GENERAL ELECTRIC REVIEW

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GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

We publish in this issue our usual annual review of progress in the electrical industry, and while there are no strikingly novel industrial developments to record, there is a thoroughly sane and healthy progress in almost every field of activity. It is particularly interesting to analyze developments and note wherein we are always making gradual but sure progress without radical changes. Most of our modern developments are improvements in methods and in machines which lead to an increase in efficiency; and again higher efficiencies are being obtained by finding each year new ways and means of getting "higher duty" out of our materials.

Economies can almost always be secured when we can operate at higher speeds, higher pressures, higher voltages, and at higher temperatures, and much of our modern progress has been made possible by the development of new materials which give a higher service duty with the same or greater factors of safety than could be secured previously by using less highly developed materials.

This general state of conditions has been more or less true for many years past, but was less noticeable in the electrical industry during the period of its most phenomenal growth, because such developments were overshadowed by the many great inventions and startling discoveries that gave the world a new industry—an industry that grew from next to nothing to be one of the most important in the increditably short period of a quarter of a century.

That we should have satisfactory progress to record each year in the electrical industry is the more remarkable when we bear in mind that electrical machines—generators, motors, transformers, etc.—have reached such a state of perfection in the conversion and transformation of energy that only a bare three or five per cent stands between their present capabilities and theoretical perfection. It is these remarkable accomplishments in the past that leave us so dependent upon an increase in the "efficiency of materials" for our present progress.

In passing, it is interesting to note the commercial aspect of the problem—our activities are largely confined to giving a better kilowatt value of machinery for a dollar, and it is this particular phase that makes the efficient use of material such an economic factor in the electrical industry. In this connection it is interesting to note that the more highly developed our electrical machines become, the greater is the kilowatt capacity per pound of material used. A more perfect general understanding of this fact would eliminate many foolish comparisons between the cost of electrical machines and machines of other classes. The object of the electrical engineer is to give as great a kilowatt capacity as possible for a dollar—not as many pounds of material as possible for a dollar.

When a problem has once been thoroughly defined and its limits set, we can consider that we are well on the road to a solution; and it is the recognition of the all-important part played by securing the materials best suited to any particular need and the determination of the most efficient means of shaping them to our purpose that has led to the appreciation of the value of industrial research work.

During the past year we have constantly been recording in these pages the results of industrial research work, and we hope to be able to continue this interesting phase of our work during the coming year; and, in further recognition of the importance of this part of our activities, we hope to publish in our next issue a review of the scientific accomplishments during 1915.

DEVELOPMENTS IN THE ELECTRICAL INDUSTRY DURING 1915

By John Liston

Publication Bureau, General Electric Company

In any line of human endeavor it is interesting and instructive to look back over a period of months with the purpose of obtaining a clear conception of the progress of that period, and of comparing this progress with the advance made during the similar preceding period; and although we could not allow the author space in this issue for a review of all the developments that have been made in the science and application of electricity during the past year (for instance, the wonderful achievements in wireless telephony), the author has given our readers a very interesting summary of those developments that bear directly on the electrical industry.—Editor.

While the year 1915 witnessed no phenomenal achievements in the application of electricity, with the possible exception of the vastly increased radius of operation for wireless telephony, there were secured certain substantial improvements and numerous detail advances in the design, construction and operation of various classes of apparatus which were indicative of a continuous and healthy growth of the electrical manufacturing industry.

A number of the power plants put into commercial service included machinery of exceptional capacities, and there was evident in several relatively new fields of application a well-defined tendency toward the exclusive use of electrical apparatus for power purposes. There was also a clear indication of increasing reliance on the automatic features of operation, supply and protection, characteristic of numerous recently designed electrical equipments.

In certain classes of apparatus, which were already highly developed, the efforts of the designing engineers were largely confined to securing an increase in the factor of safety, while in other cases refinements in design rendered possible the attainment of improved efficiency and operating economy. Units of unusual size and rated capacity were exemplified by electric railway locomotives and steam turbine generating sets.

This article is not intended to cover the entire field of the industry, but, although necessarily limited in scope, it outlines briefly some of the more important or exceptional facts in regard to the apparatus designed or constructed by the General Electric Company, which should prove of interest to the engineering fraternity.

Electric Propulsion of Ships

The decision of the Navy Department of the United States to provide electric propulsion for the superdreadnaught *California* constituted one of the most notable electrical developments of the year, interesting alike to electrical and marine engineers, inasmuch

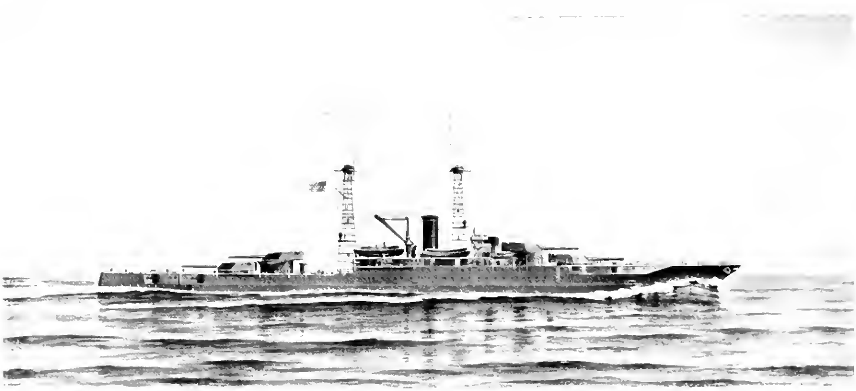


Fig. 1. U. S. Battleship *California*

as it marked an important advance in the practical application of electric propulsion for ships

The first installations for this service were on ships of relatively low tonnage, and their successful operation led to the adoption of electric propulsion for the 20,000-ton collier *Jupiter*, which has been two years in service; and now, by the award of the contract for electric propelling machinery for a 32,000-ton battleship, this form of propulsion will be subjected to severely practical tests on one of the largest and most powerful ships that have been authorized by the United States Navy. The results thus obtained cannot fail to have a widespread influence on the future design and equipment of naval and merchant ships throughout the world

The *California*, which is now being built at the New York Navy Yard, will have a maximum speed of about 22 knots, at which speed about 37,000 shaft horse power will be required. (Fig. 1.)

The propelling machinery will comprise two steam-turbine-driven generators and four propelling motors, one for each shaft. There are also two turbine-driven exciters, supplying current in addition to excitation requirements, for a complete equipment of condensing auxiliaries and ventilating motors, which are all motor-driven The exciter units are rated at 300 kw., 240-volt direct current, the generators in each case being geared to a high speed non-condensing turbine.

The main generators for the *California* are bi-polar alternators, and the propeller motors, which have a normal rating of 7500 h.p., 4000-volt, quarter-phase, 25-cycle, are wound so that they can be connected either for 24 or 36 poles. This will insure economical operation at cruising speeds of 15 knots or less, as under these conditions only one generator will be required, with the motors on 36-pole connection. For higher speeds the 24-pole connection will be used, and for maximum effort both turbines will be operated, although the ship will be able to make as high as 18.5 knots with one generator in action.

On the *Jupiter* the speed variation is secured by means of variable speed governors on the turbine, and it has been found possible by this means to hold, automatically, any desired speed within the usual ranges This method effectively prevents racing and enables the ship to maintain a fixed schedule irrespective of ordinary variations in sea, weather or steam conditions, and the same system of control has therefore been adopted for the *California*.

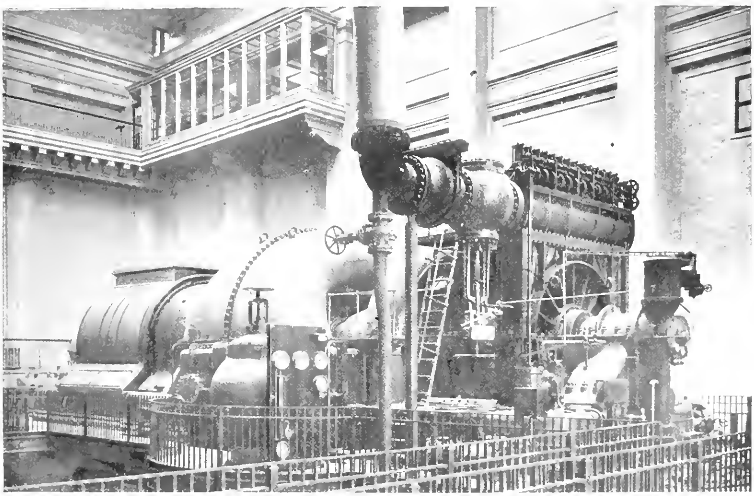


Fig. 2. 35,000 Kw. Curtis Steam Turbine in Christian Street Station of Philadelphia Electric Company

The estimated weight of the propelling machinery, without condensing auxiliaries, is only 530 tons, while the simplicity and compact arrangement of the two main generating units and the four propelling motors will give an economy in engine room space impossible to attain with any other form of propelling machinery of equal rating.

Turbines

The tendency toward the concentration of large energy capacities in single turbo-generators, which has characterized the past few years of turbine development, was emphasized by the construction and installation during 1915 of a 35,000-kw. unit, operating at 1200 r.p.m. and delivering its output at 13,200 volts, three-phase, 60 cycles. The turbine element has thirteen stages and is designed for a steam pressure of 215 lb., with 28½ in. vacuum and 150 deg. superheat. (Fig. 2.)

Like all of the large turbo-generators produced by the General Electric Company, this set constitutes a compact, self-contained unit, with both the turbine and generator mounted on a common base. The space economy thus secured is clearly indicated by its overall dimensions, especially when we have in mind the fact that it is the largest single unit turbo-generator ever built. With its self-contained exciter it has a length of only 62 ft. 7 in., a width of 21 ft. 7 in., and a height of 15 ft. 10½ in. It is of the horizontal shaft type and operates condensing, having a 50,000 square foot surface condenser; this being the largest condenser ever provided for a steam turbine.

The horizontal shaft carries a turbine rotor weighing 105,000 lb., and a generator field of 135,000 lb., the total weight for the complete unit being 1,200,000 lb.

Other large turbo-generator installations included two of 20,000-kw. rating for the Detroit Edison Company, two 20,000-kw. units for the Public Service Corporation of New Jersey, one 30,000-kw. unit for the Chicago Edison Company, and one 30,000-kw. unit which, together with the 35,000-kw. set already referred to, was installed in the Christian Street Station of the Philadelphia Electric Company.

Aside from the construction of these large turbines for the driving of electric generators, there has arisen during the year a considerable demand for relatively small turbines, to be used for economical prime mover service in place of small, high speed engines. These turbines have rendered it possible to utilize direct drive for high speed rotating machines, such as centrifugal pumps, blowers, etc , and have proven extremely flexible in operation. They are in each case selected for a particular class of service, and their horse power rating and steam consumption can be selected to meet any specific load requirements. They are ordinarily rated according to wheel diameter.

