubtedly offered the most satisfactory solution. The first trial trip with electric locomotive No. 1 was made on June 27, 1894, but the belt line was not opened for traffic until May 1, 1895. Regular service with a total of three electric locomotives was begun on August 1, 1895. An overhead distribution system was installed, but as it never proved satisfactory it was replaced in 1902 by the third rail system. Four electric freight locomotives were purchased in 1903 and another of the same type in 1906. With the increasing traffic and weight of trains the capacity of the power plant and feeder system became inadequate, with the result that in 1909 a contract was entered into for purchasing current from the Consolidated Gas, Electric Light & Power Company of Baltimore, and a synchronous converter substation was built near the center of the electrified zone. In 1910 and 1912 a total of four locomotives of a more powerful type were placed in service and the original three were retired.

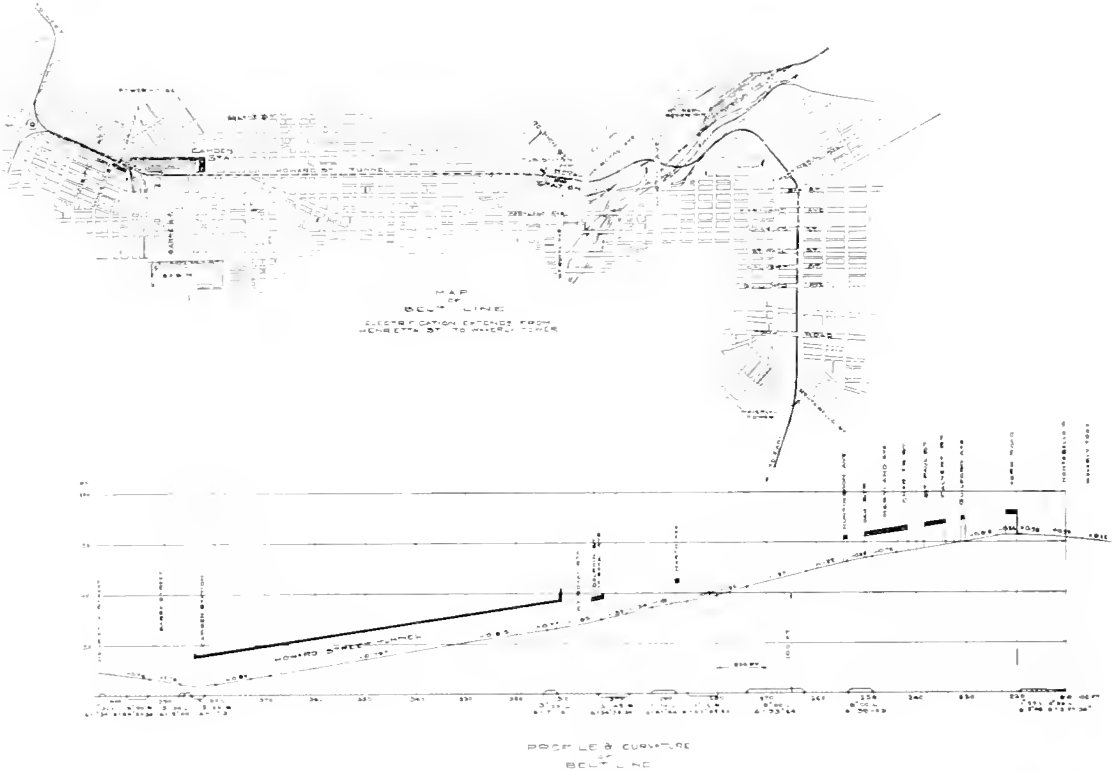


Fig. 1. Map and Profile-Curvature Diagram of the Electrified Section of the B. & O. R. R.

### Power Supply

The direct current system is used, 675 volts being maintained at the d-c. bus. Originally all power was supplied directly from the power plant, built for that purpose, located at the western end of the zone. The generating station is supplied with five 500-kw., 700-volt, direct current generators direct connected to tandem compound non-condensing Corliss engines. A large proportion of the plant output, however, is used for the railroad's shops and other purposes. As but one train at a time was handled through the zone the load was of an intermittent and high peak character. To obtain more economical operating conditions as well as to improve the voltage on the line a storage battery substation was subsequently installed near the Mount Royal passenger station, a mile and three-quarters from the power house. A booster system of control was used which included a booster located in power house, thus permitting a reduction of the generating voltage to 550 in order that current could be used for industrial motor purposes. This booster limited the power house output to 900 kw. for traction purposes which, with the battery, was sufficient to handle one freight train of 1600 tons weight including electric locomotive and one light passenger train simultaneously.

With the increase in train weights and in the amount of traffic handled there finally resulted a condition where the system of generation and distribution of power was totally inadequate to meet the demands. A study of the situation developed that power obtained from a large central station plant under a suitable rate schedule would prove the most satisfactory from an operating as well as economic point of view. In 1909, therefore, a contract was entered into with the Consolidated Gas, Electric Light & Power Company for furnishing power in the form of 13,000-volt three-phase, 25-cycle current. A synchronous converter substation was built by the railroad adjoining the Mount Royal battery station. Three 1000-kw., 650-volt synchronous converters with the necessary auxiliaries were installed, sufficient space being provided for an additional machine. The battery, which is of 3200-ampere hours capacity, at an eight-hour rate, or 3200 amperes for a period of 20 minutes, at the maximum discharge rate, has been retained for peak work and is controlled by the Electric Storage Battery Company's carbon pile regulator system. The present capacity of the station is sufficient to permit handling simultaneously two freight trains of the present tonnage rating, e.g., 2400 tons including electric locomotives, and one passenger train, which will take care of the probable traffic requirements for some time. The power plant is operated in parallel with the substation, it having been found economical to do so as long as it is continued in service. Plans are now under way, however, for closing it down in favor of purchasing current for the entire requirements of the railroad in Baltimore. Experience thus far has fully demonstrated the operating advantages and economics of purchased current, under suitable form of contract, for this character of service. The ability of a large central station system to absorb without disturbance the abnormally high peaks occuring with the simultaneous starting of trains on the grades, as well as the fluctuations of longer duration, caused by the intermittent character of the load, the ability of the railroad to increase indefinitely the demands for power without an additional outlay of capital for power plant equipment, and the elimination of the necessity of having to carry the fixed charges on reserve plant equipment are all decided advantages in favor of the use of central power station.

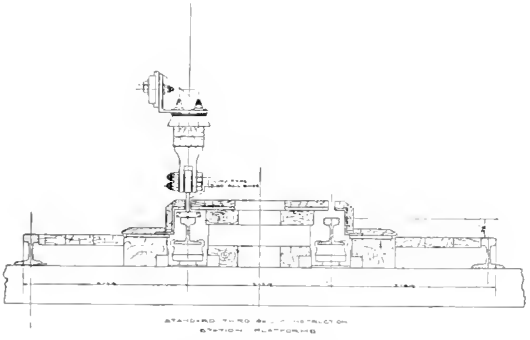


Fig. 2. Method of Mounting and Protecting the Third-Rail at Station Platforms

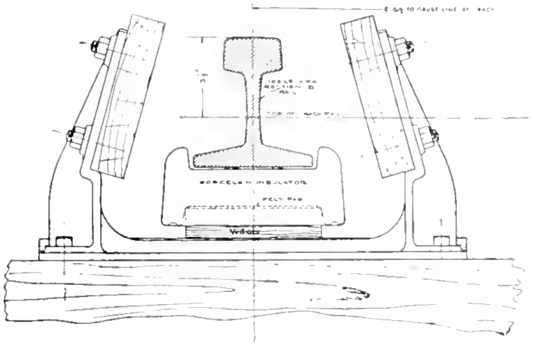


Fig. 3. Latest Type of Third-Rail Construction Adopted. This is now Standard.

### Distribution System

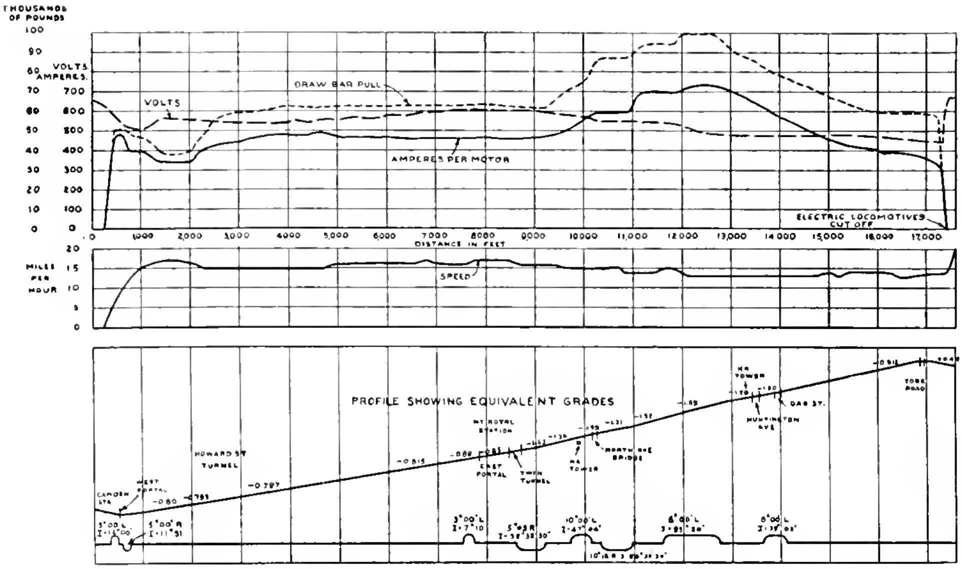
The original installation comprised an overhead system of power distribution. The contact conductor consisted of two Z bars so arranged as to form a box-like structure with a slot in the bottom. Outside of the tunnels this was supported from towers by catenary construction and in the tunnels by direct hangers. In this overhead slot the collector shoe, attached to the locomotive by a pantograph, was allowed to slide. As would be expected, from our present knowledge of methods of collecting current, the system was unsatisfactory, while the presence of gases from steam locomotives resulted in high maintenance cost. In 1902, the overhead conductors were replaced by a third-rail system, the larger part of which is still in service. On account of the flush platform construction at the passenger stations a special form of protection was provided, which is shown in Fig. 2. As a further safety precaution, automatic sectionalizing switches were installed but, proving unsatisfactory, were discontinued.

To provide a continuous supply of current to the locomotives at double slip switches, where the gaps were too great to be spanned by the third-rail shoes, a special arrangement of movable third rail is used to avoid the necessity for overhead conductors. These consist of a structural T iron located inside the crossing tracks and at such other points where the standard third rail would be fouled by trains using the crossing tracks. In the operating position these are level with the top of the third rail, but normally are lowered to the track rail level, in which position current is automatically cut off as a safety precaution. The rails are controlled from the signal towers and are properly interlocked with the switch levers.

After ten year's of service the third rail in the Howard Street Tunnel became so badly corroded, due to action of the locomotive gases and electrolysis, as to require its complete renewal, at which time the type of insulator and guard board support were modified to overcome certain faults in the original design. The design as modified has been adopted as standard for future replacement, and is shown in Fig. 3.

### Locomotives

Three types of locomotives have been used; the original locomotives designated as class LE-1, the second lot of locomotives designated as class LE-2, which were designed exclusively for freight service, and the last lots purchased designated as classes OE-1 and OE-2, which are of the Detroit Tunnel type and are used for both passenger and freight service. After 15 year's service the original locomotives were retired on account of obsolescence; one of them however, has been preserved intact for exhibition purposes as being the first electric locomotive used in this country under steam railroad conditions. Accompanying photographs show the different types of



—TEST NO 7 NOV. 5, 1913—

FREIGHT TRAIN LOCOMOTIVE NO 4031 ELECTRIC LOCOMOTIVES NO 13 & 14
WEIGHT OF TRAIN AND STEAM LOCOMOTIVES——2452.5 TONS
WEIGHT OF DYNAMOMETER CAR——37.2 TONS
TOTAL WEIGHT INCLUDING ELECTRIC LOCOMOTIVES—2709.7 TONS.
DYNAMOMETER CAR BETWEEN ELECTRIC & STEAM LOCOMOTIVES

| | CAMDEN TO MT ROYAL | MT ROYAL TO OAK ST. | OAK ST. TO YORK ROAD | CAMDEN TO YORK ROAD |
|---|---|---|---|---|
| TIME (MIN) (SEC) | MIN 6 SEC 58 | MIN 4 SEC 40 | MIN 3 SEC 8 | MIN 14 SEC 46 |
| SPEED (M P H) | 13.7 | 12.9 | 11.9 | 13.1 |
| DRAW BAR PULL | 56300 | 81930 | 66,500 | 67,160 |
| AMPS PER MOTOR | 443 | 598 | 443 | 498 |
| VOLTS (LINE) | 563 | 540 | 468 | 538 |
| WATT HRS PER TON MI | | | | 60.6 |

Fig. 4. Graphic Record of a Dynamometer Car Test made in Freight Service

locomotives, while the principal data pertaining to the electrical, mechanical and operating features are given in Table I.

### Operating Features

The service in the electrified zone is very similar to helper locomotive service except the road locomotives furnish no assistance. The ruling grade in the zone is 1.52 per cent while that of the remainder of the steam locomotive division is but 0.8 per cent. This necessitates that the electric locomotives be able to develop twice the tractive effort required of the steam locomotives. On account of the shortness of the run, steam locomotives are hauled through the zone with their trains. The electric locomotives return light as, on account of the grade, westbound traffic operates through the zone without requiring power from the steam locomotive except for starting.

The present maximum rating for freight trains handled over the belt line is 2200 actual tons, including the steam locomotive weighing 230 tons. Two class OE-1 or OE-2 locomotives haul these trains on the maximum grade at a speed of 15 miles per hour, which is nearly twice the speed obtained with the railroad's Mallet steam locomotives on corresponding grades and with full loading.

Fig. 4 shows the results of a dynamometer car test with two class OE-2 electric locomotives hauling a 2450-ton train over the belt line, the total weight of train including the electric locomotives being 2709.7 tons. These curves are typical of freight train performance excepting that the weight is above normal.

### Cost of Operation and Maintenance

Data showing the traffic handled and the total cost for operation and maintenance in dollars per thousand ton miles, including the weight of the electric locomotive, and in dollars per electric locomotive mile, including mileage running light, for a period of several years, are given in Table II. As would be

Fig. 5. Three 80-ton Freight Locomotives, Type LE-1 and LE-2, each equipped with four GE-65 Motors hauling freight train

Fig. 6. One 100-ton Freight and Passenger Locomotive, Type OE-1 and OE-2, equipped with four GE-209 Motors hauling passenger train

Fig. 7. Two 100-ton Freight and Passenger Locomotives, Type OE-1 and OE-2, each equipped with four GE-209 Motors hauling freight train

### Table I. ELECTRIC LOCOMOTIVE DATA, BELT LINE RAILROAD

| | | | | |
|---|---|---|---|---|
| Class | LE-1 | LE-2 | OE-1 | OE-2 |
| Type | 8 wheel<br>2 section | 8 wheel<br>rigid base | 8 wheel<br>articulated | 8 wheel<br>articulated |
| Year built | 1894 | 1903 and 1906 | 1910 | 1912 |
| Number | 3 | 5 | 2 | 2 |
| Rigid wheel-base | 6 ft. 10 in. | 14 ft. 6¾ in. | 9 ft 6 in. | 9 ft. 6 in. |
| Total wheel-base | 23 ft. ¾ in. | 14 ft. 6¾ in. | 27 ft. 6 in. | 27 ft. 6 in. |
| Length overall | 33 ft. 10 in. | 29 ft. 7 in. | 39 ft. 6 in. | 39 ft. 6 in. |
| Total weight | 190,000 | 160,000 | 185,000 | 200,000 |
| Number of motors | 4 | 4 | 4 | 4 |
| Type | AXB-70 | GE-65-B | GE-209 | GE-209 |
| Output of motor, one-hour rating, h.p. | 270 | 200 | 275 | 275 |
| Gear ratio | Gearless | 81/19 | 78/24 | 78/24 |
| Diameter of drivers | 62 in. | 42 in. | 50 in. | 50 in. |
| Tractive effort, one-hour rating pounds | 23,000 | 35,000 | 26,000 | 26,000 |
| Tractive effort, maximum momentary, pounds | 49,000 | 40,000 | 46,000 | 50,000 |
| Speed at rated tractive effort, m.p.hr. | 17.5 | 8.5 | 16.4 | 16.4 |
| Number of locomotives normally operated together: | | | | |
| Freight | | 3 | 2 | 2 |
| Passenger | 1 | | 1 | 1 |
| Maximum weight freight train which can be handled over belt line with above locomotive combinations, tons | | 2400 | 2200 | 2200 |

### Table II. TRAFFIC DATA AND COST OF OPERATION AND MAINTENANCE OF ELECTRIC LOCOMOTIVE SERVICE

| | 1910 | 1911 | 1912 | 1913 | 6 Months 1914 |
|---|---|---|---|---|---|
| Number of passenger trains handled | 8,390 | 6,025 | 5,989 | 6,144 | 3,045 |
| Number of freight trains handled | 10,405 | 7,810 | 7,164 | 7,578 | 3,532 |
| Mileage, electric locomotives | 199,897 | 206,738 | 189,884 | 188,988 | 89,852 |
| Ton miles including electric locomotives | 52,820,469 | 53,306,081 | 57,845,580 | 53,942,421 | 27,527,150 |
| Gross watthours per ton mile | 105 | 88 | 95 | 103 | 106 |
| Cost of current per kw-hr. at a-c. bus | $0.0111 | $0.0109 | $0.0101 | $0.0104 | $0.0111 |
| Cost of current per kw-hr. at d-c. bus | $0.0182 | $0.0144 | $0.0145 | $0.0147 | $0.0132 |

| Cost of Operation and Maintenance | Per 1000 Ton Miles | Per Loco. Mile | Per 1000 Ton Miles | Per Loco. Mile | Per 1000 Ton Miles | Per Loco. Mile | Per 1000 Ton Miles | Per Loco. Mile | Per 1000 Ton Miles | Per Loco. Mile |
|---|---|---|---|---|---|---|---|---|---|---|
| Trainmen's wages | $0.331 | $0.087 | $0.335 | $0.086 | $0.312 | $0.095 | $0.348 | $0.099 | $0.322 | $0.099 |
| Power | 1.435 | .379 | 1.049 | .271 | 1.090 | .331 | 1.210 | .346 | 1.212 | .372 |
| Oil and waste (for locomotives) | .007 | .002 | .006 | .001 | .006 | .002 | .008 | .002 | .006 | .002 |
| Miscellaneous supplies | .002 | .001 | .001 | ..... | .001 | ..... | .002 | ..... | .002 | ..... |
| Maintenance third rail, feeders and bonding | .273 | .072 | .087 | .022 | .255 | .077 | .340 | .097 | .094 | .029 |
| Inspection, repairs and cleaning electric locomotives | .206 | .055 | .203 | .053 | .172 | .052 | .233 | .067 | .171 | .052 |
| Totals | $2.254 | $0.596 | $0.681 | $0.433 | $1.836 | $0.557 | $2.141 | $0.611 | $1.807 | $0.554 |

**Table III. COST OF MAINTENANCE OF ELECTRIC LOCOMOTIVES**

| | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 6 Months 1914 |
|---|---|---|---|---|---|---|---|---|---|
| Class LE-1 locomotives— | | | | | | | | | |
| Mileage | 54,379 | 46,259 | 47,620 | 47,092 | 19,689 | 16,480 | | | |
| Cost per locomotive mile | $0.169 | $0.339 | $0.139 | $0.079 | $0.170 | $0.091 | | | |
| Class LE-2 locomotives— | | | | | | | | | |
| Mileage | 125,199 | 134,623 | 122,090 | 126,258 | 138,098 | 129,146 | 92,550 | 87,556 | 38,000 |
| Cost per locomotive mile | $0.067 | $0.062 | $0.040 | $0.029 | $0.041 | $0.044 | $0.063 | $0.054 | $0.043 |
| Class OE-1 locomotives— | | | | | | | | | |
| Mileage | | | | | 42,110 | 61,112 | 52,150 | 48,376 | 25,568 |
| Cost per locomotive mile | | | | | $0.029 | $0.051 | $0.034 | $0.073 | $0.079 |
| Class OE-2 locomotives— | | | | | | | | | |
| Mileage | | | | | | | 39,280 | 50,440 | 26,284 |
| Cost per locomotive mile | | | | | | | $0.030 | $0.067 | $0.044 |

**Table IV. COST OF MAINTENANCE OF THIRD RAIL IN DOLLARS PER MILE OF THIRD RAIL***

| Fiscal Year Ending June 30 | 1913 | | 1914 | |
|---|---|---|---|---|
| | Labor | Material | Labor | Material |
| Third rail | $231.00 | $12.00 | $259.00 | $86.00 |
| Third-rail jumpers and feeders | 29.00 | 242.00 | 36.00 | 173.00 |
| Bonding | 117.00 | 438.00 | 140.00 | 1211.00 |
| Totals | $377.00 | $692.00 | $435.00 | $1470.00 |
| Misc. exp. | $160.00 | | $67.00 | |
| Grand totals | $1229.00 | | $1972.00 | |

* Includes complete renewal of third rail, jumpers, etc., in tunnel and extensive rebonding throughout electric zone.

expected from the grade conditions the power cost is by far the largest item. The cost of current per kilowatt-hour at the d-c. bus comprises the cost of purchased current, generated current and substation operation and maintenance. As the cost of purchased current includes fixed charges while that of current generated by the railroad and substation operation does not, the figures given do not represent the total actual cost per kilowatt-hour.

Table III shows the mileage made by electric locomotives and cost of maintenance over a period of nine years. The maintenance of the class OE-1 and OE-2 locomotives has been abnormal on account of considerable number of armature burnouts, caused by overloading due to handling trains beyond their capacity. In addition as the railroad has no facilities for repairing armatures of this size the expense has been large. This trouble has now, however, been overcome and it is expected that the maintenance will again fall to the normal of between 3 and 4 cents per locomotive mile.

Table IV shows the cost of third-rail and feeder maintenance in dollars per mile of third rail for the past two fiscal years. Cost of third-rail maintenance is rather high due to considerable amount of renewal work that has been necessary. The heavy traffic conditions and the somewhat unusual amount of curvature requires rather frequent track renewals and consequent rebonding.

# DESIGN OF MOTORS FOR HEAVY TRACTION WORK

By Edward D. Priest

Engineer, Railway Motor Department, General Electric Company

This article includes a discussion of the design of electric motors for heavy traction from many different view points, considerations governing the choice of the geared or gearless type, the mounting of motors, the type of drive, the center of gravity, the number and size of motors, ventilation, mechanical losses, electrical losses and other important factors are ably discussed. Some of the earlier types of electric locomotives are considered and their motors and driving gear briefly reviewed.—Editor.


**Edward D. Priest**

It is not the purpose of this paper to discuss or compare d-c. vs. a-c. railway motors for heavy traction work, but to briefly consider general lines of design which have been followed in the past or which may be followed in the future whether motors are a-c. or d-c.

Motors for heavy traction work can be conveniently divided in mechanical construction into two general types,—geared and gearless. Either type may be applied with or without side rods.

For slow speed heavy traction work the gearless motor with a low armature speed is abnormally expensive to build and low in electrical efficiency. A gearless motor is not suited for this class of work. For intermediate speeds the gearless motor is less handicapped in this respect, and for high speeds not too seriously handicapped, since the peripheral speed of the armature approaches the speed at which it is desirable to operate any armature, geared or gearless. The question then of whether a motor for this work should be geared or gearless is largely influenced by the locomotive speed desired.

It can be assumed that within the limits of practical design the single reduction geared motor will generally have a higher total efficiency than a gearless motor for speeds under approximately 30 miles per hour, and for speeds higher than 30 miles per hour the bi-polar gearless motor will have a higher efficiency. The reason for the reduced efficiency of a gearless motor in low speed work is because of high $I^2R$ losses made necessary by the low armature speed. The increase in $I^2R$ loss is greater than the gear loss incident to the use of geared motors.

At light loads a gearless motor is especially efficient because of the absence of gear loss, and possibly bearing loss. The percentage of gear loss and bearing loss is high in a geared motor at light loads and low torque, while the percentage loss is comparatively low at low speeds and heavy torque. For short runs in which acceleration is a large factor the problem of power efficiency is somewhat complicated.

At the continuous tractive effort rating, in work for which geared and gearless motors are normally suited, the electrical efficiency of d-c. motors will vary from about 91 to 93 per cent, the geared motor generally having the higher efficiency and the gearless motor the lower efficiency.

The method of mounting motors and transmitting power from the armature to the driving wheels has a large influence on efficiency, whether the motor be geared or gearless.

A gearless bi-polar motor, with an armature mounted directly on the axle without bearings, has a mechanical efficiency of 100 per cent, practically all mechanical losses being eliminated.

If the armature of a gearless motor is mounted on a quill surrounding the axle, the quill being carried in bearings supported on the motor frame and power transmitted through a flexible drive to the driving wheels, the mechanical efficiency at the continuous rating of the motor is possibly 97 per cent.

If a gearless motor is mounted on a locomotive frame and power transmitted through connecting rods, the mechanical efficiency is possibly from 85 to 90 per cent, depending on the number and arrangement of driving parts.

A single reduction geared motor, mounted directly on the axle, at its continuous rating has a mechanical efficiency of approximately 96 per cent, and possibly 94 per cent when mounted on a quill for flexible drive through a coupling.

If a geared motor is mounted on the locomotive frame and power transmitted through connecting rods, the mechanical efficiency is possibly 85 to 90 per cent, or about the same as for a gearless motor. The mounting of a geared motor on a locomotive frame can generally be made in such a way as to reduce the number of connecting rods as compared with a gearless motor.

It will be noted, therefore, that for mechanical efficiency in transmitting power from the armature to the driving wheels, the bi-polar gearless motor mounted directly on the axle has the highest efficiency; that there is but little difference in mechanical efficiency between a geared motor mounted on the axle and a gearless motor with flexible drive mounted on a quill surrounding the axle, and that the mechanical efficiency of geared and gearless motors with side rod drive is approximately the same for each type.

The importance of high efficiency is of course largely influenced by the cost of power, which varies widely in different localities and with different conditions, so that the question of efficiency becomes more or less important depending upon the location of a given installation and other determinable factors.

From the standpoint of operation there is a great diversity of opinion concerning the correct mounting of motors on locomotives for heavy traction work. Both in this country and abroad a large number of different mountings have been tried. The side rod construction has been used in many varying and ingenious types, but in the writer's opinion it is doubtful if electric side rod locomotives can be built at a "right price" or operated with complete success. As has been pointed out, the mechanical efficiency of transmission is low and the design is to a considerable extent complicated. To transmit power from a rotary motion through a reciprocating rotary motion always seemed to the writer forced and illogical as compared with more direct methods.

While not unmindful of the advantages, at high speeds, of a high center of gravity, which can be readily secured by the use of connecting rods, it is the writer's opinion that equal and possibly superior results can be secured in a more direct and simpler construction.

It is clear that the simplest form of mechanical drive is obtained by mounting a motor, either geared or gearless, directly on the axle. If then, this type of motor permits a design of locomotive which has a higher power efficiency, satisfactory riding qualities, as regards the effect on track and road bed, no higher first cost, probably lower, and no increase in maintenance, probably lower maintenance, it would obviously seem the right type.

A low center of gravity can be compensated for by distributing the load over a greater length of track with a larger number of driving wheels and axles and by a proper design in respect to the arrangement of parts and distribution of loads. An increase in the number of driving wheels has the advantage of reducing the concentrated load per axle and also flange and rail head wear, the pressure between these parts being sufficiently reduced to prevent undue abrasion of the metal, so that, while the number of contact points would be increased, the actual wear would be reduced. The arrangement of motor axles, trucks and superstructure in a locomotive largely affects the riding qualities of the locomotive. There may be an advantage in equipping a locomotive with motors of different size or even different types, using for instance light motors on leading axles and heavier motors on intermediate axles. While at first thought this may seem complicated, in the writer's opinion it is not a serious complication.

It is not the purpose to enter into a lengthy discussion of the riding qualities of locomotives but to point out that whatever defects exist at high speeds in a low center of gravity can be successfully overcome by proper design.

The writer's conception of a motor for heavy traction work would be a motor of suitable capacity for mounting on a locomotive having a weight per axle of from twelve to twenty tons. If a geared motor, it would be of the single reduction, single geared type, mounted directly on the axle, and if a gearless motor it would be of the bi-polar type with the armature mounted directly on the axle. The driving wheels would be comparatively small in diameter, approximately 34 in. to 42 in.

For either high speed or low speed heavy traction work the natural development is toward an increase in the number of motors rather than an abnormal increase in the size of motors. It is thought that the development of motors along this line will materially cheapen the cost of locomotives, it being possible to construct frames and trucks of cheaper material and with less finish. There is a wide application for motors of moderate size, and consequently costs can be reduced by manufacturing in large quantities. The capacity of locomotives can be regulated by the number of motors and axles used.

It is quite possible to design motors so that they can be utilized partly to perform the functions of a truck, thus doing away largely with the truck frame and completely with truck journal bearings. This type of geared motor seems especially applicable to low speed work. The initial cost of electric locomotives is a handicap to the electrification of steam railroads. Anything which can be done to reduce the cost will materially promote electrification.

In the design of motors for heavy electric traction it is necessary to provide suitable means for ventilating the motors in order to secure motors of reasonable size and cost. Although motors can be designed for quite effective self ventilation with suitably designed fans constructed as a part of the armature; to obtain the most effective results external blowers are required. The capacity of a motor to perform work depends not only on its efficiency but on its ability to dissipate heat. Assuming for instance that a closed motor can dissipate 2000 watts, a self-ventilated motor can dissipate 4000 watts, and an externally blown motor 6000 watts, thus the externally blown motor has a capacity to perform much more work than a completely enclosed non-ventilated motor. It will be understood that these values are quite approximate and are used to convey a general idea of the value of ventilation.

The amount of heat which can be dissipated is influenced not only by the volume of air blown through the motor, but by the distribution of the air, i.e., the flow of air to be most effective must be properly distributed and the air should come into intimate contact with the heated parts. In passing between intake and exhaust the air should be made to take up as much heat as possible.

Another way of increasing the capacity of a motor of given weight is to increase the permissible temperature at which the motor can be run. This can be accomplished with satisfactory results by using insulating materials which will successfully withstand higher temperatures. It is the writer's opinion that electric motors will in the future be operated at materially higher temperatures than now ordinarily prevail; indeed, satisfactory insulating materials are at present available to accomplish this. Under certain conditions the ultimate permissible temperature may be fixed by power efficiency rather than by the effect of heat on the materials used. It is desirable that the temperature at which the motor is designed to run should not be controlled by limitations of insulating materials.

In designing motors it is important to secure the right relation between copper loss and core loss. In certain classes of service the core loss may be of less relative importance than the copper loss, and vice versa. A motor may have a high core loss at nominal rating, i.e., one hour run at 75 deg. C. rise, and yet have a low core loss for continuous service at light loads. If the work is largely acceleration, nominal load core losses are relatively of less importance than copper losses.

In heavy traction work motors are occasionally subjected to excessive overloads for short periods of time. This is especially true with motors designed for high speed heavy passenger service where the continuous rating of the motor is considerably under the slipping point of the wheels. Such motors should be designed to withstand high momentary copper temperatures, possibly as high as 200 deg. C. or even higher. The momentary copper losses may be abnormally large, while the amount of heat which can be radiated in the short interval of overload is small. Practically all the heat has to be stored in the copper until it can be slowly dissipated. In the design of such a motor provision should therefore be made for high temperatures and all electrical connections made so that they will not be damaged by heating.

In heavy traction work the continuous load on the motor is usually high and therefore commutating characteristics must be especially good in order that the commutator and brushes will not be damaged. Railway motors of ordinary design may be heavily overloaded with considerable sparking for a brief period, if there follows a comparatively long period of light load during which the commutator recovers, as it were, from the effects of the heavy load. Free running at a light load allows the commutator to take on a polish which removes the injurious effect of the overload.

Heavy slow speed traction motors are sometimes abused by running them down grade at high speed. With an efficient design for low speed locomotive work a high gear reduction must be used. This at a high locomotive speed, as on down grades, gives a high armature speed; too high for safe operation. In addition to this a slow speed heavy traction locomotive, if designed to the best advantage, does not have riding qualities suited for high speed running. It should be understood that there must be restrictions on the maximum speed of an electric locomotive which is designed for low speed, as there are restrictions on the maximum speed of a steam locomotive which is designed for low speed. It is fundamental that electric locomotives can not be economically designed for low speed heavy traction work and without change be suitable for high speed traction work. The two kinds of service are fundamentally different and should be differently treated.

In the past few years marked advances have been made in the design and manufacture of gears and pinions for railway motors. The use of high grade heat treated steel has very largely increased the strength and life of gears, and indirectly the average efficiency of motors, since the correct shape of the gear teeth is maintained for a longer period. Motors mounted on the axle with single reduction gearing in heavy slow speed traction work have a gear life of approximately 300,000 to 400,000 miles, and a pinion a life of approximately 150,000 to 200,000 miles. This makes the cost per mile for gears extremely low, almost insignificant. It may be stated, therefore, that there is no practical objection to the use of gears in heavy traction work because of their maintenance cost. For sentimental reasons there may be an objection to gear noise, but with well cut, well lubricated gears this can be reduced to a minimum. Practically the only objection to gears is the loss in power, but even this is low with well cut single reduction gearing.

For high speed work the gear problem is somewhat more difficult than for low speed work. The strength of gear teeth is ordinarily ample to transmit the torque of the motor up to the slipping point of the wheels. At a high speed on a rough track, due to uneven rail joints, cross-overs, etc., blows may be delivered to the teeth which theoretically are beyond their elastic limit. It is the writer's opinion that such blows are almost entirely the cause of broken pinion or gear teeth when such occur. Incorrect spacing of gear teeth or variations in the thickness of teeth, due to errors of manufacture, may at high speed cause abnormal tooth stresses. This of course can be largely overcome by accurate methods of machining. Excessive tooth strains can also be largely eliminated by the use of spring gears, i.e., gear rims held by springs so that the rim can have a slight movement in rotation independent of the axle.

Probably the first electric motors ever designed, certainly the first to be manufactured, for heavy steam railway electric traction work, were the motors used on the 96-ton locomotives manufactured by the General Electric Company for the Baltimore & Ohio Railroad. These locomotives were designed to haul trains through the B. & O. tunnel at Baltimore, and have a capacity to handle 1200-ton freight and 500-ton passenger trains, including a dead steam locomotive, through the tunnel up an 0.8 per cent grade. The design of the motors was started in the spring of 1892, but owing to delays in building the tunnel, the locomotives were not completed and put into service until July 1, 1895. They have operated successfully for many years, at times hauling 1800- and 2000-ton trains.

Although the speed at full load was low, approximately 15 miles per hour, the motors were designed without gears owing largely to the desire of the Railroad Company to avoid the use of gears and the lack of experience on the part of the manufacturer with geared motors of such large capacity. At that time heat treated, high grade steel gears, such as are now in use, were not available. The motors were designed with six poles, two motors in series on 700 volts. The armature was mounted on a quill shaft which was supported in bearings on the motor magnet frame. Power was transmitted to the driving wheels through a spider mounted on each end of the quill. Arms radiating from the spider projected between the spokes of the driving wheel. Between the arms and the spokes, blocks of rubber were interposed, the rubber being of such size and shape as to permit a considerable movement between the motor and the wheels and axle. On the whole this arrangement worked very well. It was found, however, that the cost of the rubber made it rather expensive to maintain.

With modern knowledge of motor design, especially in respect to the availability of gear drive for heavy work, motors for this class of service would unquestionably be designed for operation with gears. In fact, all locomotives of later design for use in the B. & O. tunnel service have been equipped with geared motors.

Although not for heavy haulage work an interesting example of motor design for a mining locomotive was a motor made by the Thomson-Houston Company in 1889 for the

Erie Colliery, near Scranton. This motor was mounted on the main frame of a two-axle four-wheel locomotive. Power was transmitted through double reduction gearing to a jack shaft and from the jack shaft through crank pins to sliding blocks in slotted or Scotch yoke connecting rods to the driving wheels. This was one of the first electric locomotives to be used in mine haulage in America. It was successfully operated for twenty-three years, being taken out of service about two years ago. A better construction would have been to mount the motors directly on the axle and to transmit the power through gears. The use of side rods at that time was more or less a concession to sentiment which assumed that electric locomotives should have side rods because steam locomotives had side rods.

A light locomotive of better design was built by the Thomson-Houston Company at an earlier date than this side rod locomotive. The locomotive had a two-axle four-wheel truck with a small double reduction geared motor mounted on one axle. The motor was designed in December, 1887, for the Tremont & Suffolk Mills, Lowell, Mass. It remained in service until the year 1900. This was possibly the first practical use of an electric locomotive in a manufacturing plant. The motor was known as F-6 and had about 3-h.p. capacity.

An interesting type of motor designed for a 30-ton two-axle locomotive was made by the Thomson-Houston Company in 1892. The motor was known as the L.R.R. It was a four-pole gearless motor with the armature mounted on a quill shaft surrounding the axle. Power was transmitted from the quill through a somewhat novel coupling to the driving wheels. The coupling, without the use of springs, allowed complete flexibility of movement between the quill and the axle for the full amount of clearance between the quill and axle. Mounted on one end of the quill was a spider with an inclosing outer rim. Projecting from the spider toward the driving wheel, at diametrically opposite points, on the spider, were pins of rectangular cross section. Ninety degrees from these pins were two similar pins projecting from spokes of the driving wheel. Power was transmitted from the two opposite pins on the spider to the two pins on the driving wheel through an intermediate floating member surrounding the axle and slotted to receive the pins. The floating member was carried entirely on the pins and to prevent undue movement, parallel to the axle, comparatively light springs were interposed between it and the spider, and between it and the driving wheel. The driving pins were free to slide in the slots of the floating member so that except for a movement in the direction of rotation there was freedom of movement between the motor and axle.

Probably the simplest gearless motors which have ever been designed for heavy traction work are the motors known as bipolar motors used on the locomotives which have been in operation for a number of years in the New York Central and Hudson River Railroad Grand Central Terminal service, New York. In mechanical construction it would be difficult to conceive of a simpler design. The armature is mounted directly on the axle and is free to move in a vertical direction between pole pieces attached to the magnet frame which forms part of the locomotive truck frame. These motors were designed for high speed and are remarkably efficient at free running.

# THE INTERURBAN RAILWAY OF THE ILLINOIS TRACTION SYSTEM

By H. E. Chubbuck

Vice-President Executive, Illinois Traction System

This article includes a general description of the physical characteristics, nature of service, energy supply, and equipment of one of the largest interurban systems in the world. It will be noted that in many respects the service rendered closely approximates that given by many steam railroads. The sleeping- and parlor-car equipment and freight traffic are reviewed and some interesting notes are given concerning the operation of the system.—Editor.

Like the entire electric railway industry, the Illinois Traction System has grown rapidly. The present property, with nearly a thousand miles of street and interurban track, and with light, heat and gas service in six states, had a modest beginning with six miles of track built in 1901 from Danville to Westville, Illinois. The growth of this property has followed the controlling ideas of its president, William B. McKinley, who in the early days of the interurban railroad, undertook the construction of a group of roads that would unite the substantial cities of Central Illinois in which public utilities could also be operated.

The general construction plan included tracks and roadways, comparable with those of the steam roads, and so designed that the heaviest freight and passenger equipments might be handled economically. Energy for the propulsion of the trains was to be furnished from large generating stations so located as to secure economy in fuel delivery and in the distribution of the output. The results show how well the far-sighted plans of the builders have been realized.

Numerous public utilities have been built or purchased and rehabilitated during the period of interurban development, until now electric lighting and power service is furnished in 92 cities, street railways are operated in 24 cities, gas is furnished in 13 cities, steam heat in 11 cities, and water in two cities.

Modern plants have been installed and distribution systems designed to afford good service with high operating economy.

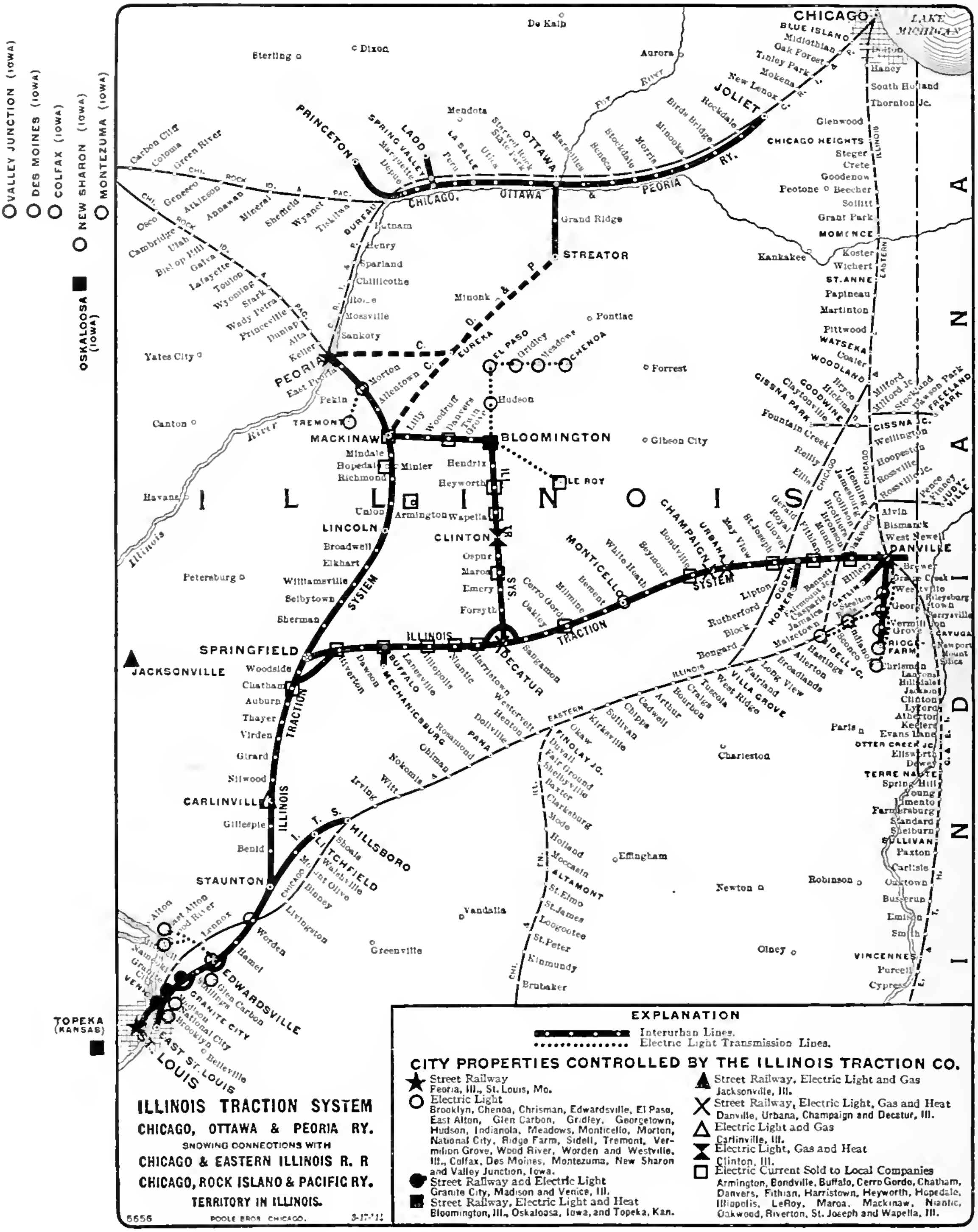
No doubt our electrically-operated railway system in Central Illinois is the most interesting part of our system, and, therefore, that will be described and some of its most notable features will be set forth in this article. A map shows the location of our Illinois interurban lines and the following table gives the mileage, equipment, etc., of the interurban system.

| | |
|---|---|
| Miles of main line track operated | 431.90 |
| Miles of passing track, sidings, etc. | 32.54 |
| Miles of shop and yard track | 13.15 |
| Miles of industrial track | 13.52 |
| Population served by road | 2,500,000 |
| Passenger motors | 89 |
| Passenger trailers | 21 |
| Parlor cars | 7 |
| Sleeping cars | 5 |
| Combination passenger and baggage | 4 |
| Express motors | 17 |
| Express trailers | 98 |
| Line motors | 6 |
| Steel locomotives | 21 |
| Box cars | 116 |
| Gondolas | 319 |
| Flat cars | 37 |
| Refrigerator cars | 9 |
| Scenery cars | 2 |
| Hopper bottom cars | 228 |
| Cabooses | 13 |
| Miscellaneous and work cars | 54 |
| Substations | 40 |
| Central power stations | 4 |
| Belt lines | 4 |
| Miles protected by block signals | 150 |

Referring again to the map of the interurban system it will be noted that the main division of the Illinois Traction System extends from Peoria on the north, to St. Louis, Mo., on the south, a distance of 174 miles. At Mackinaw Junction, about 20 miles south of Peoria, the Bloomington & Decatur division branches off the main division. From Springfield the lines extend eastward as far as Danville, a distance of about 125 miles, serving Decatur, Champaign and Urbana and intermediate points. From Danville a branch extends southward to Ridge Farm, and another to Catlin. On the eastward from Stanton, a branch extends to Hillsboro.

The company also operates a 17-mile interurban road between Galesburg and Abingdon and between Galesburg and Knoxville.

The northern branch of the McKinley interurban system is known as the Chicago, Ottawa & Peoria Railway. It extends from Joliet on the east to Princeton on the west,



Map of Illinois Traction System. Chicago, Ottawa & Peoria Railway, showing connections with Chicago & Eastern Illinois Railroad serving Ottawa, LaSalle, Peru, Spring Valley, Bureau and intermediate points. This division has 106 miles of track and at Joliet connection is made with the Chicago & Joliet Railway, which offers a through electric service into Chicago. A branch extends northward from Spring Valley to Ladd and another division extends southward from Ottawa to Streator.

**Service**

Over the entire system trains are moved in either direction practically every hour in the day and schedules are arranged to fit local conditions in accordance with traffic demands. The passenger trains operated consist of limited and local passenger service, parlor and sleeping-car service, fast merchants' dispatch freight service, general freight trains and the transportation of heavy freight, such as trains of grain and coal in carload lots. The limited passenger trains stop only at the larger towns and cities and are supplemented by local trains stopping on signal at country highway crossings. The Illinois Traction System now has in operation "belts" around the cities of Edwardsville, Granite City, Springfield and Decatur. By the use of these belt lines, long, heavy trains of standard freight cars may be drawn around the cities by electric locomotives at a good speed. This arrangement also prevents the disturbance of passenger schedules and makes possible traffic connections with steam railroads and industrial tracks to manufacturing plants that otherwise would not be easily accessible. Similar belt lines are contemplated around other cities on the line.

With the growth of the interurban system there has also followed the development of public utilities in many cities in Illinois, Iowa, Kansas and Missouri. Practically the entire mileage of the Illinois Traction System is on private right-of-way, the greater part of which is sixty-six feet or more in width. The design of the roadway and track is similar to that of steam railroads, the rails weighing seventy pounds per yard. They are spiked to standard ties and ballasted throughout with gravel, crushed stone and chatts, which are the tailings from Missouri zinc mines. All the ties installed in the past four years have been treated with a creosote preservative compound to reduce the cost of future maintenance work. A separate tie replacement fund has been established for tie renewals.

**Supply of Electrical Energy**

The generation and distribution plants, for furnishing the electrical energy used in propelling the trains, have been designed with due regard to an immediate low operating cost and future enlargement. The central stations located at Peoria, Danville, Riverton near Springfield, and Venice near St. Louis, have a total normal capacity of 27,500 kw. These plants are connected through the medium of a 33,000-volt three-phase transmission system, a large part of which is carried on an independent pole line to insure continuity of service. The generating stations have been located with due regard to the low cost of fuel and economy in distribution. At two locations large under-water coal storage tanks have been built.

Parlor-Car Train

The plant at Venice which is of the most recent design has a peak load capacity of 13,000 kw., which can be quadrupled by completing extensions contemplated in the original design. No power-driven conveying plant is required for handling the coal and ashes at this station because it is so located at the east approach of the McKinley Bridge that the coal is carried over the 800-ton bunkers in standard railway hopper cars, and the ashes fall into the cars on the ground level beneath the boilers.

The generating stations at Peoria, Riverton, and Danville include the latest types of steam-turbine-driven generating machinery. The high tension transmission lines uniting the capacity of the four large generating stations also serve for distributing energy to the forty rotary converter substations in which it is transformed and converted into 650-volt current, suitable for distribution over the trolley wires and feeders to the cars.

The accompanying illustrations show the character of the overhead distribution system. It consists of flexibly supported trolley wires, supplemented by bare copper feeders of 000 and 000,000 capacity respectively, so placed as to enable heavy locomotive-drawn freight trains to be operated along with the local and limited passenger trains, without unduly low voltage conditions.

Standard Substation and Waiting Station

Rotary converter substations are located at intervals of approximately 10 miles. These are attractive structures and most of them also serve for passenger stations. They are built of pressed buff brick, trimmed with limestone, and have French tile roofs with overhanging eaves.

### Rolling Stock

A statement of the various classes of rolling stock has been given. Standardization of equipment has been followed so that, should occasion demand, any traction car or locomotive could be hauled over any steam railroad in the United States and meet all requirements throughout in the matter of coupling arrangements, air brakes, wheels, etc.

As this system conducts a general railway business in all its branches its supply of passenger and freight equipment must necessarily be large and varied. Special types of cars must be at demand for the hauling of special classes of business and the company has made it a principle to keep its equipment right up with business demands. An example is to be found in the construction of special scenery cars for the handling of theatrical properties, automobile cars, refrigerator cars, etc. All of these special types of equipment have been designed by the company and contain many modern and special appliances not found on the equipment of other lines. Strength, serviceability, safety and comfort has been the motto of the Illinois Traction System in the designing of its passenger equipment.

The regulation passenger coaches have developed from a coach weighing 60,000 lb., and measuring 38 feet in length to a coach weighing 100,000 lb., measuring 68 ft., 4 in. in length. Motors have progressed from 35-h.p. to 200-h.p.

The Illinois Traction System has operated sleeping cars for more than six years and observation parlor cars for nearly three years. The sleeping cars are 57 ft. long, over bumpers, and 9 ft., 7 in. wide, and weigh 84,000 lb. The bodies are of a heavy substantial Pullman-type construction with segmental arch roofs. They are mounted on steam-coach type, four-wheel, steel-frame trucks with quadruple elliptic bolster springs, and are provided with the M.C.B. contour, high-knuckle couplers. There are twenty berths in each car, the design of the upper and lower berth being uniform. The cars are illuminated by seventy mazda lamps, fed from a special panel governing a Gould storage battery of sixteen cells.

### Sleeping-Car Service

A sleeping-car service is given between Peoria, Springfield and St. Louis. Two four-car trains make this 174-mile run each night. The combination motor-express cars which haul the sleeping-car trains were described in the *Electric Railway Journal* for Febuary 2, 1911, page 275. These cars are 52 ft., 6 in. long, 9 ft., 5⅜ in. wide, have an underframing and body of heavy design and are equipped with four 140-h.p. motors. These motor cars haul a trailer coach and two or three sleeping cars satisfactorily at the average schedule speed of about 23 m.p.h. which includes time

Standard Shelter

for cutting in and out extra cars at Springfield and making all station stops between 6 and 7 a.m. as the terminals are approached. The motor cars weigh about 100,000 lb. each. All sleeping-car trains are equipped with air brakes with universal valves in place of triple valves.

The sleeping-car trains have brought to this railway system traffic which it otherwise would not have had. Practically all of the passengers who now take the sleeping-car trains, both in the coaches and in the sleepers, would otherwise have taken steam trains had the Illinois Traction System not introduced the sleeping-car service. The business has gradually increased until now five sleeping cars are required, four of which are in operation daily and a fifth in reserve for over-hauling and for special parties, to which latter use it is frequently put.

### Parlor-Car Service

In 1911 the Illinois Traction System inaugurated an extensive parlor observation car service which has since been expanded, until now, seven fine, large heavy 80,000 lb. parlor cars are in use. Parlor cars are attached to limited trains. The running time of a limited passenger motor car with trailer attached from St. Louis to Danville, 227 miles, is nine hours and fifteen minutes, and the running time between St. Louis and Peoria is six hours and forty-five minutes. Thus the schedule speeds of these trains are about 25 m.p.h., including all stops and dead time at junctions.

These parlor observation cars are 57 ft. long, 9 ft., 7⅛ in. wide, are mounted on standard steam-coach, steel-frame, four-wheel trucks with quadruple elliptic bolster springs, and are equipped with the Sharon type M.C.B. coupler. There are eight double seats, twenty-two mahogany chairs and six Pullman-type camp stools in the parlor cars.

The rates for seats in the parlor cars are approximately ½ cent per mile in addition to the regular first-class fare. A minimum rate of 15 cents is observed. All terminal station agents sell seat tickets and make reservations in advance for parlor-car seats and sleeping-car berths.

The energy consumption of these limited trains with heavy observation parlor-car trailers, as compared with the same limited motor cars, shows that while the motor car alone consumes about 64 watthours per ton mile, the same motor car, when hauling the parlor car as a trailer in the same run, consumes about 46 watthours per train ton mile.

Freight and express traffic is handled by motor express cars drawing trailers and by large electric locomotives. Twelve all-steel locomotives have been built in the company's shops from designs made by its mechanical department, each weighing sixty-three tons and having a drawbar pull of 35,000 lb. A locomotive, with its four 200-h.p. motors, can handle long freight trains with the ease of a large steam railroad locomotive.

Distance Signal in "Proceed" Position. Also showing High Tension Overhead Construction, Trolley, Feeder, Telephone and Signal Wires

### Shops

Inspection and repair shops are located at each of the larger cities on the road, the work being done supplementing that of the main repair shops which are located on a fifteen-acre tract just east of Decatur. The Decatur shop machinery is housed in three large fireproof buildings, designed and built particularly for the maintenance of electric railway rolling stock. The tools in these shops are such as not only to make all repairs to cars, but to also build new equipment. A new group of shops has been started at Granite City, where a fireproof repair shop building has been constructed, designed to handle the maintenance and inspection work on the interurban cars of the division south of Springfield and on the street cars operated in the St. Louis bridge service.

**Operation**

All trains are operated under orders transmitted to the train crews by telephone from centrally located dispatchers. A complete system of remote control signal semaphores to assist the dispatchers in controlling the movements of trains has been installed over the entire road. Every possible safeguard, such as double checking of orders, spelling out the names of meeting points and the use of high grade duplicate telephone apparatus, is employed to increase the safety of operation.

McKinley Bridge, St. Louis

The rules under which the trains are dispatched and operated have been based on the best experience in steam and electric railway service.

**Automatic Block Signals**

In addition to the foregoing system of safeguards, most comprehensive plans for the protection of trains by automatic block signals have been executed. An extensive investigation resulted in the purchase of sufficient automatic block signal apparatus to protect fully 150 miles of track.

The signal equipment was made by the Union Switch & Signal Company, and attention is called to the fact that the automatic block signals adopted as a standard by this road are of the type which have given satisfaction on many thousand miles of steam railroad tracks of the larger trunk lines.

These signals are fully automatic and protect a train by displaying semaphores in the "stop" position at a sufficient distance in front, and behind it, to provide for ample braking distance in case there should be misinterpretation of the dispatcher's orders. They protect the meeting point of trains at sidings as well as curves and subways. They are also designed so that any derangement of the running rails, track bonds, signal wires or open switches would cause them to assume the "stop" position.

The workmanship of this signal installation, costing about $500,000, has been executed with a view to obtaining the maximum safety as a first consideration combined with low maintenance cost. During four years in which these signals have been in operation their performance has been more than 99.97 per cent perfect.

**McKinley Bridge**

In 1907 construction work was started on the McKinley Bridge at St. Louis and the bridge was opened to traffic in October, 1910. The length of the bridge and approaches is over 8000 feet and its carrying capacity is 12,000 pounds per lineal foot as against 10,000 pounds per lineal foot for any other structure across the river. The main bridge carries two railroad tracks through a center space of 26½ feet; two roadways 14 feet wide each are carried on cantilever brackets. The total width of the bridge over all is 65 feet and the clearance above low water is 85 feet. Under the east approach stands the Venice power plant previously mentioned. The approach on the Missouri side passes over 24 acres of freight yards owned by the company and from this approach the double tracks of the system reach into the business district of St. Louis, where there is a modern passenger station and a commodious express-freight terminal with large receiving platforms and sheds for the freight and express business.

Type of Elevator, Illinois Traction System

**Freight Traffic**

The Illinois Traction System is now handling over its lines, trains of standard railway equipment and has built up its freight and express department along standard lines established by the steam roads. The tariffs are based on those established by the steam roads and methods of operation follow closely those laid down by the well established railway systems.

Interchange arrangements exist between this electric system and many steam roads. A typical illustration of this is found at Glover, where there is a physical connection between the Illinois Traction System and the Chicago & Eastern Illinois Railway. By means of this connection a through service for package freight to and from Chicago is maintained.

At Glover there is located a transfer elevator, by means of which grain may be shipped from Illinois Traction points to Chicago, Nashville and St. Louis.

The grain shipping facilities offered by the company have developed rapidly during recent years and are becoming an important factor in the movement of crops from the big grain belt of central and southern Illinois. At present there are twenty-two elevators, ranging in capacity from 10,000 to 50,000 bushels, on the lines. The elevators are substantially built and equipped with modern grain handling machinery, which afford quick shipping facilities for the farmers in the territory.

There are six coal mines whose output is handled exclusively or partly by the Traction System.

Track connections have been established with seven roads, including the St. Louis Terminal Railway Association. Joint rates for through business have been established with eleven roads, and through rates covering grain have been arranged to Chicago, Detroit, Toledo, eastern seaboard, Mississippi River and Gulf points. In general we render to our communities every service offered by steam railroads and our frequency of trains and the convenience of our stations and terminals has won for the Illinois Traction System a steady increase in revenue.

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# MAINTENANCE AND OPERATION OF THE DETROIT RIVER TUNNEL

By J. C. Mock

Electrical Engineer, Michigan Central Railway Company

The author reviews the physical and electrical characteristics of this most interesting installation and then gives quite an extensive analysis of the traffic conditions. The locomotive mileage, the delays to traffic, and the power consumption are fully dealt with. The maintenance of both the third rail and the electric locomotives is given and the article is concluded with a brief account of the signal and interlocking system. —Editor.

J. C. Mock

On September 18, 1910, three days after the third rail was first made "alive" in the Detroit yards, the Michigan Central began operating freight trains through the tunnel. The 16th and 17th were allowed for test runs. These were made with a two-thousand-ton train of loaded coal cars and were intended to verify, under actual service conditions, the quite exhaustive tests made on locomotive No. 7500 (which was the first of these locomotives built,) during the fall and winter of 1909 on the New York Central test track near Schenectady. They also served to teach the motormen how best to handle a heavy train with a locomotive at both ends. To prevent objectionable surging, it is important to know first where and how much the brakes should be applied, where to release and where the power application should begin.

Previous to these runs the motormen's training was restricted to running the locomotives light or attached to construction trains composed of a few flat cars. The crews were selected from the switch engine crews employed in "working" the ferry boats; that is, splitting and making-up trains and placing cars on and taking them off the ferry boats. They were taken in turn and taught to operate the electric locomotives.

As the yard tracks could not be connected in a permanent way to the tunnel tracks until September 15th, the same day that third rail was first made "alive," the only training track available from July 25th to August 5th was the east-bound tunnel track as far as each summit. The third rail on the west-bound track was connected through a short time afterward.

The first official trip made through the tunnel by an electric locomotive under its own power was on July 26th, with Mr. H. B. Ledyard, Mr. W. K. Vanderbilt, Jr., and party. For about three weeks after freight traffic was started, the tunnel was operated only eight hours a day, from 8:00 a.m. to 4:00 p.m. On October 9th a twenty-four-hour freight service was established and on October 16th all passenger and freight trains were put through the tunnel.

It took all the month of October to trim up the construction work and trim down the forces and to get adjusted to the new conditions. The operating officials felt immediate relief, the delays were insignificant as compared with ferrying, and the schedules were changed. A daily record showing a summary of the details of tunnel operation for the month of November, 1910, follows. This, as will be noted, is the first full month of 24-hour tunnel service.

| | |
|---|---|
| Total tons hauled | 1,223,012 |
| Total tons hauled, east-bound | 588,042 |
| Total tons hauled, west-bound | 644,970 |
| Total cars loaded | 30,672 |
| Total cars empty | 6,469 |
| Average daily cars hauled | 1,238 |
| Average time of trip | 16.4 min. |
| Average time of trip, freight trains | 20.9 min. |
| Average time of trip, freight trains, east-bound | 18.3 min. |
| Average time of trip, freight trains, west-bound | 23.5 min. |
| Average time of trip, passenger trains | 9.2 min. |
| Average time of trip, passenger trains, east-bound | 9.8 min. |
| Average time of trip, passenger trains, west-bound | 8.6 min. |

A brief statement of the physical, electrical and traffic characteristics and conditions of the tunnel route is necessary to an understanding of the above summary and of the data which follow:

**Physical Characteristics**

| | |
|---|---|
| Length of passenger train haul | 2.8 miles |
| Length of freight train haul | 3.6 miles |
| Length, summit to summit | 13,000 ft. |
| Length of tunnel | 8,400 ft. |
| Length of open cut | 4,600 ft. |
| Length of nearly level portion of tunnel | 800 ft. |
| Length of eastern slope | 7,300 ft. of 1½% grade |
| Length of western slope | 4,900 ft. of 2 % grade |

**From U. S. Government Data**

| | |
|---|---|
| Elevation of Detroit River (mean) | 575 ft. |
| Elevation of rails at Windsor summit | 606.5 ft. |
| Elevation of rails at Detroit summit | 601.5 ft. |
| Elevation of rails at middle of tunnel | 508 ft. |

The total curvature is 2900 feet. Of this about 1300 feet is 2 deg. which is the maximum. This curvature is divided into two nearly equal parts, the inner ends being approximately 2000 feet apart, so that all but 600 feet of the subaqueous tunnel tracks are straight. It will be seen from the above data that traffic west-bound must be lifted 98.5 feet and traffic east-bound 93.5 feet.

**Electrical Characteristics**

Current is purchased at 4600 volts, three-phase, 60 cycles. A substation to convert this current to 650 volts d-c. is located on the Detroit side of the river, 3600 feet from the Detroit summit and 9400 feet from the Windsor summit. The third rail feeders running from the substation to the tunnel by way of the Detroit shaft, which has the same location, relatively, as the substation to the two summits, are as follows:

Three 2,000,000 c.m. feeders joined to the third rail at the bottom of the Detroit shaft, one to the east-bound and two to the west-bound third rail.

Two 1,000,000 c.m. feeders run to the Windsor summit to circuit breakers in the interlocking tower and then to the third rails.

Two 1,000,000 c.m. feeders run to the circuit breakers in the 15th St. interlocking tower and then to third rails.

One 1,000,000 c.m. feeder runs eastward from the substation and is connected directly to the third rail of the east-bound track at the Windsor shaft.

A 1000-kw. motor-generator set in parallel with a 650-volt, 2520-ampere (for one hour) battery supplies current to the third rails through these feeders. A detailed description of the electrical apparatus and the distributing system will be found in the General Electric Company's Bulletin No. 4834 of May, 1911.

**Traffic Conditions**

From the beginning the Detroit River Tunnel proposition was to provide facilities for the expeditious handling of the traffic, not only of the Michigan Central, but the Grand Trunk, Canadian Pacific, Wabash and Pere Marquette, the business that is required to be taken across the river at Detroit for the last four roads being about equal to the Michigan Central in both passenger and freight. When the plans were forumlated in 1904, this total was about 2000 cars daily and it was found by an analysis of the Michigan Central Railroad records of the ten year's previous that the increase in business was about 5 per cent per year. At the start of the tunnel operations, therefore, it was to be expected that the Michigan Central would have to handle about 1270 cars daily and from the record of the first month's operation, as will be seen, it was 1238 cars. The other roads have not exercised their privilege of using the tunnel and the writer does not know if their business has been as close to the estimate as the Michigan Central business. But the following data, condensed from the record of trains through the tunnel, taking the months of June and December for each of the three years 1911, 1912 and 1913, furnish a good basis for obtaining the daily average for the three-year period.

| Year | TRAINS |  | CARS |  | TONS |  |
|---|---|---|---|---|---|---|
|  | June | December | June | December | June | December |
| 1911 | 43 | 50 | 1287 | 1361 | 40,530 | 44,872 |
| 1912 | 45 | 51 | 1215 | 1368 | 38,960 | 47,960 |
| 1913 | 50 | 55 | 1422 | 1412 | 45,567 | 45,837 |

From the above we find the daily averages for the three-year period to be as follows:

|  |  |
|---|---|
| Trains | 49 |
| Cars | 1,328 |
| Tons | 44,000 |
| Train miles | 160.4 |
| Car miles | 4,652 |
| Ton miles | 151,600 |

**Passenger**

|  |  |
|---|---|
| Trains | 20 |
| Cars per train | 8.5 |
| Train miles | 56 |
| Car miles | 476 |
| Tons per train | 425 |
| Tonnage | 8,500 |
| Ton miles | 23,800 |

**Freight**

|  |  |
|---|---|
| Trains | 29 |
| Cars per train | 40 |
| Train miles | 104.4 |
| Car miles | 4,176 |
| Tons per train | 1,225 |
| Tonnage | 35,500 |
| Ton miles | 127,800 |

The character of the traffic is best shown by an example of one day's operation. Below is the record of trains run through the tunnel on August 1, 1914. All freight trains are run as extras and they have been assigned numbers, beginning with 100 as the first of the eastward and 101 as first of the westward trips. The passenger trains are given their time table numbers.