Considerable advance has been made in geared turbines and during the year several high speed turbines, driving slow speed shafts through the speed reduction gearing developed by the General Electric Company, were placed in commercial service. These turbines are direct geared to direct current generators and to 25 cycle alternators, and are also used for mechanical drive. (Fig. 3.)

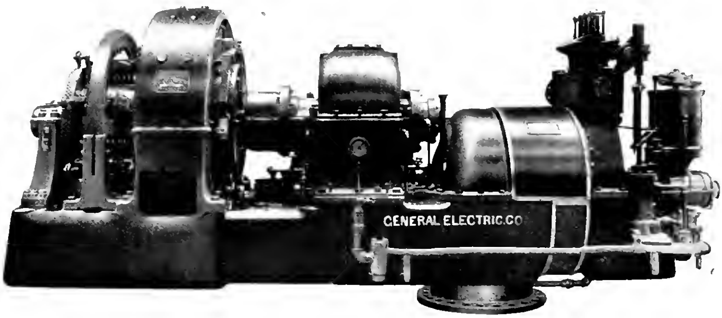


Fig. 3. Low Speed Gear for 500-kw. Turbine, 5000/900-r.p.m.

Among the new designs there were included a 1500-kw., 4000-r.p.m. turbine driving a 500-r.p.m., 25-cycle generator, and two 1750-h.p. turbines with double reduction gears which were installed as cruising turbines in the U. S. S. *Nevada*. The *Nevada* was accepted by the Government after very satisfactory official tests

Geared turbines are being more extensively used for the main drive in merchant vessels. Two of these were installed in 1915 and are now in service, while several others were under construction at the close of the year. The ships thus equipped are engaged in freight service and have ratings of from 6000 to 10,000 tons, while the energy required for individual ships ranges from 2500 to 4500 h p. and the turbines, through the gearing, give propeller speeds of from 75 to 90 r.p.m. The successful commercial operation of these gears has fully justified the high expectations which were based on exhaustive factory tests (Fig. 4.)

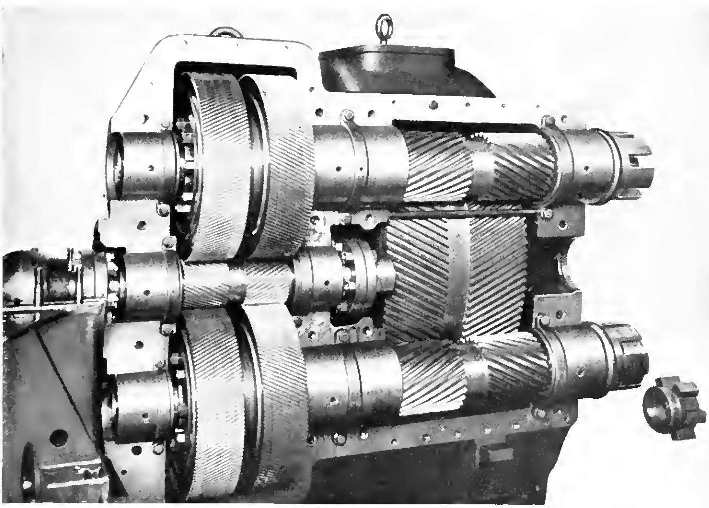


Fig. 4. A 1750-h.p. 3200/137-r.p.m., Double Reduction Gear

Gasolene-Electric Sets

The adoption, early in the year, of 5-kw. gasolene-electric generator sets for auxiliary wireless service on three large steamships, operating in the Pacific, is indicative of the reliability which can now be secured with well designed sets of this type, as this characteristic is vitally necessary in any system utilized for wireless operation on ships at sea.

For this class of service there has been developed a line of compact and highly efficient gasolene-engine-driven generating sets, especially adapted to marine conditions, which are relatively light in weight so that they can be safely and easily installed above the deep load line of a ship, where they are effectively isolated from the main power units and are available for emergency use. At the same time the two plants may, under normal conditions, be electrically interconnected and the operation of motors, lights and wireless outfits may be secured through either the main or emergency generating sets, or both. (Fig. 5.)

The reliability of these emergency sets is such that their starting is practically instantaneous, and if held simply as reserves the necessary periodical testing may be done without delay or difficulty, and without requiring the services of a skilled operator. The generator capacity selected for any ship will, of course, depend largely on the character of the work required, and whether the output of the emergency set is to be used for other than wireless service and emergency lighting.

Synchronous Converters

Perhaps the most important advance in this type of machine consists of the increased speeds which have been secured for large units. This increase can be best illustrated by reference to specific machines installed during the year, or in course of construction. Two of these are 60-cycle units, each rated at 1000 kw.; one being an 8-pole, 600-volt machine for operation at 900 r.p.m. (the former maximum speed for this class being 720 r.p.m.); the other a 10-pole, 240/300-volt unit, operating at 720 r.p.m. (the former maximum speed being 600 r.p.m.). There was also a 4000-kw. unit for 625-volt service, having 14 poles and operated at 214 r.p.m. (the previous speed for this capacity being 167 r.p.m.).

Fig. 5. Oceanic Steamship Company S. S. *Sierra* with 5-kw. Gasolene-electric Set as Auxiliary Wireless Power. Set Installed in Auxiliary Power House

At the close of the year there were six 4000-kw. converters under construction, and their completion will bring the total number of units of this capacity produced by the General Electric Company up to approximately thirty.

A device for the control of synchronous booster converters has also been developed and its operation can be readily understood from the following outline:

When a synchronous converter is driving a series booster, some device is necessary automatically to change the strength of the commutating field in order that good commutation may be secured throughout the voltage range. Formerly this was accomplished by the addition of a small shunt commutating field controlled automatically by means of contactors; but this method, although fairly satisfactory, did not give a very smooth commutating curve. The new method consists of a relay which maintains a balance between the kilowatts in the booster and the current in the shunt commutating field. The relay has two elements which are mechanically interconnected, one being actuated by the energy in the booster, and the other by the current in the shunt commutating field. The relay in turn operates a motor-driven rheostat, so that the necessary balance is maintained by an automatic variation in the strength of the shunt commutating field.

Phase Balancing Sets

In order to make it feasible to supply, from a three-phase system, 25-cycle single-phase power amounting to from 6000 to 10,000 kw., with frequent peaks of from 12,000 to 16,000 kw. of short duration, there were designed for the Philadelphia Electric Company two phase balancing sets which were under construction and nearing completion at the close of the year.

Each set consists of a 5000-kv-a. 500 r.p.m., 13,200/14,000 volt synchronous phase converter direct coupled to a 550-kv-a. 840-volt (per leg) phase voltage balancer. The sets will be capable of operating at 6000 kv-a. for one hour or 12,000 kv-a. for five-minute peaks.

The phase converter is a synchronous motor provided with very heavy squirrel-cage winding for the purpose of distributing the single-phase load equally on the three-phase system. The phase voltage balancer is a generator with two windings on the revolving field, 90 deg. apart electrically, and with its stator windings connected in series with the stator windings of the phase converter but in opposite phase rotation. The two field windings are excited from separate exciters so that by varying the relative values of excitation the resultant magneto motive force of the revolving field may be shifted in position. The exciters are controlled by voltage regulators in such a manner that the voltage of the two unloaded phases of the generator system will be kept equal to the voltage of the phase which delivers the single-phase power.

Transformers

There occurred a considerable advance in the use of the new circular coil core type transformer and as a result of previous experience a number of large capacity units of this design were built and installed. The mechanical and electrical characteristics of these transformers are such that they offer unusual resistance to the shocks incident to short circuits and high frequency disturbances, and they also possess natural advantages which secure for them very uniform operating temperatures. They have been constructed for self-cooled, water-cooled, and air blast operation, and their practical value

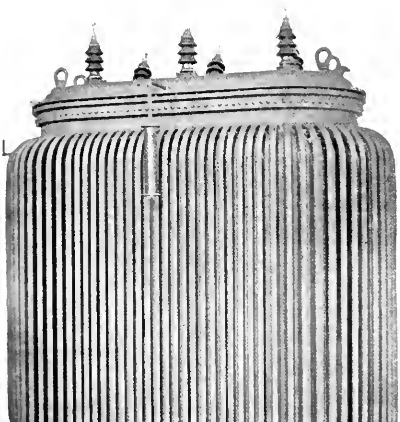


Fig. 6. A 5000-kv-a., 23,000/21,000-11,000-volt Circular Coil Core Type Self-cooled Transformer

for large capacities and the highest commercial voltages has been fully demonstrated. Typical large units of this type were adopted for hydro-electric, central station and railway supply systems during the year.

In the self-cooled type, applied in high voltage service, several three-phase units rated at 2500 kv-a. were provided for operation on 102,000-volt lines, and a single order for transformers of this type for similar service gave an aggregate rating of 43,200 kv-a.

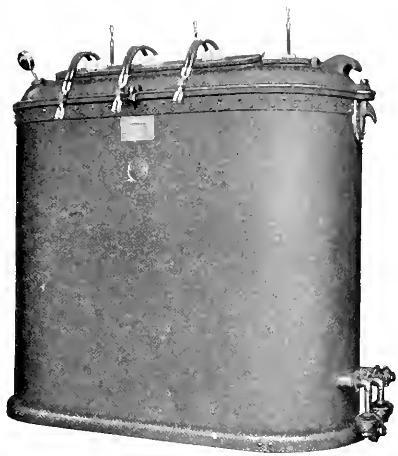


Fig. 7. A 6000-kv-a., 11,880/13,200-2300-volt Circular Coil Core Type Water-cooled Transformer

Still larger self-cooled units were produced, being rated at 5000 kv-a. for 23,000-volt service, and their great capacity places them among the largest self-cooled transformers ever constructed. (Fig. 6.)

The production of the water-cooled type included a number of units for operation on exceptionally high voltages, several single-phase 3000-kv-a. 140,000-volt units being built. At the close of the year there were under construction three-phase units of this type rated at 10 000 kv-a. for 95,000-volt service; and these, when completed, will represent the maximum capacity for this type of transformer so far produced.

An unusually large air blast transformer of the shell type was constructed and placed in operation. It is a three-phase unit for auto-transformer service, designed for a continuous output of 20 000 kv-a.; the high voltage windings being for 14,000 volts. It is notable, not merely on account of its size and the design which gives it the exceptionally strong mechanical features necessary to meet the severe service conditions under which it must operate, but it is also physically the largest air blast transformer ever built. All the transformers which have been referred to, except the large air blast shell type unit, are

Fig. 8. A 20,000-kv-a., 8100/14000-4050/7000-volt Shell Type Air Blast Auto-Transformer

of the new circular coil core type design, and adequately typify the progress which has been made for this class of apparatus.