## FREIGHT TRAINS

| EASTWARD |  |  |  | WESTWARD |  |  |  |
|---|---|---|---|---|---|---|---|
| Train No. | No. of Cars |  | Tons per Train | Train No. | No. of Cars |  | Tons per Train |
|  | Loaded | Empty |  |  | Loaded | Empty |  |
| 100 | 53 |  | 2253 | 101 | 35 | 5 | 1044 |
| 102 | 18 | 6 | 808 | 103 | 25 | 28 | 1697 |
| 104 | 7 |  | 182 | 105 | 6 | 20 | 655 |
| 106 | 53 |  | 1811 | 107 |  | 7 | 140 |
| 108 | 60 |  | 1823 | 109 |  | 50 | 1000 |
| 110 | 49 |  | 1641 | 111 | 38 |  | 1364 |
| 112 | 31 | 3 | 1343 | 113 | 27 | 10 | 1052 |
| 114 | 39 | 1 | 1630 | 115 | 6 | 24 | 789 |
| 116 | 30 |  | 1049 | 117 | 46 |  | 1378 |
| 118 | 34 | 12 | 1420 | 119 | 24 |  | 884 |
| 120 | 1 | 9 | 230 | 121 | 43 |  | 1514 |
| 122 | 19 | 37 | 1488 | 123 | 26 |  | 901 |
| 124 | 17 |  | 442 | 125 | 44 | 16 | 2217 |
| 126 | 2 | 16 | 429 | 127 | 26 |  | 824 |
|  |  |  |  | 129 | 1 | 28 | 626 |
|  |  |  |  | 131 | 34 | 1 | 1659 |
|  |  |  |  | 133 | 19 | 22 | 1271 |

## EXPRESS AND PASSENGER TRAINS

| EASTWARD |  |  |  | WESTWARD |  |  |  |
|---|---|---|---|---|---|---|---|
| Train No. | No. of Cars |  | Tons per Train | Train No. | No. of Cars |  | Tons per Train |
|  | Loaded | Empty |  |  | Loaded | Empty |  |
| DHE | 1 | 7 | 300 | 3 | 9 |  | 560 |
| 18 | 8 |  | 490 | 9 | 9 |  | 529 |
| 18 | 2 |  | 120 | 17 | 12 |  | 755 |
| 32 | 12 |  | 475 | 13 | 11 |  | 685 |
| 2 | 6 |  | 220 | 11 | 4 |  | 125 |
| 36 | 7 |  | 435 | 39 | 12 |  | 460 |
| 8 | 10 |  | 640 | 31 | 14 |  | 555 |
| 12 | 4 | 1 | 155 | 23 | 10 |  | 670 |
| 10 | 12 |  | 720 | 1 | 5 | 2 | 240 |
| 48 | 6 |  | 395 | 36 | 13 |  | 590 |
| 14 | 8 |  | 470 |  |  |  |  |
| 22 | 6 |  | 365 |  |  |  |  |

|  |  |
|---|---|
| Total number of trains | 51 |
| Total passenger and express | 22 |
| Total freight | 29 |
| Total tons, freight | 35,564 |
| Total tons, passenger and express | 9,945 |
| Total cars | 1,299 |

The foregoing details of one day's train movements are of trains varying in class and weight from local passenger trains of 200 tons to freight trains of over 2000 tons. The freight of these trains is not always of the same class. If there is not enough fast freight to make up a train of proper tonnage, other freight is added. The fast freight trains are ordinarily not over 1600 tons and other freight trains are frequently over 2000 tons. It is quite important from the standpoint of economy in operation, as well as in the saving of time, to avoid splitting any trains delivered to the electric yard that are made up and ready to be forwarded over the adjacent divisions. It is also important from the same standpoint to haul them with the least number of locomotives; since every locomotive crew consists of three men; a motorman, a second man who is called "motorman's helper," and a conductor. The conductor couples the engines and sees that the trains are in order to move. All trains above 1000 tons are ope ated by two locomotives, one being used at each end, except on an occasional express or passenger train exceeding 1000 tons. For these both locomotives are put on the head end. The head motorman controls the air. The rear locomotive is coupled into the train line the same as a car. As the locomotives are equipped with both straight and independent air brake equipment, the rear motorman can set the brakes on his locomotive but not on any part of the train.

The details of operation of a freight train with two locomotives passing through the tunnel westbound are:

(a) Coupling of locomotives by conductors (one on each end).
(b) Both motorman charge train line and head motorman applies brakes.
(c) Rear motorman cuts out train line control.
(d) Conductors inspect trains (each one-half train).
(e) Conductors signal brakes off.
(f) Head motorman releases brakes.
(g) Rear motorman whistles O.K.

NOTE.—Three whistles in Windsor and two in Detroit. By rule, all westward moves by electric locomotives are "back up" and all eastward moves by electric locomotives are "go ahead." This rule is made because the electric locomotives are the same at both ends.

(h) Head motorman repeats whistles.
(i) Leverman phones yardmaster at "receiving" yard.
(j) Yardmaster if ready to receive it says: "Let it come."
(k) Leverman clears signal.
(l) Head motorman moves train without help of rear locomotive, until rear locomotive is within about 1000 feet of bottom of grade.

Table I—LOCOMOTIVE TESTS

| | TRIP NO. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Direction. | East | West | East | West | East | West | East | West | East | West |
| Time of start. | 10:33 a.m. | 11:00 a.m. | 11:53 a.m. | 12:28 p.m. | 2:09 p.m. | 2:48 p.m. | 3:15 p.m. | 3:49 p.m. | 4:19 p.m. | 4:36 p.m. |
| Running time (minutes).. | | 17 | 16 | 16½ | 13¾ | 12¾ | 11 | 13 | 14½ | 10½ |
| Distance (miles).. | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.0 |
| Average speed (miles per hour). | | 11 | 11.6 | 11.3 | 13.5 | 14.6 | 16.9 | 14.3 | 12.8 | 17.1 |
| Speed at bottom of grade (miles per hour) | | 14 | 15 | 15 | 25 | 22 | 35 | 35 | 35 | 30 |
| Speed at portal (miles per hour). | | 11 | 10 | 10 | 10 | 12 | 12 | 12 | 6 | 20 |
| Locomotive weight (tons).. | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Weight of load hauled (tons). | 0 | 802 | 800 | 800 | 800 | 800 | 800 | 800 | 1831 | 0 |
| Total number of cars.. | | 18 | 18 | 18 | 18 | 18 | 18 | 18 | | |
| Number of loaded cars.. | | 17 | 17 | 17 | 17 | 17 | 17 | 17 | | |
| Number of empty cars.. | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| Energy consumed in kw-hr.. | 11 | | | | | | | | | |
| Start to bottom of grade (kw-hr.).. | | 21 | 3 | 12 | 1 | 16 | 4 | 9 | 0 | 2 |
| Bottom of grade to portal (kw-hr.). | | 47 | 45 | 45 | 36 | 37 | 20 | 26 | 48 | 5 |
| Portal to stop (kw-hr.).. | | 34 | 44 | 32 | 47 | 33 | 40 | 30 | 34 | 2 |
| Total (kw-hr.)... | 11 | 102 | 92 | 89 | 84 | 86 | 64 | 65 | 82 | 9 |
| Watts per ton mile.. | 35 | 41 | 37 | 36 | 34 | 35 | 26 | 26 | .... | 30 |

NOTE.—For these tests, electric locomotive No. 7505 was equipped with two 600-ampere recording wattmeters, Stewart speedometer indicating speed and recording distance. Weather—clear. Rail—dry. Temperature—about 40 degrees.

(m) Rear motorman here applies power to full multiple position of controller and as the summit is approached gradually reduces power so that when his locomotive has reached the summit the power is off.

During the movement, the rear motorman must observe the ammeter for any sudden variations and shut off power immediately when it occurs.

The maximum speed permitted is 30 miles for freight and 35 miles for passenger trains. Table I shows the results of test runs made for the purpose of determining the best speed for trains and the watts per ton-mile at different speeds. The trains are handled without surging at the higher speeds, less brake shoe wear and, of course, with less power.

### Locomotive Mileage

Until January 1, 1914, the old Third Street passenger station was used, and all passenger trains were run between the station and tunnel by steam locomotives and switched by them, so that no account was taken of the electric locomotive switching mileage. It was a rather small item, because freight trains to be taken through the tunnel are delivered by steam locomotives to the designated yard track ready to be forwarded, so that practically no switching service was performed by the electric locomotives other than an occasional damaged car being switched out of a train.

Since the new passenger yard was put into service, the switching required, because of the changes in the make up of through passenger and express trains, is now done with electric locomotives and the switching mileage is an important factor, especially as the total mileage is low; the whole tunnel operation being really a switching service. Cyclometers were, therefore, put on in order to determine the allowance which should be made for switching mileage. The following table shows the mileage record for the month of August, 1914.

| | | |
|---|---|---|
| **Freight** | | |
| Principal | 3,808 | |
| Helper | 3,808 | |
| Light | 1,821 | 9,437 miles |
| **Passenger** | | |
| Principal | 2,004 | |
| Helper | 186 | |
| Light | 486 | 2,676 miles |
| **Yard Switch** | | |
| Freight | 1,088 | |
| Passenger | 1,087 | 2,175 miles |
| Total | | 14,288 miles |

The total locomotive mileage for the three-year period, from 1911 to 1913, was 415,247; a yearly average of 138,816; and a monthly average of 11,568. If the switching mileage of 2175 for August is deducted, it will be very nearly the same as the average locomotive mileage for the previous three-year period. We find the total daily average mileage for the locomotives for all service is 377.5, but that the total train mileage for the same period is only 160.4. This apparent discrepancy is reconciled if the subdivision of service is analyzed. Referring to the August mileage: The train miles designated as "principal" are 5812, or nearly 41 per cent of the total of 14,288 and the ratio of train miles to the total for the three-year period, from 1911 to 1913, is 40 per cent.

The freight helper mileage, as will be noted, is the same as the principal mileage, indicating that every freight train is taken through the tunnel with two locomotives and in the passenger service is included express and passenger trains which occasionally exceed the tonnage hauling capacity of one locomotive.

While fewer enginemen would be required if all trains requiring two locomotives could be run as double headers, it is not possible to do so because the high draw bar pull required results in the parting of trains. While the new coupling apparatus has a drawbar pull equal to that needed to haul 2000 tons up a 2 per cent grade, all the couplers are not new and it is found much better to keep the drawbar pull below 50,000 lb. The rear locomotive provides a place for a conductor (flagman) to ride.

Detroit and Windsor are the ends of divisions and the river the frontier line between Canada and United States, so the steam locomotives and cabooses of trains arriving at these terminal points would not be taken across in any case.

The freight is classified in yards that lie just beyond the electric zone and in these yards the "made up" trains for the tunnel are inspected. Much of the fast freight, however, is through business—Chicago to Buffalo—and does not need classification in the Detroit territory. Such trains are inspected in the electric yards. These frequently contain

Table II RECORD OF NUMBER OF TRAIN DELAYS AND TRAIN MINUTE DELAYS

| | FREIGHT | | | | PASSENGER | | | | THIRD RAIL |
|---|---|---|---|---|---|---|---|---|---|
| | Train | | Locomotive | | Train | | Locomotive | | Minutes |
| | No. | Minutes | No. | Minutes | No. | Minutes | No. | Minutes | |
| **1911** | | | | | | | | | |
| 1. Broken coupler | 19 | 663 | 2 | 60 | | | | | |
| 2. Broken air hose | 5 | 245 | | | | | | | |
| 3. Broken contact shoes | | | | | | | | | |
| 4. Derailment | 3 | 330 | | | | | | | |
| 5. Brake apparatus | 2 | 80 | 1 | 30 | | | | | |
| 6. Fuses | | | 5 | 290 | | | | | |
| 7. Air signal whistle | | | | | | | 1 | 5 | |
| 8. Brake rigging in contact with third-rail cut off power | 1 | | | | | | | | 25 |
| 9. Collision | | | 1 | 25 | | | | | |
| 10. Load shifted on car | 1 | 180 | | | | | | | |
| 11. Lost power—poor contact at third rail | | | | | | | | | |
| 12. Contactors | | | | | | | | | |
| 13. Third-rail circuit breaker open on overload | | | | | | | | | |
| Total | 31 | 1318 | 9 | 405 | | | 1 | 5 | 25 |
| **1912** | | | | | | | | | |
| 1. Broken coupler | 11 | 375 | | | 1 | 7 | | | |
| 2. Broken air hose | 1 | 60 | | | 1 | 5 | | | |
| 3. Broken contact shoes | 1 | 20 | | | | | | | |
| 4. Derailment | | | | | | | 1 | 10 | |
| 5. Brake apparatus | 2 | 45 | | | | | | | |
| 6. Fuses | | | | | | | | | |
| 7. Air signal whistle | | | | | | | 1 | 11 | |
| 8. Brake rigging in contact with third-rail cut off power | | | | | | | | | |
| 9. Collision | | | | | | | | | |
| 10. Load shifted on car | | | | | | | | | |
| 11. Lost power—poor contact at third rail | | | 1 | | | | | | 25 |
| 12. Contactors | | | | | | | 1 | 4 | |
| 13. Third-rail circuit breaker open on overload | | | | | | | | | |
| Total | 15 | 498 | 1 | | 2 | 12 | 3 | 25 | 25 |
| **1913** | | | | | | | | | |
| 1. Broken coupler | 13 | 585 | | | 2 | 21 | | | |
| 2. Broken air hose | 4 | 385 | | | 2 | 41 | | | |
| 3. Broken contact shoes | | | 5 | 145 | | | | | |
| 4. Derailment | 2 | 240 | 1 | 155 | | | | | |
| 5. Brake apparatus | 3 | 75 | | | | | | | |
| 6. Fuses | | | | | | | | | |
| 7. Air signal whistle | | | | | | | | | |
| 8. Brake rigging in contact with third-rail cut off power | | | | | | | | | |
| 9. Collision | | | | | | | | | |
| 10. Load shifted on car | | | | | | | | | |
| 11. Lost power—poor contact at third rail | | | | | | | | | |
| 12. Contactors | | | | | | | | | |
| 13. Third-rail circuit breaker open on overload | 1 | | | | 1 | | | | 22 |
| Total | 23 | 1285 | 6 | 300 | 5 | 62 | | | 22 |

bad order cars which must be set out. Rigid inspection is maintained so that very few delays result from defective equipment when the heavy grades are taken into consideration. A statement of these delays for the three-year period is given in Table II, and shows clearly the nature of the defects in cars, as well as all other causes of delay.

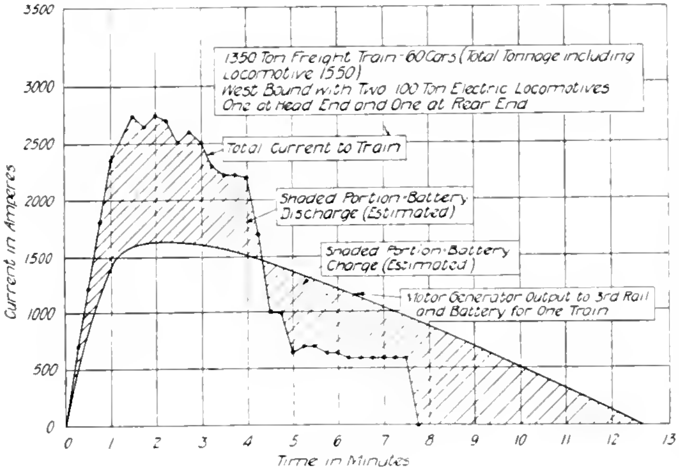


**Fig. 1. Power Curve of 1350-Ton Train**

It is quite evident that the load factor cannot be good and also that the peaks, under unrestricted operation, will be very high. While it is possible to operate with only forty-nine trains a day so that two freight trains will not be ascending the grades at the same time, it would not have been proper to require such an operating condition by limiting the power supply. Equipment was, therefore, installed of a capacity sufficient to furnish power for two trains to ascend the grades simultaneously and also to do switching. In the statement of power opposite the first item is the amount of purchased power. The records upon which bills are made are from meters located on the switchboard in the substation.

The cost per kilowatt-hour for traction, when to the cost of primary current is added only the conversion and transmission losses, and the cost of operating and maintaining the substation and distribution system, including third rail, is $0.018.

Although much of the fast freight is run in what is known as "symbol trains," which have a schedule, their time of arrival at intermediate points is by no means certain. These, as well as all other freight trains are run as "extras." It is, therefore not possible to anticipate with any exactness the hourly load, nor even the daily load, as the freight trains vary from day to day, not only in weight but in number. But if the weekly or monthly average for the period of a year is taken, it will be found quite near to that for any particular week or month, the tonnage averaging a little higher for the six winter months than for the six summer months. There is the morning and evening peak here as in every other place where there is any considerable volume of transportation, although not so marked, when considering the tonnage, as in most cases. The freight trains under normal conditions can be and are quite evenly distributed over the twenty-four hours, the passenger load super-imposed on this comparative even load causing the peaks. In one sense the load is all peaks. The light and auxiliary power averages about 150 kw. with a maximum demand of 300 kw., whereas a two-thousand-ton freight train requires nearly 3000 kw. for a few minutes. The power curve for a 1350-ton train is given in Fig. 1.

## TOTAL KILOWATT-HOURS USED

| | 1911 | 1912 | 1913 |
|---|---|---|---|
| Substation input | 4,749,145 | 4,653,290 | 5,145,745 |
| Substation output | 2,977,650 | 3,144,945 | 3,461,650 |
| Total output for traction....... | 1,758,400 | 1,844,770 | 2,223,940 |
| Total output for light and auxiliary power... | 1,219,250 | 1,300,175 | 1,237,710 |

## AVERAGES

| | |
|---|---|
| Substation input for one year.................... | 4,849,393 kw-hr. |
| Substation output for one year.................... | 3,179,748 kw-hr. |
| Traction output for one year....... .......... | 1,942,370 kw-hr. |
| Light and auxiliary power output for one year...... | 1,252,378 kw-hr. |
| Output per day for three-year period............. | 5,320 kw-hr. |
| Cost per day for traction current........... | $95.50 |
| Watts per ton mile.. | 35.1 |
| Cost per ton mile... | $0.00063 |

### Third-Rail Maintenance

The maintenance of twenty miles of third rail, including supervision, for the year 1913, was \$2,690.00; or \$134.50 per mile and \$7.40 per day. One of the principal items which goes to make up this total is the cost of replacement of burned and broken insulators. During the year 1913, there were 1200 replacements due to burning and 360 replacements due to breaking, costing \$936.00. Of the total burned insulators, 375 were on the tunnel tracks, 370 in the east-bound tunnel and only 5 in the west-bound. The great difference is due to the fact that practically all refrigerated freight is east-bound and brine drippings from these cars drops on the third rail. The application of grease and roofing paper over these insulators has greatly reduced the trouble from burned insulators, but has by no means eliminated it, and I am of the opinion that it will not be entirely eliminated until tanks to retain the brine are provided on all refrigerator cars.

| | No. Active Levers | Signals | Switches | Track Circuits | No. of Levermen |
|---|---|---|---|---|---|
| Bay City Junction (24th St., Detroit) | 48 | 21 | 25 | 6 | 3 |
| 20th St., Detroit | 155 | 82 | 73 | 76 | 4 |
| 15th St., Detroit | 172 | 75 | 72 | 60 | 4 |
| Windsor Summit | 37 | 21 | 14 | 5 | 2 |
| Windsor Tower No. 2 | 39 | 21 | 18 | 4 | 2 |
| Windsor Tower No. 3 | 29 | 17 | 12 | 0 | 2 |
| Through Tunnel | | | | 11 | |
| Total | 480 | 237 | 214 | 162 | 17 |

### Locomotive Maintenance

The maintenance force consists of:

- $\frac{1}{3}$ road foreman of engines time
- 1 mechanical man (foreman of the shop)
- 1 electrical man
- 1 air brake man
- 1 helper

All inspecting, cleaning and repairing, including the changing of tires (but not the turning of them) is done by this force at a small inspection and repair house located near the middle of the Detroit electric yard.

Taking the total cost of labor, material and supplies for the six locomotives for the period of eighteen months, from July, 1912, to December, 1913, and reducing to an average monthly basis, we have:

| | |
|---|---|
| Labor | \$406.03 |
| Material, including shop machinery | 168.77 |
| Total per month | \$574.80 |
| Average cost per locomotive mile | \$0.0498 |

The life of tires under the operating conditions up to the present is approximately three years. After two turnings they are scrapped. Tire maintenance is much the largest single item in the maintenance cost.

### Signals and Interlocking

All train movements in the electric zone are governed by interlocking and block signals. Except for the Windsor freight yard, all signals are controlled by a-c. track circuit, as well as from the interlocking machines. The table above shows the location and size of plants and number of levermen used for operating twenty-four hours each day.

Tunnel tracks between summits are signaled for running in either direction on both tracks and here only are the double-rail track circuits installed, as all four rails are wanted for the return of the propulsion current. In the yards one rail is used for the signal track control and the other one for the propulsion return current. Visual indication is given the leverman, showing what section of track is occupied by trains in the Detroit yards or the tunnel.

All the modern auxiliaries, such as, conductors platform signals, telephones and telautograph apparatus are furnished to assist in the expeditious and safe handling of trains.

# THE OPERATION OF THE THIRD-RAIL SYSTEM OF THE NEW YORK STATE RAILWAYS

By George N. Brown

Electrical Engineer, New York State Railways, Utica-Syracuse Lines

This article deals in a comprehensive way with the operation of the Oneida Line of the New York State Railways since it was electrified. The power consumption for a full year is analyzed in detail, and the efficiency of each section of the transmission and distributing system, as well as a detailed statement of the costs of substation operation for a period of six and one-half years, are given. The power consumption of both the limited and local cars is recorded and a comparison is made between the cost of maintenance of the overhead and third-rail conductors. The interruption of the power and third-rail circuits are tabulated for a period of seven years. The data should be of great value to operating men.—Editor.


George N. Brown

On June 15, 1907, the electrified division of the West Shore Railroad, known as the Oneida line, a part of the New York State Railways, was formally put in service and it might be of interest at this time to look back over the seven years of the road's operation to see just what changes have been made in the equipment and to investigate not only the continuity of power service but also what this power has actually cost.

The third-rail division of the New York State Railways, which is the electrified portion of the West Shore, extends between the westerly limits of the city of Utica and the easterly boundry of the city of Syracuse. This road was formerly double-tracked throughout, but to accommodate the different classes of service a third track was provided between Clark Mills and Vernon to allow faster units to pass the local trains. Between Oneida and Canastota a fourth track was laid to permit the electrically operated units to pass steam trains that may be held up in this section, owing to the presence of water stations and freight yards. The length of the electrified portion of the West Shore is slightly greater than forty-four miles. Of this 30.515 miles are laid with double tracks, 8.843 miles with three tracks and 4.582 miles with four tracks, making a total mileage of 105.887. The tracks throughout are laid with 80 lb. rails.

The Oneida line cars operate between the business centers of Utica and Syracuse, a distance of 48.52 miles. The limited trains cover this distance in one hour and twenty-eight minutes, making the run of forty-four miles over the West Shore in sixty minutes, with two station stops, Oneida and Canastota, and two railroad crossing stops. The local trains have a running time of two hours and two minutes, but make a detour through the city of Oneida, which adds about three miles to the total distance. Express and baggage service is also maintained, two trains operating in each direction daily, except Sunday.

### Source of Power

Power is supplied by the Adirondack Electric Power Corporation from a steam plant located in the city of Utica. Energy for the operation of the Utica lines of the New York State Railways is also obtained from this same source.

The equipment of this plant consists of four General Electric vertical turbines, having a total rated capacity of 6000 kw., the machines generating three-phase 40-cycle current at 2300 volts.

### Transmission Line

Power is transmitted to Clark Mills substation, a distance of eight miles, at a pressure of 60,000 volts on a steel tower line. These towers, with bases seventeen feet square and having a normal spacing of 550 feet, are made for a double transmission line, but at present carry only the three power wires and one ground wire. These are all of the same size, consisting of six copper wires stranded, forming a cable with a capacity equivalent to that of No. 000 solid wire and having a diameter of half an inch. The minimum clearance between conductors at any point in the span is six feet. The insulators have four petticoats and are of the pin type and were tested on 140,000 volts.

All energy is metered at Clark Mills substation on the high tension side and is paid for on the kw-hr. basis.

The transmission line, which parallels the West Shore tracks and extends from the Clark Mills substation to the Manlius Center substation, a distance of thirty-three miles, is made up of three conductors, each having a capacity of a No. 0 wire. The cables are built up of seven strands of hard drawn copper. These towers are built for a single transmission line and have a normal spacing of 480 feet. Thomas insulators of the pin type are used and spaced seven feet apart at the corners of a seven-foot equilateral triangle. No ground wire is used.

### Substations

As shown on the map, Fig. 1, there are five substations on the Oneida line, four of which are used for railway purposes, namely, Clark Mills, Vernon, Canastota and Manlius Center, and one located at Oneida City, which is used to transform energy from 60,000 volts to 2300 volts, at which the lighting and industrial loads of Oneida and Canastota are supplied. The average distance between the railway substations is approximately ten miles. The buildings are all of neat appearance, as will be seen by referring to Fig. 2, which shows also the architectural characteristics. They are constructed of brick with litholite trimmings and both the roof and the floors are of concrete. Each substation is provided with a heating apparatus and is equipped with a lavatory. An excavation beneath the floor level provides facilities for running cables and also for housing a battery of accumulators for the operation of the 60,000-volt oil switches. The electrical apparatus installed and the design of each station is identical in all respects, with the exception that no outgoing oil switch is required at Manlius Center substation, as the transmission line terminates at that point. The transmission line enters the building from the rear and in each case is connected to the high tension buses through disconnecting switches. An oil switch and disconnecting switches are installed in the outgoing line in three of the substations.

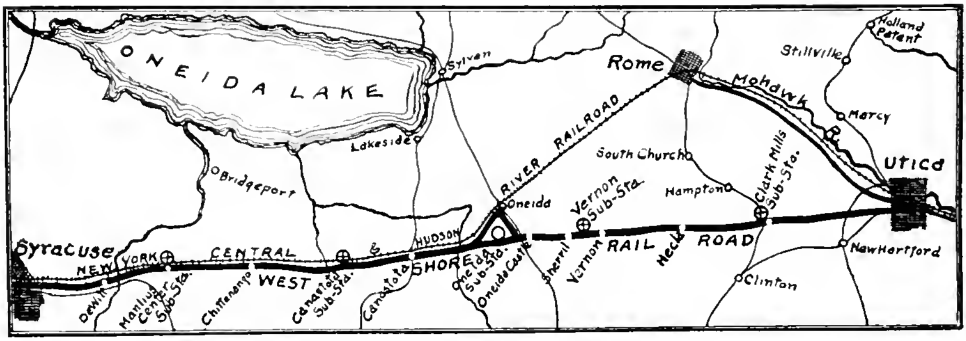


Fig. 1. Map of Third-Rail System, New York State Railways, Oneida Line

The building is divided into two sections, the operating room and the high tension compartment. The former contains the transformers, reactance coils, rotary converters and switchboard, as is shown in Fig. 3, while the latter houses all the high tension apparatus, such as oil switches, low equivalent lightning arresters, choke coils and busbars.

The equipment of each of the substations consists of two three-phase 40-cycle 300-kw. rotary converters made by the General Electric Company, together with two three-phase 330-kw. 40-cycle transformers, having a primary voltage of 34,600, and when "Y" connected 60,000 volts. The secondary when delta connected gives 370 volts. These transformers are operated "Y" connected on the primary side with delta connections on the secondary. Full load on the direct current side of the rotary converter is 500 amperes at 600 volts. These machines are started from the alternating current side on half-voltage taps from the transformers.

At the Oneida substation the electrical equipment consists of an oil switch, disconnecting switches, and three 275-kw. transformers, 40 cycles, 60,000 to 2300 volts, made by the General Electric Company. An electrolytic lightning arrester is connected to the transmission line at this point. This station, as previously explained, supplies energy for a lighting and industrial load, and is operated by the Adirondack Electric Power Corporation, power being purchased from the Oneida line.

### Operating Force

The operating force in the power department consists of one chief operator, eight substation operators, a meter inspector (who spends about one-third of his time on this line) and a change operator, who takes care of the shifting of men not only in the four Oneida substations, but also in the two substations in the city of Syracuse. To maintain the high tension line and third rail, together with some three miles of trolley wire in the city of Oneida, there are required one line foreman, two high tension patrolmen, and four linemen.

### Cost of Power

Table I shows not only the cost of operating the substations year by year since the road started operation, but also what has been paid out for power during that time. The alternating current is metered at 60,000 volts at the Clark Mills substation, and the power which is metered at the Oneida substation, plus a 1 per cent line loss, is deducted from the Clark Mills reading, leaving the net a-c. kw-hr. used for railway purposes. During 1913 a test was made to determine the various losses of transformation, transmission and conversion, following the energy from the 2300-volt busbars at the turbine plant in Utica back to the negative side of the rotaries through the return circuit. On the basis of these tests Table II was prepared, showing power data for the year 1912.

Fig. 2. Exterior View of Clark Mills Substation, Oneida Line

### Substation Load

Practically no trouble has been experienced with any of the substation apparatus during the seven years that it has been in service. At Sherrill, on this line, is located a large and growing manufacturing concern, known as the Oneida Community, which requires a considerable extra service for the transportation of its employees to and from this plant. At the present time there are a number of three-car trains and some six or eight two-car trains which are shown on the regular schedule, and most of these operate with the extra cars only as far as Oneida. This means that Vernon substation is subjected to a heavier load than any of the other substations. Fig. 4 shows the d-c. ampere load of this station on September 9, 1913, and from this chart an idea may be gained of the swings taken care of by this apparatus.

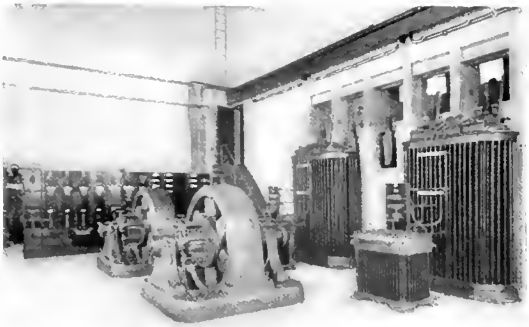


Fig. 3. Interior View of Clark Mills Substation, Oneida Line

### Changes in Substation Equipment

During the seven year's of operation a number of small additions or changes have been made to the substation equipment, either for greater safety or the betterment of the service. Chiefly among these are:

*First.* The installation of a concrete wall, one foot in height, forming an enclosure around the transformers, which in turn has a drain to the outside of the building. Drain pipes are carried from the base of each transformer to a valve housing on the outside of the substation. This box has a wire glass front and furnishes easy access to the transformer valves, and by their operation the oil can be drained from the transformer tanks. This is in line with suggestions made by the Fire Underwriters, and although it is decidedly uncommon that a transformer casing should puncture and then the oil should become ignited, yet the cost of piping up the transformers was so small that it was considered a good investment.

*Second.* It was found that a number of the mechanical oscillators on the rotary converters were damaged when the machine arced over, as at such times excessive current would flow from the armature shaft to the frame of the machine through the oscillator. This trouble has all been eliminated by placing on the opposite end of the armature shaft two small copper brushes and connecting them up permanently to the frame of the machine, which in all cases is ungrounded. This furnishes a more direct path for this current and no damage is done to the balls or raceways of the oscillator.

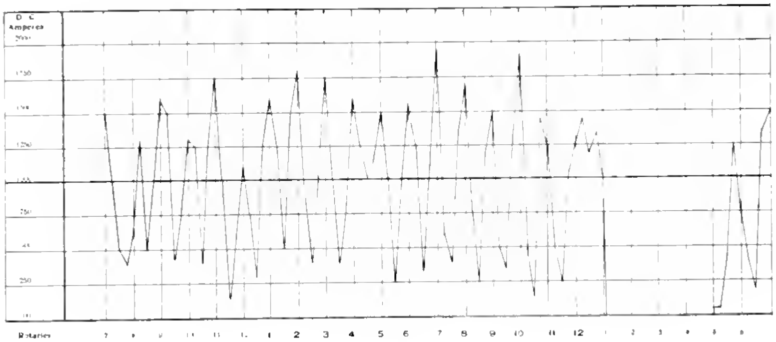


Fig. 4.

*Third.* Disconnecting switches have been placed at the back of two of the substations, Clark Mills and Vernon, so that power may be taken off from the high tension bus structure

### Table I

### NEW YORK STATE RAILWAYS, ONEIDA LINE

### Power and Power Consumption Data for the Year 1912

|  | COL. 1 | COL. 2 | COL. 3 | COL. 4 | COL. 5 | COL. 6 | COL. 7 | COL. 8 | COL. 9 |
|---|---|---|---|---|---|---|---|---|---|
| Month | A-C. Kw-Hr. Turbine Plant 2300-Volts | A-C. Kw-Hr. Clark Mills 60,000-Volts | Loss in Raising Transformers and Line | Per Cent Loss Raising Transformers and Line | D-C. Kw-Hr. Substation Output | Loss in Oneida Railway Substations Lowering Transformers and Rotary Converters | Per Cent Loss Lowering Transformers and Converters | D-C. Power in Per Cent of A-C. 2300 Volts | Net D-C. Kw-Hr. to Oneida City and Kenwood and West Shore |
| January | 483,500 | 461,100 | 22,400 | 4.64 | 367,770 | 93,330 | 19.3 | 76.06 | 359,812 |
| February | 475,850 | 455,800 | 20,050 | 4.23 | 359,100 | 96,700 | 20.3 | 75.47 | 342,671 |
| March | 449,800 | 427,200 | 22,600 | 5.03 | 343,300 | 95,640 | 21.2 | 73.77 | 333,654 |
| April | 443,450 | 420,200 | 23,250 | 5.25 | 331,560 | 88,640 | 20.0 | 74.75 | 323,792 |
| May | 443,160 | 416,600 | 26,500 | 5.98 | 333,250 | 83,350 | 18.8 | 75.22 | 325,875 |
| June | 430,500 | 403,500 | 27,000 | 6.26 | 319,730 | 83,770 | 19.5 | 74.24 | 313,759 |
| July | 461,400 | 434,200 | 27,200 | 5.90 | 345,480 | 88,720 | 19.3 | 74.80 | 337,326 |
| August | 457,700 | 431,500 | 26,200 | 5.72 | 345,910 | 85,590 | 18.7 | 75.58 | 338,085 |
| September | 493,550 | 468,500 | 25,050 | 5.08 | 374,480 | 94,020 | 19.0 | 75.92 | 364,649 |
| October | 430,600 | 405,000 | 25,600 | 5.94 | 320,750 | 84,250 | 19.6 | 74.46 | 312,949 |
| November | 424,200 | 404,300 | 19,900 | 4.70 | 324,340 | 79,960 | 18.9 | 76.40 | 315,826 |
| December | 468,300 | 450,200 | 18,100 | 3.90 | 354,560 | 95,640 | 20.4 | 75.70 | 345,451 |
| AVERAGE | 456,000 | 432,242 | 23,638 | 5.18 | 343,000 | 89,200 | 19.6 | 75.20 | 334,000 |

Deductions made as follows:
Column 1 − Column 2 = Column 3.
Column 3 ÷ Column 1 = Column 4.
Column 5 = Metered on d-c. bus.
Column 1 − Column 5 = Column 6.
Column 6 ÷ Column 1 = Column 7.

Column 9 − Column 10 = Column 11.
Column 12 = Column 11 changed to a-c. equivalent.
Column 11 − Column 13 = Column 14.
Column 14 ÷ Column 12 = Column 15.
Column 14 − Column 16 = Column 17.
Column 17 ÷ Column 12 = Column 18.

in the substation, and by closing these disconnecting switches, power can be supplied to the transmission line beyond either of these substations. These disconnecting switches simply shunt the station busbars, so that in case of any trouble in the high tension room of the substation, service would only be temporarily interrupted to the substations beyond. It is planned to install these disconnecting switches back of the Canastota substation; none being required at Manlius Center substation, due to the fact that there is no outgoing line.

*Fourth.* It has been found that when the transmission line has been struck by lightning, not only one, but sometimes a number of insulators adjacent to each other and all on the same leg, have been shattered. This has lead to an investigation and it has been determined that there are too many grounds on the transmission system, which is "Y" connected with the neutral grounded at each bank of transformers, making in all ten such grounds on the system. It is planned now to operate with only one permanent ground on the system and that one to be located at the turbine plant in Utica, and having in circuit 500 to 1000 ohms resistance. When trouble has developed on this line, after testing out and finding the affected leg, it has proven helpful to be able to operate three-phase with two wires and using the earth as a third conductor. However, this feature can be retained by having disconnecting switches in the grounded neutral at each substation.

Fig. 5. Three-car Train, each Equipped with 4 GE 73 (75 h.p.) Motors, Oneida Line

Table I (Cont'd)

| COL. 10 | COL. 11 | COL. 12 | COL. 13 | COL. 14 | COL. 15 | COL. 16 | COL. 17 | COL. 18 | COL. 19 |
|---|---|---|---|---|---|---|---|---|---|
| Oneida City and Kenwood at 3 Kw-Hr. Per Car Mile and 17 Per Cent Line Loss D-C. Kw-Hr. | D-C. Kw-Hr. Substation Output to West Shore Only | 2300-Volt A-C. Kw-Hr. Equivalent to D-C. for West Shore Only | D-C. Kw-Hr. Car Consumption | Loss in Low Tension Distribution | Per Cent Loss D-C. Transmission and Return Circuit | Estimate of Return Circuit Losses 4 Per Cent of A-C. Equivalent for West Shore Only | Third-Rail Losses | Per Cent Third-Rail Losses | Per Cent Overall Efficiency Generator to Car |
| 60,100 | 299,712 | 394,240 | 227,178 | 72,534 | 18.4 | 15,760 | 56,774 | 14.4 | 57.66 |
| 54,800 | 287,871 | 381,800 | 211,704 | 76,167 | 19.9 | 15,250 | 60,917 | 15.9 | 55.57 |
| 58,800 | 274,854 | 372,170 | 227,208 | 47,646 | 12.8 | 14,860 | 32,786 | 8.8 | 61.00 |
| 57,700 | 266,092 | 356,000 | 228,806 | 37,286 | 10.5 | 14,230 | 23,056 | 6.5 | 64.25 |
| 58,700 | 267,175 | 355,120 | 234,654 | 32,521 | 9.2 | 14,200 | 18,321 | 5.2 | 66.00 |
| 55,100 | 258,659 | 348,200 | 217,927 | 40,732 | 11.7 | 13,920 | 26,812 | 7.7 | 62.54 |
| 55,600 | 281,726 | 376,600 | 250,340 | 31,386 | 8.3 | 15,050 | 16,336 | 4.3 | 66.50 |
| 55,200 | 282,885 | 374,300 | 242,584 | 40,301 | 10.8 | 14,960 | 25,341 | 6.8 | 64.78 |
| 55,400 | 309,249 | 407,000 | 270,977 | 38,272 | 9.4 | 16,250 | 22,012 | 5.4 | 66.52 |
| 54,700 | 258,249 | 346,700 | 219,774 | 38,475 | 11.1 | 13,860 | 24,615 | 7.1 | 63.36 |
| 54,500 | 261,326 | 341,700 | 192,379 | 68.947 | 20.2 | 13,650 | 55,297 | 16.2 | 56.30 |
| 57,400 | 288.051 | 380,500 | 219,532 | 68,519 | 18.0 | 15,200 | 53,319 | 14.0 | 57.70 |
| 56,650 | 278,000 | 370,000 | 228,600 | 49,400 | 13.4 | 14.770 | 34,620 | 9.4 | 61.80 |

### Table II

### NEW YORK STATE RAILWAYS, ONEIDA LINE

### Cost of Substation Operation and Cost of Power for Past Seven Years

| Year | 1907 (6 Mo. 15 da.) | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 |
|---|---|---|---|---|---|---|---|
| Substation labor | $ 4,089.98 | $ 7,302.88 | $ 6,746.80 | $ 6,500.32 | $ 6,204.33 | $ 6,141.61 | $ 5,988.33 |
| Substation supplies and expenses | 899.59 | 2,318.38 | 1,410.76 | 1,120.88 | 1,165.59 | 1,161.28 | 1,074.09 |
| Power purchased | 22,077.79 | 45,183.36 | 48,797.87 | 50,583.43 | 46,504.29 | 44,046.97 | 39,286.38 |
| Total | 27,067.36 | 54,804.62 | 56,955.43 | 58,214.63 | 53,874.21 | 51,349.86 | 46,348.80 |
| A-c. kw-hr. purchased | 2,338,740 | 4,795,290 | 5,253,400 | 5,044,310 | 4,939,200 | 5,178,100 | 4,892,615 |
| D-c. kw-hr. output | 1,764,193 | 3,669,998 | 4,229,245 | 3,819,049 | 4,003,440 | 4,120,260 | 3,982,750 |
| Cost of power per d-c. kw-hr. | $0.0126 | $0.0123 | $0.0139 | $0.0155 | $0.0139 | $0.0129 | $0.0116 |
| Car miles | 491,539 | 996,199 | 1,219,247 | 1,346,578 | 1,238,107 | 1,233,836 | 1,210,843 |
| D-c. kw-hr. per car mile | 3.75 | 3.55 | 3.326 | 3.07 | 3.21 | 3.27 | 3.19 |

### Table III

### NEW YORK STATE RAILWAYS, ONEIDA LINE

### Data Showing Equipment and Power Consumption of Oneida Line Cars—Limited and Local Service

| Car No. | Date of Test | Weight Fully Equipped | No. of Motors | Type of Motors | Gear Ratio | Line Operated During Test | Kw-hr. Per Car Mile | Remarks |
|---|---|---|---|---|---|---|---|---|
| 532 | 1913 | 75,765 | 4 | GE 201 | 27-59 | Utica | 6.63 | Limited service |
| 532 | 1913 | 75,765 | 4 | GE 201 | 27-59 | Oneida (W.S.) | 2.00 | Limited service |
| 532 | 1913 | 75,765 | 4 | GE 201 | 27-59 | Syracuse | 3.63 | Limited service |
| 532 | Jan. 1st to Feb. 23rd 1913 | 75,765 | 4 | GE 201 | 27-59 | Syracuse Oneida (W.S.) and Utica | 2.58 | Limited and local |
| 532 | Apr. 16th to June 12th, 1913 | 75,765 | 4 | GE 201 | 27-59 | S. U. and Oneida | 2.49 | Limited and local |
| 506 | 1913 | 77,280 | 4 | GE 73 | 24-51 | Utica | 4.74 | Limited service |
| 506 | 1913 | 77,280 | 4 | GE 73 | 24-51 | Oneida (W.S.) | 2.22 | Limited service |
| 506 | 1913 | 77,280 | 4 | GE 73 | 24-51 | Syracuse | 4.70 | Limited service |
| 506 | Mar 27th to Apr. 14th, 1913 | 77,280 | 4 | GE 73 | 24-51 | Syracuse Oneida (W.S.) and Utica | 3.50 | Limited and local |

### Table IV

### NEW YORK STATE RAILWAYS, ONEIDA LINE

### Comparison of Overhead and Third-Rail Maintenance per Mile of Single Track

| Years | Utica Lines (Overhead) 128.24 Miles | Syracuse Lines (Overhead) 90.79 Miles | Oneida Line (Third Rail) 117.94 Miles |
|---|---|---|---|
| 1909 | $145.00 | $356.00 | $87.00 |
| 1910 | 131.00 | 403.00 | 52.00 |
| 1911 | 147.00 | 248.00 | 45.00 |
| 1912 | 126.00 | 220.00 | 61.00 |
| 1913 | 158.00 | 243.00 | 58.00 |
| Average | 141.00 | 294.00 | 61.00 |

### Table V

### NEW YORK STATE RAILWAYS, ONEIDA LINE

### Interruptions to Power High Tension and Third Rail

| | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 |
|---|---|---|---|---|---|---|---|
| High tension | 3 hr. 14 m. | 6 hr. 33 m. | 15 hr. 6 m. | 5 hr. | 2 hr. 30 m. | 2 hr. 39 m. | 19 hr. 47 m. |
| Third rail | 43 hr. 8 m. | 41 hr. 58 m. | 75 hr. 25 m. | 52 hr. 46 m. | 32 hr. 3 m. | 26 hr. 31 m. | 50 hr. 45 m. |

Average for the seven year's of operation:—
High tension, 7 hours and 50 minutes.
Third rail, 45 hours and 54 minutes.

**Car Equipment**

The original equipment consisted of 15 passenger cars weighing 78,144 lb. each, fully equipped, and having four GE 73, 75-h.p. motors, together with Type M control. This type of car is shown in Fig. 5; also two express cars weighing 90,000 lb. each, having the same electrical equipment. On September 1, 1912, two new steel passenger cars with parabolic fronts were added, weighing 76,100 lb. each and equipped with four GE 201, 50-60-h.p., motors, and having Type M control. This car is shown in Fig. 6. Tests were made to determine the power consumption on both these types of cars, not only for interurban service, but also for city operation. Table III shows this data both for limited and local service.

Fig. 6. Steel Car, Weight 76,100, lb. Equipped with 4 GE-201 (50-60 h.p.) Motors, Oneida Line

Fig. 7. View of Third Rail Showing Form of Jumpers Used, Oneida Line

**Third Rail**

As previously stated, there are over 105 miles of third rail. The form of rail employed is the bullhead under-running type and is of the same cross section as that employed in the electrification of the New York Central terminal; it has a further resemblance in that it is arranged for an under-running contact.

The weight of the rail is 70 lb. per yard and is supplied in lengths of 33 ft. No special composition was used to secure higher conductivity as the traffic conditions did not warrant it. The rail has, however, the equivalent conductivity of a copper cable of 1,023,000 c.m. cross section. Soldered bonds were used throughout. In Fig. 7 is shown the arrangement of the third rail on tangent track. The covering seen in the illustration is made of long leaf yellow pine in three parts and held together by No. 10 screws. The wooden covering is not subjected to any special treatment, but is painted before being applied to the rail. Another form of covering used to some extent is made of fiber and is molded in the form of the rail. From the illustration of the third rail it will be seen how the jumpers are carried under highway crossings and the method of fastening the rams' horns to the third rail. When replacements are made to such jumpers a fiber conduit is used instead of an iron pipe, as was the original installation, it having been found out that an action, either chemical or electrolytic, soon pits the pipe and allows moisture to get into the cable.

Fig. 8. View of Third Rail under Snow Conditions, Oneida Line

In regard to the cost of maintenance of the third rail, Table IV shows the comparison of overhead and third rail maintenance per mile of single track for the cities of Utica and Syracuse and the Oneida line.

With its third-rail construction, the Oneida line has never been seriously handicapped by snow. This may be due to the fact that the line extends east and west and has no deep cuts. Fig. 8 shows the third rail under snow conditions. It might be added that no effort is made to clean the snow out from under the third rail, the contact slippers on the car being sufficient for this purpose. Very little data are at hand in regard to the losses due to leakage through snow, but as far as can be determined dry snow piled around and over the third rail does not increase this leakage. When the snow starts to melt, that is, with wet snow against the third rail, the leakage is ten times greater than normal. This is also the case when there is a considerable quantity of rain falling.

On the system there are two types of third-rail insulators, one wooden and the other porcelain. Of the wooden type there are 4500 in service and of the porcelain type, 44,097. From a test section of the third rail containing both kinds of insulators, data were obtained in regard to the yearly leakage, and applying these figures to the 105 miles of third rail, it is found that the yearly loss, due to leakage, is 14,430 kw-hr. This, at the average rate of $0.0125, will amount to $180.38.

### Interruptions

Table V shows the total number of hours per year that the service has been interrupted during the past seven years on both high tension line and the third rail. This table shows an average yearly interruption on the high tension line of 7 hours and 50 minutes and on the d-c. side or third rail of 45 hours and 54 minutes. It should be borne in mind that there are two d-c. feeders out of each of the four substations and that this represents the total length of time the d-c. was interrupted on all feeders.

# TYPES AND SYSTEM OF DRIVES OF ELECTRIC LOCOMOTIVES

By A. F. Batchelder

Engineer, Railway Locomotive Department, General Electric Company

The author gives an interesting review of drive systems used on electric locomotives, from the earliest types built for heavy traction in this country up to the latest examples employed in our modern installations. The article should be of considerable value to those interested in the design of electric locomotives.—Editor.

A. F. Batchelder

The installation of electric locomotives by the Baltimore and Ohio Railway Company, for their tunnel at Baltimore, Md., in 1895, demonstrated beyond a doubt the practicability of heavy electric traction.

This first installation consisted of three 96-ton locomotives, each being designed with a running gear made up of two trucks, each of which had two axles and a short wheel-base. Each axle was equipped with a gearless motor mounted on a quill surrounding the axle, the wheels being driven through pieces of rubber, acting as springs.

These locomotives have proven to be very successful in the slow speed service required at the tunnel, but experience from their operation has given much useful data as to where improvements should be made in the design, especially where high speed is required. Later in 1903 the Baltimore and Ohio installed four additional locomotives weighing 80 tons each for slow speed freight service.

These new locomotives were made at a much smaller manufacturing cost than those of the first installation, and are different in design, having a single four-axle truck with a long rigid wheel-base with a motor geared to each axle. These locomotives were also very successful and were operated at a smaller cost of maintenance than the first type. Again in 1900 additional locomotives weighing 90 tons each were installed for higher speed service.

These 90-ton locomotives have a running gear consisting of two-axle trucks each having a short wheel-base, joined together with a hinge connection. These units are similar in design to the locomotives that had been installed at the Detroit River Tunnel on the Michigan Central Railroad in 1909. They were so satisfactory in service that the next installation made in 1912, of 100-ton locomotives, were of the same type.

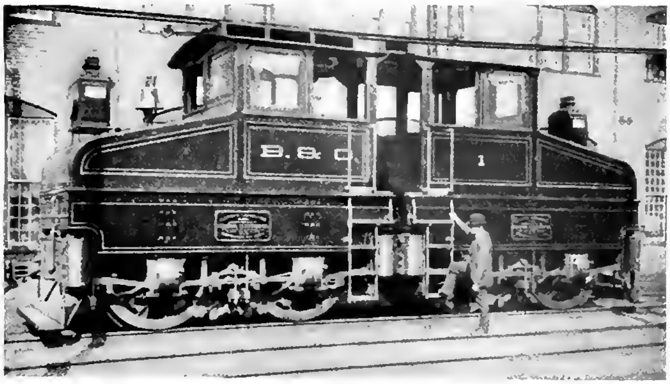
Since the date of the first installation in 1895 many other installations have been made in different parts of the world, and many different designs have been made and are in operation, or have been experimented with, in an attempt to produce the most perfect machine to meet the requirements as governed by the kind of power or by the special conditions of the railroad on which they were to operate.

A large percentage of the most important installations in America, operated both with high or low voltage direct current and with three-phase current systems, have installed the last type adopted by the Baltimore and Ohio Railroad Company for freight and low speed passenger service. Of these, the following may be cited: The two installations of the Baltimore and Ohio Railroad Company: at the Baltimore Tunnel; the two installations of the Detroit River Tunnel Company, on the Michigan Central Railroad, at Detroit, Michigan; one installation at the Great Northern Railway Company, for the Cascade Tunnel, Washington; two installations on the Butte, Anaconda and Pacific Railroad, Montana, one installation on the Canadian Northern Railroad at Montreal; one installation at the Bethlehem-Chili Iron Mines Company, Chili; one installation for the Commonwealth Edison Company, Chicago, and one installation for the Wilkes Barre & Hazleton Railway Company, Pennsylvania.

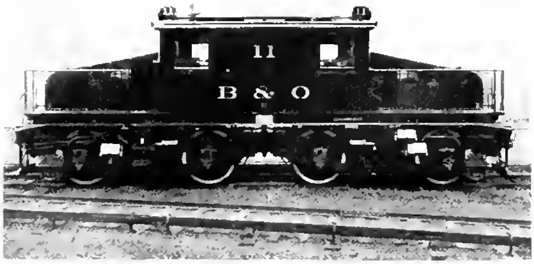
This type has the advantage of being economical to manufacture, easy and cheap to maintain, easy on flange, rails and road bed, and satisfactory for speeds up to 50 m.p.h.; all of these advantages have now been proved in service by several years of operation.


Second Installation on Baltimore and Ohio Railroad

Important installations which have adopted other types are the New York, New Haven and Hartford Railroad Company, the New York Central and Hudson River Railroad Company, the Pennsylvania Railway Company, the Norfolk and Western Railroad Company. The first and second installations of the New York, New Haven and Hartford Railroad Company for high speed passenger service were of a similar type to the first installation of the Baltimore and Ohio Railroad Company with the difference that steel springs were used in the driving wheels instead of rubber, and these locomotives were afterwards changed by adding a guiding axle to each truck. Later, other installations were made using locomotives with geared motors, but retaining the quill and spring drive feature. All the data the writer is able to get on this system of drive indicate an excessively high cost of maintenance.


First Installation on Baltimore and Ohio Railroad

The first and second installations of the New York Central Railroad Company were with running gears having a four-axle truck with a two-wheel pony guiding truck at each end. This was changed later by substituting four-wheel trucks in place of the


Third and Fourth Installations on Baltimore and Ohio Railroad

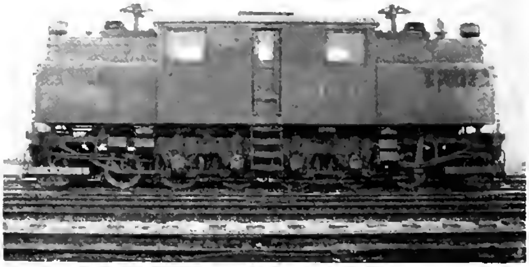
two-wheel trucks. Each of the four driving axles is equipped with a motor armature mounted direct on the axle, the field being so arranged as to allow the necessary vertical movement of the armature. This type has proven satisfactory and has the advantage over other types because of its simplicity and low cost of maintenance.

First Installation on New York, New Haven and Hartford Railroad

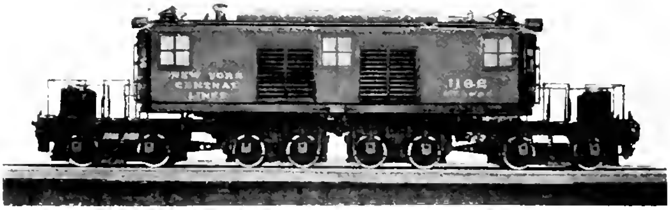
The third and fourth installation by the New York Central has the same motor construction as the first, but in order to obtain the benefit of greater starting effort, the guiding trucks are provided with motors, and in order to operate on sharp curves, the middle truck is articulated at the center. This type has all the advantage of the first, with the addition of the greater tractive effort, relative to its weight, for starting purposes. This type is satisfactory for operation at speeds up to 75 miles per hour.

The first and second installations by the Pennsylvania Railroad Company have two four-wheel trucks coupled together and a four-wheel guiding truck at each end, being the same wheel arrangement as the third and fourth installations of the New York Central, excepting that the joint between trucks, which on the Pennsylvania is a link connection, on the New York Central is a hinge connection. The motor equipment consists of two motors mounted on the main truck frames and the drive is arranged through diagonal side rods to jack shafts and then in turn through parallel side rods to the driving wheels.

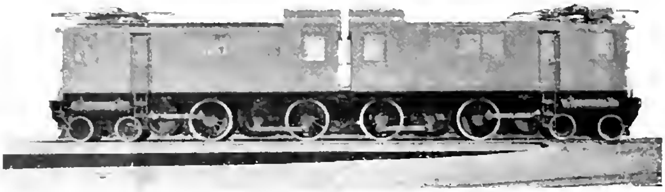
This drive was invented by the writer and was patented* by him in 1911. A sample machine was built and tested in the meantime, and the results indicated considerable losses in the transmission of the power from the motors to the wheels, and from such data as the writer is able to obtain from actual operation, the cost of maintenance is



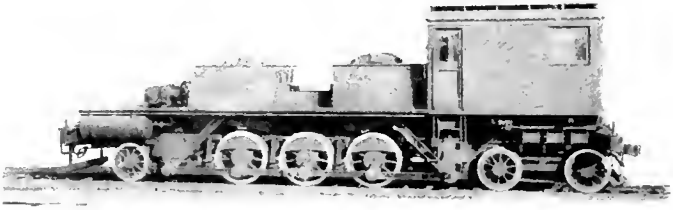
First and Second Installations on New York Central and Hudson River Railroad



Fourth Installation on New York Central



Sample Locomotive Geared and Side Rod Drive



Sample Side Rod Drive Locomotive

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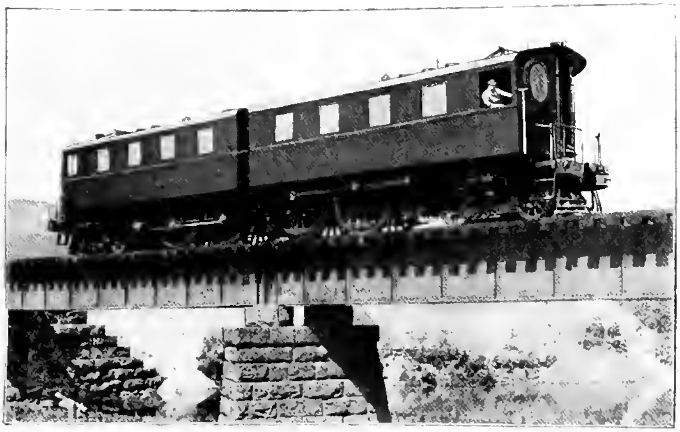
*Patent No. 988,067.

excessively high as compared with other types. The manufacturing cost is also higher than those of the New York Central type for the same capacity.

The first installation by the Norfolk & Western Railroad Company is of a similar wheel arrangement to that of the Pennsylvania Railroad, but with two-wheel guiding trucks in place of the four-wheel trucks and a hinge joint instead of the links between the trucks, and the motors are geared direct to the jack shafts which in turn are connected to the drivers through parallel rods. A design similar to the Norfolk and Western was presented at the Meeting of the American Institute of Electric Engineers, at Jefferson, N. H., in July, 1910, by the writer.

A sample locomotive with geared and side rod drive differing from the Norfolk & Western by having a jack shaft for each axle was built and tested in 1912 and the results of the test indicated this arrangement to be successful and that it could be used to advantage where it is necessary to spring support the motors to absorb the vibration due to the pulsating torque as with single-phase series motors.

It appears to the writer, judging from the results obtained in operation and from the general satisfaction given by the type of running gear and system of drive used in the last installation of locomotives adopted by the Baltimore & Ohio Railway Company, that this design may be considered generally settled and standard for freight and slow speed passenger service. For the high speed passenger service, however, it is not so apparent that the design is settled, owing to the limited number of installations for this class of service, but from such data as the writer is able to obtain on costs of manufacture, cost of maintenance, and general satisfaction in operation, it would seem that the design adopted by the New York Central and Hudson River Railroad Company has the advantage.



First and Second Installations on the Pennsylvania Railroad

# A DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE DALLAS, WACO AND CORSICANA INTERURBAN 1200-VOLT RAILWAY

By Luther Dean

Chief Engineer, Southern Traction Company

The author gives a brief description of a new 1200-volt interurban road. The article is mainly confined to a description of the physical characteristics of the railway and its equipment; some interesting notes are given concerning the construction of some of the bridges.—Editor.

The lines of the Dallas, Waco and Corsicana Interurban Railway are made up of approximately 171 miles of main-line track, with about 2 miles of second track, and about 5 miles of sidings. About 80 miles of this track were laid with 80-lb. A.S.C.E. tee-rails; and the balance, except for about 5 miles in city streets, were built with 70-lb. A.S.C.E. tee-rails.

The standard roadway section is 16 feet in width at the sub-grade on embankments and 24 feet in cuts; an allowance for shrinkage was made so as to have the embankments full width after seasoning. The embankment slopes were made so as to be one and one-half horizontal to one vertical after settlement. The highest "fill" is just south of Dallas, where a 15-ft. concrete arch culvert was built. The top of the embankment is 65 feet above the bottom of the culvert.

First quality 6 in. by 8 in. by 8 ft. seasoned white oak ties were used and they were spaced 17 ties to a rail length of 33 feet. These ties were placed on 6 inches of gravel ballast, except in paved city streets, where 6 inches of concrete was placed under the ties. This concrete was brought up to 1 inch above the top of the ties to make a foundation for the paving.

The maximum grade outside of the city streets is 2 per cent and the maximum curvature, except where governed by streets, is 6 degrees. Of the 127 miles of interurban track recently laid out and built, 91.43 per cent is of tangent track.

Eighteen steel bridges or steel viaducts, having a total length of 3513 feet, have been constructed. The longest viaduct is 1455 feet long and carries the interurban track over the main-line and side tracks of two railroads at Waxahachie, and over the Waxahachie Creek. The longest single span is 150 feet, this being one of three such spans which were used in crossing the Brazos River at Waco. The steel bridges and steel viaducts are all designed according to Cooper's specifications for E-30 loading. In constructing the piers for the Brazos River bridge, reinforced concrete cribbing was used to protect the excavation. This cribbing was made 12 inches in thickness and was beveled at the bottom so as to allow it to settle easily as the excavating progressed. It is about 16 feet in height and extends from bed rock to the bed of the river. It was built up in sections so as to carry on the excavation to better advantage and, after bed rock was reached, the bottom was sealed up and the cribbing was used as a form for the piers.

Two reinforced concrete ballast deck trestles were built, one of these trestles being 660 feet long and the second being 340 feet long. One 50-ft. reinforced concrete arch and one 40-ft. reinforced concrete culvert were also built. The reinforced concrete structures were all designed for Cooper's E-40 loading.

Pile deck trestling to the extent of 11,147 feet (equal to 2.1 miles) was built. The longest single trestle is across the Chambers Creek bottom, where the total length of opening is 1660 feet. The trestles were severely tested during the record floods in December, 1913, but they withstood the strain without damage. These floods demonstrated the necessity for large openings.

There are three terminal and three intermediate substations. The terminal substations are each equipped with two 400-kw. three-piece motor-generator sets, designed so as to deliver both 600-volt and 1200-volt direct current. The three intermediate substations and the portable substation are each equipped with one 400-kw. two-piece motor-generator set, designed to deliver 1200-volt direct current only. There are also two 300-kw. 600-volt sets in the Waco substation, these sets being used for city service.

Alternating current at 2300-volts and 60 cycles is delivered to the Traction Company at the different switchboards by the Texas Power & Light Company. The terminal substation at Waco is in the power house of the Texas Power & Light Company, and the other terminal stations and the intermediate stations are located in brick buildings measuring 40 feet by 50 feet overall with a clear inside height of 15 feet. These different substations are approximately 30 miles apart, and are located as follows:

The terminal substation in the Texas Power & Light Company's power house on the Brazos River, Waco.

Terminal substation at the city limits of Corsicana.

Terminal substation at the intersection of the Waco and Corsicana Lines, about 1 mile south of the Dallas city limits.

Intermediate substation, at Ennis, midway between the Dallas and Corsicana substations.

Intermediate substation just south of the City of Waxahachie.

Intermediate substation at Hillsboro.

The substations are all connected with 350,000 cir. mil. copper cable, and this cable is provided with cutout switches about midway between substations.

No. 0000 trolley wire is used and catenary construction is adopted outside the city streets, where a greater span construction is necessary.

The standard poles are of Idaho cedar, 35 feet in length, having 9-inch tops, and spaced 150 feet apart on tangents, but at a shorter spacing on curves. Eleven-point suspension was used with long bracket steady-braces.

The interurban cars consist of twenty-two passenger motor cars, each having an overall length of 53 feet 6 inches, an overall width of 9 feet, and a seating capacity of 56 persons; ten trail cars 54 feet 2 inches long, 9 feet wide, seating 54 persons; six motor express cars measuring 50 feet by 9 feet overall; two express trail cars with same size bodies, and two motor work cars.

Each interurban motor car is provided with four 100-h.p. motors and has a switch so that it can be operated at full speed on either 600-volt or 1200-volt direct current. The passenger motor cars have single-end control and the express motor cars are provided with double-end control. All the cars have electric heaters and both air and hand brakes.

Current at 600 volts is used within the city limits of Dallas, Corsicana and Waco, and 1200-volt current on the remainder of the system. The city cars on the four miles of city track in Waxahachie are also operated on 1200 volts.

The selector telephone system was adopted and two complete circuits (four wires) are carried the full length of the lines. No. 10 B.&S. copper wire with porcelain insulators was used throughout, and each telephone is protected by a transformer.

There are three railroad crossings where the grades could not be separated and these crossings are protected with derails and with an interlocking device designed to be operated by the conductor. The device is arranged so that the derail cannot be closed until after "danger" signals have been set on the steam line, and these "danger" signals cannot be set if there is a train within 2000 feet of the crossing unless released by a time lock which is set so as to release in thirty seconds.

# CRITICAL SPEEDS OF RAILWAY TRUCKS

By E. F. W. Alexanderson

Consulting Engineer, General Electric Company

The author deals with the theoretical considerations governing the critical speed of railway trucks, and it should be borne in mind in reading this article that the conclusions arrived at refer to trucks only and not to a car or locomotive as a whole. Critical speeds of railway equipment are of the utmost importance to the designing engineer, and the author therefore gives considerable attention to the phenomenon of "nosing," making an extended mathematical analysis of the critical speeds of railway trucks with different arrangement of motors.—Editor.

E. F. W. Alexanderson

THE theoretical possibilities for the application of electric power are wonderfully broad, and the fundamental theory for the phenomena which are dealt with in the design of electric power machinery is so simple and so well known that calculations and conclusions do usually not need to be confirmed by tests. In the construction of almost any electrical machinery, the designer therefore finds that his limitations are not in what can be accomplished by electric current, but in what it is permissible to do from the mechanical point of view with the material with which he must deal. The mechanical phenomena which constitutes these limitations are usually so involved that it is scarcely ever attempted to base a design on theoretical considerations; results are arrived at by the method of "cut and try," with the application of large factors of safety. On the other hand, it is being more and more fully realized that the different mechanical problems that are encountered in the design of high speed machinery cannot be approached at all without a reasonable understanding of the fundamental physical principles which control the operation of such machines. One of these considerations is the so-called "critical speed," or mechanical resonance. The phenomenon of critical speed can usually be determined with a considerable degree of accuracy if exact data of the physical properties and dimensions of the material that is used are available. The critical speeds that must be considered in the design of high speed rotating machines like turbo-alternators are of the same nature as the pendulum movement, and the pre-determination of this phenomenon is the subject of the same mathematical principles as the pendulum.

The subject of this article is the analysis of another form of critical speed, which, in its nature is quite different from the pendulum movement. Although it has been known for a long time that it is dangerous to run a railway truck beyond certain speeds, it is not generally realized that the movement of a railway truck is subject to a critical speed and that this critical speed can be predetermined mathematically from the dimensions and inertia of the truck and from the clearance between the flange and the rails.

The danger in operating any railway truck at high speeds is primarily due to the approach of the critical speed. Here it must be realized that if the term "critical speed" is used for the danger point for the railway truck, the nature of the action differs from the critical speeds which have the character of pendulum movement inasmuch as the pendulum effect appears only at a certain speed, beyond which it disappears again, while the critical speed of a railway truck is the speed at which mechanical oscillations become accumulative, and operation beyond this speed becomes more and more dangerous because the oscillations are limited only by the physical strength of the material in the track. The oscillations which appear at the critical speed of a truck are usually known as "nosing," and this phenomenon was first brought to general attention by experiments on the high speed car of the Berlin-Zossen Railroad. As a matter of record, it is probably remembered by most railway engineers interested in electric traction, that the experiments of the first year had to be discontinued on account of the severeness of the nosing at speeds which were considerably lower than those at which it was intended to run. During the next year the truck was rebuilt on extremely strong foundations, and with the use of a truck that fitted the track with great exactness it was possible to carry out the experiments. However, it was undoubtedly these mechanical difficulties that were responsible for the fact that the Berlin-Zossen experiments never become the starting point of any practical developments.

The nature of the phenomenon which is known as "nosing" is substantially as follows:

If the truck at some particular moment is in position on the track so that it runs towards one rail at a slight angle, the front wheel, when it strikes the rail, will be reflected by an elastic blow and the truck turned around on the track so that it will be headed towards the opposite rail at a greater angle. When the truck hits the other rail it will be reflected again in a still greater angle, and this action will become accumulative until the maximum angle is reached at which the truck can stand on the track within the limitations of the clearance between the flange and the rail. The reasons why the truck is reflected at a greater angle than the angle of impact are given in the theoretical analysis following: It is found in this analysis that contrary to the ordinary conceptions of the mechanical reflection of a single object, like a ball, the angle of reflection may be greater or smaller than the angle of impact. In order to understand in a general way, the phenomenon of "nosing," it may be sufficient to know that a certain truck when striking the track will be reflected at a greater or smaller angle than the angle of impact, depending upon the speed at which it strikes and the angle of impact. For instance, if a certain truck running at 60 m.p.h. strikes the rail at an angle of 1 deg., it may be reflected at an angle of 1 deg. At speeds greater than 60 m.p.h. it would be reflected by more than 1 deg., and at speeds less than 60 m.p.h. it would be reflected by less than 1 deg. If on the other hand the truck strikes the track at an angle of ½ deg., a speed of 85 m.p.h. would be required to reflect the truck by ½ deg. From these considerations it is apparent that if the clearance between the flange and the rail is such that the maximum angle at which the truck can stand on the track is 1 deg., the critical speed of nosing is 60 m.p.h. This means that at all speeds below 60 m.p.h. the angle of reflection must be smaller than the angle of impact, because the maximum angle at which the truck can strike the track is 1 deg. If the truck runs at a speed above 60 m.p.h., the truck may strike the track at an angle of nearly 1 deg. and there may be a tendency for it to be reflected at an angle of 1 deg. or more. Inasmuch as it is not possible for the truck to be placed at more of an angle than 1 deg., it follows that a part of the energy of the first impact is left over to increase the force of the second impact; thus the truck will be kept in a continous state of oscillation, reaching in each swing the maximum angle which is permitted by the track clearance.

The factors that determine the critical speed for any particular truck are the inertia of the truck, the distribution of masses in the truck, the frictional resistance between the wheels and the rail, length of the wheelbase, and the flange clearance.

When the front wheel of the truck strikes the rail it rebounds by an elastic blow and the truck receives a rotating movement around a certain point on the other side of the king pin, which in the following discussion will be called the center of rotation. The first step in the calculation is to determine the distance from the front wheel to the center of rotation. This is done by a consideration of the distribution of the masses in the truck and also the mass of the car which is attached to the king pin. For the sake of calculating the movement of the truck it is sufficient to consider the car as a single weight attached to the king pin. The mass of this weight is calculated separately from the distribution of masses in the car and will be called the equivalent mass of the car referred to the king pin. After the center of rotation has been determined, the inertia of the truck and the mass attached thereto can be calculated with reference to the center of rotation. Thus it will be seen that the glancing blow of the truck against the rail will give the truck a rotating movement around its center of rotation, and the kinetic energy of this rotating movement depends upon the angular velocity and the inertia of the truck with reference to the center of rotation. The rotating movement of the truck is possible only by the sliding of the wheels on the track and therefore the kinetic energy of rotation can be given to the truck immediately after the blow is used up by the friction of the truck and rails. The kinetic energy is proportional to the square of the initial angular velocity, whereas the energy absorbed by friction is proportional to the frictional torque and the angular movement. Thus it is apparent that the sliding movement, which continues until all the energy is used up, will cover an angle which is proportional to the square of the initial angular velocity. On the other hand the angular velocity is proportional to the speed of impact and the angle of impact. Thus it is apparent that if the angle of impact is twice as great in one case as in another, the speed being the same, a sliding movement will result which will cover an angle four times as great. Similarly, if the angle of impact is the same, but the speed is twice as great, the resulting angular movement will also be four times as great. If the above reasoning is expressed mathematically, an equation can be derived giving the relations between the angle of impact, the angle of reflection, the inertia of the truck and the frictional resistance.

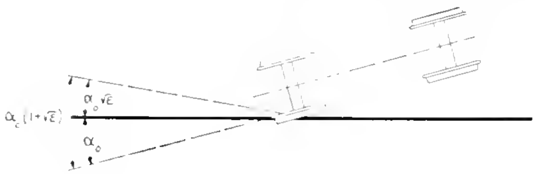


Fig. 1

### Mathematical Analysis of Critical Speed

$I$ = inertia of truck around center of rotation.

$T$ = frictional torque around center of rotation.

$W$ = weight on the wheels.

$B$ = wheel-base.

$R$ = center of from wheel to center of rotation.

$\delta$ = flange clearance.

$V$ = velocity of truck in meters per second.

$\alpha$ = angle of impact.

$\omega_0$ = initial angular velocity.

If the wheel strikes a perfectly elastic blow, it is apparent from diagram, Fig. 1, that the initial angular velocity after rebound is

$$\omega_0 = \frac{2V\alpha_0}{R};$$

or if the blow has an elastic co-efficient $\epsilon$

$$\omega_0 = \frac{(1+\sqrt{\epsilon})V\alpha_0}{R}$$

Substituting,

$$\alpha_0 = \frac{\delta}{B}; \quad \omega_0 = \frac{(1+\sqrt{\epsilon})\,V\,\frac{\delta}{B}}{R}$$

Furthermore, we know

$$T = -\frac{d\omega}{dt}I$$

Integrating this equation we get

$$t = -\frac{I}{T}\omega + C_1 = \frac{I}{T}\frac{d\alpha}{dt} + C_1$$

and integrating again

$$\frac{1}{2}t^2 = -\frac{I}{T}\alpha + C_1 t C_2$$

Substitute for determination of integration constants,

$$\omega_0 = \frac{(1+\sqrt{\epsilon})\,V\,\frac{\delta}{B}}{R}$$

we get the time for the complete movement

$$t = \frac{I}{T}\,\frac{(1+\sqrt{\epsilon})\,V\,\frac{\delta}{B}}{R}$$

Substituting this value for "$t$" in the second equation,

$$\frac{1}{2}\left(\frac{I}{T}\,\frac{(1+\sqrt{\epsilon})\,V\,\frac{\varrho}{B}}{R}\right)^2 = \frac{I}{T}\alpha$$

the condition for critical speed is:

$$\alpha = 2\alpha_0 = 2\frac{\delta}{B}$$

Hence the equation determining the critical speed is:

$$\frac{1}{2}\left(\frac{I}{T}\,\frac{(1+\sqrt{\epsilon})\,V\,\frac{\delta}{B}}{R}\right)^2 = \frac{I}{T}\,2\,\frac{\delta}{B}$$

This equation solved for "$v$" gives the general expression:

$$v = \sqrt{\frac{T}{I}\,\frac{B\,R^2}{\delta\,(1+\sqrt{\epsilon})}}$$

The formula becomes more convenient to use if the equivalent mass at the front wheel is substituted for inertia in accordance with the relation:

$$I = m\,R^2 = \frac{P}{9.8}\,R^2$$

where "$P$" is the mass in kilograms, the expression for critical speed thus becomes:

$$v = \sqrt{\frac{T}{P}\,\frac{B}{\delta\,(1+\sqrt{\epsilon})}}$$

"$T$" is the frictional torque of the wheels opposing the sliding movement. If the weight on the two axles is equal, $T$ is the same regardless of the center of rotation and can be expressed:

$$T = \frac{Wf}{B}$$

where "$W$" is the weight on the wheels and

"$f$" the co-efficient of friction. Thus we get

$$\text{Critical speed } V = B\sqrt{\frac{W}{P} \cdot \frac{9.8\, f}{\delta\,(1+\sqrt{\epsilon})}}$$

In this expression the quantities "$W$" and "$P$" are definitely known and can be calculated from the design, whereas the quantities "$F$," "$S$," and "$E$" depend upon local conditions of track. Inasmuch as the object of this treatise is to analyze and compare designs irrespectively of conditions of track, it is permissible to substitute numerical values that are representative of average conditions of track. Thus, it will be assumed:

Co-efficient of friction $f = 0.2$
Elastic co-efficient $\epsilon = 0.75$
Flange clearance $\delta = \frac{7}{16} = 0.011$ meter.

Hence, we get:

$$\frac{9.8\, f}{\delta\,(1+\sqrt{\epsilon})} = 94$$

or in round figures, 100.

Hence, we get the simple expression for critical speed

$$V = 10\, B\sqrt{\frac{W}{P}}$$

where "$B$" is the wheel base in meters,
"$W$" weight on the wheels in kilograms,
"$P$" equivalent mass at front wheel in kilograms.

Reduced to the English system this formula becomes:

Critical speed $V_c = 72\, B\sqrt{\frac{W}{P}}$ miles per hour, the units being feet and pounds.

**Shock on Track**

The shocks on the track can be expressed by the product of mass and velocity, $MV$

The mass $M$ is the equivalent mass at the front wheel designated $P$

The velocity of the shock at the critical speed is·

$$v_s = V_c \frac{\delta}{B}$$

Hence the shock

$$= P\, V_c \frac{\delta}{B}$$

At any definite speed between the critical speed the shock is proportional to the square of the ratio of the running speed to the critical speed. This assumption is based on the approximation that the angle of oscillation is proportional to the speed, and hence the velocity of impact proportional to the square of the speed.

The ratio of running speed to critical speed will be expressed by $\frac{V_r}{V_c}$

Hence, we get the shock on track at running speed $V_r$

$$\text{Shock} = \left(\frac{V_r}{V_c}\right)^2 P\, V_c \frac{\delta}{B}$$

which, reduced to numerical values for an average track, becomes

$$\text{Shock} = 1.1\, V_r^2 \frac{P}{B^2}\sqrt{\frac{P}{W}}\, 10^{-3}$$

and in English units

$$\text{Shock} = V_r^2 \frac{P}{B^2}\sqrt{\frac{P}{W}}\, 10^{-3}$$

where "$V_r$" is running speed in miles per hour.
"$P$" = equivalent mass at front wheel in pounds.
"$B$" = wheel-base in feet.
"$W$" = weight on wheels in pounds.

The following is a numerical calculation of the characteristics of a truck in a specific case. The specifications of the trucks are as shown in Fig. 2. The inertia mass of the car body referred to the king pin is calculated on the assumption that the car is designed on the principle that the other king pin should be the center of rotation for any oscillations of the car body resulting from shocks on the king pin. The equivalent mass of the car body is assumed to be rigidly attached to the king pin. For the critical speed and shocks on the track, one calculation is made assuming that the truck is spring-connected to the car body so that is is free to move and another calculation is made under the assumption that the truck is rigidly attached to the car body. The facts will lie somewhere between these two extreme assumptions.

**Specifications of Truck with One Motor**

| | |
|---|---|
| Wheel-base | 69 in. |
| Weight of truck | 9,000 lb. |
| Weight of motor | 4,100 lb. |
| Weight on wheels | 40,000 lb. |
| Inertia weight of car at king pin | 27,400 lb. |

Distribution of masses is shown in Fig. 2.

**Radius of Gyration**

$$13100\, r^2 = (42^2 \times 3600) + (10^2 \times 4100) + (27^2 \times 5400)$$

$$13100\, r^2 = 10{,}720{,}000$$

$$r = 28.6.$$

**Center of Rotation**

$$f_1 = F/2 \times \frac{27}{28.6} = 0.477\ F$$

$$f_1 + F/2 = 0.977$$

$$F/2 - f_1 = \frac{0.023}{0.954}$$

$$\frac{R + 1.6}{0.977} = \frac{2 \times 28.6}{0.954}$$

$$R = 2 \times 28.6\ \frac{0.977}{0.954} - 1.6 = 57 \text{ in.}$$

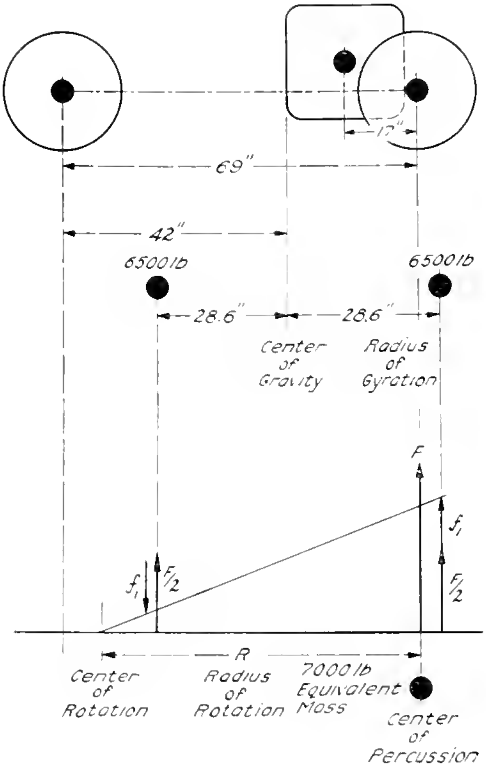


Fig. 2

**Equivalent Mass of Truck at the Wheel**

$P \times 57^2 = 6550 \times 58.6^2 + 6550 \times 1.4^2$

$P = 7000$

Similarly it can be figured that the combined mass of the truck and the car is 8700 lb.

Substituting the figures thus found in the formula for critical speed:

$P = 7000 = 3200$ kilograms

$W = 40{,}000 = 18200$ kilograms

wheel-base $= 69$ in. $= 1.75$ meters

$$v_c = 10 \times 1.75\ \frac{18{,}200}{3200}$$

$v_c = 43$ meters per second

$= 97$ miles per hour.

**Shock on Track**

Shock on track at 45 m.p.h. = 20 meters per second

$$= \frac{3200}{1000}\ \frac{20^2}{1.75^2}\ \frac{3200}{18{,}200}$$

= 170 kg. meters per second

= 1220 lb. foot-seconds.

Similarly we find for truck rigidly connected to the car.

Critical speed = 85 m.p.h.

Shock on track at 45 m.p.h. = 1730 lb. foot-seconds.

In order to illustrate the results that are obtained by using the above described method for analyzing the running qualities of a truck, a table is given showing the principal characteristics of a typical railway truck with motors suspended in different ways. Three characteristic methods are shown for the suspension of the motors, viz.: The ordinary arrangement of two inside-hung motors, one inside-hung motor, and one motor outside hung. (Table on opposite page.)

The two characteristic figures that must be examined in order to judge the running qualities of a truck are the mass of the truck referred to the front wheel and the critical speed. The mass referred to the front wheel is calculated without any arbitrary assumption and is determined from the well known principles for inertia and unsymmetrical shock. The critical speed is calculated in accordance with the principles outlined above.

The conclusion that can be drawn from the figures for the mass and critical speed are, in general, that the higher the mass and the lower the critical speed, the harder will be the shocks on the track at any speed. In order to combine the conclusion from the figures for mass and critical speed, a figure is given for the shock on a track at 45 m.p.h. This has an intermediate speed which is of interest for high speed as well as low speed equipments. In order to arrive at this figure for shock, an assumption has been made which cannot be mechanically proven to be exact, but ought to be a fairly close approximation to facts. This assumption, as stated above, is that the oscillations of the truck are directly proportional to the speed, and reaches the maximum value at the critical speed. Thus, if the critical speed is 50 m.p.h. the angle of oscillation at 45 m.p.h. would be 90 per cent of the maximum, whereas if the critical speed were 100 m.p.h., the angle of oscillation would be only 45 per cent of the maximum at 45 m.p.h. On the basis of this assumption, the shock on the track at any speed can be expressed in mechanical units. The units for the shock is the product of mass and velocity, and therefore the shocks are expressed in units of one pound at one foot per second.

In arriving at these figures, the weight of the car, as well as the weight of the truck, has been taken into account. However, the car is attached to the truck with a semi-flexible connection, and therefore the shock resulting from the weight of the car cannot be as great as the shock resulting from the truck itself. In order to determine the limits of error introduced by this unknown factor, all the figures are given in two ways; viz.: With a perfectly rigid connection between the car and truck and with a perfectly flexible connection. It will be seen that these two extreme limits give results which are not very far apart, and the true value which must lie between these limits can be determined with fair accuracy.

Inasmuch as the phenomena referred to are not subject to measurement with any degree of accuracy, or at any rate only under great difficulties, it is hoped that the method for analyzing the running qualities of trucks, as presented in this paper, will be of some value to the designers in comparing the merits of the different constructions. The object of this analysis will have been accomplished if a practical method is provided for arriving at relative values for the sake of comparison.

| Type of truck | | Two motors—inside-hung | | One motor—inside-hung | | One motor—outside-hung | |
|---|---|---|---|---|---|---|---|
| Connection between truck and car | | Flexible | Rigid | Flexible | Rigid | Flexible | Rigid |
| Wheel-base | B | 6 ft. 6 in. | 6 ft. 6 in. | 5 ft. 9 in. | 5 ft. 9 in. | 5 ft. | 5 ft. |
| Weight on wheels in lb. | W | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Equivalent mass at front wheel in lb. | P | 8,000 | 9,700 | 7,000 | 8,700 | 14,000 | 15,000 |
| Critical speed in m.p.h. | $7.2\, B\sqrt{\frac{W}{P}}$ | 99 | 91 | 94 | 84 | 58 | 56 |
| Shock on track at 45 m.p.h. lb. × ft. per second | $0.0078 \times 45^2 \times \frac{P}{B^2}\sqrt{\frac{P}{W}}$ | 1,330 | 1,800 | 1,400 | 1,940 | 5,200 | 5,800 |

# CURRENT COLLECTION

By F. E. Case

Engineer, Railway Equipment Department, General Electric Company

Both the European and American current collecting devices are reviewed in this article and considerable attention is paid to the collection of large currents and the development of pantograph trolleys for higher direct current voltage installations. A great deal of study has recently been given to the details of construction of both overhead structures and current collecting devices, and has led to the development of pantograph trolleys that can successfully collect the large currents necessary in heavy traction work.—Editor.

F. E. Case

The long familiar overhead trolley wire is almost universally used for the conduction of current to the collectors of cars used in city street service.

On account of local requirements in the cities of Washington, D. C., New York, London, Paris and a few other places, cars operating in the streets collect their current from two iron rails partly enclosed in a conduit located in the road bed between the running rails. The cost of such an installation is prohibitive except where the density of traffic is very great and local restrictions prevent the use of the trolley.

Many interurban roads use the trolley, some from preference, but more of them on account of the major portion of their lines being along highways, where a contact rail could not be installed.

Practically all 600-volt roads in this country which are operating heavy cars in trains over private rights of way exclusively, use the contact rail and shoe on account of their great simplicity and reliability.

## European Development

For many years some European manufacturers have furnished sliding bow collectors for the same operating conditions under which the trolley wheel is used in this country. The collector contact is usually an aluminum bar several feet long with a groove in its upper face in which a mixture of graphite and grease is placed for lubricating purposes.

There is nothing very special in the trolley line construction under which these bows are used, although it is necessary to provide a smooth under-run for the bow by avoiding suspension and pull-off points lower than the trolley wire. The wire is also staggered to prevent notches being worn in the bow.

The adoption of high voltage alternating current for electrified steam road and other heavy service made it necessary to provide a current collector which would better fulfill the conditions of operation. A contact rail, lying near the ground, could not be considered on account of the apparent impossibility of properly insulating it and maintaining a sufficient protection of life.

It was desirable, first, to continuously maintain a proper contact with the wire at all speeds in order to avoid sparking; second, to permit operating the cars or locomotives in either direction without lowering the trolleys or turning them around on a pivot; and third, to obtain a reasonable life of contact and trolley wire. The final result was the pantograph trolley.

Many of these trolleys are supplied with a single bow contact. This bow is from five to seven feet long and pivoted at its ends to the pantograph frame. Owing to the movement of the bow about its pivoted points, which are about twelve inches below the top, the contour of the wearing surface assumes an arc of a circle. The contact bar is of aluminum with a small percentage of copper for slightly hardening it. It is made as light as possible in order to reduce its inertia to a minimum and thereby permit operating with a light pressure against the wire. The auxiliary springs give an upward pressure of about eight pounds. If a much higher pressure was used the life of the aluminum contact bar would be greatly reduced, owing to the small area in contact with the wire.

This low contact pressure necessitates a very flexible suspension of the trolley wire, and the elimination of sags between points of support. To accomplish this the trolley wire is suspended from a secondary, or messenger wire at intervals of from ten to fifteen feet. This general method of hanging is used to some extent in this country and it practically eliminates the sag in the trolley wire as the points of support are so close together. The trolley wire is hung by loose links from the messenger wire, which permits a certain amount of vertical flexibility absent in older forms of suspension.

Continental experience demonstrated that to secure the maximum life of the trolley wire with a collector bow of the type adopted, it was necessary to use a relatively soft metal for the bow contact and provide for lubricating it. Also, that to prevent grooves being worn in the contact surface, and to distribute the wear to the best advantage, the trolley wire should be staggered from one side of the track center line to the other. In several recent installations the amount of this staggering has been at the rate of one meter per 100, necessitating the use of a very long bow contact.

Many of these catenary trolley installations use automatic tension adjusters, which maintain a substantially constant strain on the trolley wire at all temperatures. As the difference in length of the copper wire between summer and winter is about six feet per mile it is evident that the automatic device has at least a theoretical advantage in preventing excessive strains in winter and too much slack in summer.

The current collecting capacity of a single bow is about 150 amperes maximum for ordinary railway locomotive service, and a life of about 5000 miles is obtained where the trolley wire has a total stagger of three feet.

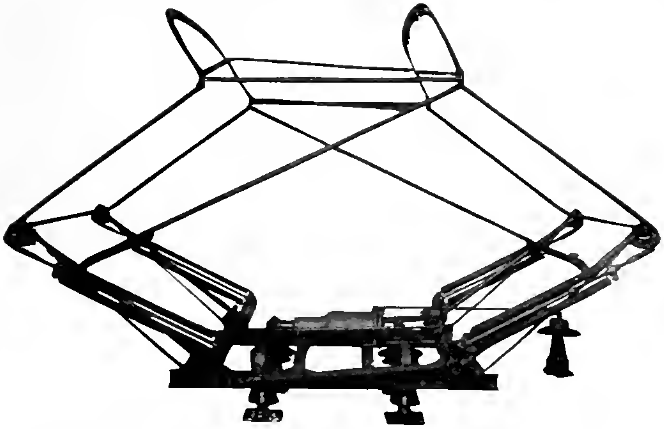


Fig. 2. A European Double-Contact Pantograph

Many high speed locomotives have been equipped with two pantograph trolleys for simultaneous operation in order to insure a continuous contact with the trolley wire. Recently, however, pantograph trolleys have been provided with two independent bow contacts for accomplishing the same purpose.

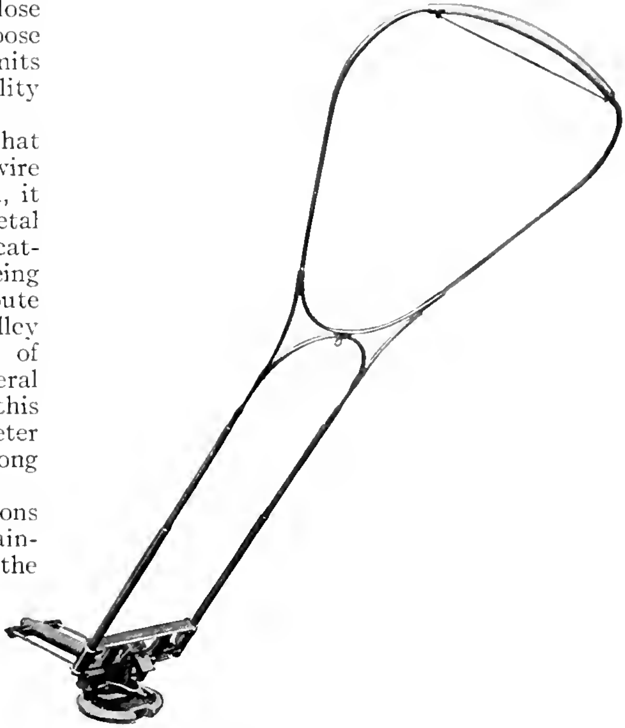


Fig. 1. A Foreign Bow Trolley for Light Service

### American Development

The trolley wheel has been extensively used in this country in a class of service where it has been taxed to its uttermost capacity. Several roads are operating cars equipped with four 125-h.p. 600-volt motors, the current being collected with a trolley wheel. The life of the wheel under these conditions is naturally much less than when operating on smaller cars and collecting less current.

No material changes have been made in the trolley wheel during the past decade. Improvements have been made in the method of lubrication, the collecting springs at the ends of the hubs and other minor features. The shape of the groove and the general dimensions of the wheel are practically fixed by the size of the trolley wire and the form of overhead frogs and crossings. It, therefore, appeared impossible to develop a trolley wheel having a materially larger collecting capacity and for this and other reasons, which will be discussed later, a different form of collector was found necessary.

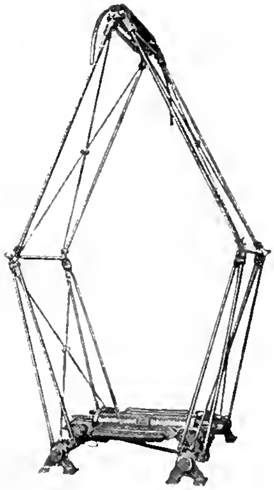


Fig. 3. A Roller Contact Pantograph

With some of the first high voltage a-c. car equipments put into service in this country, the ordinary trolley wheel was used. A form of bow collector was afterward tried but eventually it was abandoned in favor of a pantograph trolley having a thin steel collecting pan. It was found in several instances that this pan caused an excessive wear of the copper trolley wire, especially where grease was not used for lubricating it. This sheet steel pan has less collecting capacity than a trolley wheel and would not be at all suitable for heavy d-c. locomotives operating at even the highest voltage yet used.

Recent railway installations of 1200, 1500 and 2400 volts have in several cases used some form of the pantograph trolley.

The roller type of pantograph trolley has been successfully used for a number of years in the vicinity of San Francisco on heavy cars operating both singly and in trains on 600 and 1200-volt circuits.

Brass rollers five inches in diameter and twenty-four inches long were first used, but practice demonstrated that steel rollers gave a much greater mileage without apparently increasing the wear on the trolley wire. Steel roller contacts in operation upon cars and locomotives have given a life of over 15,000 miles in a service requiring the collection of 500 amperes during acceleration.

The roller contact pantograph, however, has less collecting capacity than a shoe sliding upon a rail, owing to its smaller area of contact, which is virtually no more than a point.

While the contact rail and shoe have such a decided advantage in regard to the quantity of current which can be collected, there are, in many cases, physical limitations which prevent their use, at least exclusively on 600-volt circuits. For elevated and underground railroads this method of conduction and collection has been used very successfully. For the electrification of existing steam roads, however, such questions as clearances in tunnels, over bridges and at congested terminals where there are numerous switches and cross-overs, frequently necessitate the use of a supplemental overhead conducting rail.

With the adoption of high operating voltages the general use of the contact rail, close to the ground, is questionable, as there would naturally be a certain amount of decreased reliability. A 1200-volt interurban road in California is, however, successfully operating over a portion of its line with an under-running protected contact rail. Prob-

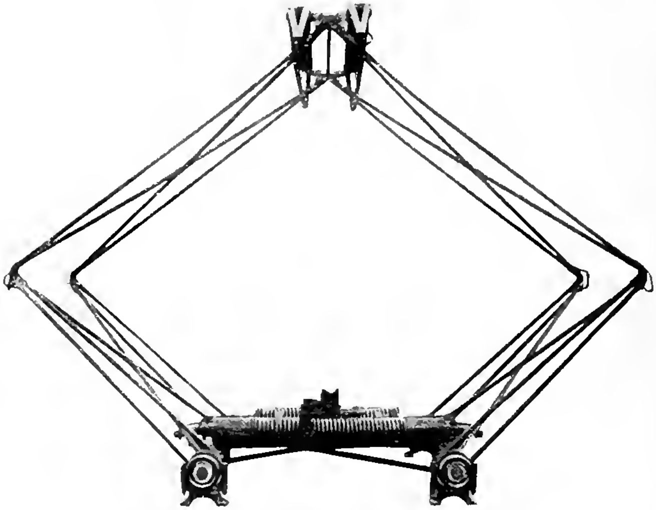


Fig. 4. A Double-Sliding-Contact Pantograph

ably this voltage is close to the reliable operating limit, but the other considerations previously mentioned may have a greater influence on the selection of the method for conducting current to the car or locomotive collectors.

Bearing in mind the limitations of the contact rail, and of the trolley wire collecting devices described, it was evident that a greatly improved form of current collection was necessary for use at increased voltages, currents and speeds.

Since the pantograph trolley possessed the advantages of not accidently leaving the trolley wire and requiring no attention when reversing the direction of train movement, it was logically chosen as the medium for supporting the collectors. The pantograph had the further advantage of being readily raised or lowered by the motorman.

The current collecting capacity of the contacts upon the existing pantographs had proved inadequate for this more severe service. Investigations and extensive life tests showed that a very material increase in the area of contact between the wire and collector was absolutely essential. It was further determined that copper contacts operating on a copper trolley wire were superior to other metals. Pantographs embodying these features have been operated in regular service and given excellent results. The copper bars are attached to pans of thin sheet steel about 42 inches long and 5 inches wide and cover approximately three-quarters of the upper surface. Pivoted arms between the pan and the pantograph frame permit the copper bars to maintain contact with the trolley wire for their full width. At the same time the arms provide for a quick movement of the contacts which enables them to rapidly follow small inequalities in the trolley line. Supplemental springs bring the pan into contact with the wire, giving a pressure of about ten pounds.

Two pans are used on each pantograph in order to insure a continuous contact with the wire and provide abundant capacity. Having two pans, permits increasing the upward pressure of the main springs of the pantograph to substantially double the amount which could be satisfactorily used with but one pan. This higher pressure makes the trolley as a whole more quickly responsive to sudden variations in height of trolley wire and ensures a more constant pressure of the contacts against the wire.

A pantograph trolley of this type has successfully collected 2000 amperes at speeds up to 40 m.p.hr. This current is more than a 0000 trolley wire can conduct for any considerable period without injurious heating.

To meet heavy service conditions, where one 0000 trolley wire would have insufficient conducting capacity, two parallel wires may be used. Such an installation has been tried with very satisfactory results. Not only is the conductivity of the overhead system doubled but the collecting capacity of the pantograph is greatly increased.

Several thousand car movements under a trolley wire with the pantograph collecting heavy currents produced a wear of the wire so slight as to compare most favorably with that obtained with the roller type of pantograph or trolley wheel when operating under their average conditions. It is essential for the successful collection of heavy currents, with this latest form of pantograph, to provide an overhead line possessing uniform flexibility.

The wear of the contacts and trolley wire is materially decreased by the use of a lubricant. Staggering the wire distributes the wear more evenly over the surface of the contacts and gives them a longer life. The side sway of the car or locomotive, together with the lateral variations in the position of the trolley wire on tangent track and curves also distribute the wear. Local conditions determine how much staggering, if any, is necessary to give the most economical life of contact. With a proper installation the contacts should wear at least three or four times as long as a good trolley wheel and at the same time collect a considerably greater amount of current.

# A REVIEW OF SOME EUROPEAN ELECTRIC LOCOMOTIVE DESIGNS

By S. T. Dodd

Railway and Traction Engineering Department, General Electric Company

The author makes a valuable analysis of European electric locomotive design and discusses not only the details of construction but also the general tendencies prevailing abroad that have led to the acceptance or rejection of particular types. The design of the electric locomotives for the Prussian State Railways, the Silesian State Railways, Baden State Railways, the Midi Railway of France, the Loetschberg Tunnel, the Simplon Tunnel and the Italian State Railways are all reviewed and discussed. The author comes to the conclusion that the development of electric locomotives in America has been more conservative and productive of more economical results than that in Europe.—Editor.

S. T. Dodd

In a number of discussions on electric locomotive design the writer has encountered arguments, based on European practice, pointing to the advantage of the side rod drive. This type of design has been repeated so frequently in European locomotives that it is quoted as showing the satisfaction with which it is regarded by Continental engineers.

In the following article the writer has attemped to analyze the conditions and tendencies of electric locomotive design in Europe. The object of this analysis is to attempt to show the extent to which various European locomotive designs have been satisfactory or otherwise, as indicated by the reports which have been published of tests on experimental types and as shown by the latest types ordered and built by European manufacturers. The study is not based on personal observations of the locomotives under discussion, but on a general review of the articles which have been appearing in the technical press during the last few years, and it gives the personal impressions obtained by the writer from such a review.

In making such a study it must be noted that the development of electric locomotives in Europe has been influenced by certain considerations differing from those that obtain in this country, and that must be kept in mind if one is to appreciate facts in their proper relations. The most important of these might be classed as follows:

(a) The influence of preconceived engineering opinions.

A good illustration of this is given by an extract from the *A. E. G. Journal* of April, 1912.

> "The two requirements already known from steam locomotive practice, namely, a high center of gravity, and the use of a parallel crank drive were already adopted for electric locomotives in the year 1902."

The fact is that on the Prussian State Railways at least the satisfactory performance of high speed steam locomotives largely determined the mechanical design of the first electric locomotives. It was planned merely to replace the boiler and fire box of the steam locomotive with an electric motor and to retain as far as possible the mechanical arrangement and method of drive of the steam locomotive. The least that can be said of such a decision is that the arrangement referred to is still open for discussion in the year 1914, and an arbitrary decision on this point 12 years ago must have tended to retard rather than to advance engineering practice.

(b) The large number of experimental locomotives built for the purpose of determining the preferred type.

Illustrations of this are to be seen in nearly every experimental electrification referred to. The European railways are largely state owned and very possibly political considerations often demand that orders for sample locomotives of practically the same type should be placed with a large number of different manufacturers. No other than political reasons would seem to justify increasing the cost of electrification with experimental locomotives to the extent that seems customary in Europe.

(c) The premature publication of locomotive designs.

The large number of manufacturers building electric locomotives and the keen competition between them seem to cause them to advertise, as contracts, orders for locomotives which are in many cases only tentative, and to describe in technical articles designs which are more or less experimental and which are changed before the locomotives are fully completed. This tendency is rather misleading to one studying European locomotives if he starts out under the impression that all designs of locomotives described in the technical press are actually built, and in successful operation.

Keeping these considerations in view we will review briefly the results of some of the most important electrifications.

### Prussian State Railways

In accordance with a law passed in 1909 it was decided to begin the electrification of the Prussian State Railways upon a stretch connecting Magdeburg, Leipsic and Halle, the total length of line being about 100 miles. As an experimental equipment to determine the types of locomotives to be selected for various classes of service, a length of 16 miles from Dessau to Bitterfeld was first electrified and equipped with locomotives. On this experimental piece of track some 12 or 15 different locomotives have been tried out.

Fig. 1 shows the experimental type of locomotive ordered for high speed passenger service. This is a 2-B-1 locomotive. A classification which indicates that it has two leading axles, two driving axles and one trailing axle. It is equipped with one large motor driving, through vertical connecting rods, a jack shaft which in turn is connected to the driving wheels through horizontal side rods. Of this type three locomotives were purchased from three different manufacturers. Each of these locomotives had a weight of approximately 75 tons with 35 tons on drivers and were to be designed for maximum speeds of about 80 miles per hour. The reports which have reached us regarding the operation of this type is that it was very successful as far as its ability to make high speeds without serious vibration was concerned. There does not appear to have been any development of the "critical speeds" which limit the operation of many other types of side rod locomotives, but some difficulties have occurred in the breakage of cranks and jack shafts. It will be noted that the connecting rod is vertical and at right angles to the side rods on the same side of the locomotive. As a consequence all the forces transmitted through the connecting rods on one side must be transmitted through the jack shaft to the side rods on the other side. The jack shaft is, therefore, subjected to a series of suddenly applied reciprocating torsion strains and these strains were regarded as the explanation of the breakages which occurred. A very liberal design of jack shafts and cranks, and great care in alignment of bearings, have not been sufficient to entirely eliminate this trouble, and in spite of the ease on the track and the successful high speed operation of the locomotive, it seems to be questionable whether this type will ever be duplicated.

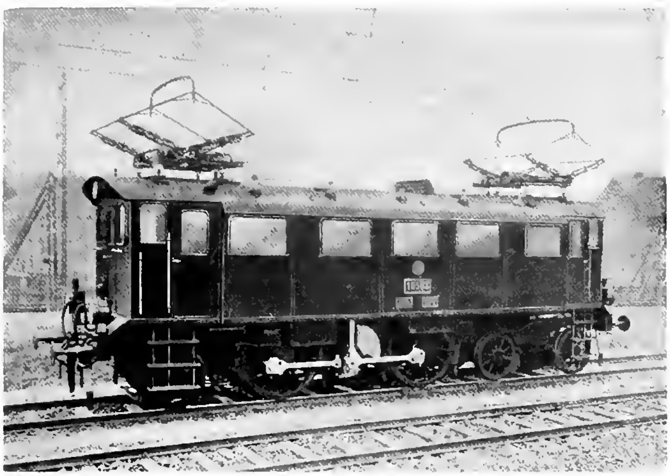


Fig. 1. Dessau-Bitterfeld Experimental Line. High speed passenger locomotive. Side rod drive with vertical connecting rods

In place of this for express service it has been decided to try a 1-C-1 type with three driving axles and two idle axles. Orders have been placed for four sample units of this type, although according to the latest information received by the writer only two had been delivered. No photographs have been published and no very definite information as to the results of the tests of this type have been obtained. Each of these locomotives is equipped with one motor of 1000-1800 h.p. The motor is placed high in the cab and drives, by a connecting rod slanting approximately 45 degrees, to a jack shaft, from which the power is transmitted through side rods to the driving wheels. The experiments upon the passenger locomotive, Fig. 1, seem to have eliminated the consideration of vertical connecting rods and to have determined that the connecting rod should have as much slant as possible in order to reduce as far as possible the reciprocating torsion strains in the jack shaft.

Fig. 2. Dessau-Bittersfeld Experimental Line. Freight locomotive with side rod drive

The experimental freight locomotive is shown in Fig. 2. This is an O-D-O type; i.e., it has no leading axles, four driving axles and no trailing axles. It is a slow speed locomotive weighing 70 tons with a rated speed of 15.5 m.p.h. and a maximum speed of 37.5m.p.h. Of this type seven units have been ordered of five different manufacturers of which five have been delivered. Looking at the subject from an American standpoint, it is a little surprising that it should have been thought necessary to do as much experimental work on this type as is indicated by the number of units ordered. There is every reason to expect that at such speeds almost any type of electric locomotive would be perfectly satisfactory. In fact, it is difficult to see the reason why a high placed motor and side rod drive should have been considered necessary for freight service. The reasons usually adduced as demanding a high center of gravity do not apply at such speeds as are attained in freight service, and the uniform success of the slow speed geared locomotive for freight work would have led to the supposition that a straight geared motor would have been selected without question for this work.

As a result of the experimental work extending over about four years, the Prussian State Railways have decided to proceed with the electrification of the whole Magdeburg-Leipsic-Halle line and have placed their order for 36 locomotives for this electrification. Of this order 26 are for medium or low speed service, and the type of locomotive selected is shown in Fig. 3. This is a geared side rod locomotive classified as a B-B type; i.e., one having two independent trucks each of which has two driving axles. It is equipped with two motors each geared to a jack shaft, which in turn is connected to two driving axles through a Scotch yoke or slotted side rod. The locomotive can develop 600 h.p. at a speed of 13 m.p.h. and is capable of maximum safe speeds of a little over 30 m.p.h.

In addition to the locomotives described above, various other types have been tested on the Dessau-Bitterfeld for the State Railways of Silesia, Baden and Bavaria. It appears that practically all the high speed, direct drive, side rod locomotives tested have given more or less trouble from developing "critical speeds" and by breaking rods, cranks and crankshafts under some conditions.

It is difficult for one not in personal touch with the developments to speak authoritatively, but apparently the result of four years of experimentation and study on the Prussian State Railways has been to discredit the direct driven, side rod locomotive and to point toward some type of gearing and side rod or simple gearing as the most satisfactory drive for medium or low speed service, while

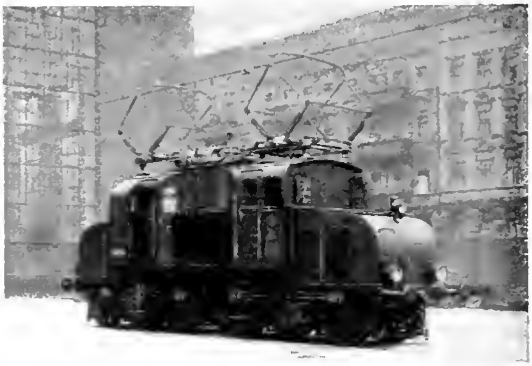


Fig. 3. Magdeburg-Leipsic-Halle Line. Medium speed passenger and freight locomotive. Motors geared to jack shafts with side rod drive

the type of locomotive for high speed or passenger service is not yet clearly indicated.

### Silesian State Railways

Another electrification of considerable extent is being undertaken at the present time by the State Railways of Silesia, the mountainous district of southeastern Germany near the Austrian border. The first section to be electrified is from Lauban to Konigzelt. This stretch is 81 miles in length and will later be extended to Breslau, a total distance of 125 miles. Trials of multiple-unit cars on this line were made on July 14, 1914, and it was then expected that regular multiple-unit service would be in operation before the end of the present year.

The Silesian roads traverse a mountainous territory with severe grades which demand heavy locomotives. The preliminary locomotive contracts and designs have evidently been largely influenced by the same considerations which affected the Prussian State Railways, and the first experimental locomotives for the line have been built and tested out on the Dessau-Bitterfeld experimental tracks. One of these locomotives is shown in Fig. 4. It is a 1-D-1 type with four driving axles, weighing over 100 tons, and driven by two large motors. The two motors are connected by sloping connecting rods to a common jack shaft which in turn is connected to the driving wheels through horizontal side rods. Two locomotives of this type by different manufacturers have been tested and according to all accounts have not given a very good account of themselves. Both these locomotives developed trouble from severe vibration at certain speeds, resulting in broken rods and cranks. Referring to this question of vibration the *Railway Gazette* (London) of October 24, 1913, says:

> "From these reasons it is probable that the heavy express locomotives for the mountainous district of the Prussian State Railways will not be of the type with an elevated motor and parallel crank action as was the first intention, but with two motors each of half the efficiency of the elevated one and with intermediate toothed gearing and sliding crank."

In addition to the two locomotives which have been built and tested for this line, a number of other interesting types have been proposed and described.

One of these is a C+C locomotive with two three-axle trucks, each of which is equipped with two motors geared to a common jack shaft which drives the three axles through horizontal side rods.

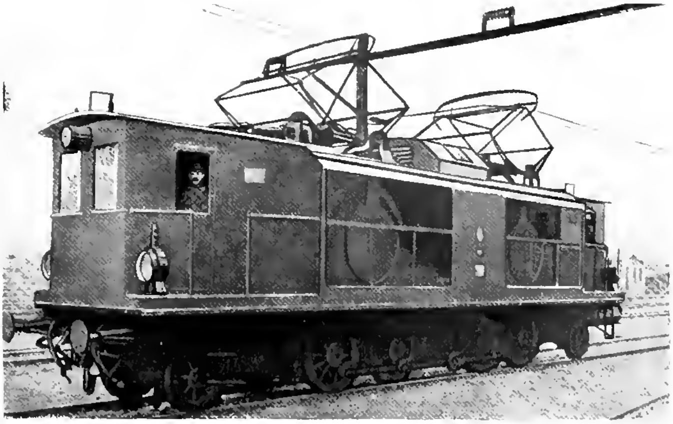


Fig. 4. Silesian State Railways. Heavy express locomotive with side rod drive

Another is a B+B+B locomotive with three two-axle trucks having one motor on each truck. The motor is geared to a jack shaft which drives the two axles through horizontal side rods.

Another is a AA+AA+AA locomotive also with three two-axle trucks, but having two motors on each truck. Each motor is geared directly to one driving axle.

A most interesting type is a 2-D-1 locomotive, the design of which is shown in the line drawing in the upper part of Fig. 5. This is equipped with one large motor of 1800 h.p., driving two jack shafts through a solid triangular rod.

The upper point of the triangle engages with the crank of the motor and the base of the triangle connects together the cranks of two jack shafts which are in turn connected to the driving wheels by horizontal rods. This is very similar to the triangular rod drive used on one of the experimental locomotives for the Midi Railway of France referred to later in this article. The Midi locomotive had two motors connected to the driving wheels through a solid triangular rod of which the apex engaged with the crank of the driving wheel, and the base connected together the cranks of the two motors. The proposed Silesian locomotive has one motor connected to the driving wheels through a triangular rod of which the apex engages with the crank of the motor and the base connects together the cranks of the two jack shafts. The Midi construction was later altered to a more flexible type and one would not anticipate any different results from one of these arrangements than from the other.

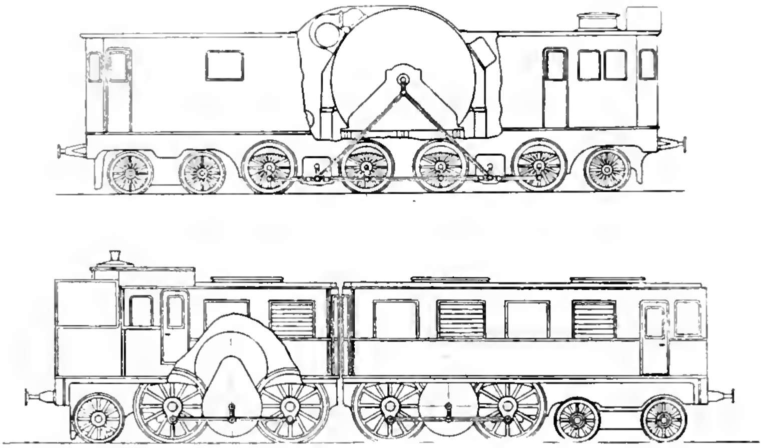


Fig. 5. Silesian State Railways. Proposed express locomotives. Upper, triangular side rod drive; Lower, geared side rod drive

It is reported that the same manufacturers are building a 2-B-B-1 locomotive for the Lauban-Konigzelt electrification, the design of which is shown in the line drawing in the lower part of Fig. 5. The fact that this has the same weight and aggregate horse power as their single unit locomotive at least gives rise to the suspicion that there is some question as to the success of the single motor triangular side rod drive.

### Baden State Railways

Another electrification worthy of mention embraces a road known as the Wiesenthalbahn in the southern part of the state of Baden. In 1909 the Baden State Railways ordered ten locomotives for the operation of their experimental section from Basel to Sackingen, a distance of 30 miles. If this installation is successful it will later be extended as far as Mannheim, a distance of 130 miles in a straight line covering probably from 200 to 300 miles of track. Of the ten locomotives described in the earlier announcements, only one has been completed, which is shown in Fig. 6. This locomotive was tested on the Dessau-Bitterfeld line. A study of the construction of the locomotive impresses anyone familiar with locomotive design with the idea that it would not be suitable for high speed service. The location of the motors at the outer ends of the locomotive made it evident that serious oscillations might be anticipated around a vertical axis which would make it hard on the track at high speeds, and the pony trucks do not look as though they had sufficient weight or friction to dampen those oscillations. Running gear troubles and instability in running might be expected to develop.

Apparently the remainder of the order of ten locomotives has been completed according to another design, of which a line drawing is shown in Fig. 7. In this design the two motors are set close together at the center of the cab and drive a jack shaft through independent rods sloping at an angle of about 45 degrees. The wheels are driven by horizontal side rods, the center one of which carries the driving box on the jack shaft crank, and the motor connecting rods are separately knuckled to this box. Unfortunately, this design does not seem to have been completely successful. The line was scheduled to be running in the latter part of 1912, but was not running a year from that date. Several articles could be referred to on the troubles developed by these locomotives, but perhaps the best summary of observations is given by Lydall (*Journal of the Institution of Electrical Engineers*, 1913, part 230, page 383), from which the following is a condensed abstract:

> "After a great deal of observation it was found that at a certain speed the connecting rods and coupling rods on both sides of any of these locomotives started to vibrate and that this vibration gradually increased as the speed rose until at a speed of about 36 km. per hr., it reached a maximum of considerable amplitude. At this speed there seemed to be the equivalent of resonance as the vibration practically disappeared as soon as the speed had risen to 40 km. per hr.
>
> "It is of interest to remark that this performance of coupling rod systems is observable on practically all locomotives in which the effort of the motors is transmitted to the driving axles by means of connecting rods. It is especially noticeable where two motors are connected to a single jack shaft and is also observable with Scotch yokes as on the locomotives for the Loetschberg Tunnel on which breakages of the yokes have taken place. The same experience, to a less extent, is found where one motor drives a single jack shaft as on the 1-C-1 for the Prussian State Railways. The same effect has also been observed on the 2-B-B-2 locomotives of the Pennsylvania Railroad although in this case the vibration is very slight."

Reports indicate that on account of the difficulties with the driving rods on the Wiesenthal locomotives it is proposed to rebuild the driving mechanism by introducing a slotted arrangement at the jack shaft, the nature of which has not been very clearly explained in publications.

In addition to the ten locomotives, two locomotives of a different type have been ordered for the Wiesenthal, only one of which had been delivered up to the end of 1913. The design of this locomotive is shown in Fig. 8. It differs from the preceding in that there is no jack shaft and the motors drive the middle one of the three driving axles, thus decreasing the total length of the rigid wheel base and the overall length of the locomotives. The driving box on the crank pin is carried on one of the motor connecting rods, instead of being carried on the horizontal rod as was done in the previous design, the other motor connecting rod and the horizontal rods being knuckled to this driving box. No adverse reports have been recorded on the operation of this so-called "double rod drive" but it has not been used in a large number of cases and until it has had considerable practical application it is too early to conclude that it is the solution of the driving rod troubles.

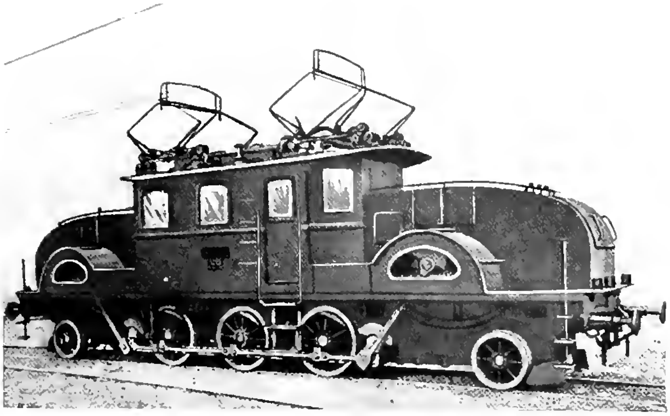


Fig. 6. Baden State Railways. Experimental locomotive with two jack shafts and side rods

**Midi Railway of France**

The Midi or Southern Railway of France has been making a study of the electrification of a line 175 miles in length in the neighborhood of Toulouse. As an experimental section there has been electrified and equipped a 15 mile line in the Eastern Pyrenees from Ille to Ville-Franche. The principal grades of this line are 2 per cent.

The road is not state owned, but the water power development is at the expense of the state so that state control is probably to a large extent effective, and the same characteristics mentioned on the Prussian State Rail-

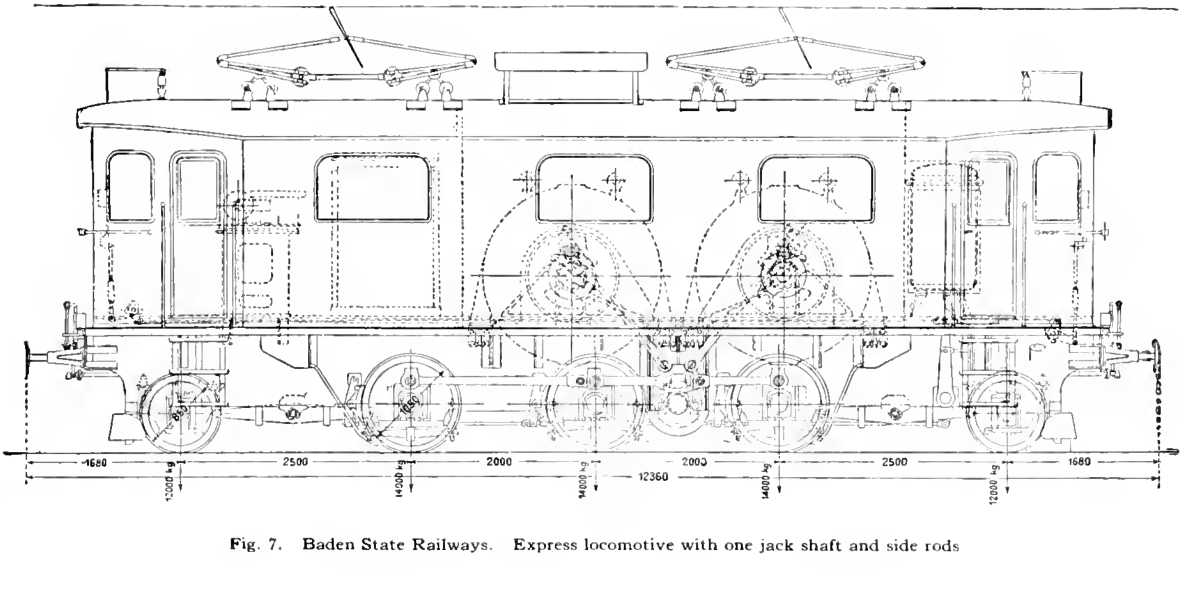


Fig. 7. Baden State Railways. Express locomotive with one jack shaft and side rods

ways are to be noted on this electrification. For the experimental installation six locomotives were ordered from as many different manufacturers. To what extent the designs of the locomotives were determined by the experimental types specified for the Prussian State Railways it is hard to say, but it is a fact that all but one of the locomotives made use of side rods in one form or another. All the locomotives were of a 1-C-1 type, having three driving axles and two leading axles. The weight of each was approximately 90 tons with 60 tons on drivers, and all were to be suitable for maximum speeds of about 68 m.p.h.

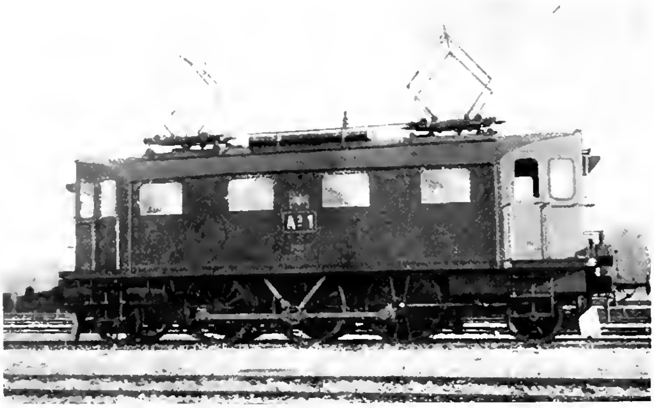


**Fig. 8. Baden State Railways. Later type of express locomotive with "double rod" drive without jack shafts**

Fig. 9 shows one of these experimental locomotives. This locomotive was equipped with two motors, each driving a jack shaft through sloping connecting rods. These jack shafts were located at each end of the locomotive, between the outer driving wheel and the leading wheel, and were connected together and to the driving wheels by horizontal side rods.

A second locomotive had a very similar arrangement of motors and driving mechanism to that shown in Fig. 9, the principal differences being in the design of the electrical apparatus.

A third type of locomotive is shown in Fig. 10. This also had two motors but instead of being connected to a jack shaft the motors were connected together through a triangular rod approximately the shape of an equilateral triangle. The lower point of the triangle engaged with the crank of the middle driving wheel and the other points engaged with the cranks of the two motors. It is apparent on inspection that the horizontal pressure of the driving rods against the lower point of such a deep triangle gives rise to vertical stresses against the cranks of the two motors, and sets up skew stresses in the motors and locomotive frame. An elaborate mathematical paper by Kleinow (*Elektrische Kraftbetriebe und Bahnen*, 1913, page 337) discusses the pressures produced by various shapes of triangular rods and shows that they may rise to excessive amounts with such a deep triangular rod. How much trouble developed from this source in the Midi experiment the writer is unable to say. After the first publication and description of the drive it was changed to the "double rod drive" which we have discussed in detail in our description of the locomotives on the Wiesenthal railroad. It will be noted that the rod shown in Fig. 10 is this "double rod" type rather than the solid triangular type first designed for this locomotive.

Another Midi experimental locomotive is shown in Fig. 11. This is a geared side rod type of locomotive equipped with two motors, each geared to a jack shaft set well down between the driving wheels. The center of the jack shaft is nearly in line with the center of the driving wheels and power is transmitted from the cranks of the jack shafts to the center wheel by a flat triangle or Scotch yoke, and from there by horizontal side rods to the other two axles.

**Fig. 9. Midi Railway, France. Experimental locomotive with two jack shafts and side rod drive**

The last of this set of experimental locomotives is shown in Fig. 12. This is a geared locomotive with three motors one over each

Fig. 10. Midi Railway, France. Experimental locomotive. Motors coupled with triangular rod

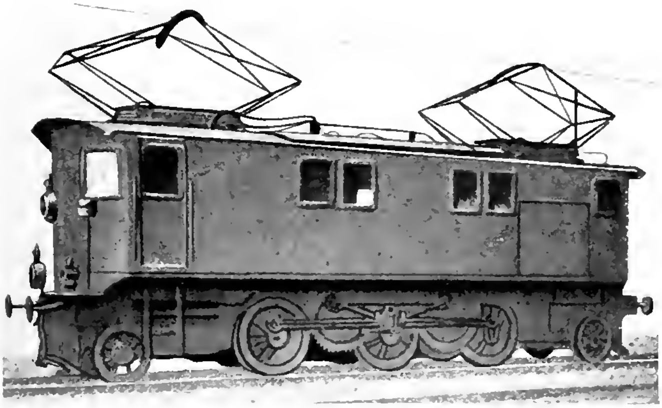


Fig. 11. Midi Railway, France. Experimental locomotive. Motors geared to jack shafts coupled with Scotch yoke

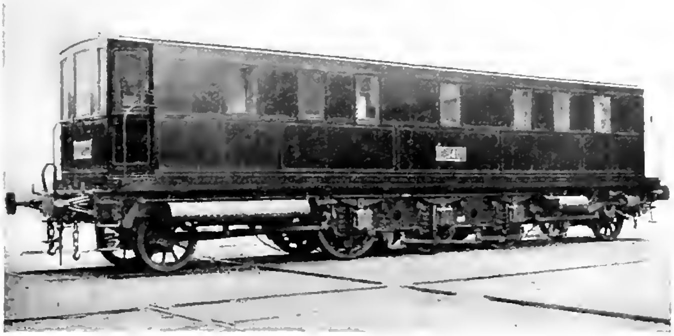


Fig. 12. Midi Railway, France. Experimental locomotive. Motors geared with quill drive.

axle flexibly supported and geared to a quill surrounding that axle.

Three of these locomotives, those shown in Figs. 9, 11 and 12, were accepted by the railroad company. The other three were rejected after experimental service, as not meeting the contract in some particular or as developing characteristics which made them inoperative. To each of the three manufacturers whose sample locomotives were accepted the railroad company has given orders for eight additional locomotives. The interesting thing to note is that the 24 new locomotives are not in any case to be duplicates of the accepted sample. The type of locomotive ordered is to have three driving axles and two trailing axles, each driving axle driven by two motors geared to a quill surrounding the axle and supported flexibly. In other words, after an investigation of the merits of different designs, the railroad company have decided on a geared type of locomotive with twin motors driving through a quill in preference to any type of side rod locomotive.

### Loetschberg Tunnel

In Switzerland the most important recent electrification is the Loetschberg Tunnel, which was put in operation about the middle of the year 1913. The construction of the Loetschberg Tunnel offers a short route from Italy to France through the Simplon and Loetschberg Tunnels and through the Province of Bern. In preparation for this the Bernese Alps Railway has been working for a number of years to provide suitable electric service when the Loetschberg Tunnel should be opened, and which would divert over this line part of the traffic which previously went through the St. Gothard Tunnel by way of Luzerne. As a part of the preparation in 1910 the Bernese Alps Railway received an experimental locomotive shown in Fig. 13. The locomotive weighed 110 tons with 75 tons on drivers. It was an articulated unit equipped with two motors, one upon each half of the locomotive. Each motor drove a jack shaft through a connecting rod having a slope of 11 degrees from the vertical, and this jack shaft in turn was connected to two driving axles through horizontal rods. The writer has no definite information as to the results of the test of this locomotive, but one might anticipate the same troubles which developed on the single motor locomotives equipped with vertical connecting rods which we have previously discussed. A second experimental locomotive was purchased of which the design is shown in Fig. 14. The locomotive is built with two separate three axle trucks and one motor on each truck. The motor is geared to a jack shaft, which in turn is connected to the driving wheels by connecting rods and side rods. The jack shaft is placed so low that the connecting rod makes a very small angle with the horizontal. The motors are placed at the extreme ends of the locomotives, and while no information has been published as to the results of the tests on this type it might be anticipated that the large value of the moment of inertia around the vertical axis would give rise to severe oscillations, and that the locomotive would be hard on the track at high speeds. The result of the tests was the adoption for the final installation of the type of locomotive shown in Fig. 15. It will be noted that several important changes have been made from the experimental type. There are five driving axles instead of six. Three of the drivers are carried in a rigid wheel base and each leading truck carries one idle axle and one driving axle. The driving axles on all three trucks are held parallel to each other and connected by horizontal side rods. The two motors are set close together in the center of the cab and geared to jack shafts, which in turn are connected to the center driving wheel by a Scotch yoke to which the horizontal rods are knuckled. The weight of the locomotive is 235,000 lb. with 172,000 lb. on drivers. The earlier reports indicated very successful and satisfactory operation of this type of locomotive, but as later discussions of this electrification have appeared it is evident that the locomotives have developed some serious defects. Apparently very serious oscillations or vibrations take place in the driving mechanism at certain speeds which are sufficient to break rods, crankshafts and yokes. The cause of these vibrations has been the subject of mathematical investigations by A. Wickert (*Elektrische Kraftbetriebe und Bahnen*, June 14, 1914) and J. Buchli (*Elektrotechnische Zeitschrift*, May

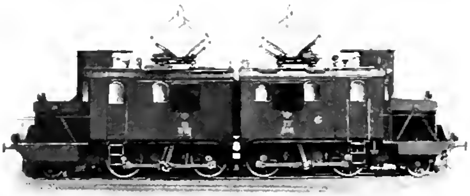


Fig. 13. Loetschberg Tunnel. Experimental locomotive with vertical side rod drive

Fig. 15. Loetschberg Tunnel. Accepted type of locomotive. Motors geared to jack shafts coupled with Scotch yoke and side rods

Fig. 14. Loetschberg Tunnel. Experimental locomotive. Motors geared to jack shafts with side rod drive

28, 1914). Perhaps the clearest statement of the troubles developed can be obtained from the following extract from Buchli's article:

> "The Loetschberg locomotives which have been in regular operation since the middle of last year develop at certain speeds very serious vibrations whose cause has for a long time been unexplained. While some of these locomotives at all speeds up to 75 km. hr. run perfectly steadily in others there appear at speeds between 35 and 42 km. hr. vibrations which in several cases have caused serious defects of the driving gear. By careful adjustment of the bearings one is able to remove the trouble. The adjustment requires labor and time and shortly after the locomotive is put in normal service the trouble occurs again. Similar vibrations as are seen on the Loetschberg locomotives I have also observed on other jack shaft driven locomotives. They appear under some circumstances so serious that the locomotive in question cannot be kept in service. The locomotives of the Pennsylvania Railroad appear to possess this same fault and I do not think I am going too far when I make the statement that every main line electric locomotive built up to this time with side rods and jack shafts shows mechanical vibrations of this character in greater or less degree. It is, therefore, not surprising that the representatives of main line railroad companies are today looking at the side rod drive with some mistrust and that the American construction of drive, the axle motor or the quill drive motor is again coming into prominence."

Both the articles referred to indicate that these vibrations can be attributed to resonance effects of oscillations in the driving system. They also indicate that by the introduction of a proper amount of elasticity in the driving mechanism these oscillations should be diminished or prevented. Along these lines it has been proposed to rebuild one of the Loetschberg locomotives with springs inserted in the gears so as to introduce a certain amount of elasticity between the motors and the yoke. Until some information is published as to the result of this test, it will be impossible to say whether the troubles on this type of locomotive have been eliminated.

The question arises why vibration effects such as are described above do not occur on the driving rod systems of steam locomotives. The fact is that a great deal more accurate adjustment is required on an electric side rod drive than on a steam side rod drive. In the electric locomotive a number of axles, jack shafts and armature shafts have to be lined up and centered very carefully, or the cranks, rods and frame of the locomotive will be subjected to excessive stresses at certain points in the rotation. The same trouble does not appear in the steam locomotive because the terminus of the driving rod system lies in the steam cylinder where the elasticity or cushioning of the steam takes up any inaccuracy in the construction. The trouble we have described on electric locomotives is exaggerated in cases where the heavy rotating members of two independent motors are connected together by a system of rods as in the designs described on the Loetschberg, Wiesenthal, and Silesian locomotives. The motors can be looked on as independent of the wheels and the wheel friction cannot dampen oscillations set up between the two motors.

### Simplon Tunnel

It is of interest to compare, with the results above described, the performance of the equipment of the Simplon Tunnel. This electrification is geographically a continuation of the Loetschberg electrification, as the Simplon electrification meets the Loetschberg at Brig, Switzerland, and extends through the Simplon Tunnel to Iselle in Italy. Four locomotives are in service in the Simplon Tunnel, two each of the types shown in Figs. 16 and 17. There will be noted a general similarity in wheel arrangement and general design between these locomotives and the Loetschberg locomotives. The Simplon locomotives have been in service since 1907 and 1909 respectively, and as far as published reports give any evidence they have not developed any of the troubles which appear to have required investigation on the Loetschberg.

Aside from the fact that one of these electrifications is single-phase and the other three-phase, the important difference as far as mechanical arrangement is concerned seems to be that the motors of the Loetschberg locomotives are larger in weight and horse power than those of the Simplon and being geared to jack shafts the motors run at higher rotative speed for the same locomotive speed. The rotary momentum of the moving parts on the Loetschberg locomotive is therefore far greater than on the Simplon.

### Italian State Railways

The equipment of the Valtellina line in northern Italy has been so often described that it is unnecessary in this article to do more than mention it. The locomotives on this line, one of which is shown in Fig. 18, have been in operation since 1904 and their success has largely led the Italian State Railways to locomotives of this Scotch yoke side rod type. A still more recent and successful type has been fully described in the technical press and is widely used on the Italian State Railways

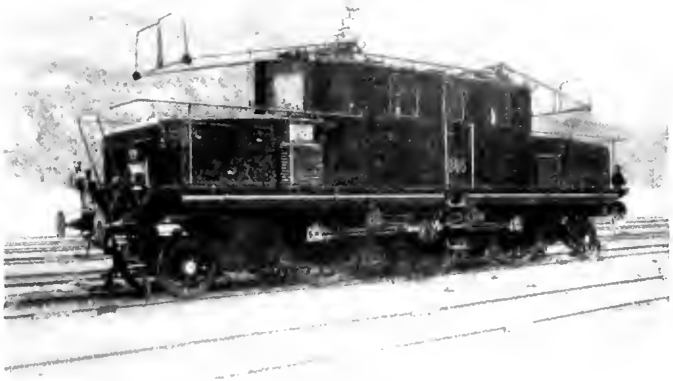


Fig. 16. Simplon Tunnel. Passenger and freight locomotive. Gearless motors coupled with Scotch yoke and side rods

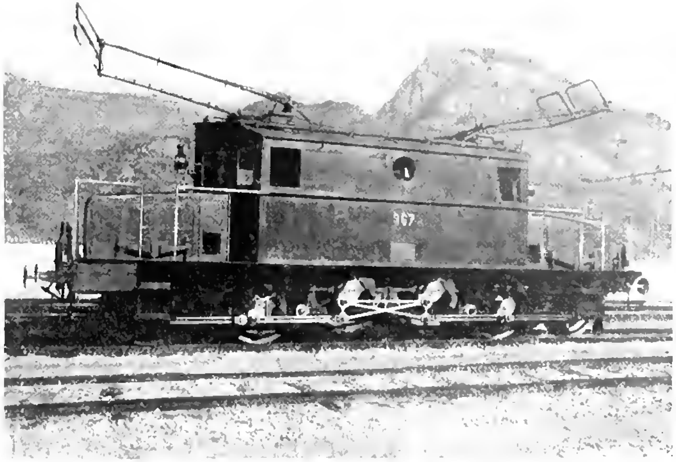


Fig. 17. Simplon Tunnel. Passenger and freight locomotive. Gearless motors with horizontal side rod drive

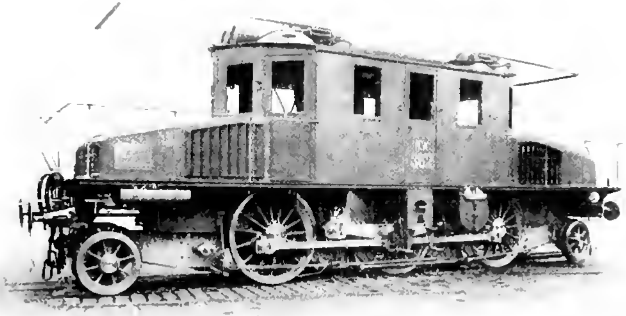


Fig. 18. Valtellina Railway. Passenger locomotive. Gearless motors coupled with Scotch yoke and side rods

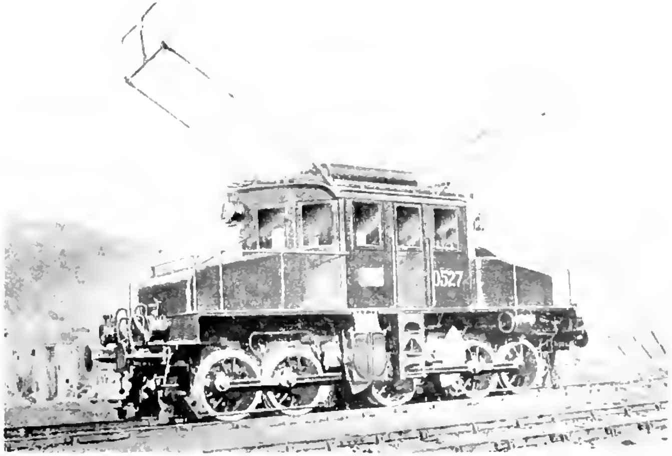


Fig. 19. Italian State Railways. Freight locomotive. Gearless motors coupled with Scotch yoke and side rods

for freight service. This type is known as the Giovi locomotive and weighs 132,000 lb., all on drivers. It has five driving axles and, like the Simplon and Valtellina types, is equipped with two gearless motors set well down between the axles, and driving the middle axle through a Scotch yoke to which the other driving wheels are attached by horizontal side rod. These locomotives are built for a maximum speed of 28 m.p.h. The first of this type was placed in service in 1908 and according to the latest accounts 40 of this type are in service and 25 more on order.