Reactances

Modern practice has included reactances in the equipment of all well designed generating plants of appreciable size, in order to prevent the occurrence of injurious strains on apparatus by limiting the momentary power delivery of generators and transformers under short circuit conditions.

Since their introduction, reactances have undergone some modification in structure and design, and, as the result of data secured in commercial operation over long periods, supplemented by exhaustive practical tests, the cast-in-concrete form of reactance has been perfected by the General Electric Company. Numerous installations have tended to confirm, under the severest service conditions, the practical value of this type as a protective element in power systems. (Fig. 9.)

Storage Battery Locomotives

A reference to certain typical locomotives which have been placed in service during the year will best serve to indicate the progress secured with this type of tractor.

Among the relatively large units is a 10-ton combination trolley and storage battery locomotive which is utilized for miscellaneous yard shifting duty at the United States Navy Yard, Portsmouth, Virginia. The two driving motors are rated at 21 h.p., 200 volts, and are of the commutating pole, totally enclosed railway type, with ball bearing armatures. The locomotive is equipped with a 200-ampere-hour storage battery, which develops energy sufficient for 800 ton-miles of travel on level track. For operation as a trolley type locomotive a pantograph trolley is provided, the equipment including an automatic switch by means of which the motor connections are changed as the locomotive alternates from trolley to battery service. (Figs. 10, 11, 12 and 13.)

Two 9-ton locomotives were supplied to the California Portland Cement Company for haulage service in quarries situated in Death Valley, California. These are operated exclusively by the storage batteries, and each locomotive is equipped with two 26.6-h.p., 250-volt motors which can be operated in either series or parallel through a suitable controller, while the storage battery has a capacity of 383 ampere-hours.

Perhaps the most interesting locomotives of this type are the four-ton units supplied to the Logan Mine Company to replace mule haulage at Monaville, West Virginia.

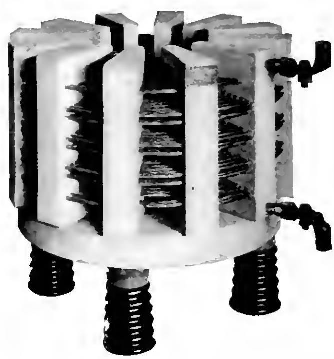


Fig. 9. Cast-in-concrete Type of Current Limiting Reactance

These small mine locomotives have an overall height of only 41 inches, with a wheel base of 44 in., and operate on a 44-in. gauge track. They can exert a normal drawbar pull of 2,000 lb., and under this load develop a speed of 3½ miles per hour. As an instance of their efficiency, it can be stated that, while they were designed for handling 150 cars per day, with an average haul of 1200 ft., it was found entirely feasible to haul 150 cars per day over an average distance of 2800 ft., with each car holding two tons of coal.

Electric Railways

Progress in electric railway operation was marked by the continued trend toward the use of higher direct current voltages. Including equipment on order there were more than fifty American railways either under construction or operating at a direct current potential of 1200 volts or higher. These include four 2400-volt systems, one 3000-volt main line electrification, and more than forty suburban and interurban systems operating at 1200 and 1500 volts.

Fig. 11. A 9-ton Storage Battery Locomotive for Quarry Work in Southern California

The 440-mile transcontinental electrification of the western lines of the Chicago, Milwaukee & St. Paul Railway brought out several new developments, most of which were modelled along the lines of accepted railroad practice.

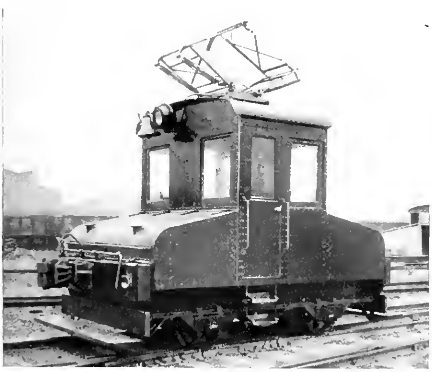


Fig. 10. 10-ton Combination Trolley and Storage Battery Locomotive

The most interesting parts of the electrification are the locomotives and the 100,000-volt 3000-volt d-c. substations, both of which involve unique features. The locomotives are without question the largest electric engines ever constructed, weighing 282 tons each, not including the oil-fired steam heating equipment which is installed on the passenger units. (Figs. 14, 15, 16 and 17.)

The most radical departure in direct current locomotive operation was the regenerative electric braking, enabling the locomotive to operate full tonnage trains over long distances and using the air brakes only for making full stops and in emergencies. A number of locomotives for the operation of the first electrified engine division were on the ground and preliminary tests were made over the tracks of the Butte, Anaconda & Pacific

Fig. 12. Four-ton Storage Battery Locomotive with Storage Battery Trailer Truck

Railway on November 13, 1915. During this initial test the second locomotive to be shipped was used, hauling 65 ore cars weighing 70 tons each and two other cars weighing 109 tons, making a total train load including the locomotive, of 4941 tons. This load was

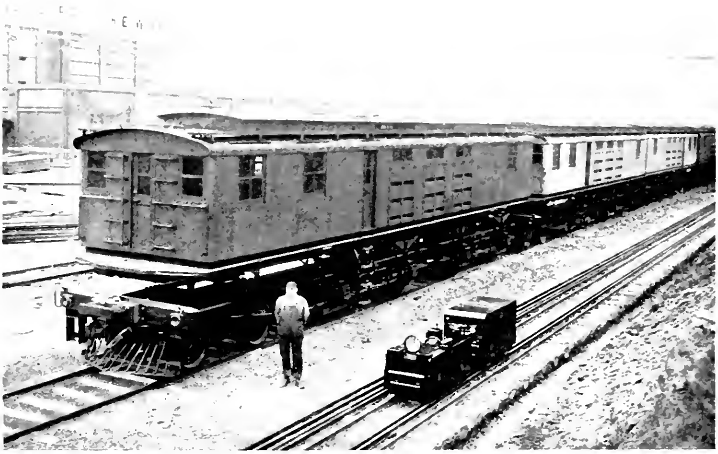


Fig. 13. The Smallest Mine Type Storage Battery Locomotive and the Largest Electric Railway Locomotive

hauled from Rocker to the Anaconda Yards without the use of air brakes, except to stop at the Durant and Anaconda Yards, electric braking being used to hold the train on the one per cent down grade with the current averaging at times as high as 880 amperes at the locomotive, corresponding to approximately 2100 kw. returned to the line at substation voltage.

The train was allowed to speed up to approximately 25 m.p.h. on the down grade and was then brought to as low as 7 m.p.h. with the electric brakes in order to determine the range of application of this method of braking. The braking proved to be very smooth and the reduction of speed from 25 m.p.h. to 7 m.p.h. was made without the slightest jar to the train. As the braking was

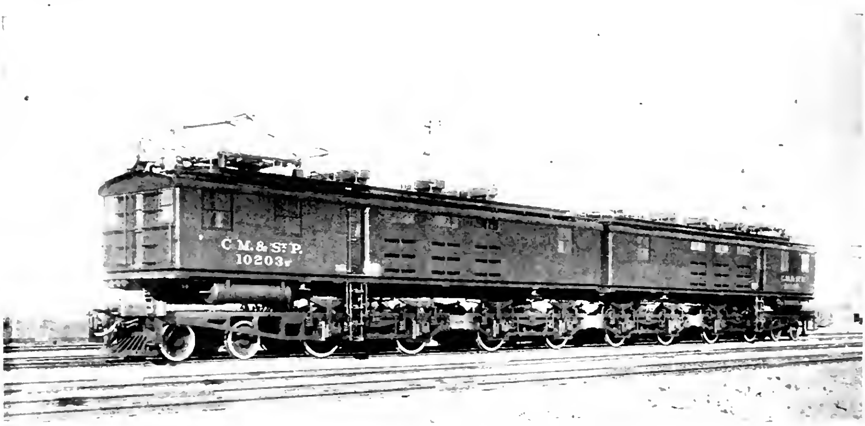


Fig. 14. Transcontinental Type 3000-volt Direct-current Electric Locomotive for Chicago, Milwaukee & St. Paul Railway

done entirely by the engine, the slack between cars was bunched, and at no time was there any danger of breaking the train in two.

Similar tests were later conducted on the main line of the Chicago, Milwaukee & St. Paul Railway between Three Forks and Deer Lodge, taking power from the 3000-volt direct current substations.

The driving motors are of unusual design in that 1500 volts is impressed on each commutator, with insulation to ground for 3000 volts. In other respects they follow the design of locomotive motors previously built. Twin gears are used, as on the B. A. & P. Railway, Detroit River Tunnel, Baltimore & Ohio, and other large locomotives. The gears are of the cushion type in which coil springs are inserted between the rim and the hub, acting as cushions, thus equalizing the strains due to sudden shocks or to varying torque.

These locomotives have a large number of devices which require a supply of compressed air; namely, air brakes, signals, whistles, bell ringers, sanders, flange oilers, pantograph trolleys, reversers and transfer switches, and on the passenger locomotives the steam heating equipment.

A new design two-stage air compressor having a piston displacement of 150 cu. ft. of free air per minute against a working pressure of 135 lb. per sq. in. furnishes air for these devices. The complete compressor

Fig. 15. Spring Gear used on Chicago, Milwaukee & St. Paul Locomotive

consists of three units—two compressors and a 3000-volt direct current motor assembled on a common base. Each compressor is complete in itself, consisting of one low-pressure and one high-pressure cylinder properly balanced. The compressors are geared to the motor so that their maximum points of load are 90 deg. apart, thus producing a well distributed load on the motor. This is the largest electrically driven air compressor yet built for railway service. It was designed with a special view to incorporating the numerous advantages

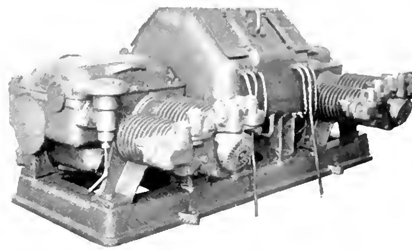


Fig. 16. Air Compressor for Chicago, Milwaukee & St. Paul Locomotive

embodied in the smaller sizes of air compressors manufactured by the General Electric Company. It is driven by the highest voltage d-c. motor so far used for this service. The motor has two sets of armature windings on one core, and one 1500-volt commutator at each end, one set of windings being connected to each commutator. The motor is of the series self-ventilated type with commutating poles, and has ample margin for successful operation at voltages considerably

Fig. 17. Morel Substation on the Chicago, Milwaukee & St. Paul Railway

above normal. Approximately 90 of these compressors are now on order.

The alternating current side of the 100,000-volt 3000-volt d-c. substation follows standard practice with this voltage. The direct current equipment is modelled after that in service on the B. A. & P. Railway, with modifications to take care of the increased voltage.

A novel method of cooling is used on the direct current generators of the synchronous motor-generator sets. This consists of a longitudinal ventilation of the armature and fields, similar to that employed on the well known G-E ventilated railway motor. Another interesting feature of the substation equipment is the provision for inverted operation in case the power regenerated by the locomotives exceeds that required by other trains operating nearby. The direct current switchboards for the Chicago, Milwaukee & St. Paul substations embody several new features, including unusually high speed circuit breakers.

Milwaukee & St. Paul Railway (G. E. Review, 1915), Imperial Railways of Japan, and several others.

Automatic Railway Substations

A novel adaptation of a number of well tried electrical devices has given very satisfactory results in the three substations of the Elgin & Belvidere Railway. This equipment consists of control apparatus which makes the substation completely automatic, thereby eliminating the necessity for the continuous presence of an attendant and saving power ordinarily expended in the light load and no load losses. (Fig. 19.)

The station is started up when the trolley voltage drops below 450 volts. This low

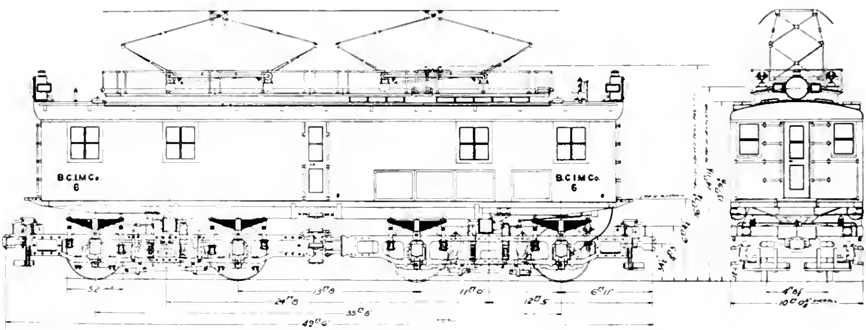


Fig. 18. Outline of 120-ton 2400-volt Electric Locomotive for Bethlehem Chile Iron Mines Company

Material progress was reported on the construction and equipment of the 2400-volt d-c. railway of the Bethlehem Chile Iron Mines Company, at Tofo, Chile. The three 120-ton locomotives are under construction and are expected to go into operation during 1916. (Fig. 18.)

The Michigan Railway Company, operating at 2400 volts between Grand Rapids and Kalamazoo, and between Battle Creek and Allegan, handled a remarkable service, running at times as high as 80 m.p.h. with two or more cars per train. This is the pioneer 2400-volt third rail line and the first road to use synchronous converters for obtaining 2400 volts.

Other roads which began operation during the year at 1200 or 1500 volts are London & Port Stanley Railway, Grand Rapids, Holland & Chicago Railway, Michigan Railway between Flint, Saginaw and Bay City, Great Falls Terminal electrification, Chicago,

voltage closes various relay circuits which start a motor driven drum controller, which in turn performs in proper sequence all the duties of an attendant, including the actual connection of the machine to the outgoing feeders. The machine then continues to operate until the current required by the cars on the section falls below a predetermined value, at which time a current relay drops out and shuts down the station.

Under this arrangement the stations start up and shut down in succession as the car passes from one station to the next. The operation is entirely automatic, depending upon the demand for power.

Pen Dell Automatic Signal Substation

A unique device known as the Pen Dell Automatic Substation for Railway Signal Service has been put in operation during the past year in signal substations on the Grand

Trunk Railway at Elsdon, Illinois, and similar equipment is under construction for substations on the Chicago, Rock Island & Pacific Railway. (Figs. 20 and 21.)

This apparatus covers an arrangement of switches connecting two sources of power to a signal line so that on the failure of one source of power another will be automatically connected to the line. The essential features of the scheme are contained in a motor-operated mechanism, one of which is used for closing an oil switch in each source of supply.

The mechanism comprises single-phase induction motor and a system of mechanical parts for transmitting the power to the switch closing mechanism. Provision is also made for varying the time interval between energizing the motor and closing the switch, as well as a low-voltage release to trip out the switch, and means to prevent the switch from closing should energy be restored to the line from another source before the mechanism completes its operation. Arrangement is made for an appreciable delay in switching on the emergency supply, thus permitting the return to normal source of power in case of short interruptions. When operating from the emergency supply, the return to normal can be accomplished automatically if so

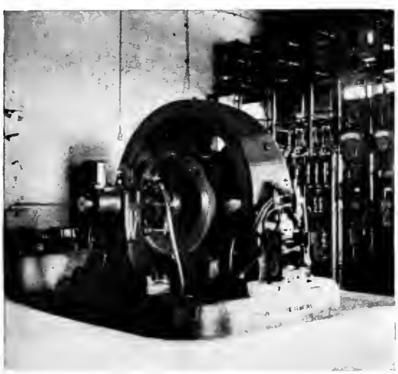


Fig. 19. Automatic Substation Equipment Installed at Gilbert on the Elgin & Belvidere Electric Railway

desired. This feature can be used to obviate the necessity for an attendant.

P. C. Control

A new type of railway motor control was placed in operation which performs the same functions as the well known Type M but differs radically in several important particulars. In this control the compressed air of the air brake system has been used to furnish power for the mechanical operation of the

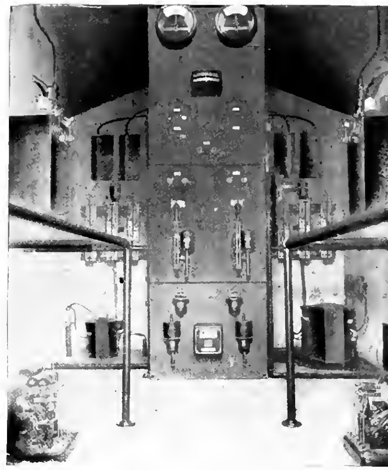


Fig. 20. Automatic Signal Substation at Elsdon, Ill., Grand Trunk Railway

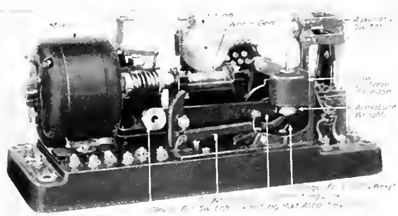


Fig. 21. Motor-driven Operating Mechanism for Automatic Signal Substation

motor controller contactors. The special features of this equipment have been described in the GENERAL ELECTRIC REVIEW for October, 1915.

Railway Motors

For some time attention has been directed toward increasing the effectiveness of railway motor ventilation by use of a multiple fan. Results obtained from motors in regular service indicate a marked increase in service capacity over the original series method and several new types of motors have been placed in operation using this improvement. For

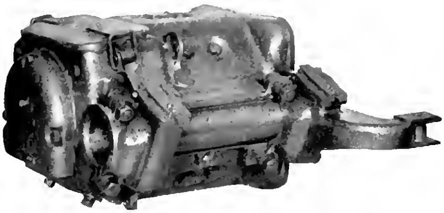


Fig. 22. Type GE-258 Motor for Light Single-truck Cars

city service the GE-247 motor built for cars having 24 to 30-inch wheel trucks is typical of the multiple fan type. Upwards of eight hundred of these motors are in service, two hundred having recently been put in service on the Metropolitan Street Railway, Kansas City. Eighty motors of this type were also sold to the Chicago, South Bend & Northern Indiana Railway for replacing obsolete equipments.

Still more recently a smaller motor of this

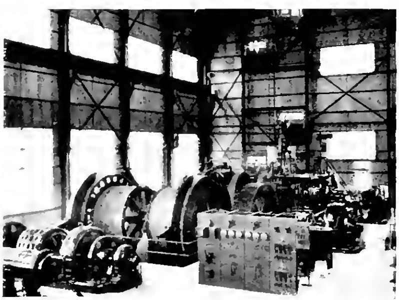


Fig. 23. View in Hoist House of Inspiration Consolidated Copper Company, showing Motor-driven Automatic Hoists and Flywheel Motor-generator Set

type was developed which is specially adapted to single-truck light weight city cars. This motor is known as the GE-258 and has a one-hour rating of 18 h.p. More than two hundred of these motors were sold in the last few months of the year. (Fig. 22.)

Hoists

Conspicuous among the hoisting equipments placed in service for mines during the year are the two large electric hoists which are now in successful operation at the Miami, Arizona, mine of the Inspiration Consolidated Copper Company. These outfits are notable, not on account of their size, but because they are the first large mine hoists arranged for automatic operation. (Fig. 23.)

The two hoists serve two shafts about 150 ft. apart, with the hoisting machinery for both units located in the same hoist house. The hoists are operated in balance, and each skip delivers 12½ tons of ore per trip. Operating on the normal schedule for which the equipment was originally designed, the combined capacity of both hoists is 10,000 tons in fourteen hours, with a capacity on the maximum schedule of 14,000 tons in the same period. These hoists are used exclusively for the handling of ore, and are not utilized for hoisting men or delivering supplies. The hoisting distance for both shafts is about 630 ft., and the rope speed is approximately 750 ft. per minute.

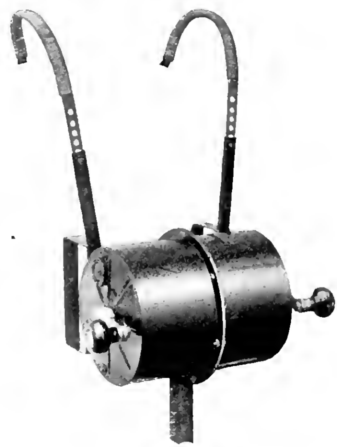


Fig. 24. Portable Master Controller

The hoists are individually driven by 580-h.p., 575-volt direct-current motors, and current is supplied to them through a single flywheel motor-generator set comprising two direct current generators, one for each hoist, with an alternating current driving unit consisting of an 850-h.p., 2300-volt induction motor; the speed of the set being 750 r.p.m. Current is normally taken from the transmission system of the hydro-electric power plant of the United States Reclamation Service at the Roosevelt Dam, but can also be supplied, when required, from the mining company's steam turbine power station.

While full provision was made for operating the hoists by hand control in the customary manner, to meet requirements of construction or maintenance work, the regular hoisting operations involved in bringing the ore to the surface are carried on automatically. The hoists are placed in service at the beginning of a shift, and start, run, stop and rest during the loading periods, in proper sequence, solely by means of the automatic control system. At the points where the ore is brought to the underground loading bins the skips are automatically loaded with definite, predetermined weights of ore.