One section of the Italian State Railways, that from Milan to Varese is equipped with direct current, the other Italian installations being three-phase. Fig. 19 shows the latest type of locomotive in service on this section. The locomotive weighs 157,000 lb., of which 102,000 lb. are on drivers. It is equipped with two 1000-h.p. motors placed high in the cab, each connected to a jack shaft through sloping connecting rods and from there to the driving wheels by horizontal side rods. The locomotive is built for a maximum speed of 60 m.p.h. at which the motors have a rotative speed of 350 r.p.m. Five locomotives of this type are in service. No publication of results in operation of these locomotives has appeared since their installation and preliminary tests about two years ago.

### Conclusion

The review of European electric locomotives which we have given above is not exhaustive. It omits a discussion of several important and interesting electrifications and types of locomotives. Among these are the geared side rod locomotives of the Rhaetian Railway in the Engadine, Switzerland, the locomotives of the Mittenwald Railway in the Austrian Tyrol, and the heavy freight locomotives of the Kiruna-Riksgransen line in northern Sweden. Sufficient illustrations have been given, however, to show the difficulties which have been encountered in the development of the direct drive side rod locomotive for high speed service, and to illustrate the fact that European engineering practice is apparently turning away from that type to some form of geared locomotive for medium speed service, and does not yet indicate what will be the finally accepted type of locomotive for high speed passenger service.

It would be very difficult to make any estimate of the investment which has been made in these experimental European electrifications. It is a well known fact that the cost of design, development, construction and testing of a large electric locomotive is a considerable item and sufficient illustrations have been given to show that a large sum must have been spent in the last few years on experimental locomotives.

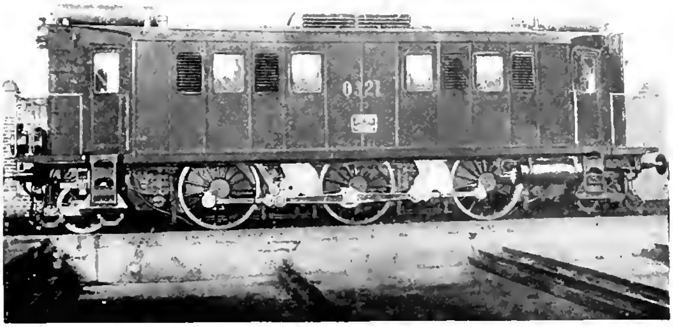


Fig. 20. Italian State Railways. Passenger locomotive with vertical connecting rods, jack shafts and side rod drive

The opinion formed by the writer from this study is that electric locomotive development in America has been more conservative and productive of more economical and satisfactory results than the same development in Europe. We have not been affected by the considerations which have forced spectacular designs on the European engineers, and our initial installations have not been loaded with sample locomotives to the same extent as theirs. Such installations as the Detroit River Tunnel, the Great Northern Cascade Tunnel, the Baltimore & Ohio Tunnel, the Hoosac Tunnel and the Butte, Anaconda & Pacific have shown the geared locomotive to be entirely successful and satisfactory for medium speed service. The development of the gearless motor in locomotive service and its unquestioned success upon the New York Terminal electrification, shows that we have been able to solve the question of high speed passenger service.

# A REVIEW OF AMERICAN STEAM ROAD ELECTRIFICATIONS

By John A. Dewhurst

Railway and Traction Engineering Department, General Electric Company

This article contains a short review of the most important steam road electrifications in America. A great deal of detailed information is given in the tables concerning the physical characteristics and equipment of these roads. The author gives a short explanation of the American and Foreign classification of locomotives.—Editor.

John A. Dewhurst

Steam railroad electrification represents a mutual growth; the electric locomotive not only grew to meet the demands of heavy traction but heavy traction grew, through precisely the same period, to demand results beyond the limitations of the steam locomotive in certain fields of operation. In general, the early development of electric traction was along the lines of the street trolley car, as the unsolved traction problem in cities presented the most attractive field. On the other hand, the conditions of the longer hauls and heavier service of the steam roads did not so favor electricity, and moreover, by that time the steam locomotive had won the place that it still holds and will hold for many years to come.

However, as a result of the enormous growth of the railroads in recent years with the accompanying traffic congestion, the limitations of the steam locomotive have been evident under three principal conditions; first, congested terminals; second, important tunnels; and third, the heavy grades experienced on mountain divisions.

Electric operation has successfully overcome each of these limitations on account of the elimination of smoke and dangerous gases in the first two conditions, and the freedom from the limitations of the steam boiler, giving a greater continuous pulling power, in the third condition involved. In such service the electric locomotive cannot only handle heavier trains but the speed is much greater, this being an important factor in increasing the service capacity of the division.

What can be done by means of electric operation in a congested terminal can be seen at the Grand Central Station at New York City, which is the terminal for both the New York Central & Hudson River Railroad and also for the New York, New Haven & Hartford. Not only are all of the local and through passenger trains of both roads operated electrically out of this station but the suburban passenger service as well; the latter being handled largely by multiple unit motor cars. To economize space the trains are brought into the terminal on two levels, the local and suburban service on the lower level and the limited trains on the upper level.

The Pennsylvania Terminal in New York City is an equally good example of the possibilities of electrification; the problem in this case could never have been solved without the electric locomotive, since the trains must be carried in tubes under the North River directly into the terminal yards. Up to 1912, the Pennsylvania Terminal was in New Jersey, the only communication with New York being by ferry boats.

The first steam road electrification of importance in this country, namely, the Baltimore & Ohio Railroad, was made for the purpose of eliminating the smoke and dangerous gases in the tunnel at Baltimore. Since then there have been four other electrifications installed to overcome the single objection of smoke in the tunnel; namely, the Detroit River Tunnel on the Michigan Central, the St. Clair Tunnel on the Grand Trunk, the Cascade Tunnel on the Great Northern and the Hoosac Tunnel on the Boston & Maine.

In general, where the tunnel is of sufficient length or where it leads directly into a station, the steam locomotive is dropped at a transfer point, the electric locomotive hauling the train through to its destination. In many cases where the tunnel occurs in the middle of an engine division, the electric locomotive is simply coupled to the train ahead of the steam locomotive and the train hauled through with the steam locomotive running light, eliminating practically all of the gases.

# PRINCIPAL STEAM ROAD ELECTRIFICATIONS IN AM

Compiled by
GENERAL ELECTRIC COMPANY
Railway and Traction Engineering Department
Schenectady, N. Y. J. A. D.
Oct. 1, 1914

| Name of Road and Section Electrified | GENERAL<br>Character of Service | GENERAL<br>Specific Cause of Electrification | GENERAL<br>Began Electric Operation | PERMANENT WAY<br>Length of Route Miles | PERMANENT WAY<br>Length of Track Miles | POWER DISTRIBUTION<br>System of Electrification | POWER DISTRIBUTION<br>Trolley or Third Rail | POWER DISTRIBUTION<br>Transmission to Substations | POWER<br>Chief Power Supply | POWER<br>SUBSTATIONS<br>No. | POWER<br>SUBSTATIONS<br>Total Equipment | No. | Maker | Classification (See text)<br>Wheels Weight Motors | Per Cent Total Wt. on Drivers |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Baltimore & Ohio, Baltimore, Md. Baltimore Tunnels | Heavy pass. and freight | Tunnel and terminal | 1895 | 3.3 | 8.4 | 600-v. d-c. | Third rail | 13,200-v., 25-cycle | Consolidated Gas, Elec. Lt. & Pwr. Co. | 3 | Combination with P.H. equip. 5-1000 kw. rot. con. General Electric | *i* 3<br>5<br>4 | GE<br>GE<br>GE | 0440-E-192-4-AXB-70<br>080-E-160-4-GE-65-600 *e*<br>0440-E-200-4-GE-209-600 | 100<br>100<br>100 |
| New York Central & Hudson River R.R., New York—Harmon | Heavy pass. | Terminal | 1906 | 34 | 251 | 600-v. d-c. | Third rail | 11,000-v. 25-cycle | Pt. Morris & Glenwood—Total 20,000 kw. GE turbines | 9 | Total—12,000 kw. GE<br>Total—24,500 kw. West.<br>Grand Total—36,500 kw. Rotary converters | 47<br>10<br>6 | GE<br>GE<br>GE | 484-E-230-4-GE-84-600<br>4444-E-224-8-GE-92-600<br>4444-E-250-8-GE-91-600 | 61.7<br>100<br>100 |
| New York, New Haven & Hartford, R.R., New York—New Haven | Heavy pass. and freight | Terminal, Gen. econ. | 1908 | 74 | 269 | Single-phase, 11,000-v.25-cyc.<br>600-v. d-c. N.Y.C. | Catenary<br>Third rail | 22,000-v. Single-phase | Cos Cob 8 single-phase turbines—Total 28,400 kw. Westinghouse | 25 | *b* 25-2000 kv-a. auto-transformers—Total 50,000 kv-a. Westinghouse | 41<br>2<br>1<br>3<br>36<br>16 | W<br>W<br>W<br>W<br>W<br>W | 2442-E-204-4-W-130<br>2442-E-273-4-W-403<br>444-E-232-8-W-409-C<br>2442-E-239-8-W-409-A<br>2442-E-220-8-W-409-C<br>0440-E-160-4-W-410 | 79.3<br>67.0<br>73.9<br>76.2<br>75<br>100 |
| Grand Trunk Ry. Co. St. Clair Tunnel Co., Pt. Huron, Mich. St. Clair Tunnel | Heavy pass. and freight | Tunnel | 1908 | 2.5 | 12 | Single-phase, 6600-v., 25-cyc. | Catenary | Direct feed | West. 2 turb. Total 2500 kw. 3-ph. | 0 |  | 6 | W | 060-E-132-3-W-137 | 100 |
| Great Northern R.R., Cascade Tunnel Washington | Heavy pass. and freight | Tunnel | 1909 | 4.0 | 10 | Three-phase 6600-v., 25-cyc. | Two-wire direct suspension | 33,000-v., 25-cyc. | 3-GE waterwheel—Total 6000 kw. 6600 v. | 1 | 4-GE transformers, Total 2550 kw. and 850 kw. spare | 4 | GE | 0440-E-230-4-GEI-506 | 100 |
| Michigan Central, Detroit River Tunnel, Detroit, Mich. | Heavy pass. and freight | Tunnel and terminal | 1910 | 6.25 | 24 | 600-v. d-c. | Third rail | 4600-v., 60-cyc. | Detroit Edison | 1 | 2-GE MG sets, 2000 kw. Total cap. Storage battery reserve | 6<br>4 | GE<br>GE | 0440-E-200-4-GE-209-600<br>0440-E-240-4-GE-209-600 | 100<br>100 |
| Boston & Maine R.R., North Adams, Mass., Hoosac Tunnel | Heavy pass. and freight | Tunnel | 1911 | 7.92 | 22 | Single-phase 11,000-v., 25-cyc. | Catenary | Direct feed | Berkshire St. Rwy. Co. | 0 | 3 switch houses | 5 | W | 2442-E-130-4-W-403-B | 78.5 |
| Penn Tunnel & Terminal R.R.—P.R.R. into New York City | Heavy pass. | Tunnel and terminal | 1912 | 15 | 95 | 600-v. d-c. | Third rail | 11,000-v., 25- and 60-cyc. | *a* 7-w. steam turb.—Total 40,000 kw. | 4 | 12-2000-kw. rot. con.—Total cap. 24,000 kw. Westinghouse | *d* 33 | W | 4444-E-156-2-W-315-A | 64.1 |
| Butte, Anaconda & Pacific R.R., Butte—Anaconda, Montana | Heavy freight and pass. | Gen. econ. | 1913 | 30 | 90.5 | 2400-v. d-c. | Catenary | Part of network 100,000-v. 60-cyc. | Great Falls Power Co., (hydro-electric) | 2 | *c* 5-1000-kw. 1200/2400-v. MG sets—General Electric | 19 Frt.<br>2 P<br>*h* 3S. | GE<br>GE<br>GE | 0440-E-160-4-GE-229-1200<br>0440-E-160-4-GE-229-1200<br>0440-E-160-4-GE-229-1200 | 100<br>100 |
| Norfolk & Western R.R., Bluefield—Elkhorn, W. Va. | Heavy freight and pass. | Tunnel, heavy grade | Bldg. 1914 | 30 |  | Split phase, 11,000-v. | Catenary | 33,000-v. 25-cyc. single-phase | 3 single-phase turbo-gen.—Total 27,000 kw. Westinghouse |  | Transformer substations Westinghouse | 24 | W | 2442-E-273-4-W-450 | 85.4 |
| Canadian Northern, Montreal, Can. | Heavy pass. | Tunnel and terminal | Bldg. 1914 | 9 | 25 | 2400-v. d-c. | Catenary | 11,000-v. 60-cyc. | Part of network, hydro-electric | 1 | *c* 2-1500-kw. 1200/2400 GE MG sets. Total cap. 3000 kw. | 4<br>2 | GE<br>Can. GE | 0440-E-166-4-GE-229-1200 | 100 |

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*a* Furnishes power to Long Island R.R. Co., 60-cycle power for lighting and auxiliaries.

*b* These transformer substations are of the outdoor type, one being located near each sectionalizing bridge. They are remote controlled from switch towers. They fulfill the double purpose of allowing a higher transmission voltage and reducing the telephone and telegraph disturbances.

*c* Momentary capacity 3 times normal.

*d* Mechanical parts built by Penn. R.R.

*e* Two running speeds—first using 4 poles—second using 8-pole connection on motors.

*f* Full field
field data on second

*g* Including 30
Westchester and Bo

## ROLLING STOCK

LOCOMOTIVES

| | No. | Maker | Classification (See text) Wheels Weight Motors | Per Cent Total Wt. on Drivers | Continuous Rating | | | | One-Hour Rating | | | | Maximum | | Mechanical Transmission | General Design of Motors | MOTOR CAR EQUIPMENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T.E. Lb. | M.P.H. | Coef. of Adhesion Per Cent | H.P. | T.E. Lb. | M.P.H. | Coef. of Ahdesion Per Cent | H.P. | T.E. Lb. | Coef. of Adhesion Per Cent | | | Motors | Trailers |
| P.H. | i 3 | GE | 0440-E-192-4-AXB-70 | 100 | .... | ... | .... | .... | .... | .... | .... | 720 | 48,000 | 25 | Gearless | Series d-c. | 0 | 0 |
| rot. com. | 5 | GE | 080-E-160-4-GE-65-600 v. | 100 | .... | .... | .... | .... | .... | .... | .... | 800 | 20,000 | 25 | Geared | Series d-c. | | |
| | 4 | GE | 0440-E-200-4-GE-209-600 | 100 | 12,200 | 20.1 | 5.1 | 660 | 25,000 | 16.4 | 12.5 | 1100 | 60,000 | 30 | Twin geared | Series d-c. comm. pole | | |
| GE | 47 | GE | 484-E-230-4-GE-84-600 | 61.7 | 7,800 | 51.6 | 5.5 | 1050 | 21,440 | 38.5 | 15.0 | 2200 | 42,500 | 30 | Gearless bipolar | Series d-c. | 192 | 19 |
| West. | 10 | GE | 4444-E-224-8-GE-92-600 | 100 | 11,400 | 57.5 | 5.1 | 1750 | 17,200 | 50.5 | 7.68 | 2320 | 67,200 | 30 | Gearless bipolar | Series d-c. | | |
| 0 kw.<br>s | 6 | GE | 4444-E-250-8-GE-91-600 | 100 | 14,000 | 53.5 | 5.6 | 2000 | 20,000 | 49.0 | 8.00 | 2600 | 75,000 | 30 | Gearless bipolar | Series d-c. | | |
| | 41 | W | 2442-E-204-4-W-130 | 79.3 | 6,400 | 66 | 3.95 | 1125 | 9,700 | 54.5 | 5.98 | 1410 | 20,000 | 12.34 | Gearless quill drive | Series compen. a.c. and d-c. | g 74 | 79 |
| | 2 | W | 2442-E-273-4-W-403 | 67.0 | 11,800 | 45 | 6.45 | 1415 | 13,200 | 43 | 7.22 | 1510 | 40,000 | 21.87 | Geared | Series compen. a-c. and d-c. | | |
| | 1 | W | 444-E-232-8-W-409-C | 75.9 | 12,000 | 42 | 6.62 | 1350 | 17,700 | 36 | 10.06 | 1700 | 40,000 | 22.73 | Geared twin motors | Series compen. a-c. and d-c. | | |
| | 3 | W | 2442-E-239-8-W-409-A | 76.2 | 12,000 | 42 | 6.6 | 1350 | 17,700 | 36 | 9.73 | 1700 | 40,000 | 22.00 | Geared twin motors | Series compen. a-c. and d-c. | | |
| | 36 | W | 2442-E-220-8-W-409-C | 75 | 12,000 | 42 | 7.27 | 1350 | 17,700 | 36 | 10.72 | 1700 | 40,000 | 24.25 | Geared twin motors | Series compen. a-c. | | |
| | 16 | W | 0440-E-160-4-W-410 j | 100 | 14,800 | 14.5 | 9.25 | 572 | 23,200 | 12 | 14.5 | 750 | 40,000 | 25.00 | Geared | Series compen. a-c. | | |
| | 6 | W | 060-E-132-3-W-137 | 100 | 18,500 | 13.5 | 14.1 | 667 | 25,000 | 10.8 | 19 | 720 | 44,000 | 33.5 | Twin geared | Series compen. a-c. | 0 | 0 |
| d | 4 | GE | 0440-E-230-4-GEI-506 | 100 | 34,800 | 15.18 | 15.1 | 1400 | 37,200 | 14.9 | 16.3 | 1500 | 69,000 | 30 | Twin geared | Three-phase induction motor | 0 | 0 |
| kw. | 6 | GE | 0440-E-200-4-GE-209-600 | 100 | 17,200 | 14.3 | 8.6 | 660 | 35,000 | 11.8 | 17.2 | 1100 | 60,000 | 30 | Twin geared | Series d-c. comm. pole | 0 | 0 |
| battery | 4 | GE | 0440-E-240-4-GE-209-600 | 100 | 17,200 | 14.3 | 7.2 | 660 | 35,000 | 11.8 | 14.3 | 1100 | 60,000 | 25 | Twin geared | Series d-c. comm. pole | | |
| | 5 | W | 2442-E-130-4-W-403-B | 78.5 | 21,000 | 25.3 | 10.3 | 1415 | 23,500 | 24.2 | 11.52 | 1510 | 68,000 | 33.3 | Geared | Series comp. a-c. | 0 | 0 |
| kw. | d 33 | W | 4444-E-156-2-W-315-A | 64.1 | f{20,000<br>12,300 | 33.7<br>54.3 | 10<br>6.15 | 1800 | 31,000<br>21,000 | 30.2<br>44.5 | 15.5<br>10.5 | 2500} | 75,000 | 37.5 | Diagonal side rod—each motor driving two axles through jack shaft | Series d-c. | 68 | 0 |
| 00-v.<br>Elec- | 19 Prt. | GE | 0440-E-160-4-GE-229-1200 | 100 | 25,000 | 16.2 | 15.61 | 1090 | 30,600 | 15.4 | 19.12 | 1280 | 48,000 | 30 | Twin geared | Series d-c. comm. pole | 0 | 0 |
| | 2 P | GE | 0440-E-160-4-GE-229-1200 | 100 | 16,200 | 24.6 | 10.12 | 1090 | 20,200 | 23.4 | 12.62 | 1280 | | | | | | |
| | h 3S. | GE | 0440-E-160-4-GE-229-1200 | | | | | | | | | | | | | | | |
| ions | 24 | W | 2442-E-273-4-W-450 | 85.4 | e{20,000<br>34,300 | 28.3<br>14.2 | 8.58<br>14.71 | 1500}<br>1300} | 43,700 | 14 | 18.8 | 1640 | 62,500 | 26.8 | Twin-motor twin-geared side rod | Polyphase ind. motor with rotating phase converter | 0 | 0 |
| 00<br>r. | 4<br>2 | GE<br>Can. GE | 0440-E-166-4-GE-229-1200 | 100 | 16,200 | 24.6 | 9.76 | 1090 | 20,200 | 23.4 | 12.2 | 1280 | 49,800 | 30 | Twin geared | Series d-c. comm. pole | 8 | 0 |

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Two running speeds—first using 4 poles ond using 8-pole connection on motors.

*f* Full field data on first line—tapped field data on second line.

*g* Including 30 motor cars of New York, Westchester and Boston.

*h* These are single trucks each with two GE-229 motors mounted in the usual manner. For switching work one truck is coupled to a locomotive the motors being connected in series with the motors of the main locomotive and controlled as a single unit. This gives a greater tractive effort and a lower speed for switching.

*i* Retired after 15 years' service on account of obsolescence.

*j* One other experimental side rod locomotive not listed.

As an example of the third limitation of the steam locomotive, the Butte, Anaconda & Pacific and the Norfolk & Western may be cited, although in the latter case the existence of a tunnel was an equally important factor. With steam operation on heavy grades, it is often necessary to break up a normal freight train into two or even three sections and haul each section over the heavy grades, using four and sometimes five of the heaviest mountain type locomotives. The service efficiency is naturally low due to the large percentage of idle weight of tenders, etc., and this coupled with the more important factors of the steaming difficulties as well as the low speeds attained, makes this class of service a very attractive field for electric operation.

Several transcontinental railroads are at the present time considering electrifying mountain divisions on account of the greater service obtained by electric operation and the reduction in operating cost.

The accompanying table gives a list of the eleven principal steam road electrifications in America. From this it is seen that approximately 1000 miles of track are electrified, involving 286 locomotives.

The system of operation or of distribution to the locomotives differs widely, there being six of these roads that use direct current, three single-phase, one three-phase, and one split phase which is a combination of a single-phase distribution and polyphase induction motor operation, obtained by means of a rotating phase converter carried on the locomotive. Both the d-c. and single-phase installations mentioned above use some form of series wound commutator motor on the locomotives, while on the two roads last mentioned the polyphase induction motor is used.

Looking at this from a different standpoint, it is noted that of the total of 286 locomotives listed, 148 are designed for direct current operation, 110 for single-phase, 4 for three-phase, and 24 for split phase. Nearly all of the New Haven single-phase engines are designed to operate on direct current as well since they enter the New York Terminal over common tracks with the New York Central, using 600 volts d-c.

There is one other electrification that rightfully belongs under this classification, although in the strict sense of the word it is not a steam road electrification. This is the Bethlehem Steel Corporation electrification of the Bethlehem-Chile Iron Mines Company in South America. This project involves three 110-ton electric locomotives operating over about 18 miles of track, the system of operation being 2400 volts d-c. These locomotives will derive their power from a substation consisting of two 1000-kw. 2400-volt synchronous motor-generator sets installed in the power house, the main power equipment being Curtis steam turbines. All of this equipment is now being built by the General Electric Company.

Regarding the heading "Classification" of locomotive types in this tabulation, a brief word of explanation might not be amiss. The scheme generally used for electric locomotives, although not standardized, is based on the standard classification of steam locomotives, the wheel arrangement being given first; the general type second; the weight third; and the motor equipment last. The wheel arrangement is based on the principle that every locomotive theoretically has three trucks, a guiding truck at each end and a main driving truck in the middle. Beginning at the head end, the wheels on each truck are counted. Thus the first New York Central type were classified as 484 type, there being a guiding truck of 4 wheels at each end and a main driving truck of 8 wheels in the middle. The common 25 to 60-ton type of electric engine having two swivel trucks, connected through king pins to the locomotive frame, is know as the 404 type, there being no main central truck. Likewise in the Detroit Tunnel or the Great Northern type there are two trucks articulated and considered to be the main locomotive truck, there being no guiding trucks, the classification in this case being 0440. The complete classification then of the first New York Central is 484-E-230-4-GE-84-600; the 484 being the wheel order, the E denoting electric operation, the 230 being the weight in thousand pounds (230,000 lb.), and the last showing that the motor equipment consists of four GE-84 motors wound for 600 volts.

It is interesting to note that the German practice differs from the American in this respect. The American classification denotes the truck arrangement without regard to which wheels are driven and which are idle. The German classification distinguishes between driven and non-driven axles as well as signifying the truck arrangement and also the side rod coupling. Beginning at one end the axles are counted on each truck, idle axles are counted numerically and driven axles are denoted alphabetically. A truck containing two driven axles would be classed "B" if the axles are coupled by side rods or "AA" if they are driven separately, as is generally the case in most American designs. A plus mark between two truck classifications indicates an articulated joint and a dash indicates that there is no articulation. Hence the first New York Central type (484) would be classed as 2-AAAA-2. The new New York Central type (4444) would likewise be classed as AA-AA+AA-AA. The Pennsylvania Terminal locomotive (also 4444) would be classed as a 2-B+B-2 the driving wheels of each truck being coupled by a side rod.

This list does not cover all of the steam road electrifications by any means. There are several electrifications not mentioned in this table that are more extensive in many respects than some of the roads mentioned. They have been classed, however, as either interurban or suburban and do not as a general thing handle through traffic. For instance, the Long Island Railroad, operating out of New York City, controls 825 miles of steam and electrified track, operating 369 motor cars, the system of distribution being by means of a third rail at 600 volts. Likewise the Oakland, Alameda & Berkeley Divisions of the Southern Pacific handle extensive suburban service. The Spokane and Inland Empire Railroad, the Ft. Dodge, Des Moines & Southern, and the Portland, Eugene & Eastern are other important electrifications which come entirely under the classification of interurban roads and would in all probability be operated by electricity if constructed new today. The following is a brief list of some of the more important steam road electrifications and mileage not classed in the previous tabulation.

This list does not include the electrification of all of the early elevated lines in Chicago and New York, and the electrification of the yards of many manufacturing plants, terminal

| Road | Total Miles Electrified | Voltage | No. of Electric Locomotives and Weights | Motor Cars |
|---|---|---|---|---|
| Long Island R. R., New York | 825 steam and electric | 600 | 0 | 369 |
| West Jersey & Sea Shore, Phila., Pa. | 150 | 700 | 0 | 109 |
| Ft. Dodge, Des Moines & Southern, Iowa | 145 | 1200 d-c. | 7 40-ton<br>2 60-ton | 20 |
| West Shore R. R. (Oneida Div.), New York | 118 | 600 | 0 | 29 |
| Portland, Eugene & Eastern, Oregon | 110 (350 future) | 1500 d-c. | 3 60-ton | 35 |
| Southern Pacific, Oakland, Alameda & Berkeley Div. | 121 | 1200 d-c. | 1 60-ton | 81 |
| Visalia Elec. Ry. (So. Pac. Co.), California | 30 | 11,000 15 cycle single-phase | 1 | 6 |
| Peninsula Rwy. Co. (So. Pac. Co.), California. | 96 | 600 d-c. | 0 | 33 |
| Paoli Div. P. R. R., Phila., Pa. | 80 | 11,000single-phase | 0 | 100 |
| Long Island Elec. Ry. Co., Long Island City, N. Y. | 26.56 | 600 | 0 | 45 |
| Salt Lake & Ogden, Utah | 60.0 | 750 d-c. | 1 35-ton | 18 |
| Erie R. R. (Rochester Div.), New York | 40 | 11,000single-phase | 0 | 8 |
| Spokane & Inland Empire R. R., Washington | 250 steam and electric | 6600 single-phase 600 d-c. | 7 50-ton<br>8 73-ton | 80 |
| Havana Central | 76.5 | 600 d-c. | 10 40-ton<br>3 60-ton | 25 |
| Wilkes Barre & Hazelton R. R., Pennsylvania. | 34 | 600 | 1 60-ton | 7 |
| Washington, Balt. & Annapolis Elec. Railway, Md. | 103 | 1200 d-c. | 0 | 47 |
| Maryland Elec., Baltimore, Md. | 25.3 | 1200 d-c. | 0 | 12 |
| Denver & Interurban R. R., Colorado | 54 | 11,000 single-phase and 600 d-c. | 0 | 14 |
| Denver & Intermountain, Colorado | 18 | 600 d-c. | 0 | 8 |
| Providence, Warren & Bristol (N. Y., N. H. & H. R. R.), Rhode Island | 24 | 600 d-c. | 0 | 30 |

yards, interurban lines, and street railway systems which were either previously operated by steam or are owned and operated by steam railroads.

Just 34 years have elapsed since the first electric engine, a mere toy today, was constructed, and only 18 years since the first notable steam road electrification. The first electrifications were made more with a view of overcoming certain physical difficulties regardless of expense, but today it is realized that, besides overcoming these difficulties, there are actual economies to be gained in the electric operation of many classes of service. However, to gain the greater economies of operation, it is necessary to make a comparatively great expenditure for equipment, since not only do the electric locomotives cost more than steam units of the same weight but it is necessary to provide substations as well as an efficient distribution system to the locomotives, to say nothing of a power house and transmission lines if power cannot be purchased directly at the substations. This all results in a greatly increased interest charge, and although the actual comparison between steam and electric operation is in favor of the latter, there must be a decided saving to induce conservative financial interests to make the expenditure, or else some other physical advantage as outlined above must be the deciding factor.

160-Ton Electric Locomotive Hauling 4550-Ton Ore Train, Butte, Anaconda and Pacific Railway

# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## HOW INSULATION BREAK-DOWN MAY BE CAUSED IN APPARATUS BY THE ADDITION OF STRONGER INSULATION

It is important in combining dielectrics of different permittivities to see that it is properly done; otherwise, the one may weaken the other by causing an unequal division of the stress. As a matter of fact, it is possible to cause break-down in apparatus by the addition of insulation, which is good and dielectrically stronger than the original insulation. That the respective dielective strengths of insulation can not be added directly will be shown in the following:

As an example, take two parallel plates rounded with a 5-cm. radius at the edges and placed 2-cm. apart in air.

(1) Apply 60 kv. (max.) between the plates. The gradient then is approximately 60/2=30 kv. per cm. max. (neglecting flux concentration at edges which is not great on account of the rounded edge). As a gradient of 31 kv. per cm. (max.) is required to rupture air, there is no break-down.

(2) Remove the voltage and insert between the plates a sheet of pressboard 0.2 cm. thick. The constants of pressboard are:

$k_2=4$ Rupturing gradient $=175$ kv. per cm. (max.) $l_2=0.2$ cm. = thickness of pressboard.

For air

$k_1=1$ Rupturing gradient $=31$ kv. per cm. $l_1=1.8$ cm. = thickness of air.

The total insulation is now 0.2 cm. of pressboard and 1.8 cm. of air. The total "strength" added directly is $(1.8\times31)+(0.2\times175)=90.8$. Apply the same voltage as before. Break-down results. The combination is actually weaker than the air alone. The addition of the pressboard because of its higher permittivity has increased the capacity of the combination and, therefore, the total flux and the flux density in the air. The gradient in the air has also been increased because of the greater flux through the air.

The combination may be considered as two condensers in series. Let $c_1=$ the capacity of the air condenser, $c_2=$ the capacity of pressboard condenser. $e_1=$ the voltage across the air condenser, $e_2=$ the voltage across the pressboard condenser, $A$ a constant including the area of the plates, and $e=$ the total applied voltage.

The total flux is

$$\psi=c_1e_1=c_2e_2$$

$$\psi=\frac{k_1A}{l_1}e_1=\frac{k_2A}{l_2}e_2$$

therefore,

$$\frac{k_1}{l_1}e_1=\frac{k_2}{l_2}e_2$$

$$e=e_2+e_1$$

$$\frac{k_1}{l_1}e_1=\frac{k_2}{l_2}(e-e_1)$$

$$e_1\left(\frac{k_1}{l_1}+\frac{k_2}{l_2}\right)=\frac{k_2}{l_2}e$$

$$e_1=\frac{\frac{k_2}{l_2}e}{k_1\ l_1+k_2\ l_2}=\frac{l_1k_2\,e}{k_1l_2+k_2l_1}=58.4$$

$$e_2=60-58.4=1.6$$

$$g_1=\frac{e_1}{l_1}=\frac{k_2\,e}{k_1l_2+k_2l_1}$$

$$\text{Then } g_1=\frac{4\times60}{(1\times0.2)+4\times1.8)}$$

$$=32.5 \text{ kv. per cm. (max.)}$$

The air breaks down since $g_1$ is in this case higher than the critical gradient value that causes the rupture of air. As the broken-down air is conducting, most of the applied voltage is then placed on the pressboard. Thus, after the air ruptures, the gradient on the pressboard is:

$$g'_2=\frac{60}{0.2}=300 \text{ kv. per cm. (max.)}$$

This is much greater than the rupturing gradient of pressboard and consequently the material then breaks down. Therefore, the 2 cm. space, which is safe with air alone, is broken down by the addition of stronger insulating material of higher permittivity.

By properly arranging insulations of different permittivities, or specific capacities, the stress may be greatly reduced in many designs.

The case discussed above is an exaggerated example of conditions often met in practice. In many power stations, little bluish needle-like discharges, (called "static") may be noticed around generator coils, bushings, etc. This "static" is simply over-stressed or broken-down air but, unlike the conditions in the example, the solid dielectric is so thick that very little added stress is put upon it by the broken-down air. Damage may be caused in the course of time, however, by local heating, chemical bombardment, etc.

F. W. P.

# GENERAL ELECTRIC REVIEW

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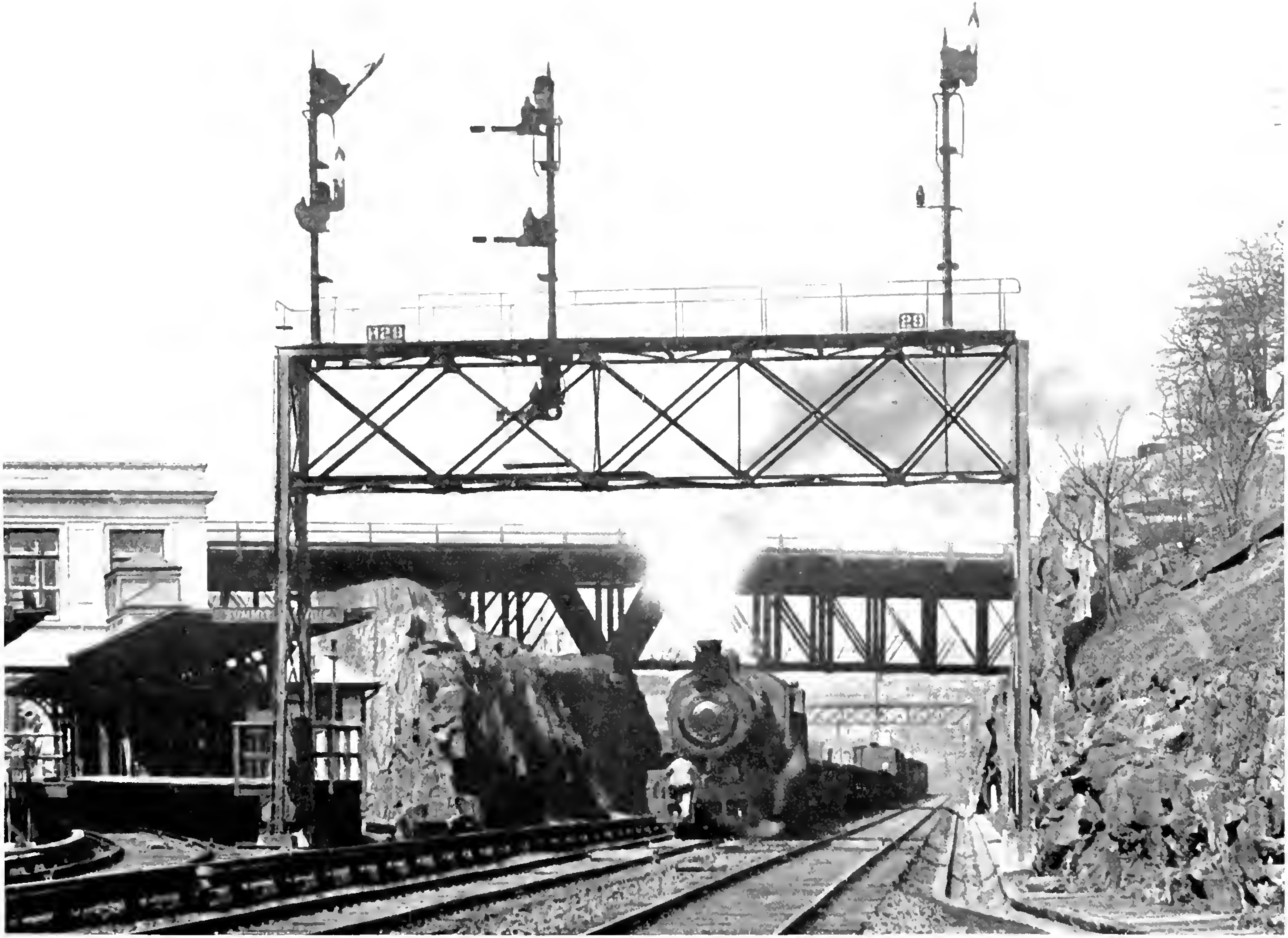

Illustrating the Article in this Issue on the Application of Power Apparatus to Railway Signaling, by Mr. H. M. Jacobs

GENERAL ELECTRIC REVIEW

## THE PATHS OF PROGRESS

In this issue we conclude a series of articles by Dr. Saul Dushman entitled "Recent Views on Matter and Energy." All of our readers who have read these contributions must have been struck by the boldness of many of the speculative theories that have recently been propounded, as well as by the fact that we seem to be on the verge of great developments in the realm of scientific thought.

The ultimate constitution of matter has been the plaything of profound thinkers for generations and the origin of energy has been no less a subject for speculative theorizing, but it has been left to the scientific minds of this generation to attempt to propound a monistic theory to account for all natural phenomena. The atomic theory originally propounded to account for the mysteries of the structure of matter was developed into an electron theory to explain electrical phenomena, and now, as a product of modern scientific thought, we have the quantum theory which is an atomic theory of energy. Thus it seems likely that we shall ultimately not only fully develop, but we may prove by patient research and experimental work, a common theory for both energy and matter which may be broad enough to include all natural phenomena. Should this be accomplished it is highly probable that all natural phenomena will be found to be governed by a few simple laws, and that the complexity of many of our scientific theories in the past has been caused by a lack of knowledge of the simple laws that govern the movements and "habits" of the ultimate "something" of which both energy and matter are born.

Such a simplification of theories would undoubtedly lead to great progress in scientific discovery and ultimately to enormous industrial developments in a multitude of different directions, and it is for this reason that all engineers and professional men in general should try to follow the trend of modern scientific thought. The series of articles referred to were written with the idea of giving a general understanding, in simple language, of some modern scientific speculations that may ultimately have a far-reaching industrial influence. We believe that there is too generally a tendency to consider all higher scientific reasoning to be beyond so simple an interpretation that the ordinary lay mind can derive any benefit following it. In reality this is very far from the truth. While it is true that it takes a great mind to translate scientific thought into simple terms, it is also true that many men have devoted much time to this task.

Scientific developments and discoveries have been almost entirely derived in the first place from speculative imaginations. All theories must be imagined before they can be propounded, tested, and proved or disproved; indeed, speculative imagination can almost be said to be the root of all progress. Those who take no trouble to familiarize themselves with the speculative imaginings of modern scientific minds are, we believe losing much that would lead to valuable inspirations that might be applied to their own work, no matter what its nature. In these days of specialists there is too marked a tendency to think a general understanding of the activities of others as of little value.

Imagination is the seed of all originality and in these days of competition there is more and more need of original thought in all industrial activities. The type of reasoning displayed in developing scientific theories by such men as Kelvin, Planck, etc., might well be imitated in many walks of engineering and business life. The imagination should be given full range and any theory arrived at should be tested till some are found that will bear the fruit desired. We believe that a careful study of the work accomplished by those great minds engaged in scientific research might give great inspiration and lead to an added efficiency in the reasoning powers of all men.

# WORKMEN'S COMPENSATION

By James O. Carr

Law Department, General Electric Company

Workmen's compensation laws are one of the products of modern conditions, and the laws throughout the union are many and varied, no less than twenty-four states having adopted laws compensating workmen for industrial accidents. No one claims that these laws are perfect and it is likely that many modifications, based on experience gained from their working, will be adopted from time to time. The author deals in a very interesting manner with many phases of the different laws already in force and discusses the pros and cons of their practical working.—Editor.

One of the most remarkable reform movements in the industrial world of the United States in recent years is that which has had for its object the enactment of laws requiring the payment of compensation to workmen who are injured in the course of their employment. The theory upon which this movement has proceeded is that the workman should be compensated for disabilities resulting from industrial accidents regardless of the question of fault, and that the financial burdens of such accidents should be borne by the industry in general rather than by the workers alone.

While this principle has been in force in some of the European countries for many years yet it is only within the past five years that the matter has been taken up actively in the United States.

A law was enacted in the State of Massachusetts in 1907 permitting employer and employee to agree on a plan of compensation and the State of Montana passed a compensation act relating to the coal industry in 1909, yet neither seemed to accomplish the desired result and little or no progress was made thereunder. It really received its initial impetus in 1909 when a commission was appointed by the Legislature of the State of New York to investigate the whole subject.

During the year 1910, two compensation laws were passed in the State of New York, one elective and one compulsory, but early in the year 1911 the compulsory law was declared unconstitutional by the Court of Appeals of the State of New York, upon the ground that it took the property of employers without due process of law. During the year 1911, compensation laws were passed in the States of California, Illinois, Kansas, Massachusetts, Nevada, New Hampshire, New Jersey, Ohio, Washington and Wisconsin, some of which were compulsory and some elective.

Since that time, compensation laws have been passed by other states so that the principle is now in force or soon will be in twenty-four different states. One of the last states to enact a workmen's compensation law was the great State of New York, where the law was passed in the month of December, 1913. That law is in many respects the most liberal to the workman and the most burdensome to the employer of any compensation law passed by the various states. It was passed more or less hurriedly with the idea that the practice of compensating workmen for injuries sustained through industrial accidents should be commenced at once and that an actual trial of the law would show wherein it ought to be amended so as to improve it for the benefit of all concerned. It has been in actual operation since July 1, 1914, and it is already evident that many changes are necessary to make the law more workable.

Many of the most prominent labor leaders in the country have said that the present workmen's compensation law of the State of New York is the best compensation law ever passed in this country. That this is so from the standpoint of the workman is undoubtedly true. Many of the employers feel that the law ought to be less burdensome to them than it is. However, this will undoubtedly be worked out satisfactorily in time.

In most of the states the law is elective, that is, the employer and the employee may elect to accept the provisions of the law or not just as they choose. In the case of the employer who elects not to comply with the provisions of the law, however, all his defenses are taken away in case the workman sues him for damages for personal injuries, so that the employer is almost compelled to accept the provisions of the law rather than to attempt to defend negligence actions and be subjected to the large verdicts which would certainly be rendered against him. If the employee elects not to accept the provisions of the law, he is relegated to the same rights which he had at the time the new law went into effect. In the opinion of many who are conversant with these compensation laws, the workman should only have the rights which existed at common law if he refuses to accept the provisions of the compensation law, the idea being to compel both parties to abide by the principle of compulsory compensation.

In some states the compensation law is compulsory, that is, both employer and employee must abide by the requirements of the law and the employer must pay the compensation therein provided.

The elective laws were passed by many of the states in order to avoid, if possible, any question as to the constitutionality of the law such as was raised at the time the first compulsory law was passed by the State of New York. The new law in many of the states provides that all workmen shall come under its provisions except farm and domestic labor. In other states, the laws are so framed as to cover only those workmen who are engaged in so-called hazardous employments. Where this has been done, however, some means have been found to include nearly all workmen. This very feature is one of the objections to the New York law because it is uncertain what workmen are covered by the law and what ones it does not cover. How much better it is for a workman to be under the protection of the compensation laws can readily be seen. As soon as he is injured, he is, in many of the states, entitled to medical attendance for a period of from two weeks to three months, at the expense of the employer. This also covers hospital treatment, medicine and other requisites. All of this is to be provided by the employer.

If the injury causes temporary disability of more than one week, in some states, and more than two weeks in others, which is called the waiting period, the workman is paid a certain percentage of his average weekly wages, ranging from 50 per cent in some states to 66⅔ per cent in others, so long as the disability continues, subject to certain limitations as to length of disability and amount paid.

In some states, in the event that an accident causes total permanent disability to the workman, he is paid the weekly percentage of his earnings for periods of time ranging from six years to the remainder of his natural life.

If the workman sustains a permanent partial disability, such as the loss of a finger, eye, hand, arm or foot, he is then paid a certain stipulated amount per week for a certain period to compensate him for the loss sustained. In some states he is also paid weekly compensation during the time of disability caused by the permanent injury; but the most satisfactory way seems to be to pay a certain fixed amount which is considered sufficient to compensate for the loss, and this is provided for in the laws of most of the states.

In some states, the workman is compensated for the loss of earning power due to injury. This is likely to prove quite troublesome as time goes on and will lead to complications, as some of the Workmen's Compensation Commissions of the various states seem inclined to hold that if a workman goes back to work and takes a different job which pays less money than he earned at time of injury, he is therefore entitled to compensation for loss of earning power.

If an injury proves fatal, then the widow, children or other dependents are paid a certain percentage of the weekly wages of the deceased workman. In some cases this compensation is paid for the life of the widow if she does not re-marry, and in others, for a certain number of years and not to exceed a certain amount. The compensation to be paid to children usually ceases when they reach the age of eighteen. In addition, many of the states require the employer to pay a certain amount for funeral expenses.

The compensation is paid to the workman in various ways. In New York, for instance, the employer pays the money to the Workmen's Compensation Commission and it in turn pays the injured workman or his dependents. This plan is unwieldy and cumbersome and is not nearly as expeditious as the practice in many other states where the employer makes arrangements to pay the workman direct the amount provided by law pursuant to an agreement made between the parties which is subject to the approval of the Commission. In some states where the principle of state insurance has been put into effect, the compensation is paid direct to the workman from the premiums paid in by the employers. In some states, the compensation must be secured to the workmen either through the medium of insurance in stock or mutual companies, through the medium of a state fund or, if the employer can give satisfactory proof of his financial ability to pay compensation to his employees, he may be permitted to carry his own insurance upon giving a satisfactory bond or depositing sufficient security to guarantee the payment of the compensation. Most employers carry insurance in either stock or mutual companies. Only the employers having a large number of employees can afford to carry their own insurance.

Various methods are adopted for handling disputes between the interested parties so that the workman may receive the compensation to which he is entitled as soon as possible after an accident.

As time goes on, many developments will take place in connection with the practical working out of these laws and we shall have a far better knowledge of them and their beneficial effects or otherwise five years hence.

That the general plan is sound and will work out to the interest of all concerned is probably conceded by all who have given the matter thoughtful consideration. The necessity for such legislation has been more or less forced upon us by the course of human events and by the many changes and developments in the method of carrying on modern industry.

Prior to 1880, the handling of business on a large scale and through the medium of great corporations was practically unknown, except perhaps with respect to railroads and the manufacturing interests in New England. Subsequent to that time, however, by reason of the great improvements in machinery, it became possible to have done by machinery the work which had formerly been done by the individual workman, and in many instances the workman was displaced by machinery. The result of this has been that in every industry the production has been marvelously increased and this feature has been largely instrumental in developing the great manufacturing industries in the United States. While enormous strides were being made in the manufacturing field, there was also a great increase in the number of industrial accidents due to the greater use of machinery and the hazard incident thereto. As a consequence, the burden on society was greatly increased because of the fact that the workman was seldom compensated for disabilities due to accidents occurring in the course of his employment.

In former years, when manufacturing was carried on in a small way by the individual employer, he usually knew most of his employees and took more or less of a personal interest in them and in their welfare. This resulted in a friendly feeling between the employer and the employee and there then existed a bond of human sympathy between them. It is also a fact that in those days the labor union was almost unknown and had little or no influence upon manufacturing operations.

With the development of the industry through the medium of machinery there came another development, that of the labor union, which today has almost a predominating influence in all parts of the country where large bodies of workmen are employed. With these developments and the creation and growth of the large corporations the human element was lost sight of in many ways. The workman was looked upon more and more as a machine rather than an individual. This, of course, was not true in every case, but it is true and must of necessity be so where thousands of workmen are employed in one industry since those in charge of the industry are absolutely unable to be in personal touch with all of the employees. This is also true where the labor unions predominate, because the members of the labor organizations seem to prefer to deal with their employers through the medium of their organizations and this has a tendency to eliminate the personal element.

In the days of small industries, when a workman was in trouble or was incapacitated through injury, he was, in many instances, looked after in some way by his employer who attempted to relieve him and his family from the loss which he was bound to sustain. It is not to be understood that this was so in every instance but it was in many cases. At the same time the employer who was engrossed in accumulating wealth undoubtedly very often overlooked the misfortune of his employee and was inclined to rely upon his legal rights in the event that any claim was made upon him for compensation.

The common law governing the relations of employers and employees in connection with injuries sustained during the course of employment was such that the employer was seldom held legally responsible for injuries which happened to the workman in the day's work. The only way in which the workman could recover money damages from his employer was by proving that the employer was negligent and that he did not fulfill the duty which he owed the employee. It can well be realized how difficult it was for the employee to sustain this burden when he was obliged to prove that he himself was in no way negligent and that his actions did not contribute to the accident; that he did not understand the risk and did not assume it and that the accident was not due to the neligence of some other employee engaged on the work. Prior to the enactment of the Employers Liability Laws, in many states even the superintendent in charge of the work was held in many instances to be a co-employee, so that if for any reason the accident happened through his negligence the employee could not recover.

The law in these respects being so harsh upon the employee and the burden on society caused by industrial accidents having increased so rapidly, it became more and more apparent that there must be some enlargement made of the rights of the employee to recover for accidents sustained in the course of his employment. As a result many of the states have from time to time passed so-called employers liability laws, placing a much greater burden upon the employer and relieving the employee in many ways. Up to the year 1912 these laws had become so drastic so far as the employer was concerned that it was more and more difficult for him to escape the payment of damages to injured workmen regardless of how the accident might have happened. This situation came about in many respects through the work of unscrupulous lawyers who became so skilled in negligence litigation that they could almost always find some means of making the case a question of fact which the Courts have held required the submission of the case to a jury. Within the past ten years the submission of such a case to a jury almost invariably resulted in a verdict for the plaintiff against the defendant. If the defendant was a corporation it was almost a foregone conclusion that the verdict would be a substantial one and that it would eventually be sustained by the Appellate Courts. Juries in the past five years have seemed to lose their reason and judgment when called upon to render verdicts in cases of this character. The amounts awarded by them have been astounding and unreasonable beyond any question. Passion and prejudice have undoubtedly prevailed in a great many cases of this character and have tended to influence the verdict. The defendant, however, has found it almost impossible to demonstrate that such was the case. The slogan has been: "The corporation is rich; it can stand it. Let's give the poor fellow a good substantial verdict."

By reason of this situation the employer who has been looking into the future has tried to establish for his own welfare as well as that of his employees, a system of compensation which would to some extent relieve the employees from the burden of industrial accident and that the employers have succeeded admirably in many cases is a well-known fact. That this should be done from a social standpoint need not be demonstrated. That it should be done from a business standpoint also requires no demonstration. The employee himself was made to realize that it was for his interest to co-operate with his employer along these lines when it became more and more apparent that the lawyers who handle negligence litigation were in almost every instance merely exploiting the injured workman for the purpose of getting the substantial fee which they would obtain in the event of the litigation being successful. The speculative feature of this class of litigation had a tendency to make the plaintiff as well as his lawyers disregard the truth in many instances, the sole object being to endeavor to obtain a verdict against the employer.

Many employers have for years been carrying on their own systems of compensation for injured and killed workmen and their dependents, and have been successful in their efforts in this direction and have succeeded in reducing the annoyance and expense incident to negligence litigation to a minimum and have thereby been able to increase the compensation and relief to the injured employee. Particularly is this true in respect to the employer who has handled his own insurance rather than by having insurance companies protect him through the medium of casualty insurance.

Undoubtedly one of the greatest incentives to the enactment of workmen's compensation laws in the various states has been the methods adopted by casualty companies in conducting their business and in adjusting claims made by employees for injuries sustained by them. The attitude of the insurance companies until very recent years has been that they would not pay anything to the injured workman if it was possible to avoid it, preferring to rely upon their legal defenses in case the workman saw fit to bring a suit. Whenever an accident happened the insurance company intervened between the employer and the employee and the employee was obliged to conduct his negotiations, if any, with the insurance company. Naturally the ordinary workman is not versed in matters of this character and he was at a tremendous disadvantage when attempting to do business with the representatives of the insurance companies. As a result he was imposed upon; he was unable to clearly understand his legal rights, and was made to understand that before he could hope to recover anything he would be obliged to go through a protracted litigation which might extend over a period of years and in the end it was possible and perhaps probable that he would be unsuccessful, in which event he would recover nothing. During all the time that this litigation might continue he would have the worry and annoyance of it and nothing to compensate him for his injury, which in many instances was serious; so that the insurance companies by use of such arguments were in most instances able to effect a settlement for a small amount and get the case disposed of. It is significant that the records show that prior to the time when compensation laws were first enacted in this country the amount disbursed by insurance companies in the way of payment of compensation to injured employees was about 30 per cent of the total premiums, the balance being used by the insurance companies for the payment of their expenses and dividends to their stockholders. Of the 30 per cent probably a large amount was paid over by employees to lawyers and others for assistance rendered by them. It can readily be seen that the real purpose for which insurance was taken out was not to insure the payment of compensation to the injured workmen when the accident was due to the fault of the employer, but rather to relieve the emoloyer from making any payment whatsoever and as a result the workman received a small percentage of the amount to which he was really entitled and in addition considerable feeling was engendered between him and the employer. It was apparent to the manufacturers who where able to look ahead that this state of affairs, coupled with the expense and annoyance incident to the harassing negligence litigation, could not continue much longer and that some remedy should be found which would make both of these things entirely unnecessary, and in addition enable both employer and his employee to work more in harmony with each other, and afford the man who was injured at his work a partial recompensation for the loss which he should sustain. The workmen were also beginning to think along the same lines.

While the employers and employees may both claim the credit for workmen's compensation legislation, yet regardless of the question as to whom the credit belongs it may safely be said that it is one of the greatest steps in promoting social welfare that has occurred in modern times. It may well be termed: "The movement to conserve human life and health through the medium of legislative enactment." As times goes on both the employer and the employee will wonder why the great waste of human life and health which we have endured up to very recent years was permitted to go on unchecked when it was possible to remedy the difficulty so readily. It will also be found after these laws have been enforced for a short time that neither the employer nor the employee would be willing to go back to the old condition of things under any consideration. That it may be classed as paternal legislation is in one sense true, but on the other hand it is agreed that paternal legislation that brings desired results to all parties interested alike is the best kind of legislation that can be enacted. There can be no ground for arguing that such a law is unjust and inequitable, so far as the principle is concerned. In the years gone by the machine in the shop when out of order was shut down and promptly repaired so that it might be again put in use for the purpose for which it was designed and thereby enable the employer to make use of it in turning out his product. In the same way the horse that was used for hauling the freight and other material around the plant when taken sick was promptly attended to by the veterinary. He was fed and cared for, and every effort made to put him in good condition so that he could again resume his work. To be sure no wages were paid to the horse but yet as compensation for the food and care which he received he performed a certain amount of work for the employer. That this condition of affairs should have been overlooked for so many years and these principles not applied to the human machine seems almost startling in the light of present day developments. Why is it that the human machine did not receive equally as good care and treatment as the others? Was it because of selfishness or neglect or failure to consider the true merits of the situation? The answer undoubtedly is that when the human machine became out of order for any reason it could promptly be replaced by another without any trouble or apparent expense, and for that reason the man who was injured in employment was displaced, for the time being in any event, by another workman who was prepared to take up his work, and if the former employee had been so disabled as to be unable to resume his employment then the new one could remain on permanently. In the case of the horse it would cost a substantial sum of money to replace him even temporarily, whereas with the human being it cost nothing, so that the action taken may properly be said to have depended entirely upon the question of cost. Nowadays the employer is finding out that it is money well invested to keep the human machine in proper working order and condition. The benefits derived from his efforts in this direction are manifold. It is seen not only in the workman himself but the benefit redounds to his wife and children and to the public in general which is relieved from any apparent burden so far as he is concerned. If a man is in good physical condition he can naturally do more work and do it better than the man who is ailing and unfit for the employment in which he is engaged. The more and the better production the manufacturer is able to put out the more business he does, the larger his income, and presumably the greater his profits. The saving to the community in general, by reason of the enactment of laws regarding compensation of workmen who are injured in the course of their employment, will more than compensate for any additional expense to which the state may be put in administering such laws. Heretofore a large portion of the time of our courts has been devoted almost exclusively to the conduct of negligence litigation arising out of accidents to employees. In fact the calendars in some of the courts in the larger cities have been almost entirely filled with these negligence actions. Without question the work of the courts in such a state as New York will be so materially decreased by the disappearance of this class of litigation that many of the judges will have time on their hands and some of them could be dispensed with. When the enormous expense that is attendant upon the operation of the courts is realized it will be seen at a glance that a great saving is to be effected. In addition to that, the workman who is seriously injured is not going to be a burden upon himself and his family and upon society in general. He is not going to be made to feel that he is dependent on charity for his existence. He is still going to be able to hold his head up among other men, knowing that so long as he is deprived of his ability to work by reason of the injury sustained in the course of his employment he is going to receive compensation to assist him to a considerable extent in caring for his family during the time of his disability. This feeling of self respect which the workman will have is in itself worth a good deal and will tend to make him in most instances a better citizen. The burden of compensating employees will be borne by the industry and when it is of sufficient amount to be at all appreciable it will be added to the cost of the production, and the consumer, which is the public, will pay for it. In this way society in general pays the expense as it really does in everything else ultimately. The workman who is compensated while injured will, by being able to receive enough to keep his family from want, also be able to keep his children in school and thereby confer an untold benefit upon them. They will not of necessity be obliged to start in work when the wage earner of the family is disabled, whereas they might be obliged to do so much before the intended time if there were not other means of support. Of course it is impossible to have legislation of this character which is not without some drawbacks and subject to much criticism. In many of the states the claim is made that the compensation is too liberal and too far-reaching in that it will be an incentive where the compensation is too high for the injured workman to remain out of employment as long as he possibly can. Of course there may be something in this, particularly if the workman carries his own insurance either through insurance companies or some fraternal organization, for by taking such insurance benefits in conjunction with the compensation paid by the employer he may derive more than the sum which he would receive when working steadily. This, however, is a condition which must be met. In some states the list of dependents is carried to extremes, persons being entitled to compensation as far remote from the injured person as grandparents and grandchildren and nephews and nieces. It is undoubtedly true that the schedule of compensation for partial permanent disability seems in many instances high but time alone will tell how burdensome this may be in the states where such compensation seems to be unduly high. Fortunately this only pertains to a class of accidents which are fewest in number. That an untold amount of good is going to be accomplished by these laws must be admitted without controversy. It is going to have a tendency to cause employers to investigate more carefully their working conditions in order that they may ascertain wherein they may reduce the number of accidents in their factories. Every accident prevented means, theoretically, so many dollars earned, because by reducing the number of accidents the expense incidental thereto will also be diminished. An employer will be warranted in expending money for the purpose of reducing the number of accidents because it will be found to be an excellent investment. The amount of stimulation that has occurred since the beginning of the agitation for workmen's compensation legislation is surprising. Many large manufacturers have been and now are spending thousands of dollars in safeguarding machinery and doing other things to decrease the hazard of the employment and make it safe for the life, limb and health of the employee. Naturally these things have a tendency to improve the efficiency of the workman and his surroundings. One of the great elements which have been found to have a very important bearing upon industrial accidents is the question of lighting and it has been shown that many accidents which could well be prevented have been caused by failure to properly light the place where the employee was performing his work. It has been found a simple proposition in many ways to place these safeguards around the employee and thereby reduce the possibility of accidents and it is undoubtedly due to the fact that it has been so simple and easy to do these things that they have been left undone for so long a period of time. In another respect, outside of compensation for industrial accidents, the employee is bound to derive a substantial benefit. The burden which the employers have had placed upon them has led them to take a much greater interest in the welfare of their employees and has put them in touch with many conditions which were unknown before. Until recent years no special effort has ever been made to fit the work to the man but it has usually been a case of fit the man to the work. The requirements of the compensation laws have given the employer a new incentive and that is to try to see that he has workmen physically able to perform the work for which they are engaged. To this end many of the employers of labor throughout the country have adopted the policy of medical examination which is believed will prove to be of untold benefit to employer and employee alike. It does not mean that the man who is not physically perfect will be shut out or prevented from obtaining employment, but it does mean that more care will be used in the employment of labor and that an effort will be made to place the man at the kind of work which he is physically able to do rather than to place him at the kind of work which he thinks he wants to do but for which he does not know he is physically unfit. Such procedure is bound to be beneficial to both parties because it will tend to improve the efficiency of the employee, thereby benefitting the manufacturer; it will tend to conserve the life and health of the employee, thereby enabling him to perform his duty to society; and by lengthening out his life it will extend the period of his usefulness to his family and the community. Society has much to be thankful for when we consider the amount of suffering and distress that is going to be saved by reason of the enactment into law of the principle of compensating workmen who are injured in the performance of the work incident to their employment and in the years to come the employers and employees will wonder why such a blessing to mankind was not brought into existence many years before.

# PRACTICAL ECONOMIES IN DISTRIBUTION WITH THEIR EFFECT ON THE COMMERCIAL POLICY OF A CENTRAL STATION COMPANY

## DOHERTY MEDAL PAPER—1914

By Harold Goodwin, Jr.*

Assistant Superintendent Distribution, The Philadelphia Electric Company

The content of this article is of great practical value to all those concerned in any way with the distribution of electrical energy through overhead lines (the conditions existing in underground lines are conformable to the same treatment as is used herein for overhead lines). This article is meritorious chiefly because, unlike others, its author has studiously avoided falling into the error of delivering either with an exposition based only on theory or a treatise founded solely on practice. A comparison of the merits of the radial and the tree systems is made; load capacity data of the secondary distributing lines are given in tabular form; and cost data of line materials and their erection are presented, also in tabular form. A careful explanation of the local factors which have to be considered in distribution problems and well-balanced helpful advice supplement the value that can be derived from the tables. Through the courtesy of *Current News* we have been able to publish this excellent article.—Editor.

### INTRODUCTION

The technical press is at present filled with notes on the cost of central station service showing at one end of the system the present low generating costs and at the other the almost fixed charges per customer's service. 'Twixt these there is a great gulf fixed and labeled "Distribution Costs." The central station man goes into competition with the isolated plant and finds his main generating costs much lower, but then he has to add "Distribution Costs" that seem to wither his chances for the business. Mr. P. Junkersfeld, in his report on "Distribution" to the last (1914) midwinter convention of the A.I.E.E., states: "The great importance of the subject of distribution of electrical energy is further indicated by the fact that, in the average central station system in a large city, the fixed charges and operating expense of the distribution system are nearly three times the fixed charges and operating expense of the power house."

Most central stations meter the output of their generating or substations and also sum up the total of customers' meter registrations and compare the two. There is a discrepancy of from 10 to 50 per cent. This is put down as distribution loss; a little is accounted for as transformer core loss and the remainder just entered mentally to the discredit of the distribution engineers.

Yet what is being done to reduce these costs and losses? Eminent engineers are working to increase turbine and generator efficiencies if only by half of one per cent. Practically all transmission systems are in the hands of competent engineers. Others of equal standing in their profession are continually devising means, by combining loads of different characteristics, by which the efficiency of the substations may be raised. These same men lay out, more or less definitely, distribution systems with rules as to voltage and phase of motors, grouping loads on transformers, maximum voltage drop from feeder end to last transformer, etc. Then what?

The operation of the generating stations, transmission systems, and substations is put in the hands of engineers; complete meter and instrument readings are continually taken and the results are checked up against those previously calculated and an efficient condition is thus maintained. But what is done for the efficiency of the system beyond the substation? The general rules on voltage, phase, etc., are given to a "practical man" who knows from experience the "one-hundred-and-one" mechanical details that enter his problem and he proceeds to build primary lines, hang transformers, run secondaries, and supply the current to meters registering with almost absolute accuracy to the fraction of a per cent. General voltage tests are made and the job is said to be a good one. A complaint may come in and the voltage being found a little low a new transformer is hung, or new secondaries are run in a manner which has caused no complaint to the "practical man" at another location and is therefore to him the proper thing.

Some "practical men" have gone further and have investigated their transformers to see that they are properly loaded and have

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* The writer desires to take occasion to express his appreciation of the excellent distribution work done by the Aerial Line Department of The Philadelphia Electric Company, which has inspired this paper, though it has been done without the confidence of these figures. He also wishes publicly to extend his thanks to Mr. William Foster for his willingness in supplying the assumed figures on costs and to Mr. N. E. Funk and Mr. Clarence W. Fisher for their assistance in the preparation of the article.

thus shown a considerable saving. This showing, with the ability which guided their work, has qualified them for higher positions which they have assumed. They have then written articles showing most beautifully the advantages of grouping load on transformers and the advantages of diversity factor and so forth; they have proceeded to the study of transmission lines and given us no end of valuable information and short cuts on the calculation of these problems. But what have they done to help the man who is still struggling to determine whether he should put a transformer in every block with small secondary wires, or only one in every four blocks with heavy secondary wires?

At this point the young technical graduate has advanced his theories and figured out a superb (!) system with conductors tapered down toward the end of the secondary, giving what he claims to be the ideal system of distribution. Suddenly a large load is to be added at a point where his conductors have been neatly tapered down; it is necessary to renew them and he comes to believe the "practical man" is correct in building with the same size conductor throughout, so he throws his theory to the winds and is lead by the "practical man." Occasionally special cases force themselves upon him and he may figure out what is the economical arrangement.

But as yet no practical man who has acquired the theory, or theoretical man who has learned the practice, has given to his fellow practical workers throughout this country even the most simple and fundamental tables of capacity and economical use of wires, except the N.E. Code rules on the ampere capacity of various sized conductors.

The "Lamp Committees" are now discussing the question of adopting one standard voltage lamp for a given system. Yet who knows for alternating current systems in general whether the range in voltage on the lamps is to be arbitrarily fixed by the committee at a maximum which they consider will still give good service, or whether the actual losses of energy in the distribution system supplying the lamps will not definitely limit the range of voltage at the different services?

It is with this vast and complicated unknown of DISTRIBUTION that this paper will deal. First will be submitted a few comments on primary systems and a preliminary set of tables for guidance of the practical man. Then a study of the fundamentals of the economic side of the situation will be made, pointing out the need for research and testing along certain lines.

Attention will be confined entirely to overhead lines and detailed discussion will only be given the transformer and secondary lines. The methods used in comparing fixed with operating charges are familiar and of course apply equally well to primary and secondary, though the almost infinite complication of the secondary problem is increased seven-fold when the primaries are considered in conjunction with it. There are, however, certain practical limitations, explained later, which enter to exclude the primary from consideration and the solutions are therefore more general than would appear at first sight.

All methods also apply to underground construction and to comparison of overhead and underground structures, though to cover completely only the subject in hand would require such a large volume that consideration of these last two subjects has been omitted entirely.

All figures on costs are altogether approximate and are not supposed to represent the experience of any one company, and are introduced simply to make the results more tangible. It would, of course, be possible to work out the whole problem with algebraic symbols leaving it to anyone interested to substitute true values and solve for the result. It would also have been possible to take these figures from "Data" or other handbooks. But they are simply assumed and are therefore not open for discussion unless their accuracy materially affects the conclusion.

The figures on maximum carrying capacity of wires are derived from Table B, paragraph 18 of the "N.E. Code," 1913 edition. All figures connected with power and voltage loss are based on the familiar formulae:

$$A = \frac{D \times W \times C}{P \times E^2}$$

$$V = P \times B$$

where

$A$ = area of conductor in circular mils.

$D$ = distance one way from source to receiver.

$W$ = load in watts.

$C$ = 2400 for 95 per cent power-factor, single-phase.

= 3380 for 80 per cent power-factor, single-phase.

$P$ = per cent power loss of delivered power.

$E$ = receiver volts.

$V$ = per cent voltage loss.
$B$ = constant given in following table for 60 cycles:

| No. of Wire B.&S. Gauge | Conductor Area Circular Mils | VALUE OF B | |
|---|---|---|---|
| | | 95 Per Cent P-F. | 80 Per Cent P-F. |
| 6 | 26,200 | 1.05 | 1.00 |
| 4 | 41,600 | 1.11 | 1.10 |
| 2 | 66,600 | 1.18 | 1.26 |
| 0 | 106,000 | 1.31 | 1.49 |
| 00 | 133,000 | 1.34 | 1.66 |
| 000 | 168,000 | 1.49 | 1.95 |
| 0000 | 212,000 | 1.62 | 2.09 |

### PRIMARY DISTRIBUTION SYSTEMS

There are two generally accepted alternating current distribution systems which can be considered regardless of the cycles, phase, or voltage so long as the latter is not above the generally accepted standard of 2400 volts. These two systems are the "tree" or "main and branch" system, and the "radial" or "center of distribution" system.

Fig. 1 shows the "center of distribution" system as submitted by Mr. H. B. Gear in Appendix II, to the report of the Distribution Committee to the last (1914) midwinter convention of the A.I.E.E. For this system very good voltage regulation is claimed on account of the radial feeds from the centers $A$, $B$, and $C$. The same writer shows in another diagram that emergency connections between the three circuits must be provided at points where they come close together. In his concluding paragraph he states:

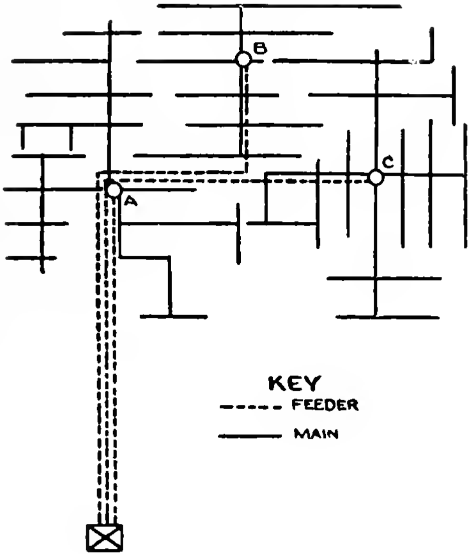

Fig. 1. Radial System of Distribution

"The feeder system must be reinforced as may be necessary from time to time to carry the added load. This involves rearrangement of connections of primary main and many complicated 'cut-overs' which add to the expense very materially."

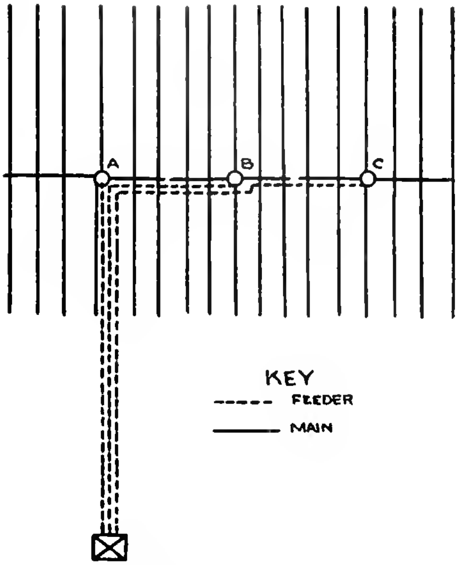

Fig. 2. Main and Branch System of Distribution

We do not doubt this writer's statement.

Now contrast this first method with the "tree" or "main and branch" system shown in Fig. 2, for covering the same section. A rough comparison will show that the wire lengths from the feeding points to the most distant points are not materially different from those in Fig. 1, and therefore the regulation must be almost the same. In fact, it is difficult to see where Fig. 1 has any advantage, so long as there are no diagonal streets.

A comparison can also be drawn on the basis of continuous service which is one, if not the most rigid, requirement at the present time. Suppose trouble occurs and a man goes out to locate and repair it. In the "radial" system he has to go around many corners and look in many places. On the "tree" system he has one straight main to travel and after clearing that, if necessary, he can travel out any branch he finds in trouble, moving quickly to the point in question.

Suppose the main feed "$B$" is in trouble in either system. See how simple it is to "cut-over" the load to "*A*" or "*C*" on the main street in Fig. 2, while in Fig. 1 it would apparently be done in an out-of-the-way corner.

Mr. Gear's opinion has been quoted on the work necessary to introduce a new feeder in Fig. 1. Notice how simple it is in Fig. 2. The breaks may be closed and the main cut into four sections and the new feeder run at a minimum expense.

In Fig. 2 there would probably be another main running directly by the substation. This would have branches on the same streets as *A*, *B*, and *C*. These would be run to meet each other on the same street parallel to the main *A*, *B*, *C*, and in case of trouble on *A*, *B*, and *C* the whole load could temporarily be transferred to the mains nearer the substation.

Consider also the simplicity of the pole line construction in Fig. 2, as compared to the many irregular dead ends and corners to be turned in Fig. 1.

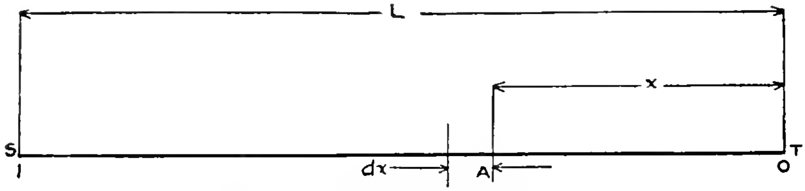

Fig. 3. Electric Circuit with Uniformly Distributed Load

But it is not intended to discuss the primary systems in this paper, so probably enough has been said to allow the assumption later in the calculations that, for all normal loads, the primary should always be present. The cost of its erection can, therefore, in general be neglected.

## LOAD CAPACITY OF SECONDARY DISTRIBUTION LINES

As stated in the introduction, it is proposed to present a set of tables of the capacity of secondary distribution systems for the use of the practical man. These alone will not show whether a given system is economical or not, but they will show the losses in any system and anyone using them may depend on his own judgment for determining the allowable losses until such time as the calculations shown in the latter part of this article have been made.

The three-wire nominal 110/220-volt single-phase secondary system has been assumed with an actual delivery voltage from the main of 112/224 volts which allows for a slight loss in the service wires and house wiring, insuring 110 volts at the lamp socket. The power loss and voltage loss are both assumed at 1 per cent. If it is decided that this is the proper loss to allow for any system the values of loads in the tables are correct; if a different loss is to be allowed the values can easily be multiplied by that per cent. An attempt will be made later to determine what that value is and it should be noted particularly that there is no reason why it should work out to an even per cent, indeed when the tables have once been multiplied it makes little difference in their use how irregular the per cent voltage or power loss may have been.

Tables have been used throughout rather than curves, because there are so few standard sizes of wire on any system that it is believed to be a more simple matter to pick the values from the tables for a few sizes, rather than from a curve covering all sizes.

The distribution of loads covered in the tables are typical:

*First:* Load concentrated at one end of secondary with transformer at opposite end.

*Second:* Uniformly distributed load with transformer at one end.

*Third:* Uniformly distributed load with transformer in center.

Any other loadings can be figured from a combination of these. All loads are given in kilowatts. The uniformly distributed load tables have been carried down to the lower hundreds of feet merely to show how enormously the capacity increases under these conditions though it is an impractical condition on a pole line since services can only be tapped from the mains at poles, which are in the vicinity of 100 feet apart.

It is interesting here to note that if the lamps of various customers are properly rated for the average voltage of the secondary supplying them, it makes no difference in the central station revenue how great the voltage drop, within a long range, since the curve of watts to volts is a straight line for a considerable distance both sides of normal rating. It does make a very considerable difference, however, in the amount of light received and current consumed by the first and last customers, since the lamps of the former will be burning above rating and those of the latter below rating.

The length to be used in calculating both voltage and power loss with a uniformly distributed load is a point of interest. It is generally known that to find the maximum voltage loss, half the greatest distance and the total load are used in the formula. However, it is probably not so well known that to find the *total* power loss only *one-third* of the total length is used. It may therefore be worth while to derive the equations for voltage drop and watts loss in the uniformly loaded circuit represented by Fig. 3.

$ST$ = an electric circuit of uniform resistance.

$S$ = source, and load is distributed uniformly towards "$T$."

$I$ = current at "$S$."

Current at "$T$" $= O$.

$E$ = potential difference between "$S$" and "$T$."

$W$ = total power loss in circuit.

Let

$i$ = current at any point "$A$" at a distance "$x$" from "$T$."

Then

$$i=\frac{I}{L}x.$$

$de$ = volts loss in a section "$dx$."

Let

$r$ = resistance of circuit per unit length.

Then

$$de=irdx.$$

$$E=\int_0^L irdx=\int_0^L \frac{I}{L}rxdx=\frac{Ir}{L}\int_0^L xdx.$$

$$E=\frac{Ir}{L}\left[\frac{x^2}{2}\right]_0^L=\frac{IrL^2}{L2}=Ir\frac{L}{2}.$$

But

$$Lr=R.$$

$$\therefore E=\frac{IR}{2}.$$

Similarly

$dw$ = watts loss in a section "$dx$."

Then

$$dw=i^2rdx.$$

$$W=\frac{I^2r}{L^2}\int_0^L x^2dx=\frac{I^2r}{L^2}\times\frac{L^3}{3}=\frac{I^2rL}{3}.$$

$$\therefore W=\frac{I^2r}{3}.$$

In order to show the method of applying the formula (page 1160 of "Introduction") to the following tables, calculation is here made of the capacity of 500 feet of No. 00 wire at 224 volts delivered with a power loss of one per cent, a power factor of 80 per cent, and with the load concentrated at the opposite end from the transformer.

The formula as given previously reads:

$$A=\frac{D\times W\times C}{P\times E^2}.$$

Since "$W$" is the unknown the formula is transposed for use:

$$W=\frac{A\times P\times E^2}{D\times C}.$$

$A$ = 133,000 circular mils.

$P$ = 1 per cent.

$E$ = 224 volts.

$D$ = 500 feet.

$C$ = 3380.

Then

$$W=\frac{133{,}000\times 1\times (224)^2}{500\times 3380}=3.9 \text{ kilowatts.}$$

This value will be found in Table II.

A similar calculation for 1 per cent maximum voltage loss may be made.

This involves the use of the formula:

$V=P\times B.$

Since "$P$" is the unknown this may be transposed:

$$P=\frac{V}{B}.$$

But

$V$ = 1 per cent.

$B$ = 1.66 (page 1161).

$$P=\frac{1}{1.66}=0.602.$$

$$W=\frac{133{,}000\times 0.602\times (224)^2}{500\times 3380}=2.4 \text{ kilowatts.}$$

This value may be found in Table I.

As noted in the first paragraph these tables are useful for determining the loss under any given conditions. Suppose a 500-foot, No. 00 secondary, similar to that used in the preceding calculations is carrying a load of 12 kw. and it is desired to know the voltage drop. Table I or the foregoing calculations show a load of 2.4 kw. will produce a drop of 1 per cent. Therefore 12 kw. will produce a drop of 12 divided by 2.4, or 5 per cent. The actual voltage drop is then 5 per cent of 224 or 11.2 volts.

The values of "$P$" as used in the foregoing formula are shown in the second column of

Tables I to VI. In the third column is shown the maximum load the circuit will carry without overheating, based on the rating of wires with other than rubber insulation in Table B, paragraph 18 of the "N.E. Code," 1913 edition.

### COST DATA ON DISTRIBUTION LINES

The following figures given in Tables I to VI are dependent on the fundamental electrical properties of wires and are entirely independent of how or when the wires are erected or the cost of erecting them. It is now proposed to consider the costs of erecting wires and their supports with a view to ascertaining the factors which need particular attention. As stated in the introduction, the figures have only the most general foundation in practice and are merely assumed and tabulated in order to show the data which

### Table I

### KILOWATT CAPACITY OF SECONDARY MAINS

Load Concentrated at Opposite End of Main from Transformer
Single-Phase; 1 Per Cent Maximum Volts Loss; 224 Volts Delivered

UPPER FIGURES KILOWATT CAPACITY—95 PER CENT P-F. (LIGHTS)
LOWER FIGURES KILOWATT CAPACITY—80 PER CENT P-F. (MOTORS)

| Wire Size B.&S. | P | Maximum | Distance in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 6 | 0.95 | 14.9 | 5.2 | 2.6 | 1.7 | 1.3 | 1.0 | 0.9 | 0.7 | 0.6 | 0.6 | 0.5 |
| | 1.00 | 12.5 | 3.9 | 1.9 | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 |
| 4 | 0.90 | 19.1 | 7.8 | 3.9 | 2.6 | 2.0 | 1.6 | 1.3 | 1.1 | 1.0 | 0.9 | 0.8 |
| | 0.91 | 16.1 | 5.6 | 2.7 | 1.9 | 1.4 | 1.1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.6 |
| 2 | 0.85 | 26.6 | 11.8 | 5.9 | 3.9 | 2.9 | 2.4 | 2.0 | 1.7 | 1.5 | 1.3 | 1.2 |
| | 0.79 | 22.4 | 7.8 | 3.9 | 2.6 | 1.9 | 1.6 | 1.1 | 1.1 | 1.0 | 0.9 | 0.8 |
| 0 | 0.76 | 42.6 | 16.8 | 8.4 | 5.6 | 4.2 | 3.4 | 2.8 | 2.4 | 2.1 | 1.9 | 1.7 |
| | 0.67 | 35.9 | 10.5 | 5.2 | 3.5 | 2.6 | 2.1 | 1.7 | 1.5 | 1.3 | 1.2 | 1.1 |
| 00 | 0.74 | 48.0 | 20.5 | 10.3 | 6.8 | 5.1 | 4.1 | 3.4 | 2.9 | 2.6 | 2.3 | 2.0 |
| | 0.60 | 40.3 | 11.8 | 5.9 | 3.9 | 2.9 | 2.4 | 2.0 | 1.7 | 1.5 | 1.3 | 1.2 |
| 000 | 0.67 | 58.6 | 23.4 | 11.7 | 7.8 | 5.9 | 4.7 | 3.9 | 3.3 | 2.9 | 2.6 | 2.3 |
| | 0.51 | 49.3 | 12.7 | 6.3 | 4.2 | 3.2 | 2.5 | 2.1 | 1.8 | 1.6 | 1.4 | 1.3 |
| 0000 | 0.62 | 69.2 | 27.4 | 13.7 | 9.1 | 6.9 | 5.5 | 4.6 | 3.9 | 3.4 | 3.0 | 2.7 |
| | 0.48 | 59.3 | 15.0 | 7.5 | 5.0 | 3.8 | 3.0 | 2.5 | 2.1 | 1.9 | 1.7 | 1.5 |

### Table II

### KILOWATT CAPACITY OF SECONDARY MAINS

Load Concentrated at Opposite End of Main from Transformer
Single-Phase; 1 Per Cent Power Loss; 224 Volts Delivered

UPPER FIGURES KILOWATT CAPACITY—95 PER CENT P-F. (LIGHTS)
LOWER FIGURES KILOWATT CAPACITY—80 PER CENT P-F. (MOTORS)

| Wire Size B.&S. | P | Maximum | Distance in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 6 | 1.00 | 14.9 | 5.5 | 2.7 | 1.8 | 1.4 | 1.1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 |
| | 1.00 | 12.5 | 3.9 | 1.9 | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 |
| 4 | 1.00 | 19.1 | 8.7 | 4.3 | 2.9 | 2.2 | 1.7 | 1.4 | 1.2 | 1.1 | 1.0 | 0.9 |
| | 1.00 | 16.1 | 6.1 | 3.1 | 2.0 | 1.5 | 1.2 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 |
| 2 | 1.00 | 26.6 | 13.9 | 6.9 | 4.6 | 3.5 | 2.8 | 2.3 | 2.0 | 1.7 | 1.5 | 1.4 |
| | 1.00 | 22.4 | 9.9 | 4.9 | 3.3 | 2.5 | 2.0 | 1.6 | 1.4 | 1.2 | 1.1 | 1.0 |
| 0 | 1.00 | 42.6 | 22.0 | 11.0 | 7.3 | 5.5 | 4.4 | 3.7 | 3.1 | 2.8 | 2.4 | 2.2 |
| | 1.00 | 35.9 | 15.7 | 7.8 | 5.2 | 3.9 | 3.1 | 2.6 | 2.2 | 1.9 | 1.7 | 1.6 |
| 00 | 1.00 | 48.0 | 27.7 | 13.8 | 9.2 | 6.9 | 5.5 | 4.6 | 4.0 | 3.5 | 3.1 | 2.8 |
| | 1.00 | 40.3 | 19.7 | 9.8 | 6.6 | 4.9 | 3.9 | 3.3 | 2.8 | 2.5 | 2.2 | 2.0 |
| 000 | 1.00 | 58.6 | 35.0 | 17.5 | 11.7 | 8.8 | 7.0 | 5.8 | 5.0 | 4.4 | 3.9 | 3.5 |
| | 1.00 | 49.3 | 24.8 | 12.4 | 8.3 | 6.2 | 5.0 | 4.1 | 3.5 | 3.1 | 2.8 | 2.5 |
| 0000 | 1.00 | 69.2 | 44.2 | 22.1 | 14.7 | 11.0 | 8.8 | 7.4 | 6.3 | 5.5 | 4.9 | 4.4 |
| | 1.00 | 59.3 | 31.4 | 15.7 | 10.5 | 7.8 | 6.3 | 5.2 | 4.5 | 3.9 | 3.5 | 3.1 |

anyone studying this subject should prepare and also to give a basis for the sample calculations made later.

Table VII shows approximate costs of erected poles when erected singly or in lots up to ten in the same vicinity. It is very evident that, particularly in the smaller sizes which are used largely in local distribution, it is very advantageous to erect a large number at one time. In fact if, in a given section, the load gradually grew so as to call for two 40-ft. poles at a time, erected throughout the year, till seven were standing, it would have been just as cheap to have erected ten in the first place. This means that ten poles could be erected ready for new business

### Table III

## KILOWATT CAPACITY OF SECONDARY MAINS

### Uniformly Distributed Load, Transformer at One End
### Single-Phase; 1 Per Cent Maximum Volts Loss; 224 Volts Delivered

UPPER FIGURES KILOWATT CAPACITY—95 PER CENT P-F. (LIGHTS)
LOWER FIGURES KILOWATT CAPACITY—80 PER CENT P-F. (MOTORS)

| Wire Size B.&S. | P | Maximum | Distance in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 6 | 0.95 | 14.9 | 10.4 | 5.2 | 3.4 | 2.6 | 2.0 | 1.7 | 1.6 | 1.3 | 1.2 | 1.0 |
| | 1.00 | 12.5 | 7.8 | 3.9 | 2.6 | 1.9 | 1.6 | 1.3 | 1.2 | 1.0 | 0.8 | 0.8 |
| 4 | 0.90 | 19.1 | 15.6 | 7.8 | 5.2 | 3.9 | 3.2 | 2.6 | 2.2 | 2.0 | 1.8 | 1.6 |
| | 0.91 | 16.1 | 11.2 | 5.6 | 3.8 | 2.7 | 2.2 | 1.9 | 1.6 | 1.4 | 1.2 | 1.1 |
| 2 | 0.85 | 26.6 | 23.6 | 11.8 | 7.8 | 5.9 | 4.8 | 3.9 | 3.4 | 2.9 | 2.6 | 2.4 |
| | 0.79 | 22.4 | 15.6 | 7.8 | 5.2 | 3.9 | 3.2 | 2.6 | 2.2 | 1.9 | 1.8 | 1.6 |
| 0 | 0.76 | 42.6 | 33.6 | 16.8 | 11.2 | 8.5 | 6.8 | 5.6 | 4.8 | 4.2 | 3.8 | 3.4 |
| | 0.67 | 35.9 | 21.0 | 10.5 | 7.0 | 5.2 | 4.2 | 3.5 | 3.0 | 2.6 | 2.4 | 2.1 |
| 00 | 0.74 | 48.0 | 41.0 | 20.5 | 13.6 | 10.3 | 8.2 | 6.8 | 5.8 | 5.1 | 4.6 | 4.1 |
| | 0.60 | 40.3 | 23.6 | 11.8 | 7.8 | 5.9 | 4.8 | 3.9 | 3.4 | 2.9 | 2.6 | 2.4 |
| 000 | 0.67 | 58.6 | 46.8 | 23.4 | 15.6 | 11.7 | 9.4 | 7.8 | 6.8 | 5.9 | 5.2 | 4.7 |
| | 0.51 | 49.3 | 25.4 | 12.7 | 8.4 | 6.3 | 5.0 | 4.2 | 3.6 | 3.2 | 2.8 | 2.5 |
| 0000 | 0.62 | 69.2 | 54.8 | 27.4 | 18.2 | 13.7 | 11.0 | 9.1 | 7.8 | 6.9 | 6.0 | 5.5 |
| | 0.48 | 59.3 | 30.0 | 15.0 | 10.0 | 7.5 | 6.0 | 5.0 | 4.2 | 3.8 | 3.4 | 3.0 |

### Table IV

## KILOWATT CAPACITY OF SECONDARY MAINS

### Uniformly Distributed Load, Transformer at One End
### Single-Phase; 1 Per Cent Power Loss; 224 Volts Delivered

UPPER FIGURES KILOWATT CAPACITY—95 PER CENT P-F. (LIGHTS)
LOWER FIGURES KILOWATT CAPACITY—80 PER CENT P-F. (MOTORS)

| Wire Size B.&S. | P | Maximum | Distance in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 6 | 1.00 | 14.9 | 14.9 * | 8.2 | 5.4 | 4.0 | 3.3 | 2.7 | 2.4 | 2.1 | 1.8 | 1.6 |
| | 1.00 | 12.5 | 12.1 | 5.8 | 3.9 | 2.8 | 2.4 | 1.9 | 1.8 | 1.5 | 1.2 | 1.2 |
| 4 | 1.00 | 19.1 | 19.1 * | 13.1 | 8.7 | 6.4 | 5.2 | 4.3 | 3.7 | 3.3 | 2.8 | 2.6 |
| | 1.00 | 16.1 | 16.1 * | 9.1 | 6.0 | 4.6 | 3.6 | 3.0 | 2.7 | 2.2 | 2.1 | 1.8 |
| 2 | 1.00 | 26.6 | 26.6 * | 20.8 | 13.8 | 10.3 | 8.3 | 6.9 | 6.0 | 5.2 | 4.5 | 4.2 |
| | 1.00 | 22.4 | 22.4 * | 14.8 | 9.9 | 7.3 | 6.0 | 4.9 | 4.2 | 3.7 | 3.3 | 3.0 |
| 0 | 1.00 | 42.6 | 42.6 * | 33.0 | 22.2 | 16.0 | 13.4 | 11.1 | 9.6 | 8.2 | 7.5 | 6.6 |
| | 1.00 | 35.9 | 35.9 * | 23.6 | 15.6 | 11.7 | 9.3 | 7.8 | 6.6 | 5.8 | 5.1 | 4.6 |
| 00 | 1.00 | 48.0 | 48.0 * | 40.8 | 27.6 | 20.7 | 16.5 | 13.8 | 12.0 | 10.3 | 9.3 | 8.2 |
| | 1.00 | 40.3 | 40.3 * | 29.5 | 19.8 | 14.7 | 11.7 | 9.9 | 8.4 | 7.3 | 6.6 | 5.8 |
| 000 | 1.00 | 58.6 | 58.6 * | 52.5 | 35.0 | 26.3 | 21.0 | 17.5 | 15.0 | 13.2 | 11.7 | 10.5 |
| | 1.00 | 49.3 | 49.3 * | 37.2 | 24.9 | 18.6 | 15.0 | 12.4 | 10.5 | 9.3 | 8.4 | 7.5 |
| 0000 | 1.00 | 69.2 | 69.2 * | 66.5 | 44.0 | 33.2 | 26.4 | 22.0 | 18.9 | 16.7 | 14.7 | 13.2 |
| | 1.00 | 59.3 | 59.3 * | 48.0 | 31.5 | 23.6 | 18.9 | 15.8 | 13.5 | 11.7 | 10.5 | 9.4 |

* Maximum allowable load; less than 1 per cent power loss.

with a chance that three might never be used and still it would cost no more than the other "piece meal" method.

Similar and indeed more striking lessons could be drawn from Table VIII, showing the cost of erected secondary wires. For instance, if the initial financial burden were not too great, and if streets were open so that it would be possible to erect secondaries in a residential section in runs of 1000 ft. at a time instead of 200 ft. at a time, No. 2 wire could be used instead of No. 6 without additional cost. This would mean a tremendous difference in the capacity of the system as can be seen by referring to these two sizes in Table VI for 1000 ft., which shows that

### Table V

## KILOWATT CAPACITY OF SECONDARY MAINS

### Uniformly Distributed Load, Transformer in Center

### Single-Phase; 1 Per Cent Maximum Volts Loss; 224 Volts Delivered

UPPER FIGURES KILOWATT CAPACITY—95 PER CENT P-F. (LIGHTS)
LOWER FIGURES KILOWATT CAPACITY—80 PER CENT P-F. (MOTORS)

| Wire Size B.&S. | P | Maximum | Distance in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 * | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 6 | 0.95 | 29.8 | 29.8 | 20.8 | 13.9 | 10.4 | 8.0 | 6.9 | 5.9 | 5.2 | 4.6 | 4.2 |
| | 1.00 | 25.0 | 25.0 | 15.6 | 10.4 | 7.8 | 6.2 | 5.2 | 4.5 | 3.9 | 3.5 | 3.1 |
| 4 | 0.90 | 38.2 | 38.2 | 31.2 | 20.8 | 15.6 | 12.5 | 10.4 | 8.9 | 7.8 | 6.9 | 6.2 |
| | 0.91 | 32.2 | 32.2 | 22.4 | 14.9 | 11.4 | 8.9 | 7.5 | 6.4 | 5.6 | 5.0 | 4.5 |
| 2 | 0.85 | 53.2 | 53.2 | 47.2 | 31.4 | 23.6 | 18.9 | 15.7 | 13.5 | 11.8 | 10.5 | 9.4 |
| | 0.79 | 44.8 | 44.8 | 31.2 | 20.8 | 15.6 | 12.5 | 10.4 | 8.9 | 7.8 | 6.9 | 6.2 |
| 0 | 0.76 | 85.2 | 85.2 | 67.2 | 44.8 | 33.6 | 26.8 | 22.4 | 19.2 | 16.8 | 14.9 | 13.4 |
| | 0.67 | 71.8 | 71.8 | 42.0 | 28.0 | 21.0 | 16.8 | 14.0 | 12.0 | 10.5 | 9.3 | 8.4 |
| 00 | 0.74 | 96.0 | 96.0 | 82.0 | 54.6 | 41.0 | 32.8 | 27.3 | 23.4 | 20.5 | 18.2 | 16.4 |
| | 0.60 | 80.6 | 80.6 | 47.2 | 31.5 | 23.6 | 18.9 | 15.8 | 13.5 | 11.8 | 10.5 | 9.4 |
| 000 | 0.67 | 117.2 | 117.2 | 93.6 | 62.4 | 46.8 | 37.4 | 31.2 | 26.8 | 23.4 | 20.8 | 18.7 |
| | 0.51 | 98.6 | 98.6 | 50.8 | 33.9 | 25.4 | 20.3 | 17.0 | 14.5 | 12.7 | 11.3 | 10.2 |
| 0000 | 0.62 | 138.4 | 138.4 | 109.6 | 73.0 | 54.8 | 43.9 | 36.5 | 31.3 | 27.4 | 24.4 | 21.9 |
| | 0.48 | 118.6 | 118.6 | 60.0 | 40.0 | 30.0 | 24.0 | 20.0 | 17.1 | 15.0 | 13.3 | 12.0 |

* Maximum allowable load; less than 1 per cent volts loss.

### Table VI

## KILOWATT CAPACITY OF SECONDARY MAINS

### Uniformly Distributed Load, Transformer in Center

### Single-Phase; 1 Per Cent Power Loss; 224 Volts Delivered

UPPER FIGURES KILOWATT CAPACITY—95 PER CENT P-F. (LIGHTS)
LOWER FIGURES KILOWATT CAPACITY—80 PER CENT P-F. (MOTOR)

| Wire Size B.&S. | P | Maximum | Distance in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 * | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 6 | 1.00 | 29.8 | 29.8 | 29.8 * | 21.8 | 16.5 | 13.1 | 11.0 | 9.3 | 8.2 | 7.3 | 6.6 |
| | 1.00 | 25.0 | 25.0 | 23.2 | 16.8 | 11.7 | 9.3 | 7.8 | 6.7 | 5.8 | 5.2 | 4.6 |
| 4 | 1.00 | 38.2 | 38.2 | 38.2 * | 34.8 | 26.1 | 20.8 | 17.4 | 14.9 | 13.1 | 11.5 | 10.5 |
| | 1.00 | 32.2 | 32.2 | 32.2 * | 24.5 | 18.3 | 14.6 | 12.2 | 10.4 | 9.1 | 8.1 | 7.3 |
| 2 | 1.00 | 53.2 | 53.2 | 53.2 * | 53.2 * | 41.5 | 33.1 | 28.6 | 23.7 | 20.8 | 18.5 | 16.6 |
| | 1.00 | 44.8 | 44.8 | 44.8 * | 39.3 | 29.9 | 23.7 | 19.8 | 16.9 | 14.9 | 13.4 | 11.8 |
| 0 | 1.00 | 85.2 | 85.2 | 85.2 * | 85.2 * | 66.0 | 53.0 | 44.0 | 37.6 | 33.0 | 29.4 | 26.4 |
| | 1.00 | 71.8 | 71.8 | 71.8 * | 63.0 | 47.0 | 37.7 | 31.4 | 26.9 | 23.6 | 21.0 | 18.9 |
| 00 | 1.00 | 96.0 | 96.0 | 96.0 * | 96.0 * | 83.0 | 63.2 | 55.2 | 47.3 | 41.5 | 36.8 | 33.2 |
| | 1.00 | 80.8 | 80.6 | 80.6 * | 78.5 | 59.1 | 47.2 | 39.4 | 33.9 | 29.6 | 26.2 | 23.6 |
| 000 | 1.00 | 117.2 | 117.2 | 117.2 * | 117.2 * | 104.6 | 83.9 | 70.0 | 59.9 | 52.5 | 46.6 | 42.0 |
| | 1.00 | 98.6 | 98.6 | 98.6 * | 98.6 * | 74.2 | 59.4 | 49.5 | 42.5 | 37.2 | 33.0 | 29.9 |
| 0000 | 1.00 | 138.4 | 138.4 | 138.4 * | 138.4 * | 132.0 | 106.0 | 88.3 | 75.9 | 66.4 | 58.9 | 53.0 |
| | 1.00 | 118.6 | 118.6 | 118.6 * | 118.6 * | 94.0 | 75.5 | 62.7 | 54.0 | 47.0 | 41.9 | 37.8 |

* Maximum allowable load; less than 1 per cent power loss.

## Table VII

## COST IN DOLLARS OF ONE ERECTED WOOD POLE

| Length of Pole in Feet | NUMBER OF POLES ERECTED AT ONE TIME | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 35 | $16.00 | $14.00 | $12.00 | $11.00 | $10.50 | $10.00 | $9.60 | $9.40 | $9.20 | $9.00 |
| 40 | 18.25 | 16.25 | 14.25 | 13.25 | 12.75 | 12.25 | 11.85 | 11.65 | 11.45 | 11.25 |
| 45 | 20.50 | 18.50 | 16.50 | 15.50 | 15.00 | 14.50 | 14.10 | 13.90 | 13.70 | 13.50 |
| 50 | 23.25 | 21.25 | 19.25 | 18.25 | 17.75 | 17.25 | 16.85 | 16.65 | 16.45 | 16.25 |
| 55 | 27.25 | 25.25 | 23.25 | 22.00 | 21.25 | 20.75 | 20.10 | 19.75 | 19.45 | 19.25 |
| 60 | 35.50 | 33.50 | 31.50 | 30.25 | 29.75 | 29.00 | 28.35 | 28.00 | 27.70 | 27.50 |
| 65 | 37.50 | 35.50 | 33.50 | 32.25 | 31.75 | 31.00 | 30.35 | 30.00 | 29.70 | 29.50 |
| 70 | 39.50 | 37.50 | 35.50 | 34.25 | 33.75 | 33.00 | 32.35 | 32.00 | 31.70 | 31.50 |

## Table VIII

## COST IN DOLLARS PER 100 FEET FOR THREE ERECTED SECONDARY WIRES ON POLES ALREADY ERECTED BUT NOT ARMED OR GUYED. 1 SPAN = 100 FEET

| Wire Size B.&S. | DISTANCE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 200 | 300 | 400 | 500 | 600 | 760 | 800 | 900 | 1000 |
| 6 | $8.50 | $6.90 | $6.10 | $5.55 | $5.15 | $4.85 | $4.60 | $4.45 | $4.30 | $4.15 |
| 4 | 9.55 | 7.95 | 7.15 | 6.60 | 6.20 | 5.95 | 5.70 | 5.55 | 5.40 | 5.25 |
| 2 | 11.20 | 9.60 | 8.80 | 8.25 | 7.85 | 7.60 | 7.35 | 7.20 | 7.10 | 6.95 |
| 0 | 13.65 | 12.05 | 11.25 | 10.70 | 10.35 | 10.10 | 9.85 | 9.70 | 9.60 | 9.45 |
| 00 | 15.30 | 13.60 | 12.95 | 12.40 | 12.05 | 11.80 | 11.55 | 11.40 | 11.30 | 11.15 |
| 000 | 17.70 | 16.10 | 15.35 | 14.80 | 14.45 | 14.10 | 13.90 | 13.70 | 13.55 | 13.35 |
| 0000 | 19.30 | 17.70 | 16.95 | 16.40 | 16.05 | 15.75 | 15.40 | 15.15 | 14.95 | 14.75 |

## Table IX

## CREDIT IN DOLLARS PER 100 FEET FOR WIRE REMOVED WHEN SAME IS REPLACED BY OTHER WIRE AND REMOVED WIRE HAS NOT PASSED USEFUL LIFE

| Wire Size B.&S. | LENGTH IN FEET OF REMOVED WIRE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 960 | 1000 |
| 6 | $0.35 | $0.35 | $0.35 | $0.45 | $0.55 | $0.70 | $0.80 | $0.90 | $0.90 | $0.90 |
| 4 | .55 | .55 | .55 | .75 | .80 | 1.05 | 1.15 | 1.35 | 1.35 | 1.35 |
| 2 | 1.05 | 1.05 | 1.05 | 1.20 | 1.50 | 1.75 | 2.00 | 2.20 | 2.20 | 2.20 |
| 0 | 1.75 | 1.75 | 1.75 | 2.10 | 2.45 | 2.85 | 3.20 | 3.55 | 3.55 | 3.55 |
| 00 | 2.20 | 2.20 | 2.20 | 2.60 | 3.05 | 3.50 | 3.95 | 4.40 | 4.40 | 4.40 |
| 000 | 2.85 | 2.85 | 2.85 | 3.40 | 3.95 | 4.50 | 5.15 | 5.70 | 5.70 | 5.70 |
| 0000 | 3.50 | 3.50 | 3.50 | 4.20 | 4.90 | 5.60 | 6.35 | 7.05 | 7.05 | 7.05 |

## Table X

## COST IN DOLLARS OF ERECTION OF A TRANSFORMER ON AN ERECTED POLE WITH PRIMARY AND SECONDARY LINES ALREADY ON POLE; ALSO COST OF CHANGING TO ANOTHER SIZE

| Group | Transformer Size Kv-a. | Original Installation | Changing to Group A | Changing to Group B | Changing to Group C |
|---|---|---|---|---|---|
| A | 1 to 10 | $5.50 | $4.00 | $5.00 | $6.00 |
| B | 15 to 25 | 6.50 | 3.50 | 5.00 | 6.00 |
| C | 30 to 50 | 7.00 | 5.00 | 5.00 | 6.00 |

through the 1000 ft. with the transformer in the center the No. 6 wire would carry 6.6 kw. while the No. 2 wire would carry 16.6 kw. This is an increase to 2½ times the capacity without additional expense if one can just look ahead far enough.

On account of the increase in load in any section it may be necessary at any time to replace small wire with a conductor of larger size. It is therefore interesting in this connection to determine how much return can be had for removing the wire which is so expensive to erect. This return is here termed "credit" and is the scrap value of the wire minus the cost of removing it. These credits are shown in Table IX for wire which may still be used over again. The credits run higher for the greater lengths because they might be returned to second-hand stock while the shorter lengths would just be cut down and scrapped. A comparison of this table with Table VIII shows strikingly the results of not building lines large enough at first to carry all load which may arise during the useful life of the wire.

Now that the poles and primary and secondary lines of a distribution system have been considered, it is time to consider the transformer which ties together the primary and the secondary mains. This has properties similar to those of poles and wires in that it costs money as is clearly shown in Table XI. It also shares with the wires in absorbing some of the energy which it transmits. But it goes further than that, absorbing energy whether it is transmitting any or not. This constant drain of energy is called the core loss, and is shown in Table XI for transformers from 1 to 50 kv-a., both in watts and in cost in dollars per annum at ½ cent per kw-hr.

There has been some discussion about the rate at which the core loss should be charged. Some would say that it must take its share of the generating substation and distribution costs, while some would merely charge its coal cost. This latter would appear to be more nearly correct since the core loss totals less than 1 per cent of the peak load and therefore has a negligible effect on the generating capacity. Its effect on the remainder of the system is so distributed over the whole that its effect is absolutely negligible. Judging it by the standards for commercial loads, it has a 100 per cent load factor on the 24-hr. basis and is so distributed that it requires no additional apparatus and it is therefore entitled to the absolute minimum rate.

Table XI also shows the cost of the various sizes of transformers and the cost of erection. From these figures with interest at 6 per cent and depreciation 10 per cent, on the basis of a life of 10 years, the cost of keeping a transformer on the line for a year has been worked out and is shown. Some would like to claim longer life than 10 years, though general experience would not seem to warrant it for the average size pole type transformer. Of course, these figures should be modified by the latest data on each system in making the calculations.

The core loss has been materially reduced in recent years. It probably makes more expensive construction to reduce the loss, and by letting it run higher the transformer should be cheaper. It is therefore the business of the manufacturing companies to obtain a true balance between these factors.

No allowance has been made for maintenance charges against the transformer since many companies have done practically no maintenance work on them and no definite figures, as to the amount necessary or how it will improve the life of the transformer or its capacity, are readily available. However, just a superficial study of the table will show that if 10 years is the true life of a 50-kv-a. transformer, without any maintenance work, work that would improve the life to 15 years could cost as much as $10.00 per year. This is easily enough to pay for most complete lightning protection, purification of the oil, and complete cleaning when out of service and still leave a very wide margin of profit.

Many people familiar with transformers can scarcely tell the difference between a 40 and a 50-kv-a. transformer when they see it on the pole. Yet the last column shows the difference is $8.10 a year. A practical man in choosing whether to put up a 40 or a 50-kv-a. transformer will very likely decide to use the 50, saying: "It will be needed in a couple of years anyway." However, it will cost $16.20 more in that time and it would cost only $6.00 (Table X) to change it. This last column (Table XI) shows that if the average size of transformers on any system could be reduced say from 15 kv-a. to 10 kv-a. it would warrant the expenditure of approximately $6.00 per transformer per annum. This is easily enough to pay for very complete tests and records of every transformer.

In this connection it is not out of place to consider briefly what tests and records are necessary. On small systems with one or two men handling all records it is very generally possible to have one set of records for all. But on larger systems it becomes necessary to have records of customers' loads in the contract department, meter department, and distribution department. Experience has shown the great difficulty of keeping these records up to date, particularly with medium size business places, where different sizes of lamps are kept on hand and used on different evenings according to the season of year and business expected. So it is an open question in the distribution department, with which only we are now concerned, whether it is necessary to keep any record of load except for the larger customers—that is, for the customers whose loads are say one-fourth or one-half of the transformer capacity supplying them. But it is evident from Table XI that it is most necessary to keep records of actual tests, showing that the transformers are working at least up to their rating, and, if they will stand it, above their ratings during the peak. The two factors that determine whether they will stand it or not are the temperature and the regulation. This is a great subject in itself and there is not space here to say more than that one central station has just started some practical in-service tests on this basis and there may be some very interesting results to report in the future.

Table XI

INITIAL COST OF, AND ANNUAL CHARGES AGAINST POLE TYPE TRANSFORMERS

Life, 10 Years; Depreciation, 10 Per Cent; Interest, 6 Per Cent; Total Capital Charges, 16 Per Cent; Energy to Supply Core Loss, ½ Cent per Kw-Hr.

| Kv-a. | COST IN DOLLARS | | | | CORE LOSS | | Total Annual Charges |
|---|---|---|---|---|---|---|---|
| | Original | Erection | Total | Annual | Watts | Cost per Year | |
| 1.0 | $20.00 | $5.50 | $25.50 | $4.10 | 25 | $1.10 | $5.20 |
| 2.0 | 30.00 | 5.50 | 35.50 | 5.70 | 35 | 1.50 | 7.20 |
| 3.0 | 40.00 | 5.50 | 45.50 | 7.30 | 45 | 1.95 | 9.25 |
| 4.0 | 50.00 | 5.50 | 55.50 | 8.90 | 50 | 2.20 | 11.10 |
| 5.0 | 55.00 | 5.50 | 60.50 | 9.70 | 55 | 2.40 | 12.10 |
| 7.5 | 75.00 | 5.50 | 70.50 | 11.30 | 75 | 3.30 | 14.60 |
| 10.0 | 90.00 | 5.50 | 95.50 | 15.30 | 90 | 3.90 | 19.20 |
| 15.0 | 120.00 | 6.50 | 126.50 | 20.20 | 120 | 5.25 | 25.45 |
| 20.0 | 150.00 | 6.50 | 156.50 | 25.00 | 145 | 6.35 | 31.35 |
| 25.0 | 180.00 | 6.50 | 186.50 | 29.80 | 170 | 7.45 | 37.25 |
| 30.0 | 200.00 | 7.00 | 207.00 | 33.00 | 190 | 8.30 | 41.30 |
| 40.0 | 240.00 | 7.00 | 247.00 | 39.50 | 225 | 9.80 | 49.30 |
| 50.0 | 280.00 | 7.00 | 287.00 | 46.00 | 260 | 11.40 | 57.40 |

As a matter of interest and for subsequent use, the copper loss and regulation of transformers are shown in Table XII. The cost of energy for copper loss has been assumed at 2 cents per kw-hr. since it is a peak load. This is discussed more fully in considering rate for energy losses in the secondary (page 1172).

The transformer has been treated in a manner slightly different from that in which the pole and wire costs were treated; that is, its cost per annum has been determined as well as the initial cost. It is now proposed to do the same for secondary wires but, since the previous tables show plainly that it is uneconomical to erect wires in short sections, figures for 1000-ft. sections only have been made up. These are shown in Table XIII.

## PRACTICAL COMBINATION OF DATA FOR ECOMONICAL RESULTS

In the preceding sections of this article the losses in various apparatus and the cost of maintaining it in service have been shown. It is now proposed to combine these to show what is the truly economical design for a secondary distribution system.

This would appear a very complicated problem, and indeed it is. But it is here that the "practical man" comes in to simplify matters. For instance, in considering the question of service to a row of houses by wires run along the rear on brackets from one end, the "practical man" says it is useless to consider running the primary lines in to a transformer placed in the center of the row, no matter how cheap a job it will make, on account of the same objections which have been advanced against the "radial system," and also on account of the life hazard of

### Table XII

### TRANSFORMER REGULATION AND COPPER LOSS AND COST PER YEAR AT 2 CENTS PER KW-HR. FOR FULL LOAD OPERATION 1 HOUR PER DAY

| Size Kv-a. | Regulation 95 Per Cent P-F. | COPPER LOSS | | Size Kv-a. | Regulation 95 Per Cent P-F. | COPPER LOSS | |
|---|---|---|---|---|---|---|---|
| | | Watts | Cost | | | Watts | Cost |
| 1.0 | 2.5 | 30 | $0.22 | 15.0 | 1.5 | 220 | $1.60 |
| 2.0 | 2.5 | 50 | .36 | 20.0 | 1.4 | 295 | 2.16 |
| 3.0 | 2.3 | 70 | .51 | 25.0 | 1.4 | 355 | 2.59 |
| 4.0 | 2.1 | 85 | .62 | 30.0 | 1.4 | 430 | 3.14 |
| 5.0 | 1.9 | 95 | .69 | 40.0 | 1.3 | 485 | 3.54 |
| 7.5 | 1.7 | 120 | .88 | 50.0 | 1.2 | 600 | 4.38 |
| 10.0 | 1.6 | 160 | 1.17 | | | | |

### Table XIII

### DATA ON ANNUAL CHARGES AGAINST 1000 FEET OF THREE-WIRE SECONDARY, EXCLUSIVE OF COST OF POLES

| Wire Size B.&S. | Initial Cost from Table VIII | Average Life Years | Depreciation | Interest | Total Capital Charges | | Maintenance | Total Annual Charges |
|---|---|---|---|---|---|---|---|---|
| | | | *Per Cent* | *Per Cent* | *Per Cent* | | | |
| 6 | $41.50 | 25 | 4.0 | 6.0 | 10.0 | $4.10 | $3.00 | $7.10 |
| 4 | 52.50 | 25 | 4.0 | 6.0 | 10.0 | 5.20 | 3.00 | 8.20 |
| 2 | 69.50 | 25 | 4.0 | 6.0 | 10.0 | 7.00 | 3.00 | 10.00 |
| 0 | 94.50 | 30 | 3.3 | 6.0 | 9.3 | 8.80 | 3.00 | 11.80 |
| 00 | 111.50 | 30 | 3.3 | 6.0 | 9.3 | 10.40 | 3.00 | 13.40 |
| 000 | 133.50 | 35 | 3.0 | 6.0 | 9.0 | 12.00 | 3.00 | 15.00 |
| 0000 | 147.50 | 40 | 2.5 | 6.0 | 8.5 | 12.50 | 3.00 | 15.50 |

### Table XIV

### ANNUAL CHARGES AGAINST A THREE-WIRE SECONDARY SYSTEM, 1000 FEET LONG, SUPPLIED BY A 30-KILOWATT TRANSFORMER IN THE CENTER, WITH A UNIFORMLY DISTRIBUTED LOAD OF 30 KILOWATTS, OF 95 PER CENT POWER-FACTOR

224 Volts Delivered; Rate, 2 Cents per Kw-Hr.; Showing Most Economical Size of Wire

| Wire Size B.&S. | POWER LOSS | | | | | ANNUAL FIXED CHARGES | | | TOTAL FIXED AND OPERATING ANNUAL CHARGES FOR DIFFERENT DAILY PERIODS OF OPERATION | | | | | | Max. Volts Loss |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Secondary | | Trans-former Copper in Kw. | Total Kw. | Annual Cost with Load on 1 Hour per Day | Trans-former | Lines | Total | 1 Hour | 2 Hours | 3 Hours | 5 Hours | 8 Hours | 10 Hours | Per Cent |
| | (From Table VII) Per Cent | In Kw. | | | | | | | | | | | | | |
| 6 | 4.5 | 1.34 | 0.43 | 1.77 | $12.90 | $41.30 | $ 7.10 | $48.40 | $61.30 | $74.20 | $87.10 | $112.90 | $151.60 | $177.40 | 7.1 |
| 4 | 2.8 | 0.84 | 0.43 | 1.27 | 9.30 | 41.30 | 8.20 | 49.50 | 58.80 | 68.10 | 77.40 | 96.00 | 123.90 | 142.50 | 4.6 |
| 2 | 1.8 | 0.43 | 0.43 | 0.96 | 7.00 | 41.30 | 10.00 | 51.30 | 58.30 | 65.30 | 72.30 | 86.30 | 107.30 | 121.30 | 3.2 |
| 0 | 1.13 | 0.34 | 0.43 | 0.77 | 5.60 | 4.130 | 11.80 | 53.10 | 58.70 | 64.30 | 69.90 | 81.10 | 97.90 | 109.10 | 2.2 |
| 00 | 0.90 | 0.27 | 0.43 | 0.70 | 5.10 | 41.30 | 13.40 | 54.70 | 59.80 | 64.90 | 70.00 | 80.20 | 95.50 | 105.70 | 1.8 |
| 000 | 0.71 | 0.21 | 0.43 | 0.64 | 4.70 | 41.30 | 15.00 | 56.30 | 61.00 | 65.70 | 70.40 | 79.80 | 93.90 | 103.30 | 1.6 |
| 0000 | 0.56 | 0.17 | 0.43 | 0.60 | 4.40 | 41.30 | 15.50 | 56.80 | 61.20 | 65.60 | 70.00 | 78.80 | 92.00 | 101.20 | 1.4 |

running primary wires open on a row of residences. This is, of course, an extreme case, but it is brother to the case of a moderate size load on a side street; that is, a street that has not been chosen for a primary branch, as in Fig. 2. The practical man says: "Let it cost more, but if any reasonable arrangement can be made, keep the transformers on the main street." Further, the junction pole at a corner would appear to be the ideal place to feed economically in both directions; but objection is rightly made that a junction pole is complicated enough without the transformers; it is already the most difficult to maintain and renew, and it usually of necessity has a street lamp. This limits the transformer poles to those in the center of the block. There may also be some alleys requiring lines and therefore junction poles, so in a block 500 ft. long there may be only two or three poles available for transformers. Considering that there may be separate light and power transformers required, apparently only one pole per block will be available for a lighting transformer, unless sufficient economy by using more can be shown to warrant the shortening of the spans and the erection of an additional pole. Then, the practical man goes further—he says: "Transformers, like all other apparatus on a line, are points of trouble," and he wants as few of them as possible, in order to maintain continuous service, so that one transformer for every two blocks would be much better. Concluding, he thinks that a secondary system, such as shown in Fig. 4, considering the primary lines running on the "main streets" would be ideal, except that the transformers would have to be moved to the pole next to the corner.

So the problem would on the whole appear to be much simplified by the apparent complications of practical conditions.

The most economical condition is, of course, when the sum of the fixed capital and maintenance charges, and the operating charges or cost of the power loss are a minimum. The question of increased or decreased consumption of current by the lamps might at first be thought to influence this problem, but it has no connection. If lamps are supplied rated at exactly the service voltage of each individual customer, it then makes no difference what is the range in voltage from the nearest to the most distant service. If lamps are supplied to all alike of the average voltage on the secondary, then the increase in consumption of some will offset the decrease by others, so far as the central station is concerned. The results of the calculations in Table XIV amply justify this assumption and preclude the necessity of further discussing the ethics of the matter.

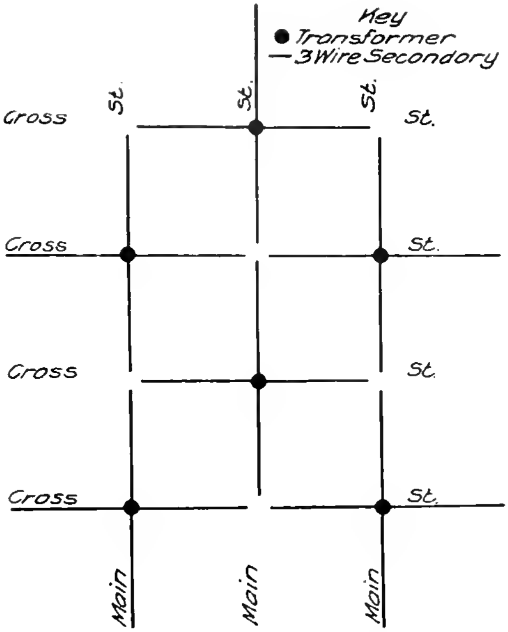

Fig. 4. Ideal Secondary Distribution

It is not proposed here to work out economical conditions for all cases but to give an example of the procedure. The case taken will be that which the forenamed practical considerations would point to as normal. Suppose there is an actual combined running load of 30 kw. in two blocks, each 500 ft. long, making a total length of secondary of 1000 ft. (This is very near the condition on the main business street of a small town or an outlying business street of a large city.) The 30 kw. can just be carried by No. 6 wire without over-heating. The question is, what size wire shall be used to supply the load. The charges for the 30 kv-a. transformer will be fixed. The charges for the wire will be fixed for each size regardless of the length of time the load is in use. The operating costs or power loss in the secondary will vary with the length of time the load is in use, and the copper loss of the transformer is included with it, since it varies in exactly the same manner. It is therefore evident that the answer, i.e., the size of wire, will vary with the length of time the load is in use. Since the load does not come on or go off suddenly or stay at any fixed value, and since it, as well as the time in use, varies throughout the year, a more general answer can be obtained by finding the most economical sizes for each period of use from 1 to 10 hours.

The charge per kw-hr. for energy losses, like the charge for core loss of a transformer, is open for discussion. It is in reality the total cost of supplying current to the class of customers supplied by the secondary line in question, minus the customer or service line and meter charges. The practical way to obtain this, until the whole subject of distribution has been given much more detailed attention than it has received to the present time, is to take the average rate per kw-hr. paid by the customers on a secondary main and subtract the average charges per kw-hr. delivered for service and meter costs. The figure of 2 cents per kw-hr. has been used in Table XIV, but is obviously very low for lighting customers. Any increase in this value would tend to increase the economical size of wire.

Table XIV needs study, rather than comment. It sums up all that has gone before and shows most conclusively that there *is* an economical size of wire to be used for every condition and that this size is not far different from what the practical man is accustomed to use, but is right in the range of commercial practice. In the particular case in hand it is probably not out of the way to assume that the load would be "on" two or three hours per day as the average. The table shows that for this use the best size of secondary is No. 0. No. 00 is so close to the same economy and with better economy if the load should run for four hours, that it is a question indeed if it should not be used.

But while the fact that the most economical size of wire can be exactly determined is of great interest, the final column is of even greater. It shows that if central stations could afford to abandon their present distribution systems and build new ones in accordance with these principles of design, the question of different lamp voltages for different customers would be settled. With the most economical size of wire the range of voltage in the hypothetical case considered is only 2.2 per cent or 1.1 per cent from the average. This is such a small amount that it is negligible, as can be seen by reference to any of the standard candle-power curves published by lamp manufacturers. Such curves show a change of only 3.5 per cent in candle-power for a 1 per cent change in voltage. (A very complete discussion of this subject is given in the report of the Lamp Committee to the Pennsylvania Electric Association, 1913.)

In other words, the central station with lines designed without regard for initial cost and with regard for total economical operation will supply service of which there can be absolutely no complaint.

This does not consider the primary losses which might cause different voltages on the different transformers. Similar calculations can, however, be made for them and it is probable that the results would be similar to those for the secondary and warrant large enough wire to offset the losses. At any rate, a practical remedy is to get a great enough load density so that the primary lengths from the first to the last transformer on a circuit are short, and it is then found with the "tree" system that there is almost no difference of voltage on the different transformers.

In Table XIV the load is fixed at 30 kw. It is interesting as another general problem to determine at what load the advantage turns—say from No. 6 to No. 4 wire, when the loads are in use three hours per day. This is determined in Table XV, which is similar to Table XIV, except that only two sizes of wire are considered, and the time is constant at three hours per day, while the load is varied from 1 to 30 kw.

Table XV shows plainly that with a load of 7½ kw. or less the No. 6 wire is the more economical, while if the load is increased to 10 kw. or above, the No. 4 wire is more economical. It is also interesting to find that the voltage loss for this maximum economical load is only 1.8 per cent or a variation of no more than 0.9 per cent from the mean value. This table should be extended to cover all sizes of wire for actual use, but the principle is the same and extension here is not considered necessary.

Next, it is interesting to consider the practical matter of replacing small wire with larger when the load has increased enough to require it. This will be done by means of the tables on the original cost of wire and credit for removal of wire when replaced by larger. (Tables VIII and IX.)

The case taken for a sample calculation will be that of the erection of No. 6 wire to carry its full capacity of 7½ kw. and later changing it to No. 0 when the load requires. The question is to find how much time must elapse between the original installation and the date of increase, in order to make it economical to erect the No. 6 wire and later change it to No. 0. The No. 6 wire carrying 7½ kv-a. for three hours per day (Table XV) costs $26.20 per year.

A similar secondary of No. 0 wire carrying 7½ kv-a. with a 7½-kv-a. transformer costs $27.45 per year, made up as follows:

| | | |
|---|---|---|
| Fixed charges for transformer........ | | $14.60 |
| Fixed charges for secondary lines.... | | 11.80 |
| Transformer copper loss | 0.120 kw. | |
| Secondary power loss (0.284 per cent)..... | 0.0213 kw. | |
| Total............... | 0.1413 kw. | |
| Cost of 0.1413 kw. 3 hours per day.. | | 1.05 |
| Total........................ | | $27.45 |

### Table XV

### ANNUAL CHARGES AGAINST A THREE-WIRE SECONDARY SYSTEM, 1000 FT. LONG AND CONSISTING OF NO. 6 OR NO. 4 WIRE, SHOWING LOAD POINT AT WHICH ECONOMY TURNS FROM ONE TO THE OTHER. LOAD IN USE 3 HOURS PER DAY AND DISTRIBUTED UNIFORMLY OVER LENGTH OF LINE. 95 PER CENT POWER-FACTOR

224 Volts Delivered; Rate, 2 Cents per Kw-Hr.

| Transformer Size Kv-a. | Annual Cost Transformer | NO. 6 WIRE | | | | NO. 4 WIRE | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fixed Charge | Total Fixed Charges | Operating Cost | Total | Fixed Charge | Total Fixed Charges | Operating Cost | Total |
| 1.0 | $5.20 | $7.10 | $12.30 | $0.75 | $13.05 | $8.20 | $13.40 | $0.60 | $14.00 |
| 2.0 | 7.20 | 7.10 | 14.30 | 1.20 | 15.50 | 8.20 | 15.40 | 1.20 | 16.60 |
| 3.0 | 9.25 | 7.10 | 16.35 | 1.80 | 18.15 | 8.20 | 17.45 | 1.65 | 19.10 |
| 4.0 | 11.10 | 7.10 | 18.20 | 2.40 | 20.60 | 8.20 | 19.30 | 2.25 | 21.55 |
| 5.0 | 12.10 | 7.10 | 19.20 | 3.00 | 22.20 | 8.20 | 20.30 | 2.85 | 23.15 |
| 7.5 | 14.60 | 7.10 | 21.70 | 4.50 | 26.20 | 8.20 | 22.80 | 3.75 | 26.55 |
| 10.0 | 19.20 | 7.10 | 26.30 | 6.90 | 33.20 | 8.20 | 27.40 | 5.55 | 32.95 |
| 15.0 | 25.45 | 7.10 | 32.55 | 14.40 | 46.95 | 8.20 | 33.65 | 9.45 | 43.10 |
| 20.0 | 31.25 | 7.10 | 38.35 | 19.80 | 58.15 | 8.20 | 39.45 | 14.70 | 54.15 |
| 25.0 | 37.25 | 7.10 | 44.35 | 29.70 | 74.05 | 8.20 | 45.45 | 21.00 | 66.45 |
| 30.0 | 41.30 | 7.10 | 48.40 | 39.30 | 87.70 | 8.20 | 49.50 | 24.00 | 73.50 |

### Table XVI

### SHOWING DERIVATION OF OPERATING COSTS IN TABLE XV, GIVING OPERATING COST FOR TRANSFORMER AND SECONDARY FOR 1 YEAR WITH USE OF 1 HOUR PER DAY. RATE, 2 CENTS PER KW-HR.

| TRANSFORMER | | NO. 6 WIRE POWER LOSS | | | | NO. 4 WIRE POWER LOSS | | | |
|---|---|---|---|---|---|---|---|---|---|
| Size Kv-a. | Copper Loss in Kw. | Per Cent | Kw. | Total Kw. | Cost | Per Cent | Kw. | Total Kw. | Cost |
| 1.0 | 0.030 | 0.15 | 0.0015 | 0.0315 | $0.25 | 0.095 | 0.0010 | 0.031 | $0.20 |
| 2.0 | 0.050 | 0.30 | 0.0060 | 0.056 | 0.40 | 0.19 | 0.0038 | 0.054 | 0.40 |
| 3.0 | 0.070 | 0.45 | 0.0135 | 0.083 | 0.60 | 0.29 | 0.0087 | 0.079 | 0.55 |
| 4.0 | 0.085 | 0.61 | 0.0244 | 0.109 | 0.80 | 0.38 | 0.0152 | 0.100 | 0.75 |
| 5.0 | 0.095 | 0.76 | 0.0380 | 0.133 | 1.00 | 0.48 | 0.0240 | 0.129 | 0.95 |
| 7.5 | 0.120 | 1.14 | 0.0854 | 0.205 | 1.50 | 0.71 | 0.0542 | 0.174 | 1.25 |
| 10.0 | 0.160 | 1.52 | 0.152 | 0.312 | 2.30 | 0.95 | 0.095 | 0.255 | 1.85 |
| 15.0 | 0.220 | 2.28 | 0.342 | 0.662 | 4.80 | 1.43 | 0.214 | 0.434 | 3.15 |
| 20.0 | 0.295 | 3.03 | 0.607 | 0.903 | 6.60 | 1.90 | 0.380 | 0.675 | 4.90 |
| 25.0 | 0.355 | 3.80 | 0.950 | 1.355 | 9.90 | 2.48 | 0.620 | 0.975 | 7.00 |
| 30.0 | 0.430 | 4.55 | 1.37 | 1.80 | 13.10 | 2.86 | 0.860 | 1.090 | 8.00 |

Therefore the No. 0 wire costs but $1.25 more per year than the No. 6 wire.

To change from No. 6 to No. 4 wire and from a 7½ kv-a. to a 30 kv-a. transformer involves charges against the expense account (Tables VIII, IX and X) of,

| | |
|---|---|
| Changing wire | $32.50 |
| Changing transformer | 6.00 |
| Total | $38.50 |

To change from a 7½ kv-a. to a 30 kv-a. transformer in connection with the No. 0 wire costs $6.00. The difference of these charges to expense is $32.50. This figure is to be compared to the difference of $1.25 in operating costs for the period previous to the change. If $32.50 is divided by $1.25 it is found that unless the smaller load is in use over 26 years before the increase comes, it would have been more economical to erect the No. 0 wire originally.

These figures are most startling. Yet they are only extreme in the fact that if any other combination is chosen the period will be longer instead of shorter. They do point out very clearly the necessity of working up tables similar to these, using absolutely the most reliable information at hand, and the extension of all these calculations to cover concentrated and other distributions of loads, as well as the case of uniformly distributed loads here used.

There is another saving that could be made by using several sections of the No. 0 wire together till the load increased to an extent to require separate transformers. This would be equivalent to "closing through" the secondaries on one of the main streets in Fig. 4, and omitting one of the transformers on this street. It could then be sectionalized, in the light of greater information on the load, at a future date. In this connection it is interesting to note that if an extreme load came on at any point the transformer could be placed directly at that point and the load would not affect the general capacity of the secondary in the slightest degree.

## EFFECT OF ECONOMIES ON COMMERCIAL POLICY

The economies that can be practised if the future load is known, as has been shown in the previous sections, are so obvious that the commercial policy that they dictate follows without argument. The engineer can build lines very economically if he is allowed to do it in large sections at a time, and if the curve of the predicted growth of load is known.

Therefore, the first step is to take a large section or even one street for three or four blocks and determine the growth of load and lay out an economical distribution to cover this; then, send the contract agent to secure the first contract. As soon as this has been done build the whole distribution system and leave it to the contract agent to come up to the mark set for him. He will have no excuses of high service costs or length of time to run service, and will simply have to hustle. Incidentally, he will be reduced from his present high place as the man who brings the new life blood into the Company and will become simply a hard-working part of the machine.

It would be possible to write at length on the methods for determining the growth of load curve and the sections of a property first to be treated, but that is a detail that can easily be worked out if the general plan is adopted.

## CONCLUSION

In conclusion, particular attention is drawn to the fact that this is but the beginning of the solution of the great problem of aerial distribution. The problem of underground lines needs treatment in a similar manner, only perhaps more urgently, since the investment is much greater. The comparison of overhead and underground lines is exactly similar, only probably even more startling in some of its results.

Let all concerned in any way in distribution bear these few facts in mind and make all their work and records conform, so that in the near future the rational solution of this ever-present problem of the central station may be reached.

# THE SUCCESSFUL OPERATION OF A TELEPHONE SYSTEM PARALLELING HIGH TENSION POWER LINES

By Charles E. Bennett

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The author describes the successful installation of a telephone line on the towers of the Georgia Railway & Power Company's Tallulah Falls 110,000-volt transmission line. The fine degree of potential balance between the two wires of the telephone line, necessary for satisfactory communication, was obtained by transposing the wires at every tower and by thorough insulation. Drainage coils are connected between the wires and to ground to relieve the line of low frequency high potential stresses, while high frequency surges are discharged through vacuum type lightning arresters, supplemented by horn gaps. A large number of tests were conducted on this line to determine the effects produced by different arrangements of apparatus, and the results are given in the text and in the accompanying oscillograms.—Editor.

The problem of locating private telephone lines on the steel towers of high voltage power lines instead of carrying them on a separate pole line is one that has been under discussion for some time, and many of the larger companies have abandoned the use of a telephone line carried on the towers on account of the many troubles occasioned by this arrangement.