The labor economy thus secured is obvious when it is understood that by means of this automatic equipment these large hoists require only one operator per shift in the hoist house who can take the place of two operators and an oiler, who would be required if non-automatic systems were utilized.

At the close of the year there were under construction and nearing completion some very large hoisting equipments, one of which comprised an 1800-h.p., 80-r.p.m. direct current motor arranged for direct connection to the hoist drums. It is important in connection with this hoist to state that the rating of 1800 h.p. is for continuous operation, with a temperature rise not to exceed 40 deg. C. The motor is served by a motor-generator set, consisting of an 1150-h.p. induction motor driving a 1300-kw. generator, and a self-contained exciter. It is a flywheel set with a steel plate wheel weighing 92,000 lb. This equipment is destined for the Elm-Orlu mines at Butte, Montana.

There was also in course of production an induction motor hoist, larger than any previously installed or under construction. It consisted of an 1800-h.p., 40 deg. C. Form M induction motor, which will drive the hoist drum through single reduction gearing, using large cut herringbone gears. This particular hoist was originally steam-driven, and the old drums will be retained. The control of this hoist is secured through primary reversing air brake contactors with liquid rheostat for secondary control, the primary voltage being 2200. This equipment was purchased by the Tenessee Coal & Iron Company.

A somewhat smaller hoisting outfit utilizing practically the same system of control as the one above referred to, consists of a 1200-h.p., 300-r.p.m. induction motor which will be applied for water hoist operation by the Lehigh Coal & Navigation Company.

The growing tendency toward the use of alternating current motors with regenerative braking control for the operation of coal hoisting towers and coal bridges was shown by a number of installations of this character during the year. This form of control renders it possible to secure, to a considerable extent, the advantages obtained with direct current motors when they are controlled by dynamic braking.

A small but very interesting form of portable master controller was developed and applied in the operation of an experimental dock winch for unloading vessels; the equipment being supplied to the City of Philadelphia for use on municipal docks.

This unquie controller, when in use, is suspended from the shoulders of the operator, and from its position when carried in this manner and its small size, became known as a "muff" controller. It weighs only fourteen pounds, and is connected to the control equipment located on the winch, by means of 90 ft. of flexible cable, thereby permitting the operator to move freely from point to point, so that the material handled by the winch may always be in view. At the same time the manipulation of the small handles on either side of the muff controller enables him instantly to secure any necessary changes in the hoisting or lowering speeds. One advantage secured by this small controller consists of the practical elimination, during the hoisting cycle, of verbal instructions or hoisting signals to the winch operator.

Steel Mills

The one feature specially worthy of note in the steel industry was the steadily increasing demand for an all alternating current drive for mills requiring adjustable speeds, each constant under varying loads.

Of the 22 speed regulating sets built by the General Electric Company for this service, all save one involve the use of the polyphase commutator (Type PCR) regulating motor; the remaining single set making use of a more or less special rotary converter and auxiliary direct current motor direct connected to the main motor. This particular set was built for the Union Rolling Mills at Cleveland, and consists in part of a 1400-h.p. motor and 325-kw. motor-generator with continuous speed control over approximately 35 per cent range. This system is specially adapted to 60-cycle induction motors requiring from 35 to 50 per cent speed range.

In point of size the largest equipments furnished with speed regulating sets by the General Electric Company included two 2000-h.p. induction motors with separate PCR sets for very closely adjustable speed control of the independent halves of a Morgan continuous mill; also a small motor and PCR set, as well as one standard 5750-h.p. mill type induction motor, and one 17,000-kw. Curtis turbine; this being the largest single steam turbine unit yet built for steel mill service.

It has been known for several years past that both the rotary converter and the PCR sets would operate equally as well with the main motor running above or below its normal synchronous speed. The great difficulty has been to secure continuous speed control at and near synchronism without sacrifice of the high maximum torque characteristics of the induction motor below synchronism. This has at last been successfully accomplished and fully demonstrated by thorough tests of equipment operating in the commercial production of steel. This simple statement covers what is the most far-reaching improvement during the past year in control of main roll drives for steel mills and will be referred to often as the "double range" type PCR set for dynamic speed control of induction motors.

Paper Mills

For driving paper machines a number of direct-current motors have been supplied, direct connected to the back shaft of the machine and securing the necessary speed range through voltage control. On the other hand, several motor drives have been provided for operation on constant potential direct-current systems, securing the required speed range with motor field control. One of these installations utilized a 90-h.p. motor capable of a speed variation of 5 to 1.

For securing the necessary reversal in the operation of platers, the usual equipment has heretofore comprised a belt shifting device operating on the same principle as that used for planer reversal, or else a beveled gear mechanical reverser has been used with hydraulic gear shift. With both these systems the driving motor operated constantly in one direction, but during the year there was developed a reversing motor drive for this service which is of special interest, inasmuch as this particular drive constitutes probably the most severe service to which a reversing motor has yet been applied. This is evident from the fact that the motor may be called upon to make as high as 40 reversals per minute. (Fig. 25.)

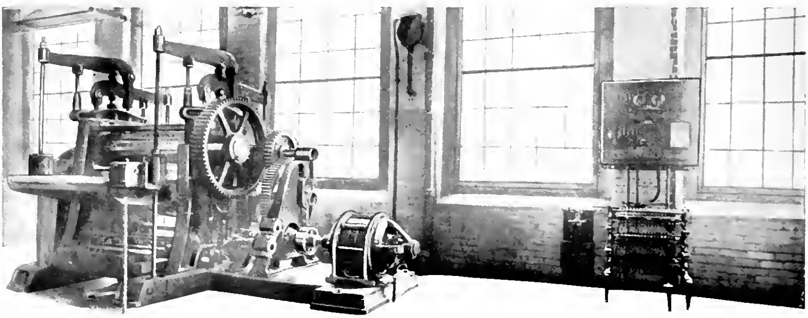


Fig. 25. A 15-h.p., 600-r.p.m., 550-volt, Form M Motor and Panel for Plater, Taylor Logan Co., Holyoke, Mass.

The equipment consists of a 15-h.p., 600-r.p.m. slip ring type motor direct connected to the pinion shaft of the plater, a small drum type master controller, and an enclosed contactor panel containing magnetically operated switches. In addition to this, there is a rheostat for the secondary circuit of the motor for limiting the current demand when the motor is reversed, and a simple mechanical relay which controls the time of closing an accelerating switch. This in turn cuts a large section of the rheostat out of circuit after the motor has reversed and approached normal operating speed.

The equipment above referred to has been in successful operation on a heavy 42-inch face plater with 18-inch diameter rolls.

Furnaces and Ovens

A considerable number of commercial installations of arc furnaces during the year gave evidence of the growing appreciation among iron and steel founders of the inherent advantages of this type of furnace for the production of crucible quality steel. A rather curious feature of the situation is found in the fact that all the recent installations, totaling about 30 units, were confined to territory west of the Hudson River and east of the Mississippi.

The adoption of electric heating for japanning ovens was very greatly extended, there being units aggregating about 12,000 kw. in current capacity installed in or near the cities of Detroit and Toledo, with an additional 12,000 kw. provided for various and widely separated automobile service stations.

These numerous installations were the logical result of exhaustive practical tests of electrically heated ovens for this class of work, in which the thermal efficiency and positive temperature control rendered possible by electric heating were most effectively demonstrated.

Arc Welding

As a result of their convenience and the satisfactory service which had been secured in railroad repairs, and in various classes of manufacturing and repair work, the use of arc welding outfits in 1915 was markedly increased; in fact, the new installations for the year almost equalled the total number of sets previously in service.

In the use of these outfits the recent tendency has been toward a more general use of small units for individual operators in contrast to the former practice of providing large equipments serving a number of operators.

Switching Apparatus

The developments for this class of apparatus were very numerous in 1915, but consisted largely of improvements in details of equipment tending to increase convenience and efficiency in operation, combined with increased factors of safety. The new line of "safety first" switchboards and the various tank lifters for oil switches are conspicuous examples of this tendency. (Figs. 26 and 27.)

Three varieties of safety-first switchboards were designed. These are known as the "panel type," "removable unit ironclad type" and "pedestal type."

The panel type board is similar to the ordinary slate switchboard, except that all live parts are suitably insulated and the back of the board is enclosed by grille work. Disconnecting switches are mounted between oil switches and busbars, field switches are mounted back of the board with handles on the front, calibrating terminals on the back of the board are connected by plugs from the front and are combined with ammeter transfer device when desired.

In the removable unit ironclad switchboard all the apparatus is mounted on and totally enclosed by an iron structure. The oil switch is mounted on a steel panel supported by an iron framework on wheels, and can be placed in or withdrawn from the stationary part of the structure containing the live parts of the circuit when the oil switch is open. This allows easy and safe inspection of the oil switches and the opportunity when desired of making use of a spare unit which can immediately be used in place of the unit drawn out.

The pedestal type switchboard consists of a line of separate iron pedestals mounting automatic oil switches. The pedestals can be placed close together. They contain the necessary current and potential transformers and disconnecting switches, and when desired ammeters, busbars and compartments for enclosing the busbars. The use of the pedestal type panels is limited to the control of circuits up to 2300 volts, and where high rupturing capacities are not necessary.

In recent installations, oil switches of the type which have heretofore been installed on the floor are mounted on iron framework of sufficient height to permit the removal of the tank without disturbing any of the switch parts, and a line of tank lifters has been provided so that one man can without difficulty raise or lower the tank of even the largest capacity switch. These tank lifters vary in construction and operating principles for different sizes of tanks. They are also available for the entire G-E line oil switches arranged for switchboard mounting.

A number of large circuit breakers were installed by the Aluminum Company of

America, at Massena, New York. The largest size consisted of direct current units rated at 20,000 amperes normal continuous current capacity at 500 volts; the aggregate capacity being in excess of 530,000 amperes.

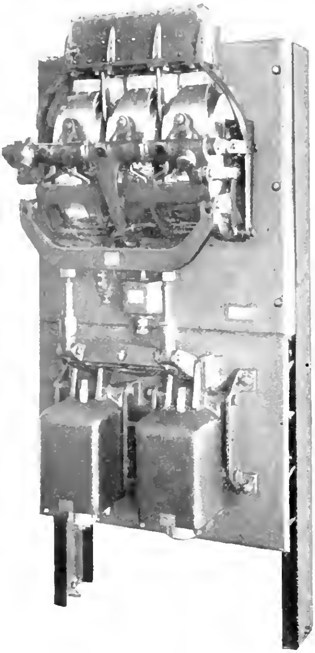


Fig. 26. 20,000-ampere, 500-volt, Direct-current Single-pole Solenoid-operated Automatic Circuit Breaker

The 20,000-ampere breakers represent the most recent construction for solenoid-operated breakers of unusually large capacity. The closing and opening movements under normal conditions are controlled from a two-point pull button control switch mounted remote from the breaker in a position convenient for the station operator. On overload or short circuit the breaker opens automatically by means of a direct acting trip which releases the locking latch when the plunger of the tripping coil is raised.