When telephone lines parallel high tension transmission lines they are subjected to influences which may under certain conditions interfere with the proper transmission of speech. This interfering influence is, in all cases, due to the static induction from the high tension transmission line. Under normal operating conditions, i.e., with fairly well balanced three-phase circuits, this influence will be slight; but with abnormal operating conditions on the transmission line, the effect created on a telephone line may increase to such an extent as to become destructive. In addition to these influences the telephone line is subjected to disturbances occasioned by lightning discharges, which, however, are very similar in character to the effects created by abnormal conditions on the transmission line, such as those occasioned by switching with unbalanced phases, arcing grounds, etc.

Under normal operating conditions the effect of the static induction upon the two wires of the telephone line is practically the same, with the result that the two wires will assume a definite potential with regard to earth. With a well insulated and properly transposed metallic line, the potentials of each wire against ground will be nearly alike, and hence there will be no difference of potential between the two wires themselves. In telephone work, however, even the smallest difference of potential between the wires will create a flow of current through the telephone receiver. This current, being alternating, produces a noise in the receiver which may be loud enough to render talking impossible. The higher the voltage of a transmission line and the closer the telephone line to the transmission line, the more prominent will be the noise in the telephone, with a slightly unbalanced telephone line. As this disturbing current is due to a difference of potential, it is obvious that the noise in the receiver is in a measure independent of the absolute value of the voltage of each line to ground, and that it cannot be eliminated unless the voltage on both wires be made exactly alike. This condition, which is termed "balanced," is realized by properly insulating and trans-

Fig. 1. Photograph of a Standard Line Tower of the Georgia Railway & Power Co., Showing the Power Wires and the Telephone Wires and Their Transposition

posing the telephone wires. The larger the number of transpositions per mile, the more nearly will the potential on the wires be equalized; and the better the insulation of the lines, the less will there be a chance for a "leak" (to ground), causing a drop of potential on that particular wire, with the subsequent result of unbalancing the line and rendering it noisy.

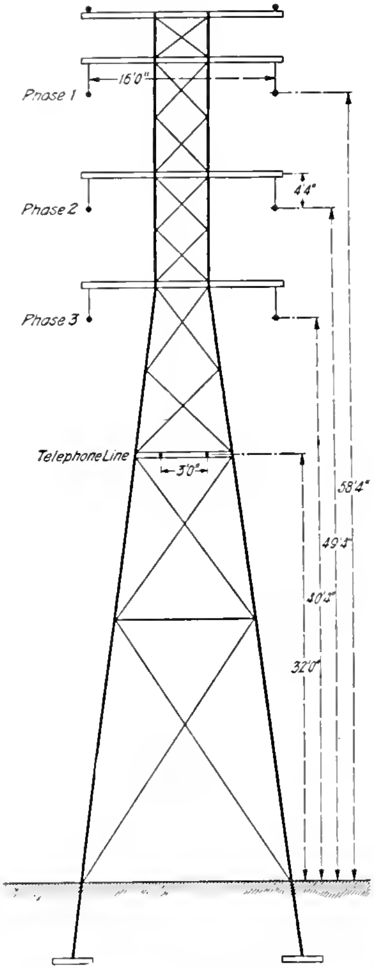

Fig. 2. Dimensioned Drawing Showing the Location of the Power and Telephone Wires on Tower

From the above it will be seen that so far as the noise of the line is concerned it can be kept within any limit, provided the telephone line is properly transposed and well insulated. On the other hand, it will be seen that the existing potential between telephone wires and ground, by reaching high potential values, may not necessarily impair the transmission of speech, but will seriously strain the insulation of the instruments and make their use dangerous.

*The transmission system of the Georgia Railway & Power Company consists of a double 4/0 circuit from Tallulah Falls to Atlanta, a distance of 90 miles, with double 2/0 circuits extending northward to Lindale and southward to Newnan from Atlanta. The line from Atlanta to Lindale is about 75 miles in length, while the line to Newnan is about 40 miles. All of these lines are operated at from 110,000 volts to 120,000 volts at 60 cycles.

This system is paralleled by a single two-wire telephone circuit located about 10 feet (diagonally) below the bottom power conductor and carried on the horizontal angle iron which forms a part of the tower.

The original layout was made with pin insulators of 11,000-volt design, but the many induced surges or steep front waves punctured them with such remarkable rapidity that is was decided more insulation—or puncture-proof quality—was necessary. From a construction standpoint it was found most convenient to re-insulate the line with suspension disks. It has been found that one suspension unit will withstand most of the

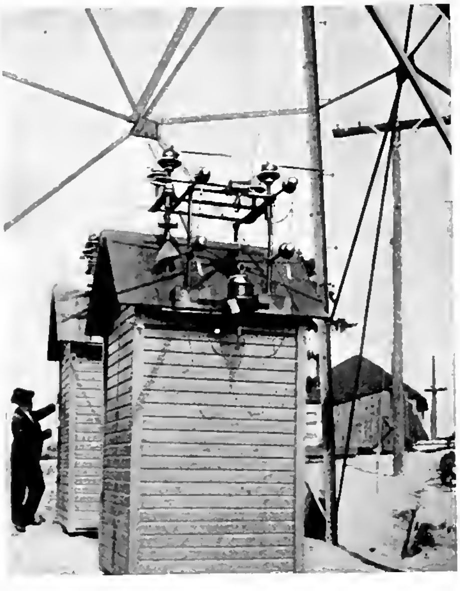

Fig. 3. Telephone Booth Connected, Showing Disconnecting Switch and Horn Gaps

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* A full description of Tallulah Falls development of the Georgia Railway & Power Company will be found in the June and July, 1914, issues of the REVIEW.

electrical stresses, but in order to secure perfect continuity, two were used. The telephone wires are spaced at three-foot centers, the wire itself being No. 4 copper clad, of 30 per cent conductivity, drawn from 400 lb. ingots in lengths of about half a mile to minimize the number of joints. All joints are made with special "figure eight" splicing sleeves about nine inches long.

The reason for using wire of this size was that it might be strung parallel to the power conductors and still be able to withstand a loading of about three-quarters of an inch of ice without exceeding the elastic limit.

Transpositions are made on all towers, which average about nine or ten to the mile. The wires are supported by suspension insulators on each side of the tower, two insulators being used at each point of support, and transpositions made with long and short loops between the insulators located on opposite sides of the tower. The transpositions are all made with the same clockwise twist, so as to make a running transposition.

Fig. 4. Front View of the Telephone and Its Protective Equipment as Installed

At intervals of four miles, telephone booths are located. They are simply frame buildings of the knockdown type, about four feet square, with a 22,000-volt switch of special construction on the roof. This switch is made with horn gaps to ground, set at approximately three-eights of an inch, and the two poles are operated simultaneously by means of a hand lever inside the booth. An insulated platform is provided in the booth on which the operator may stand while throwing the switch that cuts the station in multiple with the line. This switch is opened as soon as the operator finishes his conversation. In otherwords, the telephones in the booths are only connected to the line during the time they are in actual use, and the equipment is therefore not endangered by surges or lightning along the line, nor is the talking impaired by having a number of stations in multiple.

Fig. 5. Side View of the Apparatus shown in Fig. 4

At numerous places, convenient to working crews, the telephone line is sectionalized to facilitate the location of trouble, and at the intermediate substations 22,000-volt double-pole switches are used for this purpose.

Specially designed receiving and sending equipment is located at the power house and substations, which is standard for all stations. It comprises a horn gap to ground mounted on a bracket at the entrance to the building, and a 50-turn air choke coil; the line then passing through 20,000-volt entrance bushings to the interior, where a specially designed double-pole fused switch is inserted. From this switch the line is connected through a horn gap and vacuum arrester to a one to one

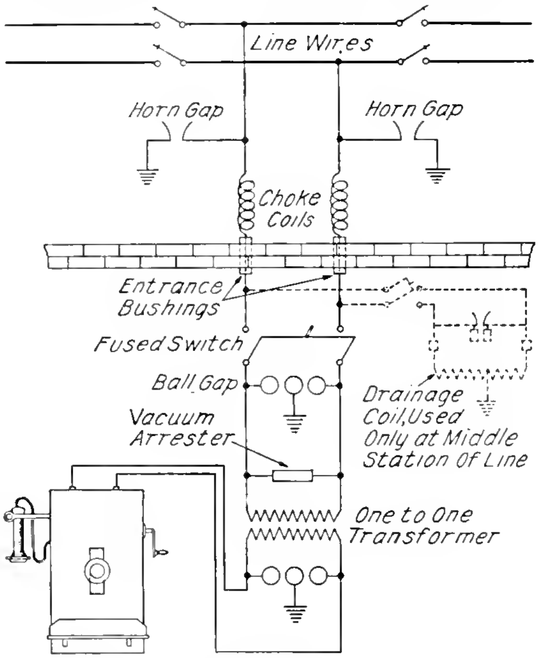

Fig. 6. Connection Diagram of a Telephone Located at a Station

Type Y-109-B insulating transformer, which in turn is connected to the telephone instrument.

The usual way to relieve telephone lines of high potential is to bridge a so-called bleeding or drainage coil across the line. Considerable experimenting was done with drainage coils on this line, and it was found that the ordinary type was not of sufficient carrying capacity. Sizes of 1 kw., 3.5 kw., and 5 kw. were soon destroyed and then a 15 kw. 2200-1100/-220-110 Type H lighting transformer was installed, which has given very good results. The telephone line is connected to the terminals of the 2200-volt winding and the middle point of this winding connected to ground. The secondaries are then left open circuited. This arrangement will offer a high inductive resistance to the talking currents, but a very low ohmic and negligible inductive resistance to the flow of current from the two wires to ground, owing to the fact that the simultaneous discharge from the wires through the coils to ground will neutralize the magnetic effects. This bleeding coil becomes an effective outlet for all low frequency currents induced from the transmission line.

Sudden changes in the transmission line, like switching, arcing grounds, lightning discharges, etc., have all the same effect upon a balanced telephone line, namely, to charge the two wires suddenly to a very high potential. Owing to the rapidity, or in other words, the high frequency with which these charges are induced on a telephone line, the small inductance of the bleeding coil, no matter how accurately balanced, is not sufficient to prevent these charges from flowing to ground, and therefore another apparatus is required which will act as an outlet for these particular disturbances. It has been found that the vacuum type arrester is best suited for this service. This arrester consists of two electrodes enclosed in a partially exhausted metal tube and connected across the line. This arrester is very sensitive to charges of high frequency and will begin to discharge freely as soon as the voltage on the lines reaches about 300 volts. The peculiar advantages of these arresters lie in the fact that the discharge occurs gradually instead of disruptively, and these discharges have no ill

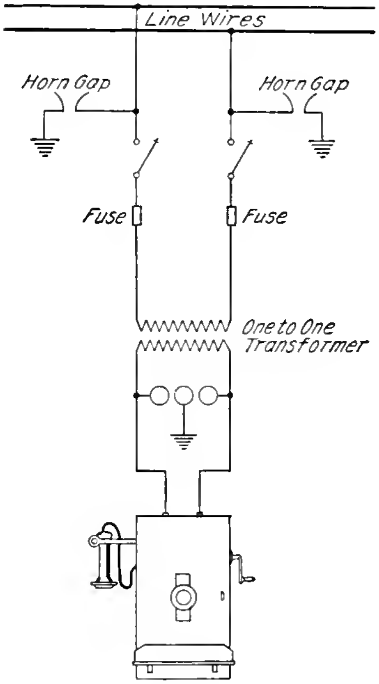

Fig. 7. Connection Diagram of a Telephone Located in a Booth

effect upon the electrodes, leaving the line perfectly clean and balanced. It is advisable to place fuses in circuit to protect this arrester from destruction should the discharges, for some reason or other, exceed the safe value for which it is built. The large gaps or horns, being set at three-eighths of an inch, form a sort of rough protection to all the equipment, should it be subjected to very high momentary potentials.

The station equipment of this system was tested by impressing 60,000 volts on it, which resulted only in the blowing of a fuse.

Calculations were made to determine the potential of the line against ground by use of the following formula, which is offered for those interested in figuring out new lines:

Let $A$, $B$ and $C$ represent the three conductors of a three-phase power circuit, and $S$ and $T$ the conductors of the telephone circuit.

Let $E_0$ be the voltage between each wire of the power circuit and ground.

Let

$r$ = radius of power conductor in inches.
$a$ = distance in inches between $A$ and ground. (Av.)
$b$ = distance in inches between $B$ and ground. (Av.)
$c$ = distance in inches between $C$ and ground. (Av.)
$s$ = distance in inches between $S$ and ground. (Av.)
$t$ = distance in inches between $T$ and ground. (Av.)

Then

$$e_a = E_o \frac{log \frac{a+s}{a-s}}{log \frac{2a-r}{r}}$$

$$e_v = E_o \frac{log \frac{b+s}{b-s}}{log \frac{2b-s}{r}}$$

$$e_c = E_o \frac{log \frac{c+s}{c-s}}{log \frac{2c-r}{r}}$$

and

$$c_s = \sqrt{e_a^2 + c_b^2 + e_c^2 - (e_a e_b + e_a e_c + e_b e_c)}$$

where $e$ is equal to potential of wire $S$ against ground. Potential of wire $T$ against ground may be found by a similar process, substituting $t$ for $s$ in the above formulae. (From Ferguson's "Elements of Electrical Transmission.")

By the use of this formula a theoretical induced potential of 5700 volts for the above line was obtained. Tests have subsequently been made to ascertain the actual value of this induced potential.

With one power line energized (the power conductors being on nine-foot centers in a vertical plane), an induced potential reading of 5600 volts from line to ground was obtained. As the high-voltage system has its neutral grounding at the power house, the voltage between each power line and ground was, of course, 63,500 volts. The current in the drainage coil neutral was 4.47 amperes at the time the above readings were obtained.

In order to ascertain the maximum potentials that could be induced on this line, the following tests were made and results obtained as indicated:

> With the top wire of one power circuit charged, an induced potential reading of 5100 volts was obtained between telephone line and ground.
>
> With the middle wire of one power circuit charged, the induced potential reading was found to be 7200 volts.
>
> With the bottom wire of one power circuit charged, the induced potential reading was found to be 10,000 volts.
>
> With the top wire of each power circuit charged, the induced potential reading was found to be 9300 volts.
>
> With the middle wire of each power circuit charged, the induced potential reading was found to be 13,100 volts.
>
> With the bottom wire of each power circuit charged, the induced potential reading was found to be 18,200 volts.

All of the above readings were taken with a 100 to 1 potential transformer and indicating voltmeter, the drainage coil being disconnected. Tests were then made with the drainage coils connected across the line at Gainesville and Atlanta and three wires of north circuit excited. Figures give current in ground connection of drainage coils.

| Line voltage | 110,000 | 50,000 |
|---|---|---|
| Current in ground connection of drainage coil at Atlanta, Ga. | 1.0 amp. | 0.6 amp. |
| Current in ground connection of drainage coil at Gainesville, Ga. | 2.6 amp. | 1.15 amp. |
| Current in ground connection of drainage coil at Gainesville with drainage coil at Atlanta disconnected from line | 3.55 amp. | 1.50 amp. |

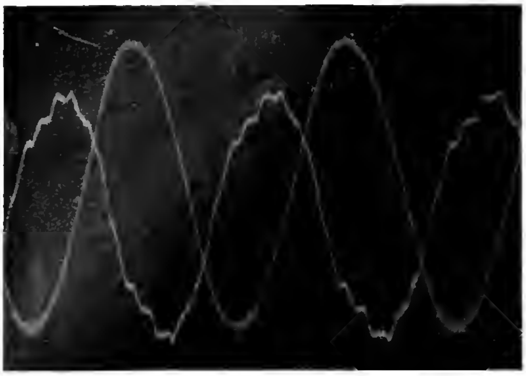

Fig. 8. Upper Curve: Line Potential Phase 1. Lower Curve: Current in Ground Connection of Drainage Coil

Fig. 11. Upper Curve: Line Potential Phase 2. Lower Curve: Current in Ground Connection of Drainage Coil

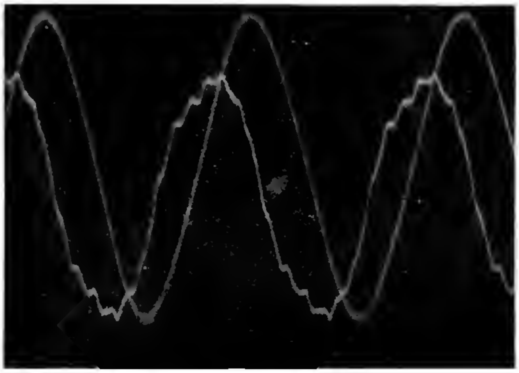

Fig. 9. Upper Curve: Line Potential Phase 3. Lower Curve: Current in Ground Connection of Drainage Coil

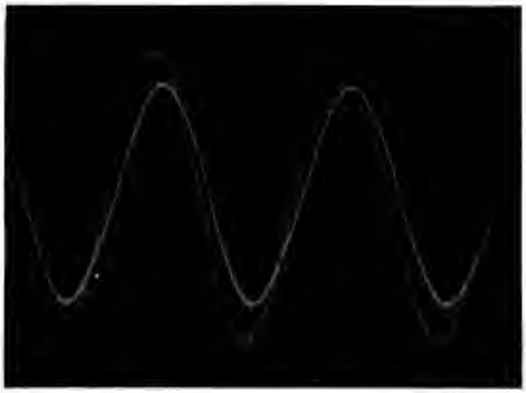

Fig. 12. Upper Curve: Line Potential Phase 3 to Ground 63,500 volts. Lower Curve: Induced Potential on Telephone Line 3500 volts

Fig. 10. Upper Curve: Current in One Wire of Telephone Line 0.8 amp. Middle Curve: Current in Other Wire of Telephone Line 0.8 amp. Lower Curve: Current in Ground Connection of Drainage Coil 1.6 amp. Record taken while Lightning Arresters were being charged

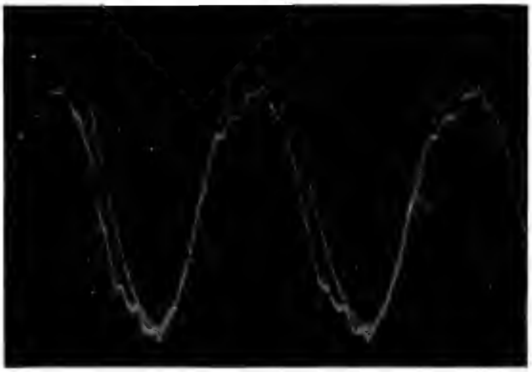

Fig. 13. Upper Curve: Voltage on Phase 3 of Power Line, while Arresters were being charged. Lower Curve: Current in Ground Connection of Drainage Coil on Telephone Line

OSCILLOGRAPH RECORDS OF INDUCED WAVES

**Fig. 14.** Upper Curve: Potential of Phase 3 Power Line to Ground. Lower Curve: Induced Potential on Telephone Circuit 5600 volts

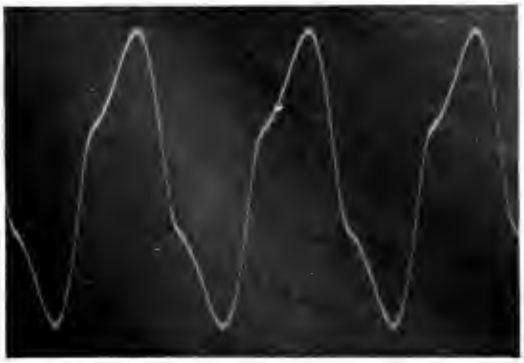

**Fig. 15.** North Circuit Charged. Voltage Curve: Voltage between Telephone Line and Ground 5100 volts

The voltage from telephone line to ground with three wires of the north circuit excited to the line voltage shown, and with drainage coils connected at both Atlanta and Gainesville, was as follows:

| | | |
|---|---|---|
| Line voltage | 110,000 volts | 50,000 volts |
| At Atlanta | 0.0 volts | 0.0 volts |
| At Gainesville | 31.0 volts | 18.0 volts |
| At Tallulah | 234.0 volts | 100.0 volts |

The following figures give the voltage from telephone line to ground with three wires of the north circuit excited to the line voltage shown, and drainage coil connected at Gainesville but disconnected at Atlanta:

| | | |
|---|---|---|
| Line voltage | 110,000 volts | 50,000 volts |
| At Atlanta | 158.0 volts | 70.0 volts |
| At Gainesville | 41.0 volts | 20.0 volts |
| At Tallulah | 240.0 volts | 105.0 volts |

Three drainage coils are now installed on the Atlanta-Tallulah line, one each at Gainesville, Tallulah and Atlanta, and the talking over the line is excellent.

If the following principles are adhered to in the construction of a telephone line, paralleling a high tension line, successful operation should follow:

1. The telephone line should be thoroughly insulated from ground, allowing a liberal factor of safety, as insulation is paramount.

**Fig. 16.*** Potential Wave on Telephone Line with One Circuit of Power Line Charged. Voltage between Telephone and Ground 4500 volts

2. The line should be constructed with as few joints as possible.
3. The ohmic resistance of the line should be as low as possible, so as not to decrease the intensity of the talking waves.
4. A perfect potential balance should be obtained between wires.
5. Transposition should be made at every tower, so as to maintain equal potential between the two telephone wires and ground.

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* From this oscillograph record, which was taken on a telephone line strung parallel to 110,000-volt power line for a distance of fifty miles but carried on a separate pole line, it can be seen that the number of harmonics is considerably greater than when telephone line is strung on towers carrying power lines.

# THE VENTILATION OF ALLEGHENY SUMMIT TUNNEL, VIRGINIAN RAILWAY

By F. F. Harrington

Engineer of Structures, The Virginian Railway Company

The ventilating equipment for the Allegheny Summit tunnel is located at the eastern portal, and was installed for the purpose of driving the smoke and gases emitted by engines on the upgrade or westbound trip ahead of the train, thus relieving the train crew from the disagreeable and unhealthful effects. Trains in the opposite direction coast on the downgrade, with the locomotive fires banked, and therefore no provision has been made for ventilating the tunnel during the passage of these trains. The plant will ultimately be automatic in operation, and the control apparatus has been built accordingly, although the track circuits have not yet been installed.—Editor.

Allegheny Summit Tunnel is located on the Virginian Railway, 277.6 miles from Norfolk, Va., between Yellow Sulphur and Merrimac.

Princeton, W. Va., 340 miles from Norfolk, Va., is the assembling yard for coal mined at points west and north along the main line and on branch lines. At this point long trains are made up and sent through to tidewater. The maximum eastbound grade from Princeton to Sewalls Point, with two exceptions, is 0.2 per cent compensated for curvature, and the maximum westbound grade between the same two points, with two exceptions, is 0.6 per cent compensated. The exceptions are at Onley Gap and Allegheny Summit, located respectively 3 and 62 miles east of Princeton. A single engine hauls 80 loaded cars of 100,000 pounds capacity from Princeton yard to tidewater without assistance, and the same engine hauls an equal number of empty cars against westbound grades, except at the summits mentioned above. At Allegheny Summit a single pusher engine is used between Whitethorne and Fagg, hauling 80 loaded coal cars eastbound on a maximum 0.6 per cent compensated grade from Whitethorne to the summit, a distance of ten miles, and 80 empty coal cars westbound on a maximum 1.5 per cent compensated grade from Fagg to the summit, a distance of seven miles.

A typical cross section of Allegheny Tunnel is shown in Fig. 3. The alignment is tangent except for about 200 feet at the east end, which is on a two-degree curve, and the grade is 1.22 per cent except for about 1000 feet at the west end, which is on a vertical curve. The total length between portals is 5176 feet and the cross sectional area is 375 square feet. It was lined with timber throughout when constructed in 1908, and afterwards concrete footings were constructed and two sections 50 ft. and 248 ft. long were lined with concrete. The remainder of the tunnel was lined with concrete last year, and as this lining contracted the sectional area and increased the heat considerably, the ventilation of the tunnel was authorized by the management to improve the operating conditions. A brief description of the ventilating plant follows:

The method employed for the ventilation of the tunnel is covered by patents held by Chas. S. Churchill and Chas. C. Wentworth, of Roanoke, Va., who furnished the general plans and specifications for the nozzle and the necessary data for obtaining bids from the fan manufacturers. The plant is illustrated by the accompanying photographs and plans, Figs. 1, 2, and 3, and is located at and connected to the east end of the tunnel. It consists briefly of two large fans operated by electric motors, one set being located on each side of the track. These fans force air through sheet iron ducts between the fans and the nozzle, and then through the nozzle, the reduced opening of which gives a high velocity to the air through the tunnel. The smoke and gases from the westbound engines on the ascending grade are therefore driven ahead, thus cleaning the tunnel and making it cool and comfortable for the trainmen. The eastbound engines, drifting on the descending grade, emit little smoke and gases, and it is not necessary to operate the fans; although this is occasionally done to clear the tunnel after their passage.

The ventilating plant was designed to deliver a volume of 590,000 cu. ft. of air per minute through the nozzle, which has an outlet area of 74 sq. ft.; this corresponding to a velocity of air in the tunnel of about 1600 ft. per minute. A thorough investigation was made of the relative economy of operation by steam and by electricity, and of the construction of a power plant and the purchase of power; it was finally decided to use electric current and purchase power from the Appalachian Power Company, which operates in that locality.

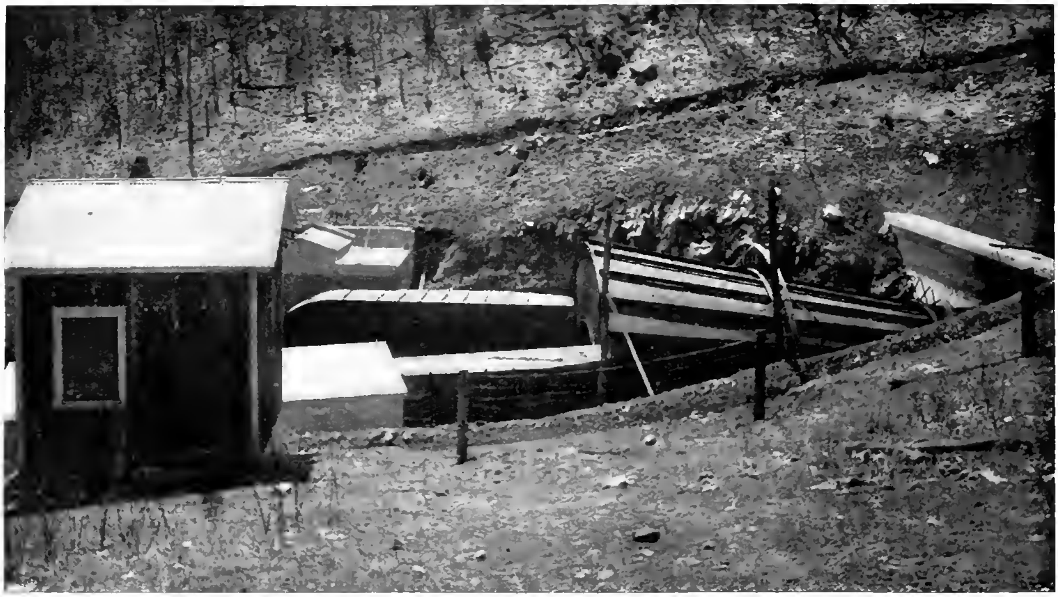
The Appalachian Power Company was organized in 1911 for the purpose of developing the water power of New River and distributing it electrically throughout southwest Virginia and southern West Virginia. It furnishes electric power for the operation of coal mines and other industrial plants in those districts. The high tension transmission lines operate at 88,000 volts and feed substations at various points, where the voltage is lowered for distribution through secondary lines to the various power consumers. A special high tension transmission line was built from Radford, Va., to the east portal of the Allegheny Summit Tunnel, where a substation was constructed which lowers the voltage to 2300 volts for the operation of the ventilating plant. The contract for electric power provides for a primary charge per kilowatt of maximum demand, and a secondary charge for current consumed based on a sliding scale. The maximum demand and the current consumed are determined by suitable meters, and a minimum annual charge is made regardless of the power consumption.

View Showing Position of Ventilating Equipment and Tunnel Portal

The fans are of the multivane type, with single inlet and top horizontal discharge, and were manufactured by the B. F. Sturtevant Company, Hyde Park, Mass. They are constructed of $\frac{7}{8}$ in. steel, $116\frac{1}{2}$ in. in diameter, $80\frac{1}{4}$ in. in width, and deliver through the nozzle 295,000 cu. ft. of air per minute when operating at 195 r.p.m. The induction motors are of the slip-ring type, rated 300 h.p., three-phase, 60-cycle, 2200-volt, 514-r.p.m., and drive the fans by means of Morse silent chains, spaced 5 ft. 6 in. on centers.

The switchboard is arranged with automatic starters for operating the motors from track circuits, but the track circuits have not been installed. The object of the automatic control is to make the plant more reliable and to reduce the cost of operation.

The switchboard consists of one main line control panel and two automatic motor starting panels mounted on pipe supports. The main line control panel consists of two three-pole single-throw oil switches with automatic overload and no-voltage release tripping coils. The incoming line feeds these switches and each controls the current to one of the motor starting panels. On this panel is also mounted an indicating voltmeter and ammeter, which shows the total input to both motors. The motor starting panels each comprise two current limit relays, one main line double-pole oil emersed contractor, and five double-pole contractors which cut out the resistance in the secondary of the motors in balanced steps and thus give equal fluctuations of current in each step. All of the control apparatus is located in the motor house on the north side of the track, and the two three-wire lead-sheathed cables to the motors on south side of track are installed underground in 6-in. conduit. The motors are protected from lightning by choke coils and multigap type lightning arresters.



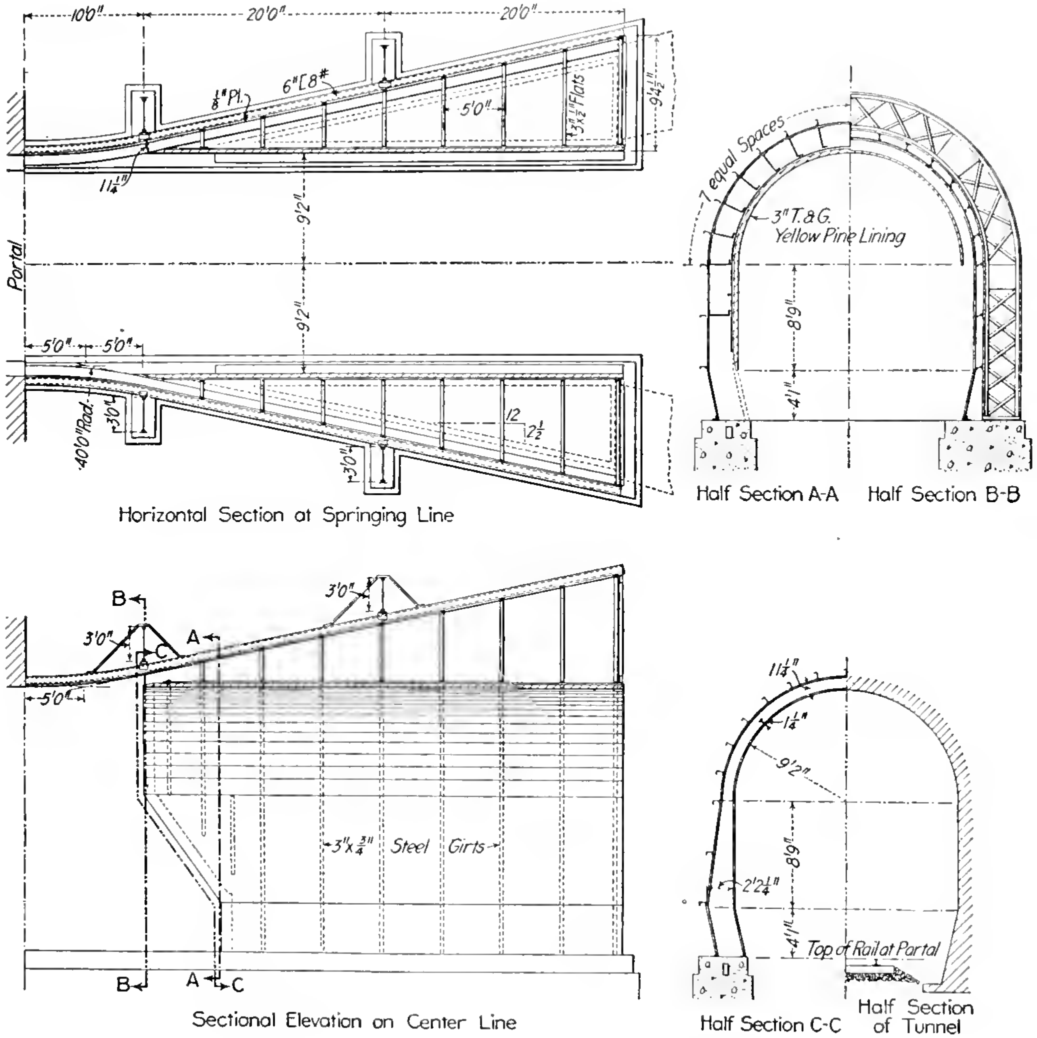
Side View of Ventilating Equipment

The blowing nozzle is constructed of steel, with the exception of the inner lining which is of heart long leaf yellow pine, tongued and grooved and bolted to steel girts. It is made to conform to the dimensions of the tunnel where it connects to the portal, and is 50 ft. long outside the tunnel. The inner lining is also of the same form and dimensions as the tunnel; but the outer lining, made of $\frac{1}{8}$-in. steel plates, is enlarged in the form of a conical surface with cross sections parallel to the inner lining from a point 5 feet from the portal to the face of the nozzle. The minimum distance between the inner and outer linings at a point 10 ft. from the portal is $11\frac{1}{4}$ in.; and the area of the contracted opening is 74 sq. ft. measured on the projection at right angles to the axis of tunnel. The front of the nozzle is provided with openings to which the air ducts from the fan housings are connected. The nozzle is thoroughly braced and is air tight. It was manufactured and erected by the Roanoke Bridge Company, Roanoke, Va.

The air ducts between the fan housing and the nozzle are made of $\frac{1}{8}$-in. sheet steel and braced with angle irons. Particular attention was given to the construction of these ducts and the fan housing in order to prevent excessive vibration from the operation of the fans.

The foundations for the ventilating plant are of concrete and the motor houses are of reinforced concrete and brick. In order to save expense the floors of the motor houses were placed about 8 ft. above the top of the rail, and concrete stairways and lookout platforms are provided for the convenience of the operator. The motor house on the north side of the track is larger than that on the south side, in order to provide room for the switchboard for both motors. The foundations and motor houses were constructed in accordance with plans furnished by the Railway Company.

The ventilating plant was put in operation April 1, 1914. Anemometer tests were made, which showed an average air velocity in excess of the contract requirements and an actual power consumption of about 600 h.p. Train tests indicated that a speed of from 14 to 15 miles per hour could be attained, with the smoke driven ahead of the engines, thus giving good ventilation in the tunnel under ordinary operating conditions. A bulletin has therefore been issued to limit the speed of westbound trains to 14 miles per hour, and at this rate the regular freight trains will not be required to slow down in going through the tunnel. The fans operate only for westbound trains, and the time of running is ordinarily less than ten minutes. A train dispatcher's telephone is installed in the motor house to enable the operator to keep in touch with the train movements in both directions and to communicate with the Appalachian Power Company at Bluefield, through the dispatcher's office at Princeton, in case of current failure or for any other reason. The total cost of the ventilating plant was about $30,000.



Sectional Views of Nozzle and its Relation to Tunnel

# THE ELECTRIC FIELD

By F. W. Peek, Jr.

Consulting Engineer, General Electric Company

All electrical design is dependent primarily upon the characteristics of the electric field surrounding a charged conductor. The magnetic component determines the layout of the iron circuits and the amount of the inductive effects; the electrostatic component determines the question of insulation and the capacity effects. The following article presents, with analyses, the results of experiments to secure a graphical record of the formation of these magnetic and electrostatic components of the normal electric field.—Editor.

In order that electrical energy may flow along a conductor, energy must be stored in the space surrounding the conductor. This energy must be stored in two forms; electromagnetic and electrostatic.

The electromagnetic energy is evinced by the action of the resulting stresses; for instance, the repulsion between two parallel wires carrying current, the attraction of a suspended piece of iron when brought near the wires, or, better yet, if the wires are brought up through a plane of insulating material, and this plane is dusted with iron filings, and gently tapped, the filings will form in eccentric circles about the conductors. These circles picture the direction of the magnetic lines of force of the magnetic field. This field only exists when current is flowing in the conductor. Fig. 1 is an experimental plot of such a field made by placing a sheet of blueprint paper on the plane and exposing to sunlight after the filings had arranged themselves. Such plots of magnetic fields are quite familiar to most of us. In designing the magnetic circuits in apparatus, it is generally of importance to lay them out in such a way that the magnetic flux is uniformly distributed. If the lines are overcrowded in one place it may mean local loss and heating.

If high voltage is placed between two conductors there will be an attraction between them. A suspended piece of dielectric, as a glass fiber, will tend to turn in definite directions at different points around the conductor. If the conductors are brought up through an insulating plane, as before, and the plane is dusted with a dielectric, such as mica filings, and tapped, the filings will form in arcs of circles beginning on one conductor and ending on the other conductor. Such an experimental plot is shown in Fig. 2.* The dielectric field is thus made as tangible as the magnetic field. Insulation breaks down at any point when the dielectric flux density at that point exceeds a given definite value. In high-voltage apparatus it is therefore

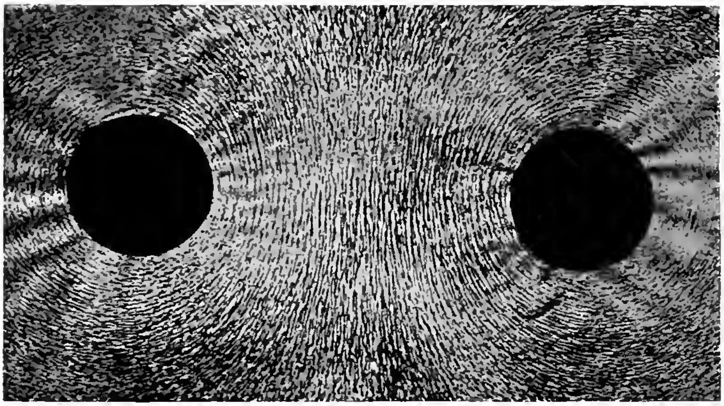


Fig. 1. A Photograph of an Iron-Filing Map of the Magnetic Lines of Force about Two Cylinders

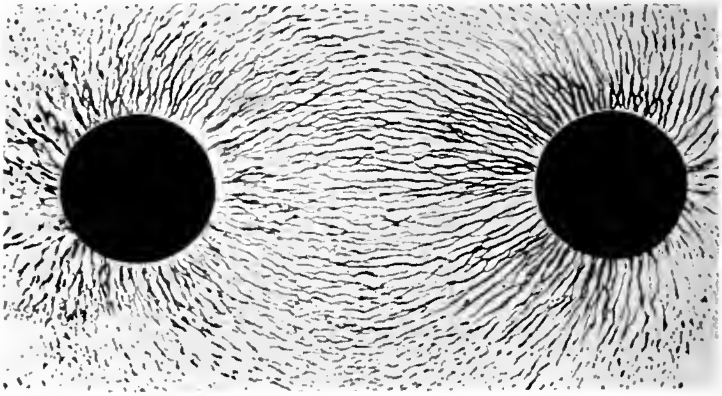


Fig. 2. A Photograph of a Mica-Filing Map of the Dielectric Lines of Force between Two Cylinders

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* Fig. 2 was made at 10,000 volts. The conductors were 3 cm. in diameter and were at a spacing of 9 cm. between centers.

important to so design the dielectric circuit that the flux density is uniform or in proportion to the breakdown density of the insulations at the different parts of the circuit. In Fig. 2, the density is greatest at the conductor surface and break-down will occur there first. The dielectric flux density at any point is proportional to the volts per cm. (or voltage gradient) at that point. The strength of insulation is generally expressed in terms of the voltage gradient.

Fig. 3 is the superposition of Figs. 1 and 2. It represents graphically the magnetic and dielectric fields in the space surrounding two conductors which are carrying energy. The power is a function of the product of these fields and the angle between them.

Fig. 4 is the mathematical or exact plot corresponding to Fig. 3. In comparing Figs. 3 and 4 only the general direction and relative density of the fields at different points can be considered. The actual number of lines in Fig. 3 have no definite meaning. The dielectric lines of force in Fig. 4 are drawn so that one twenty-fourth of the total flux is included between any two adjacent lines. Due to the dielectric field, points in space surrounding the conductors have definite potentials. If points of a given potential are connected together, a cylindrical surface is formed about the conductor; this surface is called an equipotential surface. Thus, in Fig. 4, the circles represent equipotential surfaces. As a matter of fact, the intersection of an equipotential surface by a plane at right angles to a conductor coincides with a magnetic line of force. The circles of Fig. 4, then, are the plot of the equipotential surfaces and also of the magnetic lines of force. The equipotential surfaces are drawn so that one-twentieth of the voltage is between any two surfaces. For example: If 10,000 volts is placed between the two conductors, one conductor is at +5000 volts, the other at −5000 volts. The circle (∞ radius) midway between is at 0. The potentials in space on the different equipotential surfaces, starting at the positive conductor, are +5000, +4500, +4000, +3500, +3000, +2500, +2000, +1500, +1000, +500, 0, −500, −1000, −1500, −2000, −2500, −3000, −3500, −4000, −4500 and −5000. A very thin insulated metal cylinder may be placed around an equipotential surface without disturbing the field. If this conducting sheet is connected to a source of potential equal to the potential of the surface which it surrounds, the field is still undisturbed. The original conductor may now be removed without disturbing the outer field.

The dielectric lines of force and the equipotential surfaces are at right angles at the points of intersection. The dielectric lines always leave the conductor surfaces at right angles. The equipotential circles have their centers on the line passing through the conductor centers; the dielectric force circles have their centers on the neutral line.

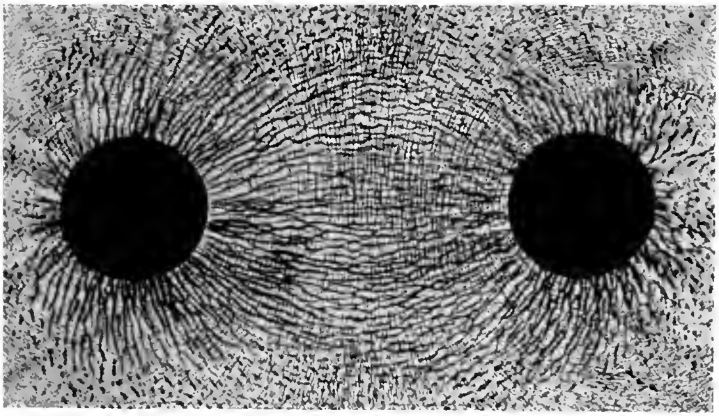

Fig. 3. A Photographic Superposition of Figs. 1 and 2 Representing the Magnetic and Dielectric Fields in the Space Surrounding two Conductors which are Carrying Energy

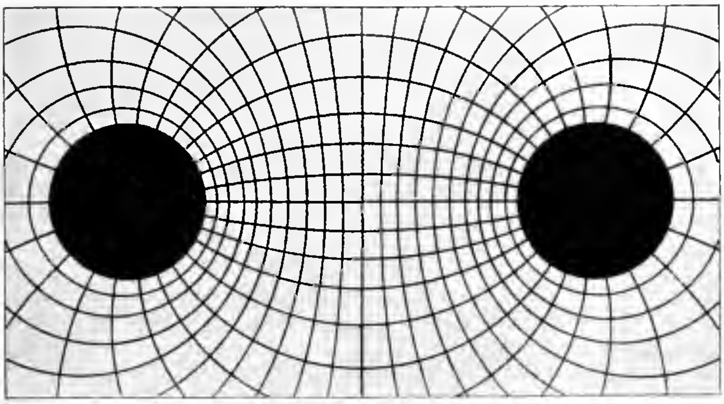

Fig. 4. A Mathematical Plot of Fields shown in Fig. 3

The dielectric and magnetic fields may be treated in a very similar way. For instance, to establish a magnetic field a magnetomotive force is necessary; to establish a dielectric field an electromotive force is necessary. If in a magnetic circuit the same flux passes through varying cross sections, the magnetomotive force will not divide up equally between equal lengths in the circuit. Where the lines are crowded together the magnetomotive force per unit length of the magnetic circuit will be greater than where the lines are not crowded together. The magnetomotive force per unit length of the magnetic circuit is called the magnetizing force. Likewise, for the dielectric circuit where the dielectric flux density is high a greater part of the electromotive force per unit length of circuit is required than at parts where the flux density is low. Electromotive force or voltage per unit length of dielectric circuit is called electrifying force, or *voltage gradient*. If iron or material of high permeability is placed in a magnetic circuit the flux is increased for a given magnetomotive force. If there is an air gap in the circuit the magnetizing force is much greater in the air than in the iron. If a material of high specific capacity or permittivity, as glass, is placed in the dielectric circuit, the dielectric flux is increased. If there is a gap of low permittivity, as air, in the circuit, the voltage gradient is much greater in the air than in the glass.

The dielectric circuit must always be considered in the proper design of high-voltage apparatus. The fields for various other conductors may be plotted with mica filings in the same way.

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# SOME NOTES ON BUS AND SWITCH COMPARTMENTS FOR POWER STATIONS

By Emil Bern

Switchboard Engineering Department, General Electric Company

The bus and switch compartments of a station are vital to the continuity of service and safety of the system; and therefore their design deserves the most careful study. This article incorporates a description of certain important advances that have recently been made in apparatus. It states the fundamental rules for determining the dimensions and the construction of fire-proof bus and switch compartments; and it also classifies the different typical designs and discusses their relative merits.—Editor.

Large capacity power stations have outgrown the switchboard having switches, connections and buses supported on the board proper as the electrically operated switches of large capacity are usually installed in the position which is most convenient with respect to high potential buses and heavy connections. The buses and all parts of the switching system must be most carefully protected to avoid short circuits; and at the same time they should be designed to withstand the abnormal conditions caused by short circuits or overloads. For heavy currents at medium high voltages, the objects just named seem to be best accomplished by installing the buses, connections and switches in masonry compartments.

The purpose of this article is to discuss briefly certain typical designs of fire-proof compartments for switching apparatus, based on the familiar type of oil switch illustrated in Fig. 1 and Fig. 2. The construction of the two types of switches is the same, except for the arrangement of the oil vessels and their contacts. In both constructions the walls of the cells are built of brick or concrete and the top and bottom of soapstone slabs. While not shown in the illustrations, there are flame-proof doors in front of the cells. These are hung from steel work at the top so as to swing open easily in case of an explosion in the cell.

### Bus Compartments

Concrete has gained in favor over brick for masonry work and therefore the majority of today's bus and switch compartments are built of concrete. In some cases complete forms are made, usually of wood, and the whole compartment poured. This procedure gives the most substantial construction. It is more often the case, however, that concrete slabs are used set in cement. When this scheme of construction is used, the compartment is so designed that it will require but a small number of different size slabs. Fairly accurate work can be obtained by this method, and the cost of forms is reduced materially.

Where the design of the compartment is not too complicated, and where the desired dimensions agree with the size of bricks available, brick construction is usually the most convenient for smaller compartments. This is especially true in cities where concrete work cannot be handled conveniently on account of lack of space. The shelves or partitions are then usually made of soapstone or slate, but sometimes of concrete. Oftentimes bricks vary considerably in size, which makes accurate work very expensive since close adherence to certain dimensions often necessitates cutting the bricks or making abnormal bonds. For this reason it is usually more satisfactory to cut and drill the buses and connections when installing them than to make them up beforehand from the compartment drawings.

The design of fire-proof bus compartments is usually such as to enclose or to separate the different phases of the buses and connections by masonry. The masonry portions of the compartments must be considered as being at ground potential; therefore, the general dimensions of the compartments are determined primarily by the minimum allowable distance between live parts and ground for the voltages used. This rule has already determined the most important dimensions of bus supports and the switching apparatus.

Fig. 3 shows sections of typical bus compartments with their fundamental dimensions for different voltages based on average capacities and conditions. From the values given in the table any bus compartment can easily be designed. It is, of course, necessary to first determine the dimensions of switches, busbar supports, buses, connections and the clamps for attaching the connections to the buses; and also to take into account mechanical clearance and convenience in installing the material. The compartment shelves are usually made about two inches thick; but sometimes are thicker when made of concrete for large compartments. The thickness of the barriers between phases is determined by the mechanical strength of the structure; this also applies to the thickness of compartment walls. In brick compartments there is very little choice, for the dimensions of the brick usually predetermine them. In concrete structures the thickness of the walls and barriers is generally from three to four inches.

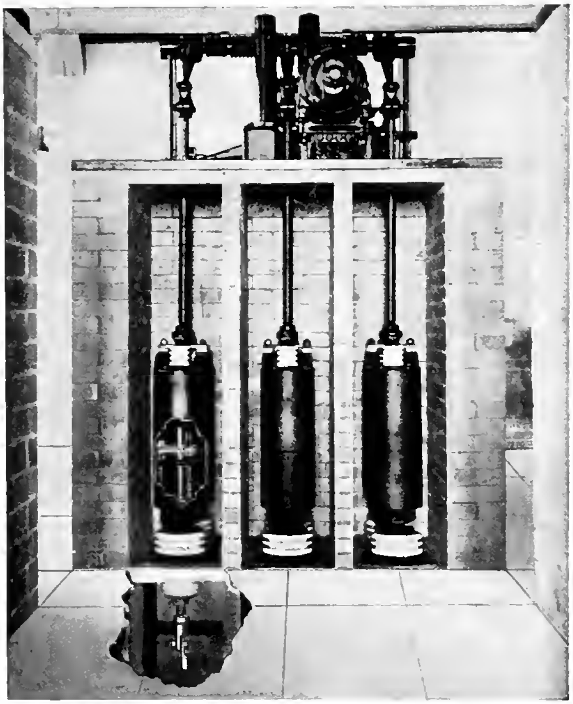

Fig. 1. Bottom-Connected Oil Switch. Parallel Arranged Contacts

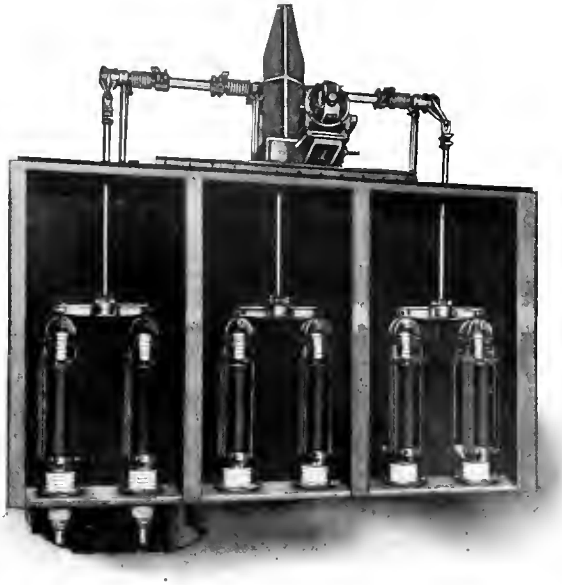

Fig. 2. Bottom-Connected Oil Switch. Tandem Arranged Contacts

### Disconnecting Switches

Several different types of disconnecting switches are used. For voltages up to 3300 they are generally mounted on marble bases without insulators. When provided with insulators they are usually mounted on slate or steel bases. The steel base has the advantage of occupying small space, it preserves the adjustment of the switch, and is less liable to injury during shipment and construction work. Fig. 3 shows several methods of mounting disconnecting switches in compartments.

| Volts | A Ground Dist. | B | C | Volts | A Ground Dist. | B | C |
|---|---|---|---|---|---|---|---|
| 2,500 | 2″ | 9″ | 12″ | 45,000 | 14″ | 34″ | 34″ |
| 6,600 | 3″ | 10½″ | 14″ | 70,000 | 21″ | 45″ | 45″ |
| 15,000 | 3½″ | 12″ | 15″ | 90,000 | 27″ | 56″ | 56″ |
| 22,000 | 6″ | 20″ | 20″ | 110,000 | 33″ | 72″ | 72″ |
| 35,000 | 10″ | 25″ | 25″ | | | | |

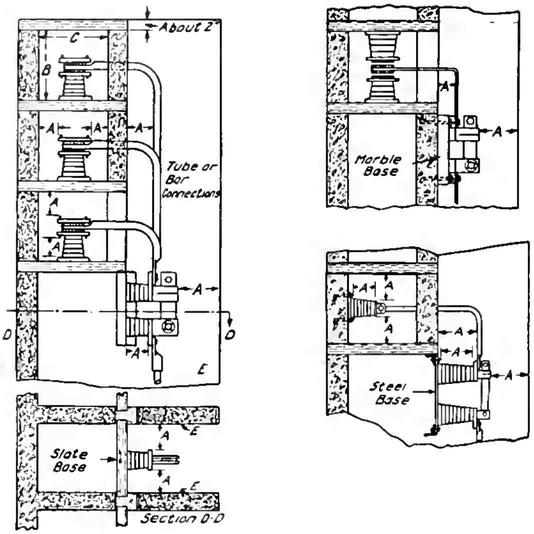

Fig. 3. Dimensioned Sectional Views of Typical Bus Compartments for Various Voltages

Disconnecting switches are occasionally used for isolating horizontal sections of the bus, and in this case are located in the compartments in a straight line with the bus, with the insulators secured either to the shelf or to the back wall of the compartment. If the bus is heavy enough and is securely anchored, it can serve as the hinge and clip for the switch, thus simplifying the construction somewhat. Whatever type of switch is used, care must be taken to see that proper clearance to ground is obtained with the blade in any position.

To withstand, mechanically, stresses incidental to momentary short circuit and heavy overloads, it is necessary that the buses and connections be securely anchored, while at the same time provision must be made for the expansion and the contraction of long buses due to temperature changes. The bus supports may be secured either to the shelves or to the back wall of the compartment, but must be located near openings so as to be accessible for cleaning and inspection. For convenience in joining connections to the bus, the busbars are usually arranged horizontally, i.e. laid on side.

The available space for the switching equipment determines to a great extent the design of the compartments. Sometimes the buses are located on the floor below the oil switches, which construction is very desirable when using bottom-connected switches, provided the disconnecting switches between the oil switches and the bus are located so that a person operating them can see whether the oil switch is open or closed. To meet this condition, and thus eliminate the danger of operating the wrong disconnecting switch, they may be installed in a sub-compartment in the oil-switch cell just above the floor. A door for this sub-compartment, of the same width as the oil switch, helps to determine without question which disconnecting switches belongs to a certain oil switch.

### Buses in the Floor

Fig. 4 shows a simple arrangement of oil switches with sub-compartments, disconnecting switches and the buses installed in the floor. The buses are supported and are accessible from below. Barriers of asbestos lumber or similar material may be provided between the connections of different phases, if considered necessary. If disconnecting switches are required on one side of the oil switch only, the parallel arranged oil switch may be used and installed against the wall, as shown in section A, Fig. 4. With disconnecting switches on both sides of the oil switch, it is possible to arrange all of them in the sub-compartments by providing space back of the oil switch for operating them, or by using the tandem arranged switch as shown

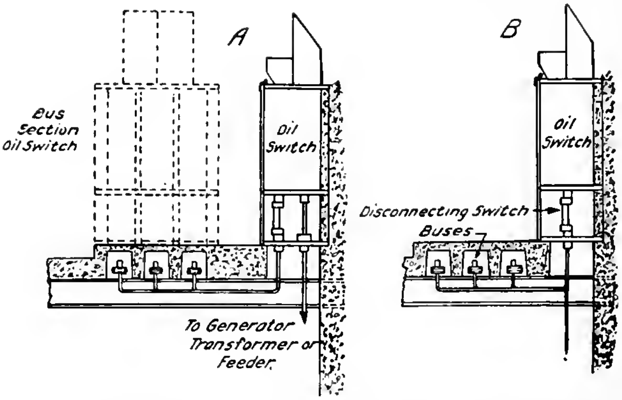

Fig. 4. Two Arrangements for Oil Switches with Disconnecting Switch Sub-Compartments and with Buses in the Floor

in section *B*, Fig. 4. With the first arrangement, a bus-section oil switch may be installed directly over the buses; while with the tandem arranged switches, the construction can be materially improved and made more compact by locating the bus-section oil switch in line with the other switches.

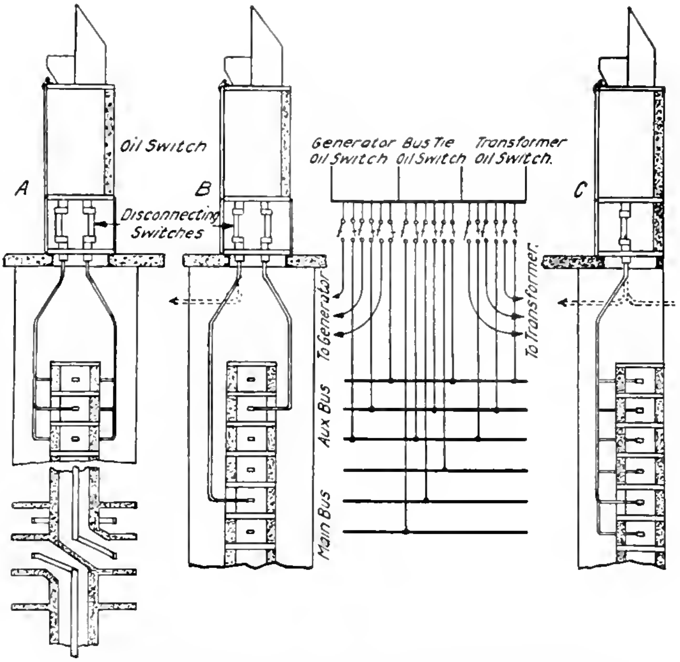

Fig. 5. Standard Arrangements for Oil Switches with Disconnecting Switch Sub-Compartments and with Bus Compartments beneath the floor

**Buses in Compartments Below Oil Switch Floor**

Fig. 5 shows different features of a construction with bus compartments on the floor below the oil switches, and with disconnecting switches arranged in sub-compartments. *A* represents a bus-section switch; and *B*, a bus-tie, generator, or transformer switch connected according to the diagram. *C* shows the application of the tandem arranged oil switch to the same conditions as *A* and *B*. If the room containing the bus compartments is used for other purposes also, it is advisable to provide doors between the barriers to guard against accidental contact with the connections.

**Bus and Switch Compartments on Same Floor**

It is often necessary to install the bus and switch compartments on the same floor, and in some cases this floor is immediately above the transformer compartments, so that the connections between the different elements cannot be made under the floor. A very compact construction of this kind is shown in Fig. 6, which provides for bus-tie, transformer, and generator switches connected the same as in Fig. 5. This construction requires, however, a set of disconnecting switches arranged horizontally in the buses. Passages through the compartments can easily

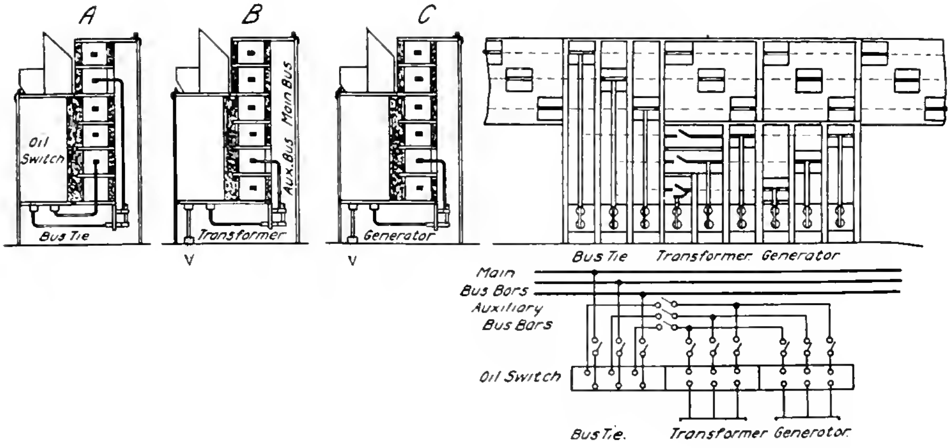

Fig. 6. Arrangements wherein the Switch and Bus Equipments are located on the floor. Electrically these connections are identical to those of Fig. 5

be provided under the main bus, as indicated in the Figure.

Another construction providing the same electrical connections is shown in Fig. 7. Here false floors must be provided over the connections, unless these can be carried through and under the floor. This false floor over the connections between the oil switches and the compartments consists of removable slate slabs resting on vertical brick or concrete barriers between the connections. With this construction it is necessary to provide doors for the compartments as well as for the oil switches. Section *A* shows the construction of a bus-tie connection, section *B* a generator or transformer connection, and the plan view *C* a combination of the above for connecting a generator to its transformer or to the main bus in the same manner as indicated in the diagram of Fig. 6. Section *D* shows how a feeder circuit may be connected to the main bus, and how the instrument transformers may be installed in line with the auxiliary bus compartment if desired. Disconnecting switches may also be accommodated in this compartment for isolating the instrument transformers from the line when energized from the other end.

A bus-section oil switch with disconnecting switches may be installed as illustrated at *E*, but it must, however, be placed at right angles to the main compartment.

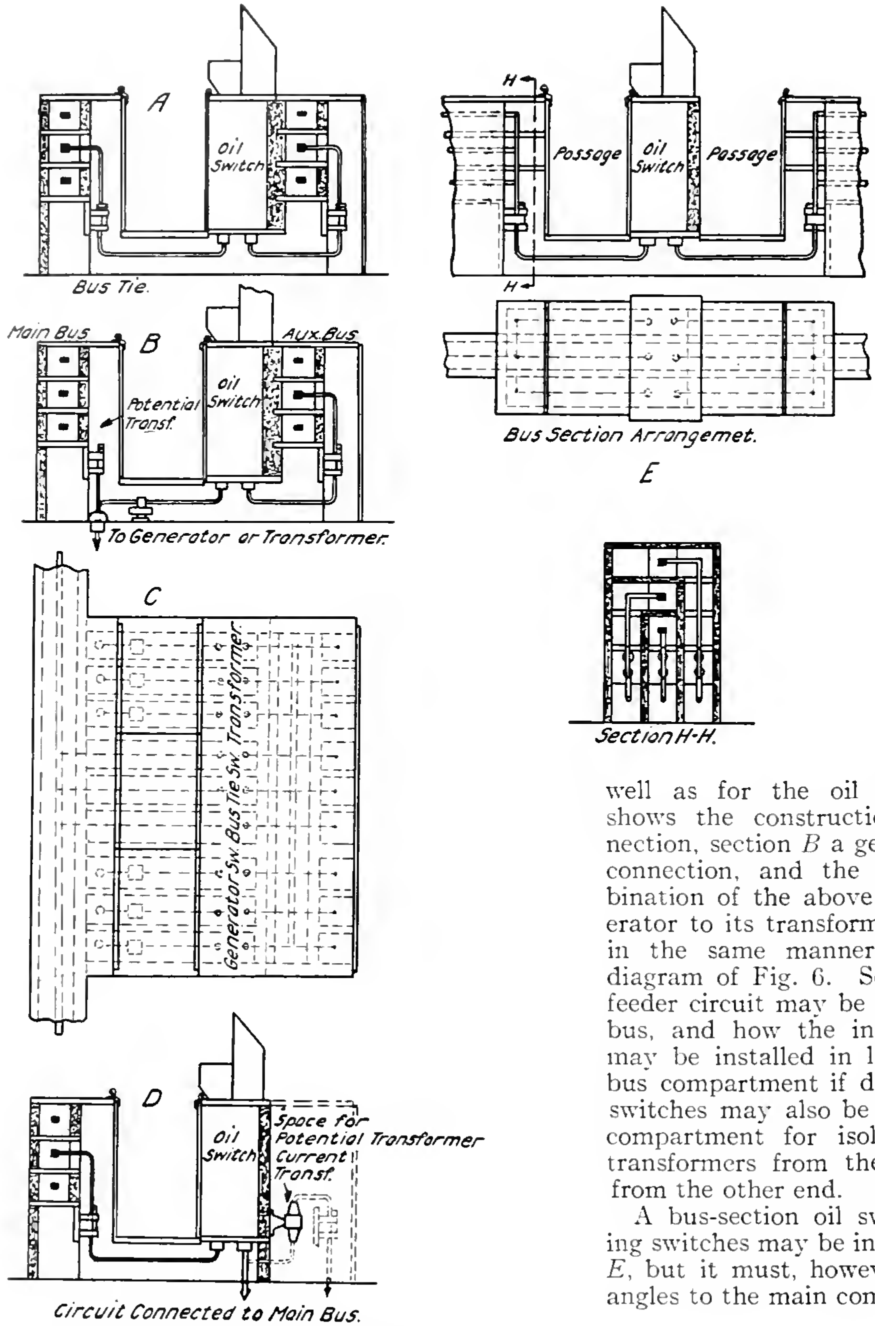

Fig. 7. Arrangements wherein the Switch and Bus Equipments are located on the Floor. A different but equivalent scheme to that shown in Fig. 6

# PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

Part III (Nos. 13 to 18 inc.)

By E. C. Parham

Construction Department, General Electric Company

## (13) TRANSFORMER LEADS REVERSED

Fig. 1 is a diagrammatic sketch of the connections for two direct-current generators connected to supply lights and power by three-wire distribution. Between the middle or neutral wire and either outside, the voltage of one dynamo is available (110 volts); between the two outside wires, the voltage available is that of *A* and *B* in series (220 volts). Lamps are connected to adjacent wires and 220-volt motors to the outside wires.

Wherever three wires are run, the neutral should be the middle one, because, as indicated in Fig. 1 (b), should the neutral and one of the outside wires become accidently interchanged some of the lamps are likely to be blown up and 220-volt motors connected to the outside wires will not speed to their rated r.p.m. In Fig. 1 (c) the distributing wires are arranged correctly but the two generators are indicated as having been connected so that their voltages are in opposition instead of in addition. In this case it is still possible to get 110 volts between the middle wire and each outside wire, but the middle wire is no longer a neutral wire; it has become the return wire for the outside wires and has to carry the sum of their currents instead of the difference. Furthermore, the voltage across the outside wires is zero.

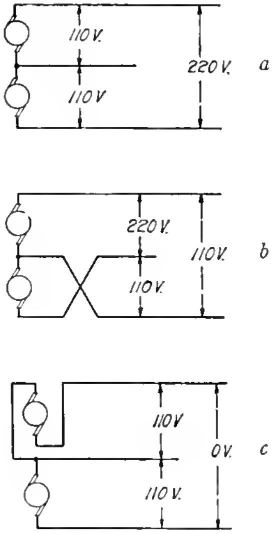

Fig. 1

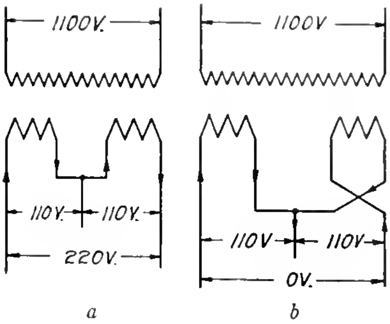

Fig. 2

These sketches are suggested to explain to an operator why he might not be able to start a motor from the outside lines of a recently connected three-wire service when supplied from a single-phase transformer, even though the lamps are operating normally across both 110-volt legs.