Illumination

In the year 1915 illumination attained a very high development both as an art and a science. As a distinct branch of electrical engineering, illumination has been receiving systematic attention for a number of years. This year the Panama-Pacific International Exposition stands out as incontrovertible evidence of the validity of this separation. The Committee on Progress of the Illuminating Engineering Society reports as follows: "In its use of light the Panama-Pacific International Exposition furnishes the most striking example of the progress of illuminating engineering that has ever been presented. It is an almost complete report in itself."

In summing up the progress made in illumination, the logical place to start is with the raw material—the light producer or lamp. While the incandescent lamp has perhaps made advances over the arc lamp, this latter means of producing light has not by any means been neglected.

The gas-filled incandescent lamp placed on the market in 1914 has been extended to include all sizes of multiple lamps from 100 watts to 1000 watts, and of series lamps from 60-candle-power to 1000-candle-power. A number of changes in the mechanical construction of the lamps have eliminated

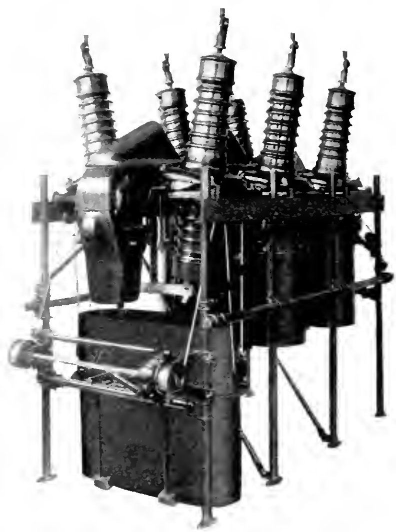


Fig. 27. A 45,000-volt Oil Switch Mounted on Framework showing Arrangement of Tank Lifter

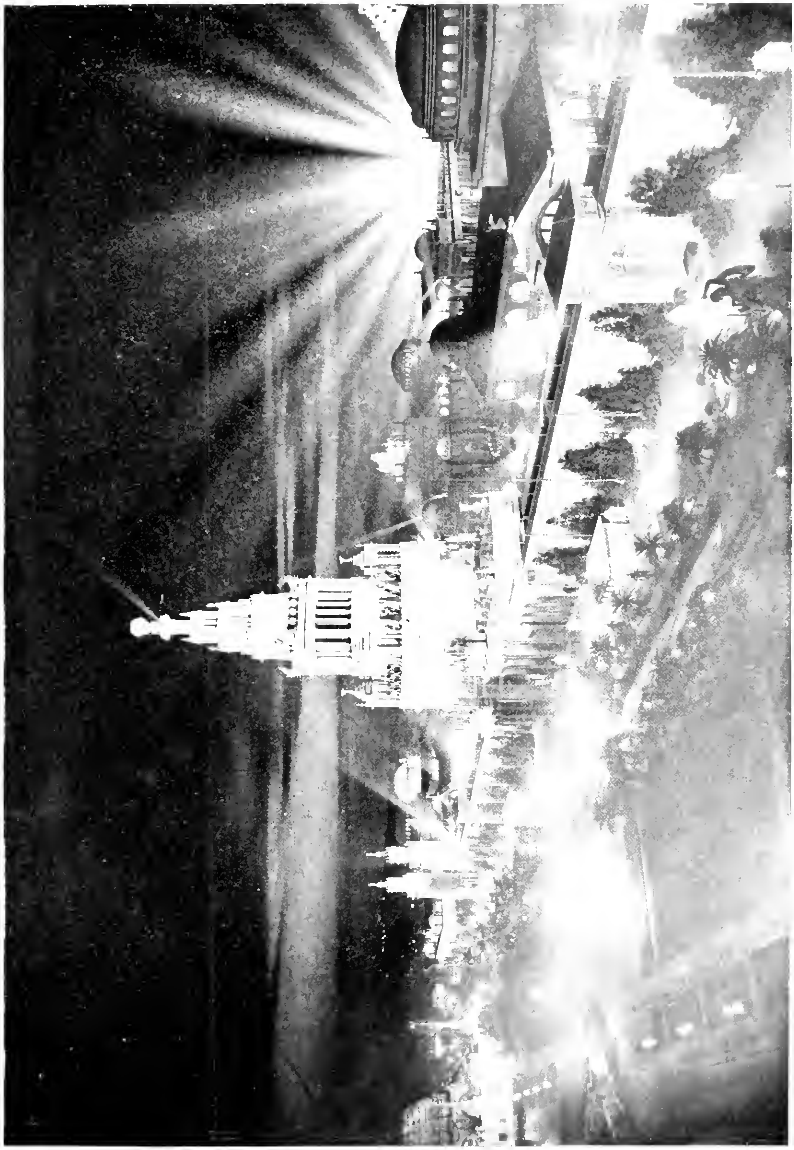


Fig. 28. Twilight View Looking down Avenue of Palms, from Festival Hall

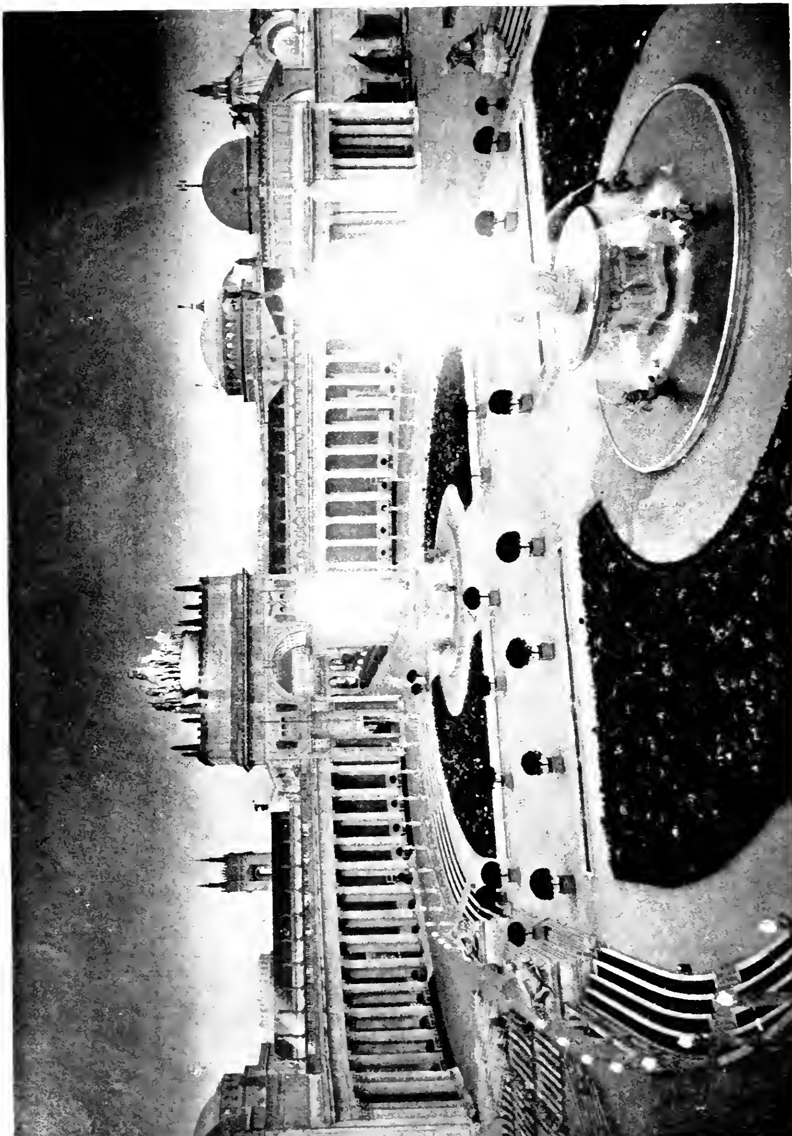


Fig. 29. The Fountains of the Rising and Setting Sun in the Court of the Universe at the Panama-Pacific International Exposition

the defects which existed in the early lamps. Higher efficiencies have also been realized.

The luminous arc lamp, which represents the latest development in arc lamps, still retains its supremacy in ornamental and utilitarian street lighting. Numerous mechanical improvements and standardizations of parts has characterized the construction of the luminous arc lamp during the past year.

The application of these light sources for modern illumination effects is best illustrated by the Panama-Pacific International Exposition, which, as stated before, stands out as the greatest example of modern illumination. It was here that the flood lighting of buildings was introduced and the luminous shadow had its inception. The necessity for creating shadow effects in lighting, if the true architectural features are to be preserved, was fully demonstrated. As a result of the wonderful effects obtained at the Exposition, flood lighting has spread all over the country and we see commercial buildings employing this means for attracting attention. This has in turn made necessary the development of projection apparatus and concentrated light sources such as the flood lighting projector and the concentrated filament incandescent lamp.

Color has been scientifically employed in both the interior and exterior lighting systems to create the atmosphere or psychological effect intended by the architect and decorator. The pleasing influence of colored light has also been made use of as exemplified by the electric scintillator.*

The combination of light source and art structure has proved a practical form of lighting unit. The fountains of the Rising and Setting Sun, in the Court of the Universe, have their shafts made of diffusing glass and contain Mazda lamps aggregating 500,000 candle-power. Horizontal and vertical surfaces amounting to one-half million square feet is lighted by these two units.

The lighting of high bays by direct lighting units has proved itself a satisfactory and economical means of lighting such interiors when properly designed reflectors prevent the wasteful distribution of light on the vertical surfaces.

Indirect and semi-indirect lighting methods are being employed more extensively than before, owing to the higher efficiency of incandescent lamps and the appreciation of the eye protection afforded by these methods.

In short, the greatest advances made in illumination during 1915 have been an appreciation and observance of its artistic and physiological aspects.

* See GENERAL ELECTRIC REVIEW, June, 1915.

ELECTRICITY ON THE NEW YORK STATE BARGE CANAL

By E. W. Pilgrim

Power and Mining Engineering Department, General Electric Company

Inland transportation of freight by canal, wherever the topography of the country will permit, has been in vogue the world over for many years. For delivering slow freight, this mode of transportation is obviously ideal on account of the low rate of charges. Of late years, however, the freight service furnished by railroads paralleling canals has improved faster than the service offered by the canals, which naturally has resulted to a very considerable extent in routing slow freight by rail (in addition to perishable or quick delivery shipments, these of necessity falling to the lot of the railroad). To render adequate the waterway service along the two principal lines of travel in New York State, the old existing canals have been undergoing complete reconstruction on a large scale. It is expected that this work will be completed soon; the carrying capacity is estimated to be about 25 times that of the canals it supersedes. In the following profusely illustrated article, the author has ably described the function that electricity has played in the construction of this $130,000,000 undertaking and will play in its operation.—Editor.

The history of canals in New York State dates back to 1792, when two private companies were given charters permitting them to build and operate canals within the State. About 1808 agitation for state-built canals was begun. In 1817 the work of construction was commenced on the original Erie Canal, which was finished in 1825. The prism dimensions of this canal were 28 ft. wide at bottom, 40 ft. wide at water level, and 4 ft. deep.

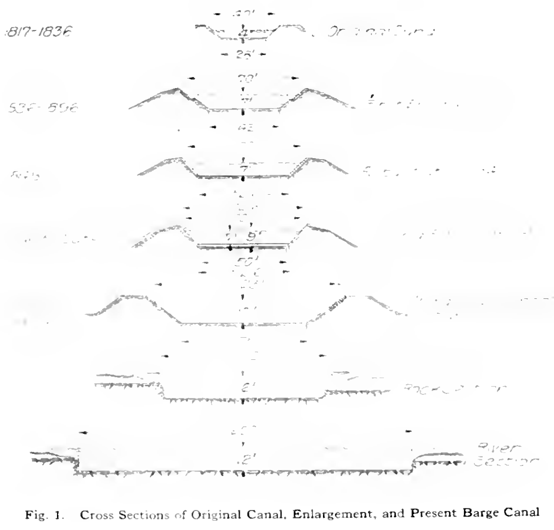


Fig. 1. Cross Sections of Original Canal, Enlargement, and Present Barge Canal

The original Champlain Canal, begun in 1817 and finished in 1823, had prism dimensions of 26 ft. at bottom, 40 ft. at water level, and was 4 ft. deep.

The original Oswego Canal, begun in 1825 and finished in 1828, had prism dimensions of 26 ft. at bottom, 40 ft. at waterline, and was 4 ft. deep.

The original Cayuga & Seneca canal, constructed between 1826 and 1828, had prism dimensions of 28 ft. at bottom, 40 ft. at waterline, and was 4 ft. deep.

Three enlargements of the above canals have been made.

First, the prism was enlarged to 56 ft. at bottom, 70 ft. at waterline, and 7 ft. deep; second, in 1896–98 the depth was increased to 9 ft., but this improvement was only completed in part; third, in 1905 work was begun on the present enlargement, known as the Barge Canal system, which consists of improvements in all four of the old canals, but differs from them in that the Barge Canal is chiefly a canalization of rivers and lakes, land lines being used only where rivers and lakes are not available or where dams or rifts in rivers make a short land line advisable.

The channel in rivers and lakes is 200 ft. wide and 12 ft. deep, while the land lines are 75 ft. wide at bottom, 125 ft. at water line, and 12 ft. deep. A clearance of 15½ ft. is required from water line to the lowest girders on bridges.

It is eminently fitting that prominence be given to the New York State Barge Canal, inasmuch as this undertaking rivals the Panama Canal as an engineering feat, and by many is considered to outrank it in numerous features.

In comparison there are six pairs of locks on the Panama against 57 locks on the Barge Canal. The Barge Canal contains a flight of five locks, located along a distance of about a mile and one-half, at Waterford, N. Y., which have the greatest lift of any locks in the world, elevating boats to a height of 169 ft., or within one foot of twice the total lift of the Panama locks.

The Panama Canal is 50 miles long, built through an undeveloped country where the authority of the commission is supreme. On the Barge Canal there are 440 miles of construction in new canals and 350 miles of intervening lakes and rivers, making a total of 790 miles of canal built through a thickly populated territory where many property rights hampered the engineers. Much of the work was along rivers and lakes requiring coffer dams and precautions against spring floods and ice jams. At one lock, at Scotia, N. Y., quicksand was encountered which required the use of pneumatic caissons. Dams across the Hudson and Mohawk rivers added other engineering problems.

The first lock in the Barge Canal system is at the Troy dam in the Hudson River. This is Federal water, and both dam and lock were built by the United States Government. From here the Champlain Canal follows the Hudson River north as far as Fort Edward, with the exception of two short land lines near Schuylerville and Fort Miller. From Fort Edward to Fort Ann the canal is a land line following a natural depression. From Fort Ann, Wood Creek has been canalized to Whitehall, where Lake Champlain is entered By way of the canal it is 57 miles from Waterford to Whitehall, 111 miles to the northern end of Lake Champlain, and 89 miles by way of the Richelieu Canal to the St. Lawrence River

The Hudson River above Troy, N. Y., has been made navigable by building a new dam above Waterford and using four existing dams that were built for power purposes. The Erie branch leaves the

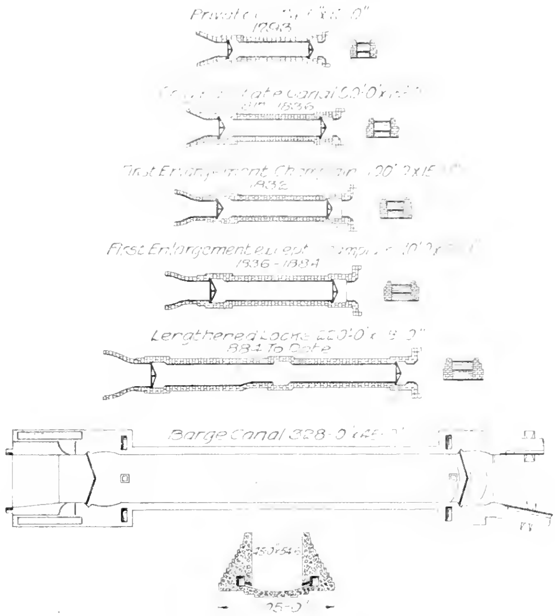


Fig. 2. Lock Dimensions and Cross Sections of Original Canal, Enlargements, and Present Barge Canal

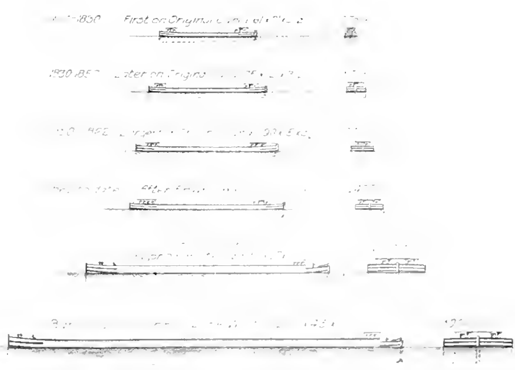


Fig. 3. Dimensions and Tonnage of Original Canal Boats, and Present Barge Canal Boats

Hudson River at Waterford and follows a land line about $2\frac{1}{2}$ miles to the Mohawk River, the Cohoes Falls in the Mohawk River making this land line necessary. Here boats are lifted through 169 ft. by a series of five locks, these five locks displacing sixteen locks on the old canal.

After entering the Mohawk the canal takes the course of the river to Lock No. 16 near St. Johnsville; the river being made navigable for this distance by a series of eight movable dams and two fixed dams, one at Crescent where the canal enters the river, and one at Visschers Ferry.

From Lock No. 16 to Lock No. 20, at Utica, the canal follows the river, with the exception of a number of short land lines through islands and to straighten bends, thus shortening the course. From Utica to Sylvan Beach, where Oneida Lake is entered, the canal is land line.

At the western end of Oneida Lake the canal enters the Oneida River, following it to Three Rivers, where the Seneca River and the Oneida River flow together to form the Oswego River. From Three Rivers junction the canal traverses the Seneca River to Lock No. 25 at Mayspoint. Here the Clyde River joins the Seneca River, and the canal enters the Clyde and continues to Lock No. 27 at Lyons, N. Y. From Lyons to Tonawanda the canal is a land line, and from Tonawanda

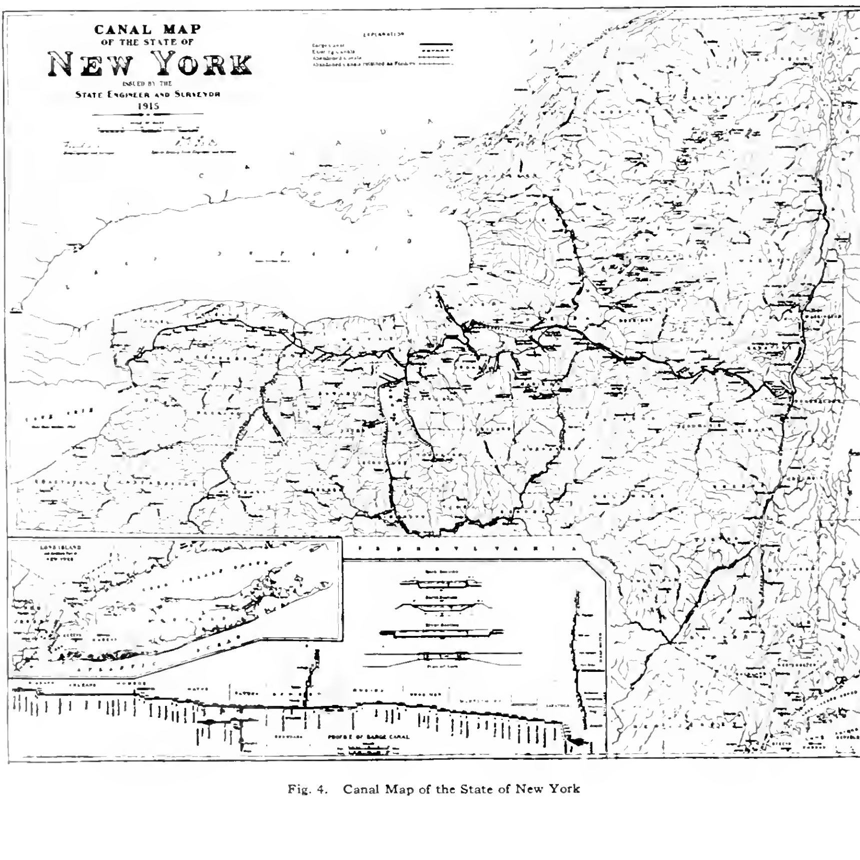


Fig. 4. Canal Map of the State of New York

Fig. 5. Dam across Hudson River, Lock 1, Champlain Canal, Waterford, N. Y., showing Taintor Gates on the right and Power House on the left

Fig. 6. Dam across the Mohawk River at Crescent, N. Y.