Fig. 2 (a) indicates the normal connections of the single primary and double secondary of a single-phase transformer when connected for three-wire secondary supply. It will be noted that the arbitrarily selected current directions are the same, indicating that the e.m.f. of each secondary coil boosts the e.m.f. of the other secondary coil so that the e.m.f. of the outer terminals is the sum of the individual e.m.f's, just as in the case of the d-c. generators of Fig. 1 (a). Fig. 2 (b) indicates the wrong connections to which one operator's trouble was due. One of the secondary leads had been interchanged in bringing it through the bushing. This connection gave the same conditions of voltage distribution as in Fig. 1 (c).

It is important that careful attention should be given when making connections, as in this case, for example, the error might be discovered only after an attempt was made to start a motor between the outside wires or after undue heating of the middle (on account of having to carry the sum of the outside currents instead of the difference) was noted.

### (14) IMPORTANCE OF EQUALIZER

Fig. 3 shows the connections of two generators of which $A_1$ and $A_2$ are armatures, $F_1$ and $F_2$ are series fields, $K_1$ and $K_2$ are individual line switches, and $E_1$ and $E_2$ are equalizer switches.

If $E_1$ and $E_2$ are closed while either machine is carrying the load, part of the current of the loaded machine will pass through the equalizer to and through the series field of the idle machine, the circuit effect of the equalizer being to place the series fields of the two machines in parallel. The closing of the equalizer switches adds to the no-load excitation of the incoming machine and thereby enables this machine to take its share of the load, assuming the correct no-load adjustments to have been made. Within certain limits, the equalizer will prevent one machine from driving the other as a motor in case they should be thrown together when the voltage of the one is considerably below that of the other, since the current through the equalizer and series field of the low-voltage machine increases its excitation. As stated, there is a limit to this automatic regulation because the equalizer possesses resistance and because the excitation due to the equalizing current is only a part of the total excitation of the machine. While the automatic division of the load upon the two machines will be impaired seriously by an unnecessary high-resistance equalizing connection, it is improbable that such an equalizer would cause sudden trouble in the operation of the generators. If the resistance of the interconnection, however, is infinite (caused by the equalizing switches being open), it is a practical certainty that arc-overs or other like troubles will soon occur. Operators, therefore, should be sure that all equalizing switches are closed between the machines that they are about to parallel.

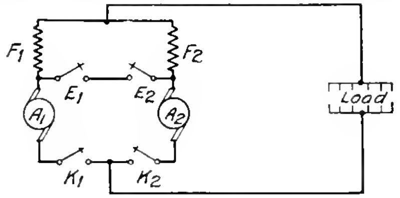

Fig. 3

### (15) SPARKING CAUSED BY LOAD CHANGES

The series field shunts for generators of low and moderate current capacity are made of German silver ribbon; those for heavy current machines are made of cast-iron grids. In either case, the shunts are constructed non-inductively. The scheme of connections employed is indicated in Fig. 4.

A shunt is arranged to have such a resistance that the portion of the armature current which passes through the series field (the portion not "by-passed" or shunted) will be correct to give the desired degree of compounding. The size of the shunt which will be required is determined experimentally since this method of procedure is simple and is satisfactory in most cases.

Among a group of motors which receives its electric energy from one generating source there will occasionally be one or more large motors that are frequently started and stopped, thereby causing sudden large changes in the output of the generator. Under such conditions a generator will require a different type of series field shunt, viz., an inductive shunt. If an non-inductive shunt is used, the self-inductance of the series field winding will force more than a proportionate amount of current through the shunt during a period of sudden increase in load current, and, conversely, it will cause the series field winding to retain more than a proportionate share of the load current during a period of sudden decrease in load current. This unequal rate of change of current in the shunt and series field winding will cause a distortion of the field magnetism. Such a displacement of the flux will probably result in more or less serious sparking at the brushes. A shunt which is non-inductive will not maintain a *constant* proportional division of the current between it and the series field winding (i.e., will not maintain the series field current proportional to the load) during the period of a rapid change of load. Therefore, the condition of widely varying load may prevent a non-inductive shunt from performing its function properly.

When the conditions of the load are sufficiently severe as to make it necessary to overcome this variable division of the load current between the shunt and the series field winding, because of the bad commutation produced thereby, satisfactory operation can be secured by including an inductive element in the shunt. This arrangement is indicated in Fig. 5, in which *F* is the series field, *NS* the non-inductive part of the shunt, and *IS* the inductive portion. This latter consists of copper wire wound on an iron core having an air gap that can be varied to give the desired amount of self-induction. The total ohmic resistance of the inductive and non-inductive parts in series must be such as to give the required degree of compounding for steady currents; the resistance of the inductive part must be adjusted by trial to give sparkless commutation when the load is suddenly varied. Since the inductive part necessarily has some ohmic resistance, a change of taps in this part in order to change its self induction will also change its ohmic resistance and hence the total ohmic resistance of the shunt. Frequently, the whole inductive change can be made by means of the air-gap, which, of course, will not change the ohmic resistance. Final adjustment will require a trial of several combinations of inductive and non-inductive shunt.

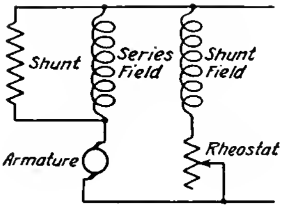

Fig. 4

As a practical illustration of the operation of shunts, reference may be made to an instance where momentary sparking of generators and their tendency to flash over was caused by the starting and the stopping of heavy direct-current motors in a cement mill. An inductive shunt was later obtained and connected in series with the non-inductive shunt, and then the resistance of the latter was decreased until the combined resistance of the two elements, inductive and non-inductive, was the same as the resistance of the original non-inductive shunt alone. In this particular case it was unnecessary to make any adjustments of self-induction in the inductive shunt because by coincidence the amount happened to be correct.

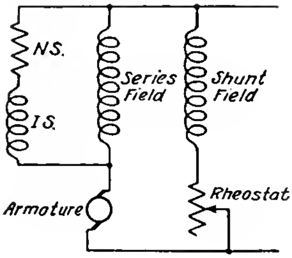

Fig. 5

### (16) REVERSED FIELD COILS

If one or more field coils are reversed on a generator of any type, one result is to lower the voltage obtainable from the armature. In the case of a direct current generator, sparking at the commutator will also suggest the possibility of reversed field coils; in the case of an alternator, however, as there is no commutator, the sparking symptom will be absent. In any case, the magnitude of the effect will depend somewhat on the relation between the number of reversed poles and the total number of poles in the machine.

A large alternator, which was excited from a multi-polar generator, was packed so full of mud and wood as the result of being submerged during a flood that it had to be dismantled for cleaning. The exciter also had been through the same experience. After reassembling, it was impossible to generate normal voltage. Everyone attributed the trouble to dampness and the two machines were baked "almost to death" in a determined effort to dry them. Finally, it was noticed that both machines were about dry and that further drying was not improving the conditions materially. Further, it was observed that there was more sparking at the exciter commutator than formerly. An investigation disclosed a field spool of reversed polarity. This error of assembly was corrected and it was supposed that all trouble had been eliminated. On starting, however, it was found to be impossible to get the alternator voltage much higher than it was before. (The effect upon the exciter voltage could not be observed because there was no direct current voltmeter available.) Then it was suggested that some of the poles of the alternator might be reversed, as in the case of the exciter. This proved to be the case: Out of a total of 32 poles, five poles of reversed polarity were found distributed around the revolving field. The correcting of this fault enabled normal voltage condition to be restored.

### (17) RIDGING OF COMMUTATOR

By ridges on a commutator are meant those alternate high surfaces which remain when intervening grooves are cut in the commutator by the brushes. This may be due to sparking (visible or invisible), to lack of end-play in the armature, to tracking of the brushes (that is, placing the brushes along circumferential lines on the commutator so that certain zones of the surface are not subjected to brush wear), or to excessive brush tension. Sparking which may be so slight that it cannot be seen in a well-lighted room becomes evident in a dark room. This kind of sparking may be due to using the wrong quality of brush. Even with staggered brushes end-play is essential to good permanent commutator operation. The movement can generally be obtained by insuring that the machine is actually level, but if the amount of play is insufficient it should be secured in some way even if it is necessary to turn off the inside end of one of the armature bearings. The brush tension should be no greater than is required, the proper amount being obtained by trial and observation. When the brushes are not properly staggered, even if the commutation is of the best, the unwiped part of the commutator in course of time will stand above the wiped part, unless this tendency is overcome by well-applied sanding of the ridges. If both lubricating and standard brushes are used on a machine, they should be distributed as far as possible so that each kind is correctly staggered in regard to that and the other kind.

Notwithstanding the fact that all ordinary precaution had been taken, the skilled operators of a certain station seemingly found that a ridge on one commutator could not be prevented. It was finally noticed that all the positive brushes were staggered with regard to each other, as were also the negatives; the positive tracked positive, and the negative tracked negative, and the positives were cutting grooves. On re-arranging the brushes correctly on the holders all grooving and ridging stopped.

### LAMPS FLICKERING

The full lines of the diagram in Fig. 6, represent the connections of a two-pole, direct-current armature mounted upon the same shaft with a circular, iron-cored reactance, the two members constituting the main feature of a so-called three-wire generator. The end connections of the reactance are tapped to diametrically opposite points of the armature winding and it is very essential that these points be diametrically opposite. From the center of the reactance is run a wire called the neutral; this neutral, in conjunction with the two outside wires from the generator, constitutes the three-wire distributing line. The reactance is simply a device by means of which the internal neutral, or half-voltage point of the armature, may be reached. Half of the series field winding of the generator is placed in one main, or outside wire, and the remaining half in the other to help balance the voltage when the load becomes unbalanced.

With balanced load, the current in each main is the same and the current in the neutral is zero. The turning off of lamps on one side and not on the other tends to raise the voltage of the more lightly loaded side; this tendency is partly neutralized by the weakened series field on that side acting to lower the voltage. The reactance carries alternating exciting current all the time, and it carries direct current only when the load is unbalanced. In this latter case there is a neutral current and it is equal to the difference between the current in the two mains.

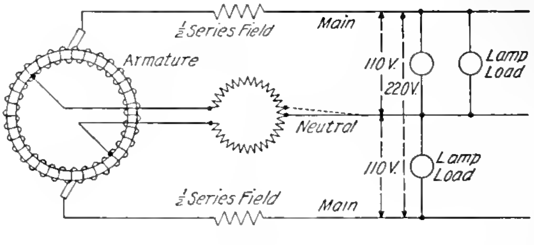

Fig. 6

A case of severe flickering of the lamps furnished with energy by a certain three-wire generator was traced to the tap of the neutral wire on the reactance coil being off center, as shown by the dotted line in Fig. 6.

# RECENT VIEWS ON MATTER AND ENERGY

## Part IV

By Dr. Saul Dushman

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In this issue, the last of the series, the author indicates the manner in which the atomic theory of matter has been affected by the atomistic theories of electricity and energy. The result of all the recent investigations and speculations has been to strengthen more firmly the position held by the older theory of the atomic and molecular structure of matter. The greatest interest now centers in the question as to the structure of the atom itself, and in this connection the views of Rutherford and Bohr seem to be in best accord with actual observations.

## ATOMIC THEORY OF MATTER

It is evident from what has been stated so far that the tendency of modern physics is to adopt atomistic views in the explanation of all phenomena. We have an atomic theory of electricity, an atomic theory of energy and we have been familiar for over a century with an atomic theory of matter.

The theory in which Dalton found such a simple explanation of the fundamental laws of chemical combination has, as is well known, been regarded as unnecessary by one school of chemists, while a number of others have adopted the faith of their colleagues, the physicists, and prefer to speak of atoms and molecules rather than of international and reacting weights.

It is not our intention in this paper to enter into any polemical arguments as to which attitude is the more correct. We are here concerned mainly with a recital of experimental facts and a presentation of the theories which have been put forward in explanation.

### Applications of Kinetic Theory of Gases

The first great impetus to the adoption of the atomic and molecular theories of the structure of matter was undoubtedly given by the speculations of Maxwell, Boltzmann and Clausius. The kinetic theory of gases indicated simple relations between the viscosity, heat conductivity and diffusion coefficients of gases; the validity of these relations has been confirmed experimentally.

Similar considerations were extended to the case of solids and liquids, and we have observed that in this manner Boltzmann was able to calculate atomic heats and to account for the law of Dulong and Petit. More recently, the study of the motions of ultra-microscopic particles, such as are present in colloidal solutions has led to results that are in splendid accord with the deductions from the kinetic theory of gases. The number of molecules per gram-mol of any substance has been determined in half a dozen different ways, and it is quite justifiable to state that "today we are counting the number of atoms in a given mass of matter with as much certainty and precision as we can attain in counting the inhabitants in a city. No census is correct to more than one or two parts in a thousand," and there is little probability that the number of molecules in a cubic centimeter of a gas under standard conditions differs by more than that amount from $27.09 \times 10^{18}$.*

### Observations in Support of Atomic and Molecular Theories

The study of radio-active phenomena has given powerful support to these atomic and kinetic conceptions; we see the disintegration of atoms going on under our own eyes, as it were. The spinthariscope is tangible evidence of atoms in motions, and very recently C. T. R. Wilson[1] has succeeded in photographing the tracks of alpha and beta particles as they shoot out spontaneously with immense velocities.[2]

The investigations of J. J. Thomson on positive ions which ought to be mentioned in this connection, have enabled us to measure, independently of other methods, the masses of the positively charged molecules that are repelled from the anode of an ordinary X-ray discharge tube. The method used is practically the same as that used for the

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* R. A. Millikan, Science, *37*, 119, (1913); General Electric Review, *16*, 489, (1913).

[1] Proc. Roy. Soc. *87*, 277 (1912).

[2] See photographs of the tracks of alpha particles in General Electric Review, July 1913

determination of $e/m$ for the cathode rays.[3] Not only has J. J. Thomson determined in this manner the nature of the different constituents of a gas mixture, but he has also shown that this method of chemical analysis is infinitely more refined than any other method hitherto used.

Similarly S. C. Lind[4] has shown that in the case of chemical reactions produced by alpha particles, the weight of evidence is in favor of the theory that each alpha particle produces one ion by bombardment of molecules and that subsequently these ions react to form neutral molecules.

### Arrangement of Atoms in Crystals

Experimental evidence of the atomic structure of matter has been obtained recently by still another method. It has already been mentioned that considerations based on the quantum theory led to the conclusion that X-rays are merely electromagnetic waves of extremely short wave-length ($10^{-5}$ to $10^{-9}$ cm). To measure these wave-lengths in the usual manner by means of a ruled diffraction grating was therefore out of question. It occurred to Laue that in the regular arrangements of atoms in a crystal we have gratings whose lines are naturally "ruled" so closely that their distances are of the same order of magnitude as the wave-lengths of X-rays. On passing the X-rays though a crystal diffraction patterns were obtained, and from the photographs of these it was found that the observed wave-lengths were of the same magnitude as those calculated.

But within the past year still more interesting results have been obtained by Bragg and Bragg,[5] who have used this method to determine the structure of crystals. We can now see, as it were, the manner in which the atoms in a crystal of rock salt or zinc blende are arranged, and we can even tell whether these atoms are at rest or vibrating about some position of equilibrium. Thus, we find that in a crystal of *NaCl*, the sodium and chlorine atoms are arranged in the form of a cubical lattice-work with chlorine and sodium atoms situated in alternate corners, so that for example "the sodium atom has six neighboring chlorine atoms equally close with which it might pair off to form a molecule of *NaCl*." In the case of the diamond the results obtained are equally striking. Every carbon atom is found to be united to four neighbors in a perfectly symmetrical way, while six carbon atoms are linked into a ring similar to that used to represent the benzene molecule. These results are among the most interesting that have been obtained in recent years.[6]

In view of these observations, the stereochemical models of the organic chemist are endowed with an even greater degree of approximate reality than was hitherto dreamed of.

We are getting a glimpse, as it were, into the innermost structure of the molecules, and are learning daily more and more about the manner in which their constituent atoms are bound together.

### Structure of the Atom. Theories of J. J. Thomson and Stark

But not only do we know something about the *structure of the molecule*, we are also in a fair way to knowing something about the *structure of the atom*, the unit out of which molecules are built up. We have learned already that the atoms must contain electrons. The obvious conclusion is that besides electrons the atom contains also a positively charged residue or nucleus. In what manner are these electrons and nucleus related to each other, and to the properties of the resulting atom? Here we touch upon the most fundamental problem of physics as well as chemistry.

Of the many attempts that have been made in recent years to formulate a theory as to the structure of the atom, those of J. J. Thomson and of Stark are among the most important. Here we can only mention these theories very briefly.[7]

According to Thomson the atom consists of a positively charged outer sphere with the electrons arranged uniformly on one or more spherical shells inside. By means of this theory it is possible to account for the fact that the properties of the elements are periodic functions of the atomic weight; also, for the existence of certain valency relations.

Stark's theory lays most emphasis on the existence of so-called valency electrons. He

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[3] The beam of positive rays is passed through magnetic and electrostatic fields acting at right angles to each other and to the path of the rays. From the photograph obtained when the deflected beam strikes a senstitive plate, it is possible to calculate $e/m$; consequently, if there is more than one kind of ion, its presence is revealed by a separate streak on the plate. See Proc. Roy. Soc. 89, pp. 1–20, 1913, for full details, also a recent monograph on "Positive Ions" by J. J. Thomson.

[4] Trans. Am. Electrochem. Soc. *24*, 339 (1913).

[5] W. L. Bragg. Proc. Roy. Soc. *89*, 248–277 (1913).
W. H. Bragg. Proc. Roy. Soc. *89*, 277–291 (1913).

[6] See also still more recent papers by W. L. Bragg and W. H. Bragg in Proc. Roy. Soc.

[7] An excellent discussion is given in Campbell's Modern Theory, second edition, Chapter XIII.

imagines that a chemical combination between two atoms "represents not a direct attraction of one atom for the other, but a simultaneous attraction of both atoms for the same electron which thus forms a bond between the atoms." On this theory, "the energy of chemical combination represents the change in the potential energy of the valency electrons connecting the atoms which takes place when they transfer some of their lines of force from the electro-positive to the electro-negative atom. It will be the greater the less the attraction of the former atom for an electron, and the greater the attraction of the latter."

By far the most important contribution that has yet been made to this subject is, however, contained in a series of papers by N. Bohr[8] that appeared during the latter half of the past year.

### Interpenetration of Atoms

To understand the arguments advanced by this writer, it is necessary to refer to a number of experiments that were carried out in Rutherford's laboratory and which led him to a new conception of the structure of the atom.

Rutherford and Geiger found that when the alpha particles from radium or other radio-active substance met a thin gold leaf, most of these passed though the metal with only slight deflection, but now and then one of these particles was completely deflected around so that it returned towards the side of the source. This phenomenon, known as the scattering of alpha particles, was found to obey the same laws as the repulsion of one electric charge in motion by another charge of similar sign at rest.

The moving alpha particle carries a positive charge which is twice as great as that of the electron. It is in fact the same as the helium atom with two positive charges.

From the amount of scattering suffered by some of these particles, the conclusion was drawn that at some point in their paths these particles *pass through the very intense electrostatic field caused by a positive charge whose magnitude is approximately equal to one-half the atomic weight of the metal through which the scattering occurs.* Furthermore, the conclusion was drawn that the alpha particle must approach the repelling positive charge (or nucleus) *within a distance which is infinitesimal as compared with the radius of the atom.* While the radius of an atom is about $10^{-8}$ cm., the experiments on the scattering of alpha particles by hydrogen showed that the former must have approached the hydrogen nucleus so closely that their centers were only $1.7 \times 10^{-13}$ cm. apart. In other words, it was necessary to conclude that the *alpha particle penetrated within the atom of the other metal.*

### Rutherford's Atom Model

These results led Rutherford to assume a structure of the atom which is quite different from that of J. J. Thomson. According to the former "the atom must be assumed to consist of a positively charged nucleus surrounded by a system of electrons which are kept together by attractive forces from the nucleus. This nucleus is assumed to be the seat of the *essential part of the mass of the atom, and to have linear dimensions exceedingly small compared with the linear dimensions of the whole atom.*" Furthermore, as the magnitude of the positive charge in this nucleus corresponds to half the atomic weight, it is necessary to assume that the number of electrons rotating about the nucleus is equal to one-half the atomic weight.

The difference between the atom models of Rutherford and Thomson may be illustrated by means of the diagrams shown in Fig. 1.

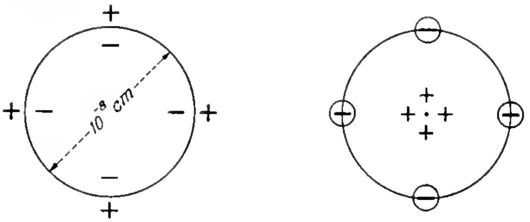

Fig. 1

In this connection it is worth noting that as a result of experiments on the scattering of X-rays, Barkla was led some years earlier to conclude that the number of electrons in the atom must be equal to one-half the atomic weight.

### Bohr's Theory of the Structure of Atoms and Molecules

While the experimental results thus pointed towards a nuclear structure of the atom, it was found that there are apparently good theoretical reasons for assuming that such an atom would be quite unstable. According to the classical electro-dynamics an electron rotating about a positive charge would very quickly radiate its energy in the form of

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[8] Phil. Mag. 26, 1–25; 476–502; 857–875 (1913).

electromagnetic waves, its orbit would grow smaller and smaller, with increasing speed, until finally the electron struck the positive nucleus. No such objections could, however, be raised against the model of Thomson.

But according to Bohr the difficulties in the way of assuming Rutherford's atom model disappear when account is taken of the fact that the classical electro-dynamics has been found inadequate in describing the behavior of systems of atomic size. "By the introduction of Planck's constant $h$, the question of the stable configurations of the electrons in the atoms is essentially changed," and it *is on the basis of Planck's theory of energy* that Bohr builds up a theory of the structure of atoms and molecules.

The principal assumptions made by him are as follows:

(1) That the electrons revolve in circular orbits about the positive nucleus, with an angular momentum which is the same for all the electrons in the atom. That is, for each electron, $mvr = h/2\pi$, where $m$ denotes the mass, $v$ the velocity, and $r$ the radius; or the angular momentum is equal to Planck's constant divided by $2\pi$.

(2) That in the stationary state the dynamical equilibrium of such a system can be discussed by the help of the ordinary mechanics. In other words, the relation between the frequency of rotation ($\nu$), the average kinetic energy of the electron, and the radius of the orbit ($r$) can be calculated by the laws of ordinary dynamics.

(3) That in the stationary orbit no energy is radiated. This is contrary to the classical electro-dynamics. When, however, in consequence of emission or absorption of energy, the frequency changes, the problem is no longer one that can be dealt with by ordinary dynamics. During the latter process there is an emission or absorption of a *homogeneous* radiation, whose frequency ($\nu$) is the average of the frequencies of rotation before and after the energy change. The amount of energy radiated or absorbed is then equal to some integral multiple of $h\nu$.

From these assumptions Bohr deduces a number of interesting results. Assuming, as known, the values of the elementary charge $e$, the mass of the electron $m$, and Planck's constant $h$, he calculates the radius of the electronic orbit to be equal to that of the atom and the frequency of the energy radiated to be about the same magnitude as the frequency of ordinary visible radiation.

Furthermore, he calculates the ionization voltage, that is, the work required to expel an electron from an atom, and obtains a result that is in agreement with observed values.

Bohr also shows that his theory enables him to account for the well-known laws of Balmer and Rydberg connecting the frequencies of the lines in the line-spectra of the ordinary elements. He finds

$$\nu = \frac{2\pi^2 me^4}{h^3}\left(\frac{1}{a^2} - \frac{1}{b^2}\right)$$

where $a$ and $b$ are integers and the other letters have the usual significance. The quantity before the bracket should be equal to the Rydberg constant of which the observed value is $3.29 \times 10^{15}$. Bohr's calculated value is $3.26 \times 10^{15}$.

### Nuclear Charge. Atomic Number

On the basis of the above assumptions, Bohr also shows that the configuration of any system of electrons, i.e., the frequency and linear dimensions of the rings, is completely determined when the nuclear charge and the number of electrons in the different rings are given. Corresponding, however, to different distributions of electrons in the rings, there will, in general, be more than one configuration satisfying the conditions of angular momentum and stability. The physical and chemical properties thus depend upon the number of electrons, or nuclear charge, and the mode of arrangement of these electrons. The experimental evidence supports the hypothesis that *the nuclear charge* of the *atom of any element corresponds to the position of the element in the series of increasing atomic weights.* Thus, the oxygen atom being eighth in the series, should have a nuclear charge of eight unit charges and eight electrons.

The periodic table of the elements thus assumes a new significance. The order of the elements in this table corresponds to the number of unit positive charges of the nucleus. According to Bohr's theory, *the physical and chemical properties of the atom depend upon the magnitude of this nuclear number;* since, however, any given number of electrons may often assume different configurations it is possible for two or more elements to exist having the same nuclear charge, that is, *the same place in the periodic table*, but possessing *different atomic weights*.

This is quite in accord with the conclusions reached by Soddy and Fajans independently, from a consideration of the transformations that occur in the radio-active elements. The discussion of these deductions is, however, reserved for a subsequent paragraph.

Again, according to Bohr's theory the emission of characteristic X-rays is accounted for as being due to the removal of an electron from an inner ring. On the other hand, the radio-active changes depend upon transformations occurring within the nucleus itself. The formation of a helium atom from an alpha particle is a case of the actual formation of an atom from a positive nucleus and two electrons.

### Bohr's Theory of the Method of Formation of a Hydrogen Molecule

Bohr gives a very interesting picture of the manner in which two hydrogen atoms form a molecule. The hydrogen atom has the simplest imaginable structure; it consists of a nucleus of unit positive charge and one electron revolving round it. "The nuclei of two such atoms repel each other. The revolving electrons of two atoms close together, if rotating in the same direction, constitute two parallel currents of electricity, and these attract one another and arrive in the same plane." The molecule thus consists of the electrons that revolve like the governor-balls of an engine about an axis formed by the two nuclei. Bohr calculates the energy that would be liberated in the process of combination of the atoms and obtains a result in substantial agreement with the value previously calculated by I. Langmuir.[9]

If the value of a theory is to be measured by the number of observations it correlates and by its suggestiveness then Bohr's theory of the structure of atoms and molecules is one of the most important contributions to scientific literature that has been made in recent years.

### Other Theories of Atomic Structure

J. J. Thomson[10] and, more recently, Peddie[11] have suggested other atom models. According to the former, the intra-atomic forces need not necessarily obey the observed electrostatic laws, and he assumes that the forces acting upon an electron in the atom are, firstly, a radial repulsive force, varying inversely as the cube of the distance from the center and diffused uniformly throughout the whole of the atom, and secondly, a radial attractive force, varying inversely as the square of the distance from the center and *confined to a limited number of radial tubes in the atom.* On the basis of this theory Thomson is able to account for the relation between velocity of emission of electrons and frequency of incident radiation as demanded by the quantum theory; and he is also able to account for Balmer's law.

Professor Peddie would also explain the variation in properties of atoms and molecules in a similar manner as due to structural conditions within the atom rather than to the failure of the ordinary dynamical equations in the case of such systems, and along with Thomson he postulates regions of attractive force alternating with regions of repulsive force.

Bohr's theory has, however, proven so far to be the most stimulating conception of atomic and molecular structures and while there are, no doubt, a good many difficulties in the way of accepting it as it stands there are very many reasons for believing it to be a much closer approximation to the truth than any other theory.

### High Frequency Spectra of the Elements

Within the present year Moseley, working at Manchester University, has followed up these speculations of Bohr by actually determining the magnitude of the nuclear charge of the atoms of most of the elements. When the atoms of any element are bombarded by electrons traveling at high velocity, they emit characteristic X-rays. Bohr showed that there is a definite relation between the charge on the nucleus of these atoms and the frequency of the characteristic X-rays emitted. Moseley, therefore, made the different elements anti-cathodes in an X-ray tube, thus bombarding them in succession with cathode rays, and then measured the wave-length of the X-rays emitted. For this purpose he made use of Bragg's method of reflecting the rays from a rock-salt crystal and photographing the resulting diffraction pattern. Knowing the distances between the atoms of the rock-salt cyrstal and the angle at which the X-rays are reflected from the surface of the crystal, it is possible to calculate their frequencies.

In this manner Moseley found that the relation between $\nu$, the frequency of the X-rays emitted by the bombarded element and $N$, the charge on the nucleus, is given by the formula:

$$\nu = A(N-B)^2$$

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[9] J. Amer. Chem. Soc. *34*, 860 (1912), also Phil. Mag., Jan., 1914.

[10] Phil. Mag. *26*, 792–799, (1913).

[11] Phil. Mag. *27*, 257–268, (1914).

where $A$ and $B$ are constants for each set of characteristic rays. He has determined in this manner the *atomic numbers* of all the elements from aluminum, 13, to gold, 79. There appear to be only three elements in this range which have not been discovered by the chemist. The atomic weight thus appears to have vastly less importance than the atomic number. In fact, as stated above, there may exist two or more elements having different atomic weights but exactly the same atomic number.

### Isotopic Elements

By examining the very high frequency radiation (gamma rays) emitted by radium $B$ and by bombarding lead with beta rays from radium $B$, Rutherford has found that both these elements give the same characteristic rays, indicating that they have the same atomic number, 82. Now so far as their chemical and physical properties are concerned, the *two elements behave identically the same; yet the atomic weight of lead is 208, while that of Ra B is about 214.5.*

Lead and radium $B$ are not the only examples of elements that differing in atomic weight yet occupy the same place in the periodic table. Soddy has found a number of similar cases among the other radio-active elements, and he has designated them *isotopes* (occupying the same place). These elements are absolutely inseparable by all chemical methods derived so far; yet they differ in that respect which has hitherto been taken to be the most important characteristic of an element—its atomic weight.

It that is true, then the atomic weight of a so-called element is really the average value of the atomic weights of the isotopes of which it is constituted, and ought to depend upon the particular proportion in which the isotopes happen to be present.

In agreement with this conclusion it has recently been shown by Richards and Lembert[12] that lead from radio-active sources has an atomic weight of 206.6, while ordinary lead has an atomic weight (determined by the same method in parallel analyses) of 207.15. The difference is much greater than any possible experimental error. It must furthermore be observed that both specimens of lead are identical in all other respects. Thus, both give the same ultra-violet spectrum.

### Is Mass Entirely Electromagnetic in Origin?

And now we must mention briefly one more conclusion which is probably more far reaching than any yet deduced. According to Rutherford and Bohr, the nucleus of an atom is infinitesimally small compared with the dimensions of the atom, yet practically the whole mass of the atom is concentrated in this nucleus. Now let us quote Rutherford himself.

"It is well known from the experiments of Sir J. J. Thomson and others, that no positively charged carrier has been observed of mass less than the hydrogen atom. The exceedingly small dimensions found for the hydrogen nucleus add weight to the suggestion that the hydrogen nucleus is the *positive electron*, and *that its mass is entirely electromagnetic in origin.* According to the electromagnetic theory, the electrical mass of a charged body, supposed spherical, is $\frac{2}{3}\frac{e^2}{a}$, where $e$ is the charge and $a$ the radius. The hydrogen nucleus consequently must have a radius about 1/1830 of the electron if its mass is to be explained in this way. There is no experimental evidence at present contrary to such an assumption."[13]

For some time we have been familiar with the idea that the mass of the negative electron is electromagnetic in origin; if the same holds true for the positive electron or hydrogen nucleus, then we are forced to conclude that all matter is really a manifestation of electrical charges in motion.

## CONCLUSION

In the above remarks an attempt has been made to present to the reader in a general and confessedly superficial manner some of those concepts which have been evolved in physical science during the past decade. We have seen that in analogy with the ordinary atomic theory of the structure of matter there has been developed not only an atomic theory of electricity but also one of energy.

These theories are, however, not to be regarded as opposed to views previously held, but rather as an attempt to obtain a deeper comprehension of the innermost mechanism of natural phenomena. In a word, while the physics of the past century dealt with nature microscopically, and emphasized the idea of *continuity*, the physics of the present regards nature microscopically and finds that underneath the apparent continuity there exist distinct *discontinuities.*

For the chemist as well as physicist a knowledge of the investigations which have

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[12] Jour. Am. Chem. Soc., 36, 1329 (July, 1914).

[13] Phil. Mag., March, p. 494 (1914).

led to these new speculations are of extreme importance. Objection may of course be raised to these speculations because of their obviously hypothetical nature. The argument may be advanced that since the theory of today is apt to be cast aside in favor of the theory of tomorrow, what then is the use of any theory at all? As Royce states:[14]

"If certain general theories are mere conceptual constructions, which today are, and tomorrow are cast into the oven, why dignify them by the name of philosophy? Has science any place for such theories? * * * Why not say, plainly: Such and such phenomena, thus and thus described, have been observed; such and such experiences are to be expected, since the hypotheses, by the terms of which we are required to expect them, have been verified too often to let us regard the agreement with experience as due to merely chance; so much then with reasonable assurance we know; all else is silence—or else is some matter to be tested by another experiment? Why not limit our philosophy of science strictly to such counsel of resignation? Why not substitute, for the old scientific orthodoxy, simply a confession of ignorance and a resolution to devote ourselves to the business of enlarging the bounds of actual empirical knowledge? * * * "Why not 'take the cash and let the credit go?' Why pursue the elusive theoretical unification any further, when what we daily get from our sciences is an increasing wealth of detailed information and of practical guidance?

"As a fact, however, the known answer of our own age to these very obvious comments is a constant multiplication of new efforts towards large and unifying theories."

The scientific investigator overwhelmed with numerous observations and results of experiments in different fields finds an actual need for some unifying conception that will make it easier to understand the manner in which all these varied phenomena are correlated.

The scientific imagination, that uncontrollable product of the human intellect, can no more be stifled by a rule of logic than freedom of thought could be repressed by any theological dogmas. And surely it is worth while to make an error occasionally if the net result be an increased enthusiasm and inspiration to increase further the sum of human knowledge.

In conclusion, the writer wishes to express his sincere appreciation of the kindly interest taken in this paper by both Dr. W. R. Whitney and Dr. I. Langmuir, without whose encouragement and inspiration it would not have been attempted.

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[14] Introduction to the translation of Poincare's "Foundations of Science."

# THE ELECTRIFICATION OF CANE-SUGAR FACTORIES

By A. I. M. Winetraub
Engineer, Zaldo & Martinez, Havana

The author here discusses the "steam balance" of a sugar factory, as well as the points of superiority of electric motor drive over steam-engine drive. By "steam balance" is meant that condition obtaining when no more steam is generated than needed for high-pressure cooking and for mechanical power, the exhaust from the latter being sufficient for all the low-pressure cooking purposes. In the economical operation of a cane-sugar factory, the important factor is rather to *maintain* a "steam balance" than simply to *create* it. This can be done only by the use of apparatus which provides a means of regulating a portion of the steam flow to suit momentary conditions. It is shown that the only apparatus possessing this function in a satisfactory degree is a steam turbine of the extraction type coupled to an electric generator. The author also compares steam drive with electric drive for factory power and shows the great saving in favor of the latter method, as well as the reasons for its greater reliability, thus further confirming his conclusions that only by electrification can cane-sugar factories obtain the utmost in reliable operation and financial economy.—Editor.

Another very satisfactory season of electrically operated cane-sugar factories has just been completed in Cuba; and while the previous seasons left very little doubt that proper electrification meant an unqualified success, the present season, beside upholding the past record, strengthens the conviction that the adoption of electric drive practically imposes itself upon cane-sugar factory operation.

Cuba has the distinction of being the pioneer in applying the alternating-current system on a large scale to sugar factories, and the results obtained have been so gratifying and convincing that foreign countries have followed the lead. To-day this system is being introduced in Australia, Hawaii, and other cane growing countries. There is hardly an owner of a sugar factory in Cuba who has not seen at least one of the electrified sugar mills. Of the replies to a circular letter sent to sugar mill owners, 80 per cent were unconditionally in favor of electrification. This statement, made by the interested companies, is in itself a fair proof of the satisfactory features visibly apparent in an electrified factory, but the engineer can obtain more than a superficial proof by a careful analysis of the conditions.

The advantages obtained by the electrification of a cane-sugar factory are, of course, not limited to fuel economy only, although this latter has been proved to be in itself a very considerable item. As will be shown herewith, there are other gains equally important and far reaching in insuring uninterrupted efficient operation at a reduced cost of production.

No matter whether an electrical equipment is being selected for a new sugar house or whether the problem involves the electrification of an already existing steam-driven factory, the first and foremost consideration should be that of creating and maintaining a *steam balance*. The *steam balance* in a sugar factory may be defined as the condition under which live steam will be generated to an extent only sufficient to furnish the required mechanical drive and that ordinarily necessary for the high-pressure cooking apparatus, the exhaust from which after deducting condensation losses will be just enough for the ultimate evaporation and concentration of the entire dilute.

In an already existing steam-driven factory, with probably an upset steam balance, there is another very important consideration, viz., that of designing an equipment which will produce and maintain the steam balance with such an expenditure of money that the combined interest and depreciation of the new *and superseded plant* will be more than covered by the total economy thus secured.

There still are a few makers of sugar factory machinery who, although admitting that in an existing steam-driven factory electrification can show a great decrease in the cost of production, are skeptical about the application of electricity to newly designed factories. The main argument they advance is that a steam balance can be created in a new steam-driven factory when properly designed.

While it may be true that a steam balance can so be created, it will be shown in the following that an electrical equipment having properly designed turbine-generators is the only one which will *maintain* the balance. Furthermore, such advantages as reliability, ease of control, cleanliness, low cost of installed equipment, economy of lubrication, flexibility of installation, reduced operating expenses, reduced repair expenses, maintenance of cooking apparatus in an efficient state, and others can only be obtained by the use of an adequate electrical equipment.

In an ordinary sugar factory, the initial steam pressure at the engine is about 75 lb. gauge per square inch and the exhaust about 8 lb. gauge per square inch. In expanding one pound of steam from this initial to exhaust pressure, the engines will use up therefore 918,000 — 835,000 or 83,000 ft-lb., leaving theoretically available in the exhaust (assuming no condensation) 835,000 ft-lb., which is over ten times the energy used for mechanical drive. Usually the available heat in the exhaust steam of a sugar factory is at least seven and a half times that used by the steam engine to do the mechanical work, and with ample heat protective covering may be even eight times that amount. This fact therefore must not be lost sight of, viz., that by far the greatest portion of the heat energy contained in the live steam appears in the exhaust and is not used for mechanical drive. After a steam balance design has been arranged to give, with a certain steam consumption of engines, the required heat for evaporation in the form of exhaust steam, every additional heat unit used in excess for mechanical drive in the cylinders of the steam engines necessitates the release of eight heat units into the exhaust. These of course will be wasted if the balance of the steam requirements has been reached before.

With a lack of steam balance it is sometimes necessary to employ live steam for cooking and, at others, to waste exhaust steam. This means taking no advantage of the heat units in the steam for mechanical drive in the former case and wasting heat units in the exhaust in the latter case.

It would be a comparatively easy matter to obtain a steam balance for any sugar house if the milling and evaporating conditions were uniform and constant. This, unfortunately, is not found to be so in practice for both the mechanical drive, with the corresponding exhaust steam production, and the requirements of evaporation vary due to field, yard, and factory circumstances, and, what is worse, the variations are independent of each other and may not occur at the same time.

Let us assume that, at a certain period "B," the crushing and milling engines in a steam-driven factory are operating at full load and are producing an exhaust which is just sufficient for the evaporation of the juice extracted and diluted some time before, say at period "A," which is now being evaporated at period "B." If, for any reason, at period "C," the milling capacity in tons per hour is reduced, the quantity of exhaust steam is also reduced due to the lessened mechanical load, and is therefore insufficient for the dilute obtained at period "B." In this case live steam would have to be employed for evaporation. On the other hand if, at period "C", the load increased there would be an excess of exhaust steam for evaporating the dilute from the cane crushed at period "B," which would result in a consequent waste of exhaust steam.

A still better illustration of this condition is available in a cane-sugar factory where several tandem grinding rolls are operating.

The change-over from operating one or two of these sets at a time may mean an excess or a lack of exhaust steam for evaporating the dilute accumulated before the change-over, and the steam balance, if such existed previously, is thereby upset.

It has been suggested that low-pressure turbine-generators be installed to utilize the exhaust steam from milling engines and to have electric motors drive the pumps and other mechanical appliances about the factory. While this arrangement appears to be satisfactory to a certain extent, it implies the use of large condensers in connection with the turbine-generators and involves the feature of evaporating the dilute by means of live steam; for with such an arrangement there would be no exhaust steam available for cooking. This would call for a complete revolution in the manufacture and operation of cooking apparatus. The suggestion of utilizing the exhaust steam in low-pressure turbines has been originated mainly because of the desire for creating and maintaining a steam balance.

There have also been other suggestions to eliminate the difficulties attending an excess of exhaust steam, most of which apparently disregard the fact that instead of attempting to utilize in one way or another the heat contained in an excess of exhaust it is naturally more logical *not to produce this excess of exhaust steam.*

The problem of obtaining maximum fuel economy can unquestionably be solved with such an equipment as will give:

(1) Sufficient exhaust steam for cooking at all times.

(2) A variable supply of exhaust steam.

(3) A control of exhaust steam production to give only the needed exhaust.

(4) An automatic governing device to make the exhaust production directly proportional to the cooking requirements.

It requires no special effort to see that a sugar house which is equipped to fulfill these conditions will take care of all requirements and will at the same time secure a steam balance with its consequent ideal fuel economy.

Extraction-type steam turbines have been used quite extensively in electric power plants for furnishing electric light and power and, at the same time, supplying exhaust steam for general heating purposes. The conditions in a sugar factory are not materially different from those just mentioned and there is absolutely no reason why such an arrangement when suitably adapted to a sugar house should not give ideal results.

Fig. 1 is a diagram illustrating the principle involved in accomplishing the desired end. The letters *A* illustrate extraction-type steam turbine-generators which have their exhaust lines connected to a common condenser. An extraction connection is shown from the first stage of each turbine leading into a common exhaust receiver. The crushers and mills are in this case steam-driven and their exhaust is also led to the common exhaust receiver. Between the first stages of the turbines and the common exhaust receiver there are installed automatically operated valves *B*, which are interlocked with the valves *C*. Valves *B* and *C* are set in such a manner that when the pressure in the exhaust receiver is maintained at 6 to 8 lb. per square inch or higher, valve *B* is shut and *C* is wide open.

With such an arrangement, let us assume that the crushing and milling engines are furnishing sufficient exhaust for the assumed cooking requirements, and that the turbines are operating fully condensing which gives high fuel economy. When the demand for exhaust steam in the cooking apparatus is greater than can be supplied by the crushing and milling engines, the pressure in the exhaust main drops and automatically opens valve *B* and closes valve *C* until the pressure in the main exhaust pipe is again 6 to 8 lb. At this time, valve *B* again closes and the turbine again operates condensing.

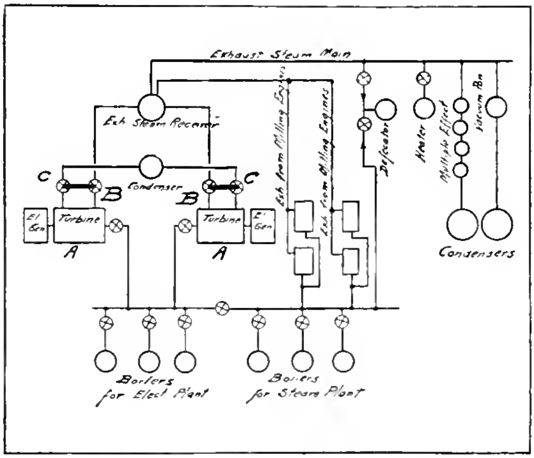

Fig. 1. A Diagram showing an Ideal Arrangement for the Utilization of Steam in an Electrified Cane-Sugar Factory

Valves *B* and *C* can be designed in such a manner as to afford a partially opened *B* valve with a correspondingly partially closed *C* valve. Then, the turbine will operate non-condensing only to the extent of that portion of the steam which passes through the first stage and is then extracted for cooking, while the remainder of the steam taken by the turbine passes through to the condenser and effects a correspondingly economical consumption.

Since the exhaust steam from operating the crusher and grinding rolls is never sufficient for the entire evaporation of the dilute, it is advisable, in a sugar factory where the crushers and rolls proper are to be electrically operated, to have one non-extraction turbine-generator exclusively for the mills and crushers and to have another one or two turbine-generators of the extraction type to compensate for the lack or excess of exhaust steam as described. The non-extraction turbine-generator should have a capacity equal to about 50 per cent of the total mechanical drive in the factory and should operate non-condensing, its exhaust steam being carried into the exhaust receiver just as in the case of the steam-driven crushers and mills.

The turbines operate normally non-condensing, feeding their exhaust steam into the exhaust pipe line for evaporation of the dilute. When the quantity of exhaust steam exceeds the requirements, the pressure in the exhaust line rises and operates a valve which diverts the excess exhaust steam into the condenser. If the quantity of exhaust steam from the turbine is insufficient for the cooking requirements, the pressure in the exhaust pipe line drops and the valve is operated automatically in such a manner that more exhaust steam is fed into the exhaust line and less is diverted into the condenser. When all the steam exhausted from the turbine is required in the exhaust pipe line, the valve opens wide, the condenser connection is automatically shut, and the turbine operates non-condensing.

Fortunately, when operating entirely non-condensing, with as low a steam pressure as the 80 lb. per square inch that is available in most sugar mills, and exhausting at about 6 to 8 lb., the steam turbine consumes over twice as much steam as when exhausting into a 26-in. vacuum. This is decidedly a favorable feature in the operation of a sugar factory, for the arrangement described can furnish the factory with enough exhaust steam to fulfill its maximum requirements and, when not as much is required, the portion of steam that is not needed is condensed and effects the operating efficiency corresponding to the vacuum in the condenser.

The proper control of the electrically-driven air and injection pumps, that serve the auxiliary condenser which operates in connection with the extraction turbines, can be obtained by automatic starting and stopping devices that are governed by the valves *B* and *C*. Similar arrangements can be made in case the exhaust from the turbines should be carried to the central condenser, or manually by means of signals operated by the valves *B* and *C*.

In the suggested layout the feature which will undoubtedly arrest the engineers' attention is the one pertaining to the operation of the extraction turbine at times under a vacuum with the consequent necessitated use of a condenser and additional cooling water.

If it is remembered, however, that the vacuum may be as low as 25-in. and still give decided advantages and, above all, that the turbine condenser is an emergency equipment which is to operate only when the steam balance is endangered, and, if it is further remembered, that the condenser is to take care of only a part of the steam input to the turbine, it will be readily appreciated that the size of the condenser, the water it requires, and the attention to its auxiliaries are of very little importance compared with the enormous advantages to be derived.

It must always be kept in mind that when steam is extracted in the manner suggested, from the first stage of a turbine, it has been used efficiently in the first stage for producing power, and the steam which passes through the remaining stages has been used on the regular condensing basis of efficiency and therefore the arrangement when taken as a whole is very efficient.

Knowing that the condenser's duty is mostly to condense the excess of exhaust steam and this on the basis of vacuum efficiency, it will at once appear that the quantity of steam to be taken care of and therefore the condenser required are not of alarming proportions.

In most cases, it will probably be possible to connect the vacuum end of the extraction turbine to the main condenser of the sugar factory so that the additional requirements would be reduced to pumping only a little more cooling water and operating the air pump a little faster.

To correct for a steam balance in a 1000-bag per day sugar factory which consumed about 80,000 lb. of live steam per hour and which was unbalanced to the extent of wasting as much as 18,000 lb. of exhaust per hour, it has been found that with the installation of only a 300-kw. extraction turbine the otherwise wasted exhaust steam could be made available to evaporate, in the effects and vacuum pans, some 30,000 lb. of maceration water* which in the case under consideration meant over 20 per cent maceration on cane.† In this case some 350 horse power of steam engines could be replaced by electric motors which would eliminate that amount of unnecessary exhaust, there being an excess of exhaust steam in the factory; and a steam balance could be obtained with an extraction of almost 5,000 lb. of steam from the turbine.

With this turbine, requiring about 12,000 lb. of steam at the throttle (80 lb. initial, 6 lb. back pressure) and operating with 5,000 lb. extraction, the size of the condenser for 26 in. vacuum need therefore be of a capacity to take care of only 7,000 lb. of steam per hour, which is indeed not of a size to give any serious concern.

It is to be noted in the diagram of the suggested arrangement of steam-driven crushing and milling engines, Fig. 1, that the boilers operating the extraction turbine-generators (and which are intended for all mechanical drive excepting the mill drivers proper) are shown to be separate from the boilers intended for the milling engines proper. This of course does not mean that new boilers are required in an already existing steam-driven factory that is to be electrified, or that additional boilers than would otherwise be required are needed for a new plant to be installed along the lines suggested.

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* To best explain the expression "maceration water" it is deemed advisable to quote the following from authorities on the subject:

"When water is poured on the bagasse the residual juice in the bagasse is diluted, and after recrushing the bagasse to its former content of juice, it will contain the same amount of dilute, but therefore less saccharine, causing less loss of sugar, so that maceration considerably improves the juice extraction. (H. C. Prinsen Geerligs, 1909, "Cane Sugar and its Manufacture.")"

"At the present time two schemes are employed in washing out sugar from the bagasse; in the one which is sometimes distinguished as imbibition, water preferably hot is sprayed on the bagasse as it leaves one mill; in the other known as maceration the partly exhausted bagasse is drawn through a bath kept with diluted juice which has already been extracted. (Noel Deerr, 1905, "Sugar and the Sugar Cane.")"

† The degree of extraction is often conveyed by speaking of the percentage of maceration water as compared to the total weight of cane ground. In this case "20 per cent maceration on cane" means that the weight of water added was 20 per cent of the total weight of the cane ground.

Generally speaking of the total boiler capacity of a cane-sugar factory, 50 per cent furnishes steam for the mills proper and 50 per cent for the other drivers about the plant; and it is possible to divide the total intended capacity of the boilers into batteries so that each may take care of their apportioned duties.

The most likely reason causing a drop in boiler pressure is the variable load on the crushing and milling engines and if the boilers feeding them are separate from the other drivers, the load on which is practically constant, there will be the consequent advantage of constant steam pressure to the turbine-generator that is to operate the electric motors, a feature which is by all means desirable.

It is of course appreciated that with a variable load on the mills proper the quantity of bagasse and its quality are variable and therefore this has a bearing on the pressure of the boilers assigned to the electric drive, but it is practicable indeed to arrange for the bagasse supply in such a manner that constant pressure may be maintained on the "electric" boilers with a constant fuel supply.

It has been claimed in this paper that the steam balance can be *maintained* only with a properly designed turbine-generator equipment.

In no sugar factory will conditions remain absolutely invariable from crop to crop as regards steam consumption, and a steam balance once created in such a factory has a tendency to be upset by the addition or deduction of machinery.

If, instead of using turbine-generators of the extraction type, we should attempt to use compound or triple expansion units with the intermediate or low-pressure cylinders acting as "stages" in the same manner as the stages of an extraction turbine, it would perhaps be possible to make arrangements in such a manner that, in accordance with demanded requirements, the intermediate and low pressure cylinders may be by-passed and steam thereby be exhausted at a higher or lower pressure for cooking or even below atmosphere to the condenser. This, however, would mean driving the pistons of the corresponding cylinders "dry," or without steam at times, a feature which is by no means advisable.

As can be seen, the variable quantity of low-pressure steam is not obtainable therefore with a piston-type steam driver and the steam balance which has as a basis just this condition is only obtainable from a stage-type rotary steam unit with an extraction arrangement such as the Curtis extraction-type turbine.

The manager of an important factory in Cuba which has an output of about 150,000 bags of sugar per season calculated that interruptions in his mill represent $6.00 per minute, or over $8000 per actual milling day. This should amply indicate the importance of uninterrupted operation in a sugar factory and it only remains to show that the electric motor affords protection against such interruptions.

Excluding the mill drivers proper, crystalizers, and centrifugals, the most important drive in a sugar factory is practically that required for pumping only. All pumping, with the exception of that for masse-cuite and molasses, can and should be done by centrifugal pumps due to their lack of valves and reciprocating motion. Pump interruptions are due mainly to the sticking or breaking of valves and to the failing of the cylinder lubricating system. The centrifugal pump eliminates these difficulties entirely because it has no valves and does not require internal lubrication. The advantages to be derived from using high-speed pumps of this type are therefore obvious. The benefits of simplicity and reliability which are obtained by the use of centrifugal pumps are easily augmented by the adoption of electric motor drive. Furthermore, an electric motor would be the logical selection for driving a centrifugal pump, since both are naturally high-speed machines and can be coupled together directly.

As to the application of electric motors to the pumping of masse-cuite and molasses, steam troubles are avoided inasmuch as no complicated oiling system or close attention is required with electric motors; and this of course also holds true for the other drives about the factory, such as crystalizers, centrifugals, blowers, conveyors, air pumps, etc.

With the advent of the new rotary air pump, the application of the electric motor becomes still more universal; and there is really no drive where the electric motor could not show superior operating characteristics, a decreased measure of attention required, and a greater degree of continuity of operation.

From a very carefully controlled sugar factory in Cuba producing 1100 bags of sugar of 325 lb. each per day of 23 hours, a careful analysis of the results furnished the following data.

The total cost of the extra fuel purchased during the crop season of 160 days was $20,000.

The live and exhaust steam piping *for the small engines and pump connections only* was found to have over 7500 square feet of radiating surface and the value of fuel being taken at 25 cents per million B.t.u. or about $7.00 per ton of coal equivalent, it was calculated that over $4,000 was lost in radiation and condensation per crop, which represents 20 per cent of the amount spent for extra fuel.

The piping mentioned takes care of approximately 1500 h.p. in engines and assuming, when electrified, a wiring loss of 2½ per cent, which is indeed reasonable when considering a properly distributed alternating-current installation, we have a loss of 37.5 h.p.

With a consumption of 25 lb. of steam per horse power hour lost, the steam loss per season of 160 days of 23 hours each would be 3,450,000 lb. of steam.

Assuming that with $7.00 worth of fuel we can produce 19,000 lb. steam ($7.00 per ton of coal), the cost of the lost power would be

$$\frac{3,450,000\times 7}{19000}=\$1270$$

Considered against the $4000 this shows a difference of $2730 which represents a saving of over 13½ per cent of the purchase of extra fuel.

On the basis of conditions as found in the sugar factory referred to, further comparison has been made relative to the labor and incidental material expense.

| | Steam | Electric | |
|---|---|---|---|
| Labor expense during crop, per day.... | $65.19 | $26.55 | |
| Labor exp. lay-by, end of crop, per day | 2.79 | 0.28 | |
| Labor expense pumping station....... | 3.33 | 0.00 | |
| | $71.31 | $26.83 | |
| Or, a total for 160 days | $11,409.60 | $4292.80 | |
| Labor balance in favor of electric drive... | | | $7116.80 |

The lay-by labor expenses at the end of the crop are due to dismounting the machinery and coating it with non-rusting material to protect it while standing idle for 200 days.

The labor expense of the pumping station is due to the fact that, in the case of this steam sugar factory, it is necessary to have a small pumping station at a distance of one mile from the factory, a condition which applies to practically all sugar mills in Cuba.

The time lost in starting the engines when stopped on dead center, in slow acceleration, and in other general features which would cause complete shut down of the mills proper can be assumed to be four minutes daily at $6.00 per minute, or a total of $3,840 for a crop of 160 days. This item is not chargeable to the "electric" column.

| | Steam | Electric | |
|---|---|---|---|
| Material for repairing pipe coverings per crop day.... | $1.25 | $0.06 | |
| Material for piston packing, lubricators, spares, etc., per crop day.... | 19.87 | 1.10 | |
| Paint, painting tools and labor per crop day....... | 1.20 | 0.12 | |
| Oil and grease per crop day....... | 13.83 | 2.50 | |
| Cotton waste per crop day....... | 1.87 | 0.60 | |
| Repairs and oil at pumping station per crop day.... | 0.25 | 0.10 | |
| | $38.27 | $4.48 | |
| Or, a total for 160 days | $6,123.20 | $716.80 | |
| Material balance in favor of electric drive. | | | $5,406.40 |

To resume, we have in favor of electrified sugar factories the following items:

| | |
|---|---|
| (A) Saving in transmission losses................ | $ 2,730.00 |
| (B) Saving in labor..... | 7,116.80 |
| (C) Saving in incidental material............. | 5,406.40 |
| (D) Saving, interruptions | 3,840.00 |
| Total.... | $19,093.20 per crop. |

The values given in the "steam" column are amounts actually spent in the sugar factory under consideration, while the ones in the "electric" column are computed values from carefully analyzed obtainable conditions during a crop of 160 days with an assumed electrical layout and quite liberal help. It should be noted that the comparison is made on the basis of all drives other than for mills proper, which latter have in this case been assumed to be steam driven. Remembering now that the factory makes 1100 bags of sugar per day or about 175,000 bags per season, the saving just mentioned, which it must be recalled is *exclusive of fuel economy*, represents almost 11 cents per bag of sugar or over 2 per cent of the average value at which a bag of sugar was sold in Cuba during the last crop.

The fact must not be lost sight of that these data as obtained apply to an exceptionally well managed factory and that the advantages of an electric drive over the average steam drive will be decidedly greater than the ones just shown.

The exhaust steam from a turbine-generator contains no oil, as is the case with the reciprocating engine; and, if turbine-generators are used in a cane-sugar factory, the heating coils and the calandria of the evaporating apparatus will receive no heat-insulating oil coatings. It is well known that the efficiency of the cooking apparatus in cane-sugar factories is greatly impaired by such scales, the transfer of heat from the exhaust steam to the liquor being greatly diminshed. Any arrangement which will avoid the forming of such scales and which will maintain the heating surfaces in a maximum heat transmitting condition must be productive of economy not only in time and fuel but also in maintenance cost of the heating apparatus.

With a properly designed, well constructed and installed turbine-generator equipment, it is undoubtedly possible to obtain at least an additional ¼ per cent yield due to the possibility of increased maceration; and in the mill under consideration an 11¼ per cent yield could be obtained instead of an 11 per cent. This represents an increased revenue of 2¼ per cent which, translated into dollars and cents on the basis of last crop's average prices (3¾ reales per arroba; i.e., approximately 2 cents per lb.), means an extra income of $19,775. Outside of the saving in fuel it may be expected therefore that a proper electrification of this mill should produce a saving of about $40,000, which in itself is indeed a respectable sum to pay for interest and depreciation on an electrified mill to cover the new and superseded machinery.

# NOTES ON THE USE OF THERMO-ELECTRIC APPARATUS IN HIGH FREQUENCY SYSTEMS*

## PART II

By August Hund
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This article is a continuation of one which appeared under the same title in the October, 1914, issue of the Review. The present installment deals with different combinations of thermo-elements, such as the thermo-cross and the three-thermo-cross methods, which provide sensitive means of determining the reasonance curve and the logarithmic decrement of a circuit.—Editor.

The actual dissipation of energy in *A*, Fig. 9, is

$$W = V.I_2 \tag{31}$$

If only the thermo-couples *I* and *III* are used, the deflection of the galvanometer will be

$$\begin{aligned}\alpha &= K\ .\ I_v\ .\ I \\ &= K^1(V+V_1)\left(I_2+\frac{I_v}{2}\right) \qquad (32)\\ &= K^1\left[V.\,I_2+\left(V_1.I_2+\frac{I_v}{2}(V+V_1)\right)\right]\end{aligned}$$

This shows that the indicated energy is larger by the quantity

$$K^1\left(V_1\ .\ I_2+\frac{(V+V_1)I_v}{2}\right)$$

Since

$$I_v = \frac{V+V_1}{R}$$

we obtain the expression for the deflection of the wattmeter as follows:

$$\alpha = K^1\left\{VI_2+\left[V_1.I_2+\frac{R.I_v^2}{2}\right]\right\} \tag{33}$$

The correction factor, $\left[V_1.I_2+\frac{R.I_v^2}{2}\right]$, must be separately determined for each value of the energy to be measured. This can be done automatically by the addition of the two thermo-couples, *II* and *IV*, as shown in Fig. 9. The thermo-couples *I* and *III* would measure the energy according to equation (33). The thermo-couple *IV* measures the energy $V_1\ I_2$; and the thermo-couple *II*, if made half as sensitive as the other thermo-couples, will measure the energy $\frac{R.I_v^2}{2}$. Then

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*ERRATUM.—*The title for Fig. 6 which occurred in Part I of this article, GENERAL ELECTRIC REVIEW, October, page 986 should have read as follows:*

*"Fig. 6. The Thermo-couple system shown in Fig. 2 shunted to measure heavy currents. When a proper value of self-inductance is used in the two branches, the system will give accurate readings at any frequency."*

by properly connecting these thermo-couples, as shown in Fig. 9, the actual energy can be measured directly.

The following is a description of a recent application of the thermo-cross bridge to the measurement of resonance and to the determination of the logarithmic decrement. This determination has usually been carried out by the method of Bjerkness, in which either the self-induction or the capacity of the circuit is varied until the current becomes a maximum at resonance. Such a Bjerkness curve is represented by the expression

$$\int_0^\infty i_2^2\, dt = \textit{function}\ (\lambda) \qquad (34)$$

where $\lambda$ is the wave length and $i_2$ the instantaneous value of the current in the resonator circuit. It is essential that the energy of the oscillator circuit (Fig. 10) be kept absolutely constant since any variation in it affects the current indicator in the resonator circuit. In order to overcome this objectionable feature, L. Mandelstam, N. Papalexi and others* worked out an improvement by causing both the oscillator and the resonator currents to act on the indicator.

Their resonance curve is represented by

$$\int_0^\infty i_1.i_2\, dt = \textit{function}\ (\lambda) \qquad (35)$$

where $i_1$ and $i_2$ are the instantaneous values of the current in the oscillator and resonator circuits, respectively. These are defined by the equations

$$i_1 = Io_1 \epsilon^{-\delta_1 t}\ \sin\ (2\ \pi\ ft + \Psi_1)$$

$$i_2 = Io_2 \epsilon^{-\delta_2 t}\ \sin\ (2\ \pi\ ft + \Psi_2).$$

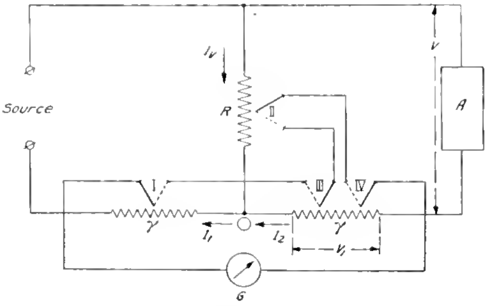

Fig. 9. A Scheme of Connections which is an Improvement over that shown in Fig. 8

In the theory, as worked out by Mandelstam and Papalexi, it is shown that resonance takes place when

$$\int_0^\infty i_1.i_2\, dt = 0,$$

at which time the currents $i_1$ and $i_2$ have a phase displacement of about $\Psi_1 - \Psi_2 = 90$ degrees with respect to each other. The resonance curve reaches its maximum for a definite amount of tuning, which is dependent on the decrement of the resonator and oscillator circuit. Since this is a zero-method, it is inherently independent of the energy variations in the oscillator circuit, and is obviously therefore preferable to the previously described Bjerkness method. In place of the short-circuit-ring-dynamometer, which is used for the current indicator in the Mandelstam and Papalexi method, a thermo-cross bridge may be substituted, thus procuring a considerably higher sensibility in range, accuracy and ease in manipulation.

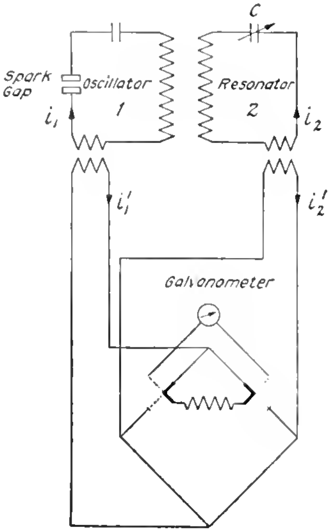

Fig. 10. A Scheme of Connections for Applying the Thermo-Cross Bridge to Determine the Resonance Curve of Circuit 1 and to Measure the Logarithmic Decrements of Circuits 1 and 2

In order to illustrate this method the diagram of connections is given in Fig. 10. The currents $i_1^1$ and $i_2^1$ have practically the same phase difference as $i_1$ and $i_2$ of the oscillator and resonator circuits (if the coupling induct-

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*L. Mandelstam and N. Papalexi, Ann. d. Phys., 33, 1910,
M. Dieckman, Diss. Strassburg, 1907,
H. Rohmann, Diss. Strassburg, 1911,
L. Kann, Phys. Z., 12, 1911,
L. Isakow, Phys. Z., 12, 1911.

ances are small). The galvanometer deflection $\alpha$ becomes

$$\alpha = k \int_0^\infty i_1^1 . i_2^1 \, dt$$

$$= k^1 \int_0^\infty i_1 . i_2 \, dt \qquad (36)$$

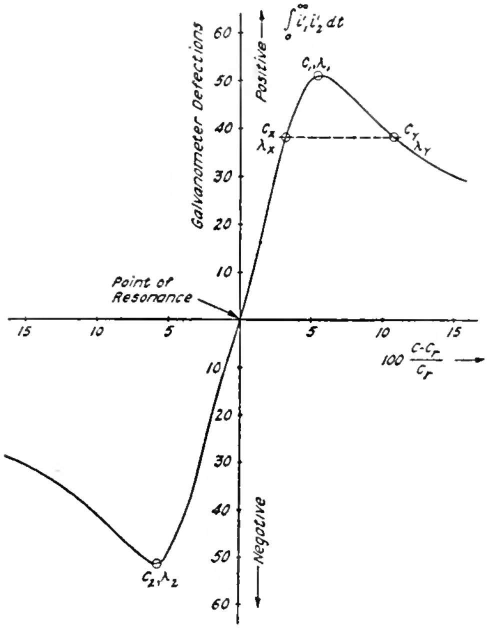


**Fig. 11. A Resonance Curve taken with the Method Shown in Fig. 10**

since

$$\int_0^\infty \left(\frac{i_1+i_2}{2}\right)^2 dt - \int_0^\infty \left(\frac{i_1-i_2}{2}\right)^2 dt = \int_0^\infty i_1 . i_2 \, dt.$$

A representative resonance curve as obtained by this method is given in Fig. 11. The deflections of the galvanometer are plotted against $100 \dfrac{C-C_r}{C_r}$, where $C_r$ is the value of the capacity at resonance and $C$ is the value of the capacity when the resonator circuit is not in tune with the oscillator. It will be noted that the curve is very slanting at the point of resonance. It is evident, therefore, that this method is very sensitive since a very small change in the capacity $C$ corresponds to a considerable variation in the integral value

$$\int_0^\infty i_1^1 . i_2^1 \, dt.$$

Another combination of thermo-elements which can be used for measuring the

$$\int_0^\infty i_1 . i_2 \, dt$$

values of two oscillating circuits is due to M. Dieckman†, who arranged three thermo-crosses as shown in Fig. 12. In this method the thermo-elements *I*, *II* and *III* are connected in series with a galvanometer, and the connections are so made that the effects of *I* and *II* are additive and *III* is subtractive. The electromotive force of each thermo-element is as follows:

*I* is directly proportional to $n_1^2 i_1^2$
*II* is directly proportional to $n_2^2 . i_2^2$
*III* is directly proportional to $(n_1 i_1 + n_2 i_2)^2$.

The values of $n_1$ and $n_2$ depend upon the ratio of the coupling turns in the oscillator and resonator circuits, respectively. With these connections one is able to obtain galvanometer deflections which are proportional to

$$\int_0^\infty i_1 . i_2 \, dt,$$

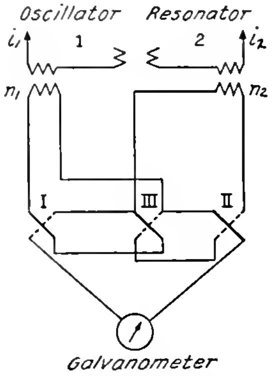


**Fig. 12. A Scheme of Connections using a Combination of Three Thermo-Couples to Determine the Resonance Curve of Circuit 1 and to Measure the Logarithmic Decrements of Circuits 1 and 2**

since

$$\alpha = k \left[ \int_0^\infty n_1^2 . i_1^2 \, dt + \int_0^\infty n_2^2 . i_2^2 \, dt - \int_0^\infty (n_1 . i_1 + n_1 \, i_2)^2 \, dt \right] \qquad (37)$$

where $\alpha$ is the galvanometer deflection and $k$ is a constant.

---

† M. Dieckman, l. c.

The curve marked

$$\text{“}\int_0^\infty i_1 . i_2\, dt\text{”}$$

in Fig. 13 is plotted from the results obtained by this method. The abscissae are degrees on the scale of the condenser which is inserted in the resonator circuit and the ordinates are deflections of the galvanometer. The Bjerkness curve,

$$\int_0^\infty i_2^2\, dt,$$

is also shown in Fig. 13 in order to facilitate comparison between the two methods. This latter resonance curve is the plot of data as secured by means of an ordinary thermocouple, such as is shown in Fig. 2. The couple was inserted in a separate circuit which was loosely coupled to the resonator. It is well to note that the maximum point of the Bjerkness curve comes at exactly the same abscissa as the zero point of the

$$\int_0^\infty i_1 . i_2\, dt \text{ curve.}$$

In this section a short discussion on the measurement of the logarithmic decrement will be given in order to point out the wide field of application of the thermo-cross bridge and the three-thermo-couple method. The sum of the logarithmic decrements may be computed from an ordinary resonance curve, such as the

$$\int_0^\infty i_2^2\, dt$$

curve of Fig. 13, from the formula

$$\begin{aligned}\triangle_1+\triangle_2 &= \pi . \frac{C_r-C}{C}\sqrt{\frac{I_{2\,eff}^{\,2}}{I_{2\,r\,eff}^{\,2}-I_{2\,eff}^{\,2}}}\\ &= \pi . \frac{C_r-C}{C}\sqrt{\frac{\alpha}{\alpha_r-\alpha}} \qquad (38)\end{aligned}$$

In this formula $\triangle_1$ and $\triangle_2$ are the logarithmic decrements of the circuits *1* and *2* respectively of Fig. 12, $\alpha$ is the deflection of the galvanometer which is proportional to

$$\int_0^\infty i^2\, dt$$

and corresponds to the value $C$ of the capacity which is in circuit *2*, and $\alpha_r$ corresponds to $C_r$ at which value the circuit *2* is in resonance with circuit *1*. If the corresponding wave lengths $\lambda$ and $\lambda_r$ be introduced, equation (38) would become

$$\triangle_1+\triangle_2 = 2\,\pi . \frac{\lambda_r-\lambda}{\lambda}\sqrt{\frac{\alpha}{\alpha_r-\alpha}} \qquad (38a)$$

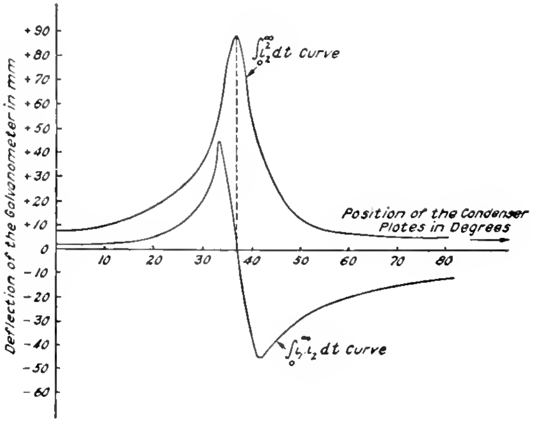


**Fig. 13.** **In this Fig., Curve** $\int_0^\infty i_1 i_2\, dt$, **which is taken according to the Method shown in Fig. 12, is shown compared with Curve** $\int_0^\infty i_2^2\, dt$, **which is plotted from data obtained by the Ordinary Bjerkness Method**

If the logarithmic decrements are to be determined from the

$$\int_0^\infty i_1 . i_2\, dt$$

curve in Fig. 13 for the two maximum integral values, the following formulae may be used

$$\left.\begin{aligned}\triangle_1+\triangle_2 &= \pi . \frac{C_1-C_r}{C_1}\\ &= \pi . \frac{C_r-C_2}{C_2}\\ &= 2\pi . \frac{\lambda_1-\lambda_r}{\lambda_1}\\ &= 2\pi . \frac{\lambda_r-\lambda_2}{\lambda_2}\end{aligned}\right\} \qquad (39)$$

In this case $\lambda_r$ and $C_r$ are the values of circuit *2* at resonance, for which condition

$$\int_0^\infty i_1 . i_2\, dt = 0,$$

$\lambda_1$ and $C_1$ are the values of wave length and capacity respectively at maximum positive deflection of the galvanometer, while $\lambda_2$ and $C_2$ are the corresponding values at maximum negative deflection of the galvanometer (see Fig. 11). If the extreme parts of the

$$\int_0^\infty i_1 \, . \, i_2 \, dt$$

curve are too flat and the corresponding wave lengths and capacities can only be approximately determined, the following formulae may be used

$$\triangle_1 + \triangle_2 = \pi . \sqrt{\left(\frac{C_x - C_r}{C_x}\right)\left(\frac{C_y - C_r}{C_y}\right)} = 2\pi \sqrt{\left(\frac{\lambda_x - \lambda_r}{\lambda_x}\right)\left(\frac{\lambda_y - \lambda_r}{\lambda_y}\right)} \tag{40}$$

where $C_x$ and $C_y$ are the values for the capacity and $\lambda_x$ and $\lambda_y$ are the values for the wave length. All these values correspond to the intersection of the

$$\int_0^\infty i_1 \, . \, i_2 \, dt$$

curve with any line parallel to the abscissa, such as is shown in Fig. 11. In this case it is convenient to plot the galvanometer deflections against the capacity or the wave length of the resonator circuit.

# APPLICATION OF POWER APPARATUS TO RAILWAY SIGNALING

## Part III

By H. M. Jacobs

Signal Accessories Department, General Electric Company

This article is the last of a series of three on the subject of railway signal power apparatus. The first, or introductory article, described in a general way the underlying principles of the various systems in common use, and the second dealt only with electrically controlled signals for both automatic block work along the right-of-way, and for interlockings at stations, terminals, crossovers, etc. The present article describes a few installations on some of the leading roads of the East and Central West, dealing particularly with the equipment at certain interlocking towers that has been put in service within the past three years.—Editor.

It may be said with a degree of certainty that the sole thought in the mind of the average traveler relative to movements of trains is the desire to reach his destination safely and on schedule time; but to a technical man, or one interested in railroading, some knowledge about the great organization of trained workmen who devote their energies to the accomplishment of these ends, and of the vast amount of equipment involved, adds interest to the journey.

The demand for a reduction in train schedules and better service has increased tremendously the responsibilities of the signal department of the various railroads, and railway signaling may now be rightly considered a science in itself. It is manifestly to the advantage of any road to establish certain standards, as this will minimize the amount of supplies to be carried in its storehouses, and reduce the first cost because of the ability to purchase in large quantities and to duplicate orders.

Each road, in solving its own problems, has thus evolved its own standards, until we now have almost as many standards as there are railroads. The Railway Signal Association, composed of men in the employ of signal departments of railroads and representatives of manufacturers interested, was formed to bring about a crystalization in standardization, to obtain an economical and satisfactory product, and to establish a certain excellence in manufacture to meet the exacting requirements.

There are, however, certain standards to which the various roads hold tenaciously; and it should be so, for each is dependent on its particular traffic requirements, the system of signaling installed, the available power for power-operated systems, and other elements too numerous to mention here. It is beyond the scope of this article to deal with signal requirements and standards; only the power equipment accessory to the operation of the signal system will be considered.

A few of the more recent installations of the past three years are described here, and in addition the equipment for some installations not yet placed in service and others installed to handle a problem not encountered in ordinary power service.

### NEW YORK CENTRAL & HUDSON RIVER RAILROAD CO.

The automatic signals and track circuits on the New York Central are operated from storage batteries arranged in duplicate groups at each location and so connected to a charging switch (previously described) that while one group is supplying power to the signals the other may be connected to a series charging line, in series with similar groups at other locations. Power stations, located at points where commercial power is available, supply these lines at a voltage of from 350 to 600, as conditions require, and maintain a constant current of 5 amperes. A single-panel switchboard controls the generator and the two feeders, but the current in each line is maintained at the proper charging value by means of series plate-type rheostats. These rheostats are mounted in some instances on the wall and in others on the back of a separate panel which also provides starting and control apparatus for the motor. The station is protected by choke coils and Type ME lightning arresters on each line, and the same kind of arresters are attached to the return wire at mile intervals.

At the electric interlockings there are required three distinct batteries, one floating on the charging circuit and two in duplicate; the main or machine battery to deliver 110 to 142 volts for operating the signal and switch motors, the lock and indicator batteries 12 volts, and separate track batteries 2 volts for supplying power to each track circuit within the limits of the interlocking. These batteries are charged in series, or separately in various combinations, from specially designed mercury arc rectifiers having a high and low voltage tube. The low voltage batteries alone may be charged from the high voltage tube in series with a variable resistance.

The New York Central uses the type of switchboard recently standardized by the Railway Signal Association for charging under the conditions just described, as well as the line charging panel and the motor and line control panel. The rectifier is a slight modification of the standard panel arranged to obtain the double voltage range.

The most recent installation, shown in Fig. 1, is the interlocking near Rome, N. Y. Directly back of the motor-generator set is the two-way line charging panel for the signals on either side of the interlocking limits. The single feeder panel is for future signaling over the Rome, Watertown & Ogdensburg Railroad. The rectifier panel stands at the left of the four-panel board adjacent to the motor and line control panel. The two interlocking control panels are at the right.

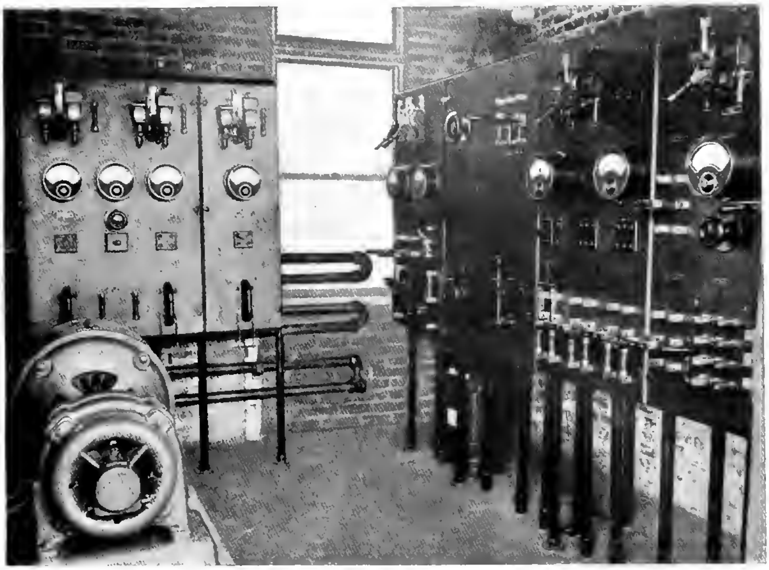


Fig. 1. Power Station, Electric Interlocking, near Rome, N. Y.
New York Central

Short interruptions of the power supply or minor breakdown of part of the charging equipment at one of the 600-volt line charging stations causes little or no concern, but continued failure or destruction of the station would be a serious matter. To provide against this emergency the railroad has fitted up a baggage car as a portable substation. It contains a single cylinder 6-kw., 600-volt gasolene-engine-generator set, a 600-volt d-c. to 110-volt d-c. motor-generator set, a three-panel switchboard, and complete substation equipment. The car may be run on a siding and the charging line temporarily tied in.

## BOSTON & ALBANY RAILROAD

A little over a year and one-half ago, the Boston & Albany put in service an installation of d-c. automatic signals and interlocking at Worcester, Mass. The top floor of the signal tower contains the interlocking machine, the ground floor the five-panel switchboard, power units and relay rack, and the basement the storage batteries. Three-phase, 60-cycle, 440-volt power from a commercial source is delivered to the switchboard for the induction motors of the two sets and for a 10-kw., 440/220-volt single-phase step-down transformer that is connected to a mercury arc rectifier for charging the main 65-cell lead-type storage battery for the interlocking machine. The rectifier equipment is unique in that it is mounted on a 90-inch three-section panel containing instruments and switching equipment to match the rest of the switchboard. The interlocking battery is not furnished in duplicate and must therefore be charged during operation. A fixed resistance may be cut into circuit to draw from the rectifier sufficient current to maintain the arc on low fluctuations of load when circumstances require that the interlocking machine be operated directly from the rectifier. As it is not advisable to raise the voltage on the interlocking machine to the high value necessary to complete the battery charge, an end cell switch has been installed.


Fig. 2. Railway Signal Battery Charging Apparatus Installed in Baggage Car for Emergency Use. New York Central & Hudson River Railroad

One panel contains station lighting switches and 10 battery charging switches for the track circuits within the limits of the interlocking. The local track batteries are charged from the rectifier, and the track and motor batteries on either side of the interlocking are charged in series, similarly to the method of the New York Central & Hudson River Railroad previously described, from a 550-volt d-c. railway source controlled from a switchboard at Jamesville, a few miles away. The charging line is carried through the d-p. d-t. lever switches on the right-hand panel, simply looping through the station. In case of failure of this source these switches may be thrown down onto an emergency generator circuit, the charging being controlled on this panel by the generator and two rheostats, one in each line feeder extending in opposite directions from the station. This generator is one unit of a three-unit emergency set, the other two units being an induction motor and a 110/175-volt d-c. generator to supplant the rectifier.

One panel controls the charging of the duplicate lock and indicator batteries from a small two-unit motor-generator set not shown in Fig. 3.

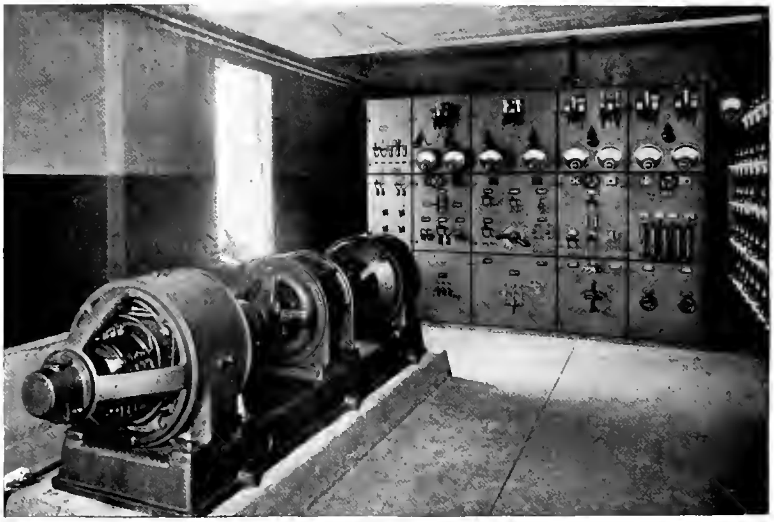


Fig. 3. Power Equipment for Direct Current Signaling Installation on the Boston & Albany Railroad, Worcester, Mass.

The commercial supply is practically immune from a prolonged failure, and as the provision for emergency is so complete and the switching arrangement so flexible, the possibility of a total failure is most remote.

### LAKE SHORE & MICHIGAN SOUTHERN RAILWAY

The Lake Shore & Michigan Southern Railway recently placed in service a battery charging equipment for the automatic interlocking plant at Toledo, Ohio, the switchboard of which is rather unique. Two mercury arc rectifier equipments are provided, the panels of which match and line up with the switching panel, and the switching arrangement is such that the batteries may be charged in every conceivable combination.

The battery equipment consists of one main 55-cell interlocking battery, two duplicate 6-cell group track batteries, two duplicate 10-cell group lock and indicator batteries, and a variable (20 to 90 cells) Edison portable battery. Under normal conditions the portable batteries will be charged from one rectifier and the main battery from the other. The track batteries and lock and indicator batteries are connected to d-p. d-t. battery transfer switches in such a way that the discharge circuits can never be broken. The batteries connected in the charging sides of these switches may be charged simultaneously either separately or in series with either the main battery or the portable batteries; or it is possible to charge alone either the track batteries, the lock and indicator batteries, or a small number of portable batteries from the low voltage tube on one of the rectifiers. This condition so seldom arises that it was deemed unnecessary to provide two tubes on both rectifiers. A six-pole throw-over switch is provided to interchange connections from the high voltage to the low voltage tube on the rectifier to meet this special condition.

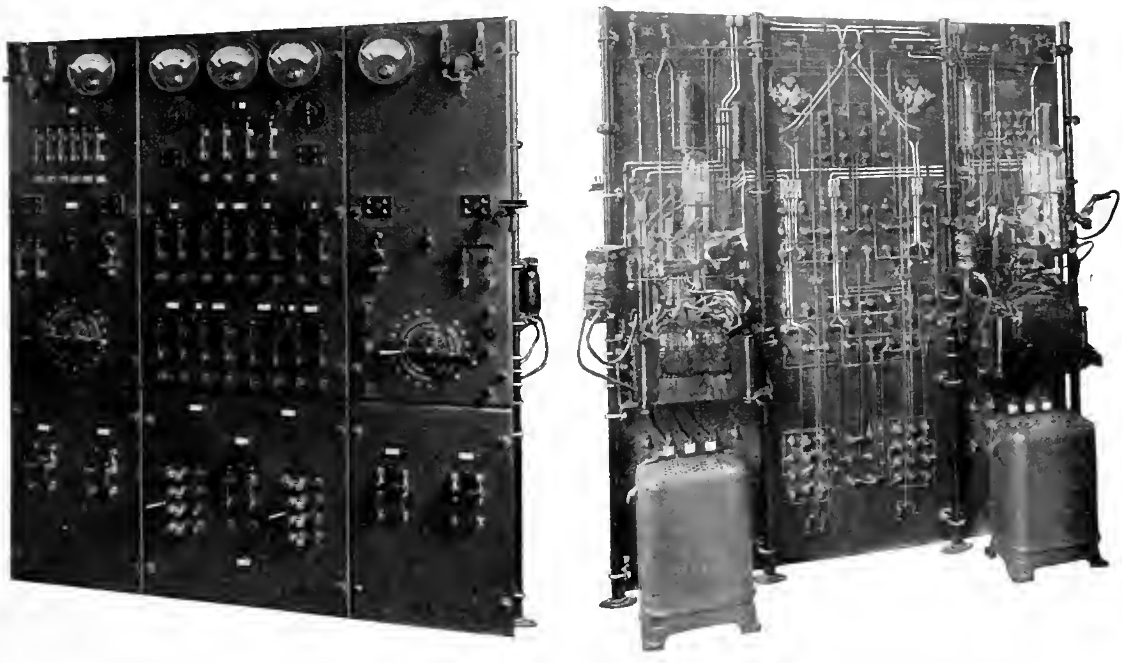


**Fig. 4. Single-Phase Mercury Arc Rectifier and Battery Feeder Switchboard for Charging Signal Batteries, Lake Shore & Michigan Southern Railroad, Toledo, Ohio**

The switchboard also provides four 220-volt single-phase a-c. lighting circuits, each supplying a number of transformers having secondary taps to provide 10, 11, 12, 13, 14 or 15 volts for lighting the signals.

### PENNSYLVANIA RAILROAD COMPANY

The Pennsylvania Railroad has recently completed an installation of automatic block signals on the main line between New York and Pittsburgh, and between Philadelphia and Washington. This comprises a total of 895 track miles equipped with alternating- current automatic block signals, and 91.2 track miles changed from direct-current to alternating-current automatic signals. Over this distance the signals are fed from a transmission line supplied at intervals from the company's power plants, the spacing between plants being determined approximately by the load of the intervening sections of the line. Each station has sufficient capacity to feed in both directions to adjacent stations. Under normal conditions each station may be operated at half-load feeding in one direction, or only alternate stations may supply power in both directions, the other stations being for emergency service. The line is further sectionalized at each signal location in such a way that should a short circuit occur the faulty section may be cut out and power fed to the remainder from the two adjacent stations, thus making all signals operative.

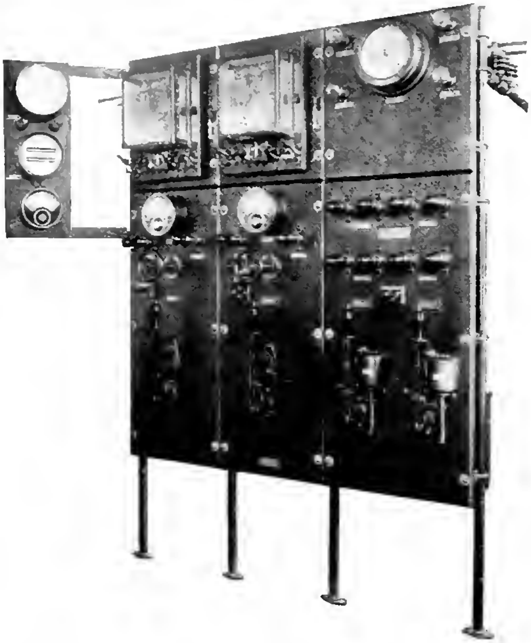


**Fig. 5. Switchboard for Controlling Two 240-volt Single-Phase Generators and Two 3300-volt Single-Phase Feeders for Alternating Current Signaling System, Pennsylvania Railroad**

It is important to note a high degree of standardization throughout the whole system. In 18 stations the steam-engine-driven units are all 35-kv-a., 220-volt, single-phase, 60-cycle generators. The feeder panels with one exception are all arranged to feed in two directions. Fourteen stations have two generating units each with individual generator control panels, four stations have one unit and generator panel, and one station has a 25 kv-a. gasolene-engine-driven unit with generator panel and one-way feeder panel, the equipment of all panels for similar duty being identical. Fig. 5 illustrates a two-generator, two-way feeder switchboard, and Fig. 6 the installation at the station operated by the gasolene engine-driven unit. In order to minimize the responsibility of the operator each exciter has its own voltage regulator, so that synchronizing is simplified as much as possible. The power generated at 220 volts is stepped up to 3300 volts before going to the switchboard. Power circuits are made and broken on oil switches, and plug type disconnecting switches are mounted on the panels. All parts customarily exposed, whether low tension or high tension, are either completely covered by asbestos lumber cases or bushings securely clamped, so that it is impossible for the operator to come in contact with any live part, at either front or back of board. When the movements of the semaphore blades are retarded by weight of sleet or snow, and it is advisable to hasten the movements, the line voltage is boosted 10 per cent without readjustment of the voltage regulators by opening a small lever switch at the side of the regulator base. Aluminum cell static dischargers are connected to the lines where they leave the station.

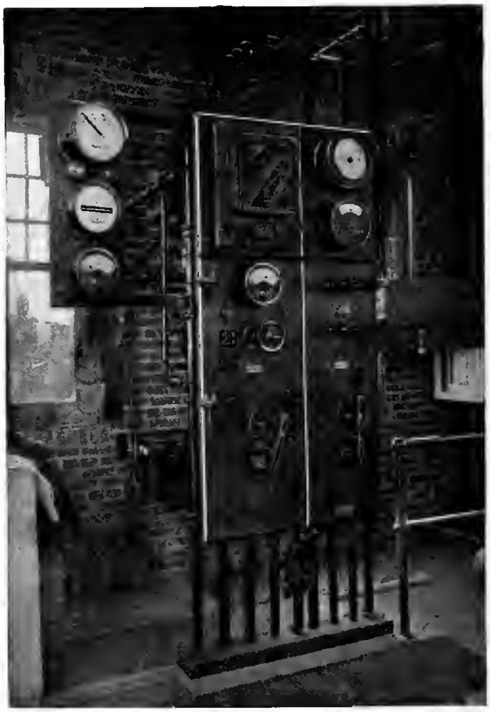


**Fig. 6. Railway Signal Power Station Installation, Pennsylvania Railroad**

The transmission lines consist of two No. 4 or No. 6 B.&S. gauge copper wires heavily insulated and embedded in asphaltum pitch in wooden trunking approximately two feet under ground. The sectionalizing outfit at each signal location consists of an iron mechanism case enclosing a d-p. d-t. non-automatic oil switch, a short-circuit indicating relay, a 3300/110-volt, 600-watt or 1000-watt transformer, and two primary plug cutouts. The transformer is connected to the middle terminals of the oil switch, the two throws of which are independent, so that when both sides are closed the transformer is connected across the line feeding through; or the transformer may be fed from either side with the other side open, or cut off entirely by opening both sides. The short-circuit indicating relay is connected in series with the line of the normal power supply side, and when actuated by heavy overload or short circuit the armature plunger will latch up and give a permanent indication until restored to normal by an attendant. When a short circuit occurs in any section, the relays in every sectionalizing outfit between the generating station and the faulty section will be actuated by the abnormal current and indicate by the position of the plunger that trouble is beyond. An attendant will then open the outgoing side of the oil switch in the last sectionalizing case giving the indication, and the incoming side of the oil switch in the next adjacent sectionalizing case, in order to cut free the faulty section, after which power may be supplied to the remainder of the line from power stations on the two ends. It is thus evident how in a very short time a faulty section may be cut free with minimum interruption to the system. The relays in the outfits adjacent to an interlocking tower have their auxiliary contacts connected to an indicating lamp in the tower, to assist in locating the trouble.

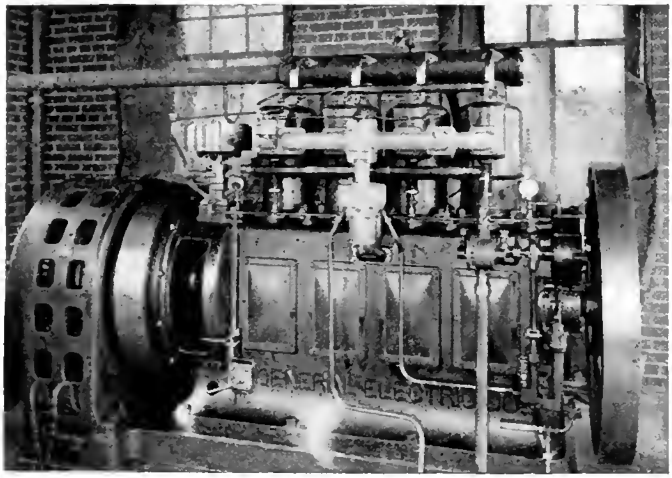


Fig. 7. Gasolene Engine Set in Power House, Pennsylvania Railroad

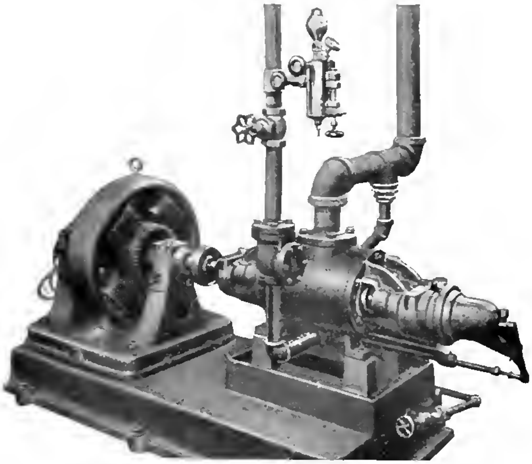


Fig. 8. Turbine-Driven Self-Excited Alternator, Pennsylvania Railroad

At Monmouth Junction, N. J., the Pennsylvania Railroad has installed two small steam turbine-driven alternating-current generators, 5-kv-a., 110-volts, single-phase self-excited. A duplicate set is installed at the North Philadelphia station, and a fourth, similar in every way, except for operation on compressed air, is in service at Rahway, N. J. These units are only 6 ft. 3 in. long, 28¾ in. wide and 36¾ in. high.

## CENTRAL RAILROAD OF NEW JERSEY

The accompanying illustration (Fig. 9) is typical of ten installations on the Central Railroad of New Jersey made during the past two years by the Union Switch & Signal Company, and indicates the standard for battery charging service for the particular kind of signaling installed.

The motor-generator sets (in duplicate) are arranged for d-c.—a-c. or a-c.—d-c. conversion, depending on the particular kind of commercial power available. The generators are 45-ampere, 20/50-volt shunt wound machines, for charging Edison A-6 225-ampere-hour storage batteries. The interlocking battery consists of two duplicate groups of 16 cells each, and the track batteries of two duplicate groups of 12 cells each. Each track battery is subdivided into six groups of two cells each, discharged in multiple and charged in series. The twelve groups of track batteries (six on charge and six on discharge) are so connected to the 13-blade charging switch that the multiple-series discharging groups are connected in series to the charging circuit and the series charging group in multiple-series to the track circuit on each throw of the switch without interrupting the track circuit supply. The four-pole double-throw transfer switch likewise interchanges the interlocking batteries without interruption. The interlocking battery may be charged separately or in series with the charging group of track batteries, and the latter may be charged separately through small fixed resistance by a very simple switching equipment. By means of turn button type ammeter switches one ammeter serves to indicate both the charge and discharge currents of both sets of batteries without conflict.

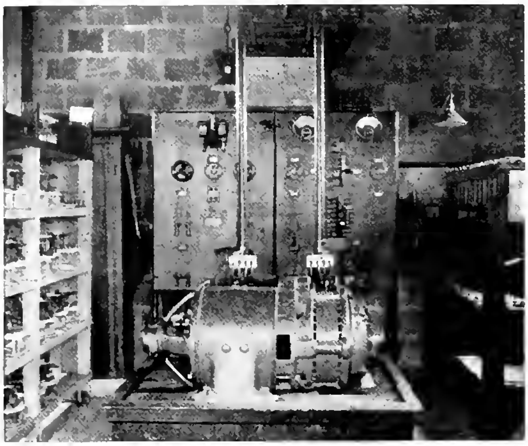


Fig. 9. Battery Charging Equipment, Central Railroad of New Jersey

The more recent installation in the Jersey City Terminal yards provides a-c. track circuits and lighting in towers "A" and "B," while direct current for charging the interlocking batteries is supplied from a mercury arc rectifier. Alternating current is supplied normally from a 575-volt source through either one of two duplicate 575/110-volt transformers and distributed to the various lighting and track circuits. Emergency a-c. supply is available at 2200 volts. This is stepped down to 575 volts, and a transfer equipment consisting of two double-pole contactors and a control relay provides for automatically supplying power therefrom without noticeable interruption upon failure of the normal source, and automatic resumption upon its return. All this control equipment is mounted on a panel 76 in. high and 32 in. wide. The arrangement in tower "C" is somewhat different. The accompanying illustration, Fig. 11, shows only an a-c. feeder panel with transfer equipment similar to that in towers "A" and "B."

### CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

The Chicago, Milwaukee & St. Paul Railway has recently put in service the last 40 miles of a 458-mile alternating-current automatic block signal installation, on which construction work was begun in 1912. This comprises five separate divisions, all double

Fig. 10. Signal Tower, Central Railroad of New Jersey

track, with ten substations, viz., Savanna to Elgin, Ill., having three substations; Lake to Rondout, one substation; Milwaukee to North La Crosse, three substations; Bridge Switch to Hastings, two substations; and Minneapolis to Hopkins, one station. From these stations 543 automatic signals and 96 semi-automatic signals are supplied. All stations receive their power from 60-cycle commercial source, and with one exception all stations on any one division are supplied from the same system so that the load between stations may be picked up by either station without interruption or danger of interference between two unsynchronized power systems. Magnetic locks are provided on the oil switch at the Savanna station and on the oil switch feeding to Savanna in the Forreston two-circuit station, to make connection between these two stations impossible, as the supply sources here are two independent systems.

The panels are all 90 in. high and of natural black slate, with the exception of the station at Sparta, which is blue Vermont marble to match and line up with an existing board. Power is metered and controlled at the voltage received. The panel equipment consists of a single-phase watthour meter, an automatic oil switch with time-limit overload trip for each feeder, and a voltmeter for the bus.

Transformers are located in the outgoing feeder circuits to step-up from the receiving voltage to 4400 volts for transmission. A spare transformer, equal in capacity to that of the heaviest feeder, is installed in each station, together with primary and secondary switching equipment.

The stations on the ends of the section are single feeder, and the intermediate stations double feeder, and of such capacity that the total load may be carried by alternate stations if desired. Emergency operation is thus provided under all conditions, in a manner similar to that on the Pennsylvania Railroad already described.

With the exception of the Portage station, the commercial power supply seldom, if ever, fails. In order to guard against rather frequent interruption at the Portage plant, an auxiliary equipment has been furnished, which consists of a two-unit motor-generator set, the motor being of the synchronous type driving an a-c. generator to charge a 90-cell Edison storage battery. The switchboard and set are furnished with such automatic control equipment that upon failure of the a-c. power supply, the set will run from the storage battery, supplying the signal line from the a-c. machine at normal voltage and frequency without interruption. A synchronizing equipment is provided so that upon resumption of the commercial supply the a-c. machine may be synchronized and operation resumed as before. This equipment has been in satisfactory operation for over nine months.

The Chicago, Milwaukee & St. Paul Railway is particularly fortunate in having ample and satisfactory commercial power available and has carried out the idea of standardizing power apparatus to a very high degree.

### NEW YORK, NEW HAVEN & HARTFORD RAILROAD

Directly across the tracks from the Boston & Albany installation described is the interlocking tower and power plant controlling the alternating-current signals and interlocking on the New York, New Haven & Hartford Railroad. The tower is of pleasing architectural design, is of concrete construction and three stories high. The upper story contains the interlocking machine, the ground floor the switchboard duplicate power units and relay racks, and the basement the storage batteries and transformers for the incoming line.

The switchboard consists of two induction motor panels, two d-c. panels, a storage battery panel, two a-c. generator panels, and the synchronizing and speed regulator equipment. The three units comprising the duplicate motor-generator sets are a three-phase, 60-cycle, 440-volt induction motor, a 7½-kv-a., single-phase, 60-cycle, 440-volt self-excited alternating-current generator, and a 10-h.p., 90/160-volt shunt wound d-c. machine. Only one set is in operation at a time, the other being held in reserve.

Under normal conditions the motor supplied from the commercial power source drives the set, the signal circuits being supplied from the a-c. generator, while the d-c. machine either charges or floats on the storage battery. Upon failure of the commercial power supply the d-c. machine automatically acts as the motor of the set, operating from the storage battery. Speed is held constant by an automatic speed regulator. The battery has capacity sufficient to thus operate the system one-hour. Upon resumption of power, it is unnecessary to synchronize the motor, as it is of the induction type.

### DELAWARE, LACKAWANNA & WESTERN RAILROAD

A little less than two years ago, the Delaware, Lackawanna & Western Railroad put in service an electro-pneumatic interlocking plant at Montclair, N. J. The power plant shown in the illustration is located in the basement of the signal tower and consists of two duplicate induction motor-driven air compressors, duplicate sets of Edison A-10 batteries for the interlocking and for track circuits, three motor-generator sets for battery charging, and a switchboard to control all.

Fig. 11. "The Yankee" passing Signal Tower at Worcester, Mass. N. Y., N. H., & H. R.R.

The air compressors are each of 100 cu. ft. per minute capacity and of the four-cylinder two-stage type, and are driven through double-herringbone gears by three-phase, 60-cycle, 1800-r.p.m. induction motors starting on external resistance in the rotor circuit and controlled from the switchboard.

The motor-generator sets are of unit frame construction. The motors are three-phase 60-cycle, 220-volt machines, and the shunt wound generators are rated for 75 amperes, 15 volts.

The main batteries for the interlocking are arranged in two duplicate sets of 16 cells each, and the track batteries in duplicate sets of two groups, four cells per group, or a total of eight cells per set. The two duplicate sets of main battery are so connected that, when interchanging them from charge to discharge and vice versa, the discharge circuit is never interrupted. The track batteries are so connected to a five-pole double-throw switch that the two component groups of the charging set are in series and those of the discharging set in multiple; and by reversing the position of the switch the duty of the two sets of batteries, as well as the connections, are interchanged without disturbance to the discharge line.

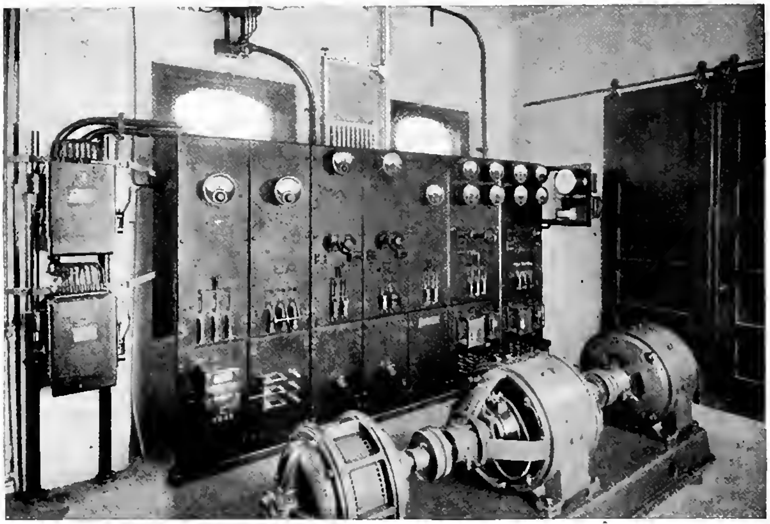


Fig. 12. Power Equipment for Alternating Current Signaling Installation on New York, New Haven & Hartford Railroad, Worcester, Mass.

The switchboard is so arranged that, by running all three motor-generator sets at the same time, the track batteries may be charged from any one, and the main battery from the other two connected in series; but should any one set be disabled the main battery may be charged from the remaining two, and when the charge is complete the track batteries may be charged from either one of these. Thus by alternating the times of charge the two sets of batteries may be charged one at a time from the two motor-generator sets, so that the disability of the other set will not cripple the system.

With the exception of the air compressor governor, which is located on the wall, the automatic starting equipment is all mounted on the switchboard. The air governor is set for operation between 80 and 90 pounds per square inch. A six-pole double-throw lever switch connects one or the other of the compressors to the operating circuits.

### LONG ISLAND RAILROAD

The recent electro-pneumatic a-c. signal installation on the Long Island Railroad at Jamaica, N. Y., requires four separate interlocking towers, all of which receive a-c. power at 2200 volts, 25 cycles, which is transformed to 220 volts for delivery to the switchboard. The compressed air for operating the switches and signals is obtained from the company's car shops at Morris Park, near tower "R."

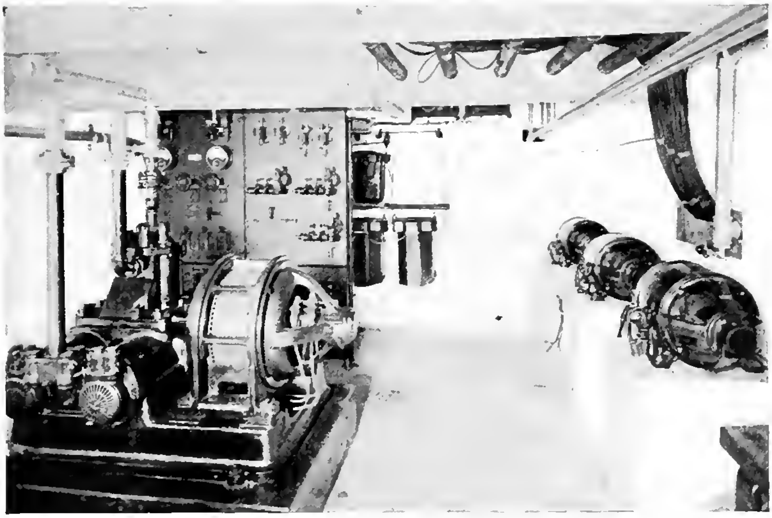


Fig. 12a Power Station in Electro-Pneumatic Interlocking Tower, Delaware, Lackawanna & Western Railroad

Both steam and electric trains pass through the interlocking, but by far the greater number are electric, as the lines to New York and Brooklyn are electrified. 500-volt d-c. propulsion current is supplied from the insulated third rail.

In each of the two small towers, "R" and "MP," the motor-generator set for charging the duplicate 7-cell lead type interlocking battery consists of a 220-volt, single-phase, 25-cycle induction motor and a 25-volt, 25-ampere shunt wound d-c. generator. The switchboard distributes at 220 volts single-phase to the induction motor and to the track circuits, and from the latter further transformation is made at each track section to a lower voltage. It also supplies one of two duplicate transformers for the signal lighting circuits through the upper contacts of a relay held in by energy from the a-c. circuit. Upon failure of the a-c. supply this relay connects the lighting circuits to the d-c. storage battery.

At each of the two larger towers "J" and "JE" the switchboard distributes at 220 volts single-phase to the motor, track circuits and lights. On account of the more extensive distribution of the lighting feeders, it is not feasible to supply them at low voltage as from the two smaller towers. To provide the feature of having emergency power available for the lighting circuits when desired, the motor of the set is made of the synchronous type, excited from the d-c. machine, and upon failure of the a-c. supply the d-c. machine will run as a motor from the storage battery and the a-c. machine as a single-phase generator, supplying only the lighting circuits. To govern this emergency action a master relay energized from the a-c. source having upper and lower contacts, an automatic starting equipment and two field rheostats for the d-c. machine, are required. The connections to the two rheostats, are interchanged by the master relay, one rheostat being in circuit when the machine is generating and the other—for governing the speed of the set—when motoring.

The control circuits are so connected through the relay contacts and a third blade of the lighting switches that should the a-c. power fail in the daytime, when the two lighting switches are open, the set will come to a standstill if charging the batteries, or remain at a standstill if in this condition. When the lighting switches are closed, the set, if charging the battery, will continue to run from the battery; but, if the set is at a standstill, the automatic starting equipment will immediately become active and start the set, throwing power on the lighting circuits from the a-c. machine within a very few seconds.

Fig. 13. "JE" Tower, Long Island R.R., Jamaica, N. Y.

The automatic equipment is arranged so that upon reversal of the set the lighting circuits are cut free from the 220-volt bus, otherwise the set would become overloaded and pump back on the supply line. A switch is provided in the starting control circuit so that the set may be started at any time desired.

The switchboards and sets in the two larger towers are exactly the same in design and arrangement, the only difference being in capacity of equipment, to provide in one a normal charging rate of 40 amperes and in the other 60 amperes.

### SOUTHERN RAILWAY

The General Railway Signal Company have now under construction four signal installations on the Southern Railway which require seven substations and two power stations. Four of the substations: Lynchburg, Va., Morristown, Tenn., Howell and Gainesville, Ga., are exact duplicates, receiving the power from commercial sources at 2200 volts, three-phase, 60-cycle and delivering 30 kv-a. at 4400 volts, three-phase, The substation at Coster, Tenn., receives power at 220 volts and delivers 30-kv-a. at 4400 volts, three-phase, 60-cycle. The two remaining substations are "outdoor type," that is, a steel switch house is located at the foot of a pole structure supporting the transmission line and houses the switchboard, instruments, meters and instrument transformers. The power transformers, disconnecting switches, choke coils and lightning arresters are supported on the pole structure. The power houses at Monroe and Whittles, Va., are exact duplicates except in capacity.

In these nine stations standardization has been strenuously adhered to. One power station has a capacity of 50 kv-a., three-phase, and the other power station and six substations 30-kv-a., three-phase; the remaining substation, connected temporarily single-phase, will ultimately be the same.

All stations bear a similarity in layout and arrangement of apparatus. Disconnecting switches are provided at the low tension side of power transformers and at the line side of the high tension apparatus. The automatic oil switch, ground detector, current and potential transformers for the meter instruments, inverse time-limit overload relay, choke coils and lightning arresters are connected in the 4400-volt circuit in the order given. One potential transformer is between the power transformer and the oil switch to indicate whether power is available from the supply.

The switchboards of the four duplicate substations consist of two panels 90 in. high, each of two sections of natural black slate mounted on pipe supports and surmounted by the ground detector. Two incandescent lamps in goose neck brackets afford ample illumination for the horizontal edgewise instruments directly beneath. Current may be read in any phase on the one ammeter by a three-way ammeter switch, and a short-circuiting switch is provided to protect the instrument against the heavy starting load. Switches are provided for station lighting. The watthour meter is mounted on the subbase.

The two power house switchboards each consist of three panels similar in height of sections, material and mounting to the four substation switchboards. The high tension feeder equipment and its comparative arrangement in the circuit is identical with that in the substation feeders. As the generator voltage is 220, the triple-pole fused main switch acts as a disconnecting switch for the low tension side of the power transformer. A voltage regulator and the customary equipment for controlling the generator and its exciter are provided.

The substation switchboard at the Coster power house consists of two panels 90 in. high, each of three sections of blue Vermont marble mounted on angle iron supports to match and line up with the existing power switchboard. The equipment is identical with the two power-house switchboards, except for the omission of the regulator and panel, rheostat handwheel, exciter switch and exciter instruments, with the consequent reduction in width of the low tension panel.

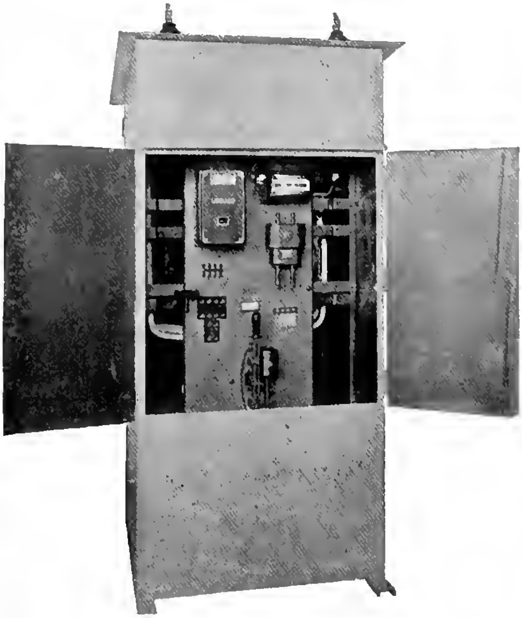


**Fig. 14. Front View of Outdoor Substation, Three-Phase, 4400-Volt Railway Signal Line, Southern Railway**

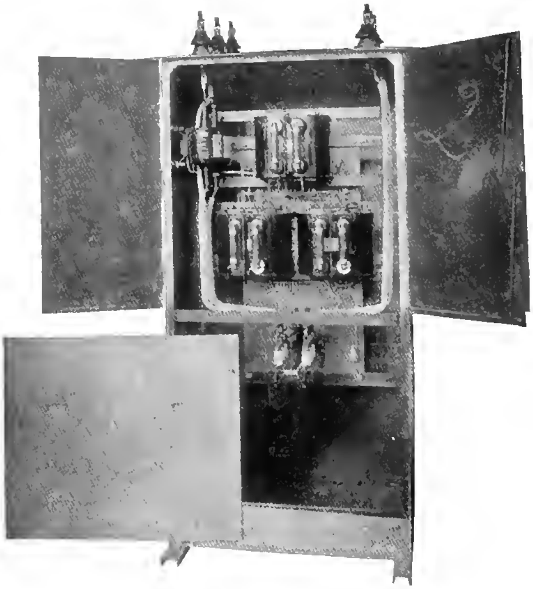


**Fig. 15. Back View of Outdoor Substation shown in Fig. 14**

Figs. 14 and 15 show front and rear views of the first outdoor type substation of this particular class for railway signal purposes. Two of these stations are to be installed, one at Inman, S. C., and the other at Austell, Ga. They are duplicates except that the latter is temporarily connected single-phase, although the full three-phase equipment is furnished so that it may be made three-phase in a few moments by slight changes in the instrument transformer secondary circuits. The equipment is the same as that for the other substations, except that no provision is made for reading current. The instrument transformers and high tension connections are clearly shown in the back view. A lamp with key socket provides ample light for reading instruments.

### SIGNALING ON INTERURBAN LINES

Hand-controlled lamp signals for turnouts and sidings and stretches of single track have been in use for some time, as well as the automatic permissive signals so common on single track portions of the city lines which permit movement of any number of cars in only one direction until the section is clear before allowing a movement in the opposite direction. These, however, place no restriction on the spacing between cars and give no indication as to the condition of the track ahead.

Interurban service is akin to railroad service in that it requires heavier rolling stock, increased speed and a definite time schedule to be maintained under all conditions of weather. Such rapid strides have been made in the development of interurban equipment in the past few years that automatic block signaling has become not only a refinement, but a necessity.

The latter half of the year 1913, saw a great many extensive signal installations on interurban roads, notably the lines in Ohio, Indiana and Illinois, on the Scranton & Binghamton line in Pennsylvania, and on the New York State Railways near Rochester and Syracuse.

In nearly every instance the switchboards, power transformers and switching equipment are installed in the same substation with the rotary converters that supply the motive power. Power is taken from the mains supplying the rotary converters (usually 370 volts, 25 cycles) and stepped up through duplicate transformers to 2200 volts for distribution to the 2200/110-volt transformers supplying the block sections. In some instances the transmission voltage is 4400.

In most cases the switchboards are 90 in. high and of two or three sections, slate or marble, to match the existing switchboard. Where unnecessary to line up with existing boards, 48 in. panels on 76 in. supports are usually furnished. The controlling equipment for a two-circuit-feeder panel usually consists of two fused lever switches supplying the step-up transformers, two oil switches with inverse time-limit overload relays and alarm bell attachment, two current transformers and ammeters with an illuminating lamp, and an alarm bell to give notice of an open oil switch.

Boards installed at the end of the signaled territory are only single-circuit, but in those cases where the signaling will be extended at some future time the boards in many instances have been made of ample size to contain the equipment for two circuits, although equipment for only one circuit is furnished.

On many switchboards that have the ammeter connected in the supply side of the step-up transformer, it has been necessary to furnish a switch to short circuit the ammeter on energizing the line because of the heavy momentary rush which sometimes occurs when connecting the transformer—particularly a low frequency transformer—to the supply line under load. To eliminate this trouble and get away from an oil switch which has a rupturing capacity far in excess of what is required on such low capacity circuits a switchboard has been developed and built for the Union Switch & Signal Company, for an installation on the Scranton & Binghamton road. The double-pole circuit breaker in the low tension side furnishes ample overload protection, and ordinary outdoor type plug cutouts guard against possible trouble from the outside. The low tension sides of the duplicate transformers are connected to the d-p. d-t. lever switch and the high tension sides to the plug switches and only one pair of plugs furnished, so that the inactive transformer will be dead. For two circuits either duplicate panels or a panel with double this equipment would be furnished.

## NEW YORK, WESTCHESTER & BOSTON RAILWAY

The New York, Westchester & Boston Railway, connecting White Plains and New Rochelle with New York City, is the only strictly suburban electric railroad built from the ground up without an old road bed as a basis. It consists of a four-track section approximately seven miles in length connecting with the four main tracks of the Harlem River branch of the New York, New Haven & Hartford Railroad system near 174th Street, New York City, and extending northward to Columbus Avenue, Mount Vernon, where it separates into two double-track lines, one continuing northward to White Plains, 9.4 miles, and the other eastward to New Rochelle, 2 miles, where it again connects with the New Haven system.

Transportation systems in New York City are universally direct-current furnished by substations; this road, however, from its connections with the New Haven system and the successful operation of the installation there existing, naturally installed the same system. Power is purchased from the New Haven power house at Cos Cob, Conn., the connection being made at the end of the New Rochelle branch sixteen miles distant. The transmission is three-phase, 11,000 volts, the conductors being carried on the extended posts of the steel compound catenary structures. Though only one phase is used for propulsion, the three-phase circuit is carried from the point of supply to the machine shops, elevator motors, pumps, and substation for the signal system.

On steam roads either direct- or alternating-current signal circuits may be selected; on roads having direct-current for propulsion using both rails for both propulsion and signal current, the latter must be alternating; but on roads using alternating-current for both propulsion and signaling, employing both rails for both circuits, the frequency of the latter must not be a low harmonic of the former. This is necessary because of the fact that the signal relays must be selective as to frequency. Suppose the propulsion current to be 25-cycle and the signal current

60-cycle, each supplied from a different source. Now if the former should rise to 30 cycles, or the latter drop to 50 cycles, the frequency of the signal circuits would be just twice that of the propulsion circuit and serious trouble result from false signal indications. To obviate such difficulties and maintain a certain fixed ratio between the frequencies of the two circuits, a motor-generator set supplied from the same source is necessary.

Ordinary fiber-insulated rail joints at the ends of the blocks serve to isolate the track circuits in each block; but to permit the continuous flow of the return propulsion current impedance bonds are installed in pairs at each block end across the two rails, one on each side of the insulated joints. These are coils wound on an iron core, with the middle taps of the coils of each pair connected together. They are enclosed in an iron case mounted between the rails with the top practically flush with the surface of the ballast. An installation is shown in Fig. 8 of the first article of this series (December, 1913). The propulsion current passes into both ends of one bond, through the common wire, and into the two rails of the other block through the two ends of the other bond; and thus, by setting up neutralizing magnetic fields in each bond, passes across the block section with a negligible energy loss. As the signal current flows in opposite directions in the two rails, it flows through the bond from end to end, and as the bond is highly inductive, a choking effect is introduced which permits only a negligible portion to pass through, shunting practically all the track circuit current through the track relays.

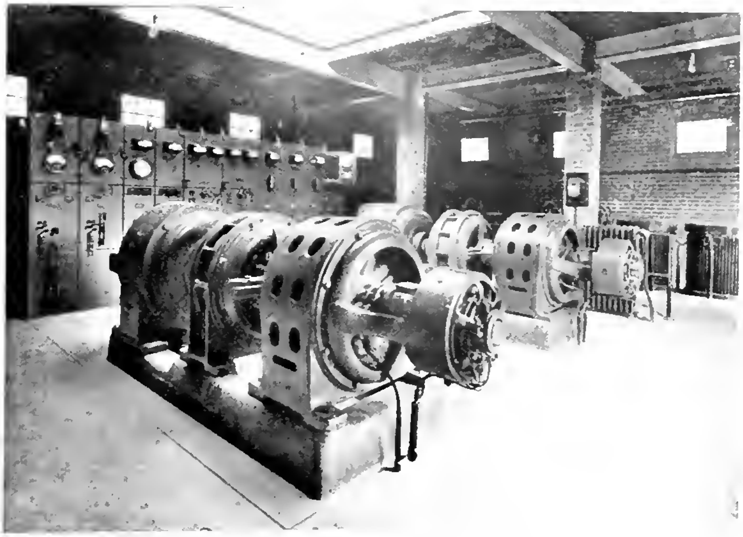


**Fig. 17.** Interior View of Signal Substation shown in Fig. 16

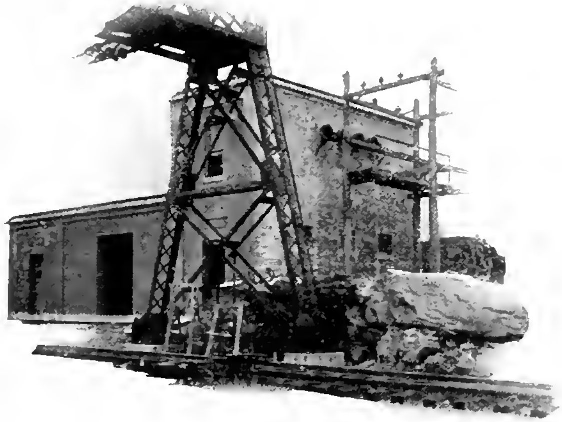


**Fig. 16.** Exterior of New York, Westchester & Boston Rwy. Signal Substation, Columbus Ave., Mt. Vernon, N. Y.

The signal substation at Columbus Avenue, Mount Vernon, is a brick structure of one story, with a high tension gallery at one end for the entrance of the two three-phase, 11,000-volt duplicate lines. Only four wires are brought into the building, as the completing wire for each set of lines comes from the grounded tracks. The gallery contains the high tension multigap lightning arresters, disconnecting switches, choke coils, a d-p. d-t. disconnecting switch for selecting operation between the two pair of lines, high tension series inverse time-limit, overload relays for tripping the two main oil switches downstairs, and high tension instrument transformers, all insulated to stand a surge potential of 30,000 volts. Surges are frequently set up by disturbances on the propulsion circuit and the phases are badly unbalanced because the voltage regulators on the Cos Cob generators regulate on the "propulsion" phase, which necessarily fluctuates greatly.

The ground floor of the substation is divided into three parts, viz., the high voltage section directly under the gallery containing the two line switches and duplicate banks of step-down transformers, the operating room, containing the switchboard and duplicate motor-generator sets, and the battery room.

From the disconnecting switch in the gallery selecting between the two incoming lines, all the apparatus is in duplicate. One complete equipment consists of a small panel for a d-p. s-t. oil switch (double-pole because one leg of the three-phase circuit is grounded); three delta-connected transformers stepping down from 11,000 to 440 volts; a four-unit motor-generator set consisting of 75-h.p., Form K induction motor, a 10-pole, 37-kv-a., 2200-volt, 60-cycle single-phase alternating-current generator with 3-kw., 125-volt exciter, and a direct current machine to operate between 110 and 160 volts as a generator to charge the storage battery, and 110 to 90 volts as a 75-h.p. motor; and controlling equipment for each machine on the switchboard. One set is of sufficient capacity to take care of the probable ultimate requirements of the road, so that the other may be always kept as a spare.

Under normal conditions the d-c. machine is either charging or floating on the battery. Upon failure of the power supply, the low voltage trip attachment opens the main line oil switch, cutting off the induction motor, whereupon the d-c. machine acts as the motor of the set. The speed regulator on the d-c. machine and the voltage regulator on the a-c. machine are so nicely adjusted that a failure and subsequent resumption of supply power produces no noticeable effect on the signal supply. Upon resumption of power the operator closes the main line switch (it being unnecessary to synchronize as the motor is of the induction type), and the operation is resumed, the d-c. machine charging at a greater rate because of the depleted condition of the battery.

The switchboard consists of d-c. generator-motor panel, induction motor panel, and a-c. generator panel, each in duplicate, and the three twin-circuit feeder panels. The d-c. panels each have a starting switch for starting the set from the storage battery, although it is usually started from half voltage taps on the transformers through double-pole, double-throw lever switch on the motor panel. The d-c. panels also have circuit breaker, double reading ammeter, line switch and rheostat handwheel for regulating the charging. On the back of each panel is another rheostat that is cut into circuit by the speed regulator when the d-c. machine is motoring, but this is set to maintain proper speed under full load.

The battery is of sufficient capacity to drive the set under full load for 25 minutes, beginning with a full charge, before the voltage falls to 90. When it reaches this value a circuit breaker located on the back of the board and calibrated to trip out at 90 volts, or under, will open the circuit in order to save the battery from destruction. This precaution is hardly necessary, for failures have been at most only of few minutes' duration.

The generator panels also provide exciter control, and the speed regulator relays and contactor equipment are mounted on the subbases. The three feeder panels feed in all three directions from the junction point, each supplying twin single-phase lines through a d-p. d-t. oil switch having a common trip coil. The duplicate signal mains carried on the extended posts of the catenary bridges supply step-down transformers for the signals and track circuits. The lines are run in pairs so that should one become grounded or defective, or require repairs at any point, that portion between the two adjacent sectionalizing outfits may be cut out and operation continued through the other.

The seven interlocking plants are all built along similar lines. Direct current for operating the switches and interlocking functions is furnished from a 110-volt storage battery. The switchboard, Fig. 17, taking power at 110 volts, 60-cycle, single-phase from duplicate transformers supplied from the signal transmission line for furnishing power to the track circuits and lights on either side of the tower controls the small motor-generator set for charging the battery by continuous floating.

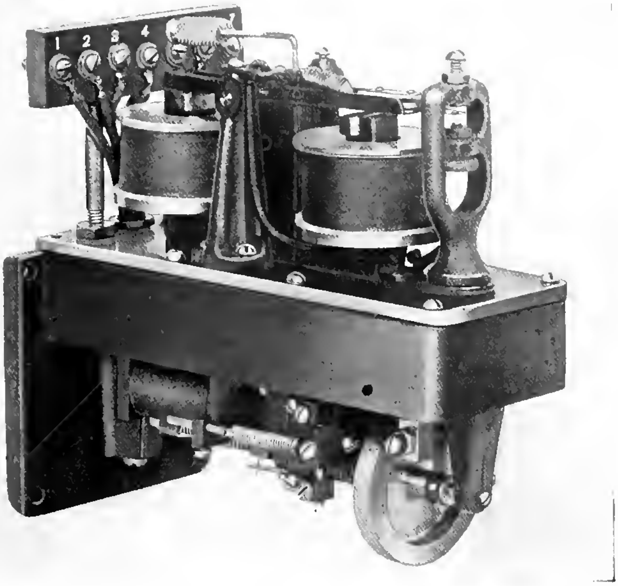
# FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

## FAULTY-FEEDER LOCALIZER

In the operation of a high-tension electrical system, it frequently happens that a single wire arcs to ground. This arc may be caused by lightning, weak insulation, or some remote disturbance on the system. Unless this arc is extinguished it will very quickly cause considerable damage such as burning off the wire, breaking an insulator, or arcing to the other phase wires, thus causing a short circuit (a non-grounded neutral system is here assumed). It is the function of the arcing-ground suppressor to promptly extinguish this arc before damage results.

Suppose the fault to be of permanent nature. If there are a number of feeders connected to the bus there is no way of telling on which one the arc has occurred. The faulty-feeder localizer is designed to select the faulty feeder and light the corresponding indicating lamp, thus giving this important information to the station operator. With this knowledge the operator can substitute a good feeder for the faulty one, cut off the defective feeder, open the switch of the arcing-ground suppressor and the system has been returned to its normal operation without even a momentary delay to any substation. (This assumes that the insulation of the system is high enough to stand operation with one-phase wire grounded for a short time.) It should be noted that while the faulty-feeder localizer and arcing ground suppressor form an ideal combination either device may be operated independently.

The localizer consists of a set of interconnected relays (one relay for each feeder). These relays have two coils each, the pulls of each coil of the pair are balanced against each other, and the only relay which operates is the one in which an unbalancing occurs. By properly connecting up the relays, they are made independent of all load current, no matter how unbalanced. A time-limit device is added to the relay to make it independent of momentary surges. These two parts form a unit and there is one unit for each feeder. The relays are mounted on the back of a panel. This panel carries on its front the indicating lights and also the switches necessary for retaining the balanced condition of the relays under different operating conditions. This balancing operation is very simple. If a feeder is in service its corresponding relay switch is placed in the upper position. If the feeder is out of service the relay switch is thrown down.



Faulty-Feeder Localizer

The relays are operated from the feeder current transformers. It is necessary to have a current transformer in every high-tension wire of every cable on which it is desired to operate the localizers. The transformers in a single feeder have to be of the same type and ratio; however, it is not necessary for transformers on different lines to be similar. It is possible to use either the meter transformers or the overload relay transformers (provided a complete set is installed on each feeder) without interfering with either of these devices. An alternate arrangement is to install separate current transformers for the localizer.

The localizer is not intended to prevent a fault developing and consequently, will not do so. It only indicates the defective line after the fault has developed. A. H. D.

# QUESTION AND ANSWER SECTION

The purpose of this department of the Review is two-fold.

First, it enables all subscribers to avail themselves of the consulting service of a highly specialized corps of engineering experts, or of such other authority as the problem may require. This service provides for answers by mail with as little delay as possible of such questions as come within the scope of the Review.

Second, it publishes for the benefit of all Review readers questions and answers of general interest and of educational value. When the original question deals with only one phase of an interesting subject, the editor may feel warranted in discussing allied questions so as to provide a more complete treatment of the whole subject.

*To avoid the possibility of an incorrect or incomplete answer, the querist should be particularly careful to include sufficient data to permit of an intelligent understanding of the situation. Address letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.*

## Announcement

In the 1914 Annual Index of the General Electric Review, included in this issue, there appears a complete classified index of the Question and Answer material for this year. It is recommended that this index be kept at hand in order that the greatest service to be derived from the solutions of past problems may be conveniently available.—Editor.

### TRANSFORMER: EXPLOSION

**(122) What is the initial cause that later results in an oil-cooled transformer blowing-up or exploding?**

**What is the action following the primary cause that actually produces the explosive effect?**

**What attention is given in the construction of standard transformers to the prevention of explosions?**

The condition which renders favorable the possibility of an explosion within the tank of an oil-cooled transformer is that of an accumulation of hydrocarbon gases and hydrogen mixed with air between the surface of the oil and the transformer cover. Provided no vent is supplied whereby the inflammable gases may escape from the case, an accumulation of them may result from an electric arc or succession of arcs beneath the oil surface.

Although confined, no inflammable mixture of gases and air will explode unless raised to its flash temperature by a flame, spark, etc. Where explosions have occurred, the ignition may be attributed to an arc, or to corona on the conductors or leads, above the oil surface.

Since it is far preferable to avoid the possibility of having an explosion occur and since it has been found impracticable to design a tank to resist a severe explosion should it take place, standard transformers are equipped with "breathers" or gas vents which, besides minimizing the condensation of moisture, permit the escape of the generated gases fast enough to prevent the production of a highly-explosive mixture.

R. K. W.

### CATENARY TROLLEY CONSTRUCTION: STRESS FORMULAE

**(123) Will you please publish or furnish references to a set of formulae from which the stress occurring in the messenger cable and in the trolley wire, as used in catenary construction, may be obtained. It is desired that they apply to a line having hangers about 10 ft. apart and spans varying from 90 to 150 ft., and that they take into account variations of temperature from −20 deg. to +120 deg. F. and at least an 8-lb. wind and a $\frac{1}{2}$ inch ice load, also combinations of these conditions.**

As far as we know, no set of formulae has been arranged that will give exact results when applied to catenary trolley construction. Since the messenger cable has approximately uniform loading only at normal temperature, ordinary transmission line formulae are not strictly correct. They are, however, often used where actual test measurements are not at hand. Useful formulae have been published at various times of which consideration may be given to the following:

*Proceedings A.S.C.E.*, June, 1908—Mr. R. D. Combs.

*Elect. Rwy. Journal*, October, 1908—Mr. R. L. Allen.

*Overhead Electric Power Transmission*, Mr. Alfred Still.

*Handbook on Overhead Line Construction*—N.E.L.A.

C.J.H.

### TURBINES: RELIEF VALVES LOW-PRESSURE END

**(124) What is the reason for not installing relief valves on the low-pressure end of Curtis turbines?**

Any small valve which could be provided on the shell of a large turbine to allow for a discharge into the station could only be considered as a signal or alarm, for it would not be practicable to place in such a position on the machine a valve that would be sufficiently large to be of any material benefit in preventing excessive pressure in the shell. In fact, any small relief valve placed on a large turbine is more liable to prove to be a source of danger than to be one of benefit, for the reason that the station operators might consider this valve would prove to some extent a safeguard in operation which, of course, it could not.

The larger the turbine the greater the degree to which this statement holds true. Operating engineers, realizing this, arrange to install an atmospheric relief valve on the condenser or on a connection between the turbine and the condenser. This valve is made to have sufficient capacity to prevent an excessive pressure being built up in the shell should the condenser fail at any time.

In the case of small turbines it would be practicable, of course, to place a relief valve of ample dimensions on the machine. However, it has been commonly experienced that in practically every case the operator prefers an atmospheric relief valve that can be piped up to discharge out of doors; and, consequently, since it seems best, the uniform practice of not installing low-pressure relief valves on all size Curtis turbines has been adopted.

E.D.D.

# GENERAL ELECTRIC REVIEW

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