Fig. 7. Dam across the Mohawk River at Lock 7, Erie Canal, Visschers Ferry, N. Y.

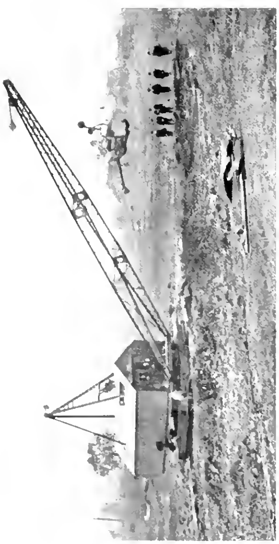


Fig. 8. Electrically operated drag-line Excavator. Hoist motor, 112-h.p., 900-r.p.m., 550-volts, three-phase, 60-cycle; swing motor, 22-h.p., 900-r.p.m., 550 volts, three-phase, 60-cycle

Fig. 9. Out-door type of Portable Transformer Station for the Excavator shown in Fig. 8

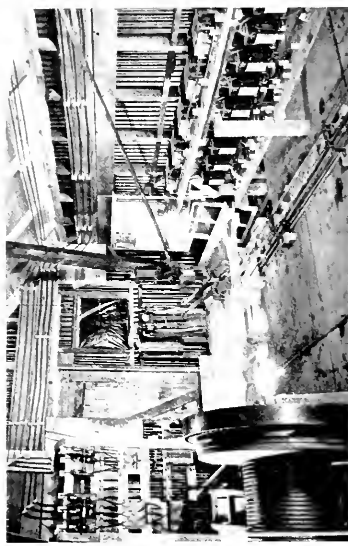


Fig. 10. Interior View of the Excavator shown in Fig. 8

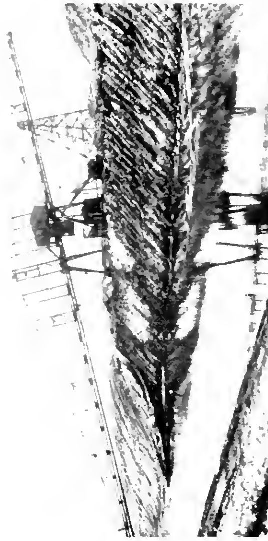


Fig. 11. Cantilever Frame Using a Drag Scraper Electrically Operated by a 225-h.p., 500-r.p.m., 440-volt, 25-cycle, three-phase Induction Motor

to Lockport, where the canal enters the Niagara River, Tonawanda Creek is followed.

The Oswego Canal extends from Three Rivers to Oswego on Lake Ontario, the Oswego River being used the entire distance. The Seneca and Cayuga Canal joins the Erie Canal at Lock No. 25 at Mayspoint, and follows the Seneca River to the head of both Cayuga and Seneca Lakes. About 72 per cent of the length of the whole system is through rivers or lakes.

The canal was built by contract, under the State Engineer's supervision, and a great variety of machinery was used in its construction and installed for its operation. All of this cannot be described here, but such of the apparatus as employs electricity for power is shown in the illustrations.

Fig. 12. Movable Dam across Mohawk River, of which type there are eight between Scotia, N. Y., and Fort Plain, N. Y., varying in length from 370 to 590 ft. and raising the river level 14 ft. at Lock 8; 15 ft. at Locks 9 and 10; 12 ft. at Lock 11; 11 ft. at Lock 12, and 8 ft. at Locks 13, 14 and 15

The gates, valves and capstan machinery used in passing boats through the locks are all operated by motors. Power is supplied at 250 volts, continuous current, from a power house at each lock, except in a few cases, where the locks are very near each other and one power station is made to serve two locks. The power stations are heated by electricity and the locks are lighted by arc lamps.

Above Waterford, N. Y., where the canal enters the Mohawk River, a large dam, known as the Crescent dam, was built by the State. This dam is 1922 ft. long, 39 ft. high, and is built on a 700-ft. radius. Here is located the only alternating-current power house on the system, the current generated being used for the operation of the Waterford flight of five locks and two guard gates. Power is transmitted at 2200 volts, three-phase, 40 cycles to substations at Locks Nos. 3 and 5, where two 35-kw. induction motor-generator sets supply continuous current for operating the lock motors. There is one similar station at Lock No. 1 on the Oswego Canal; but here the State purchases alternating current from the local power companies.

In most cases the generators are of the vertical shaft type, 50 kw. or 75 kw., 250 volts, with speeds from 155 r.p.m. to 660 r.p.m., depending on the head. The weight of the armature and waterwheel and the water thrust are carried by a roller thrust bearing on top of the generator which runs in oil supplied from a storage tank on the crane rail at top of the building. The oil is fed to the thrust bearing through a sight feed gauge, and works its way down through the steady bearings to the gear case enclosing the gears for driving the governor, and from the gear case it flows to the filter tank, whence it is pumped back to the storage tank.

Horizontal shaft generators geared to hydraulic turbines are used in a few stations where the turbine speed is slow due to low head.

Through the Mohawk Valley, from Schenectady to Fort Plain (Locks Nos. 8 to 15 inclusive), where movable dams are used, the power is supplied by two 25-kw.

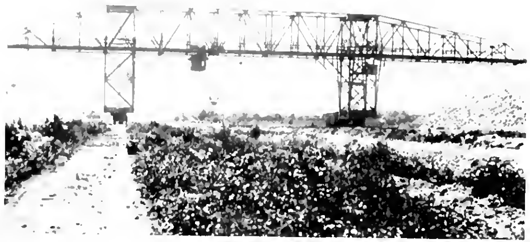


Fig. 13. Bridge Conveyor used for excavating in Deep Rock near Rochester; extreme length 428 ft. Electrically operated by four 80-h.p. hoist motors, four 30-h.p. trolley motors, and two 30 h.p. travel motors all direct-current series, 220 volts

Fig. 14. Hydraulic Dredge Electrically Operated. Pump motor 700-h.p., 375 r.p.m., 2200-volt, variable-speed, 25-cycle, three-phase; cutter machinery motor, 200-h.p., 500-r.p.m., variable-speed; winch motor, 75-h.p., 500-r.p.m., 2200-volt, variable-speed; several small motors on pumps, etc.

Fig. 15. An interior view of dredge shown in Fig. 14

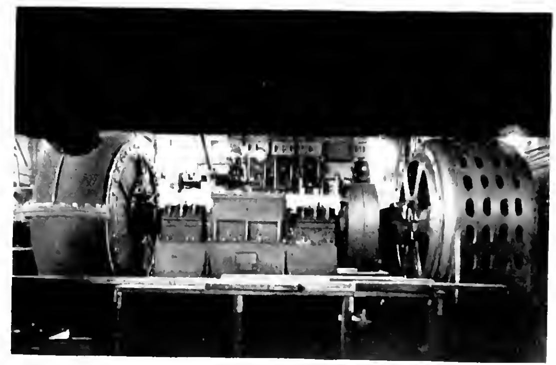


Fig. 16. A view of the pump and its motor on the dredge shown in Fig. 14

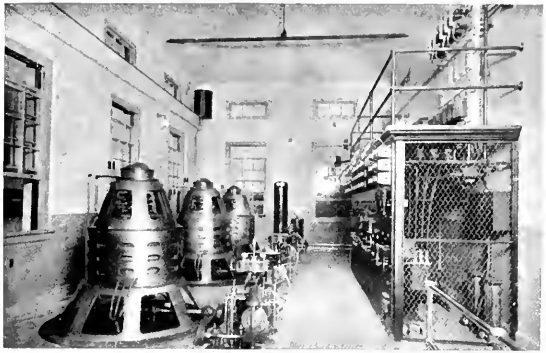


Fig. 17. Power House at Crescent Dam containing three 100-kw., 12-pole, 400-r.p.m., 2200-volt, three-phase, 40-cycle generators and switchboard

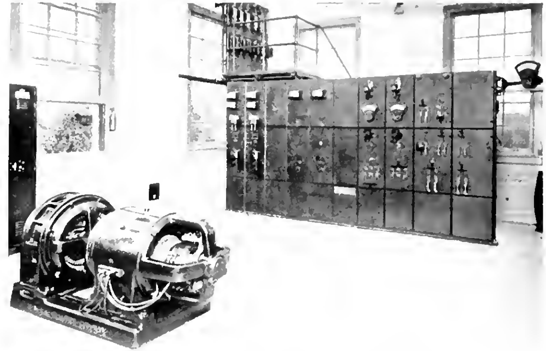


Fig. 18. Typical Substations; 35-kw., 1200-r.p.m., motor-generator set and switchboard. Induction motor 50-h.p., 1200-r.p.m., 2200-volt, three-phase, 40 cycle; generator 35-kw., 1200-r.p.m., 250-volt, compound-wound, commutating-pole

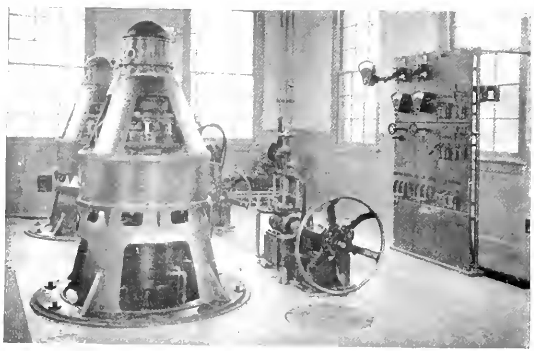


Fig. 19. Power House, Lock 5, Champlain Canal. 50-kw., 260-r.p.m., 230-volt, compound-wound commutating-pole generator, three-panel switchboard, water governor and motor-driven governor pump. This station is typical of power houses having vertical shaft generators

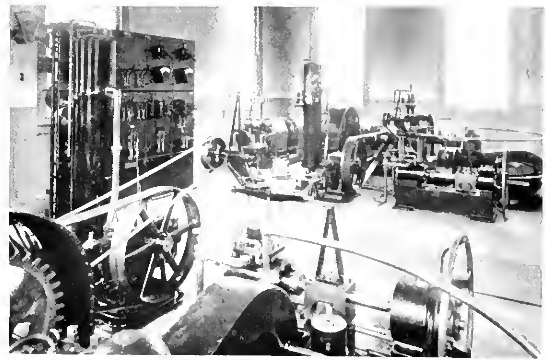


Fig 20. Power House, Lock 8, Champlain Canal. 50-kw., 280-r.p.m., 250-volt, horizontal geared type compound-wound commutating-pole generator. This station is typical of stations having horizontal-shaft generators. The 15-kw., 1200-r.p.m., 100-volt series booster shown in the corner of the room is used to raise the voltage on the lines running to Lock 7 about two miles away

gasolene-electric sets, as there is no head when the dams are raised. Gas-electric sets are used also at three other locks where the

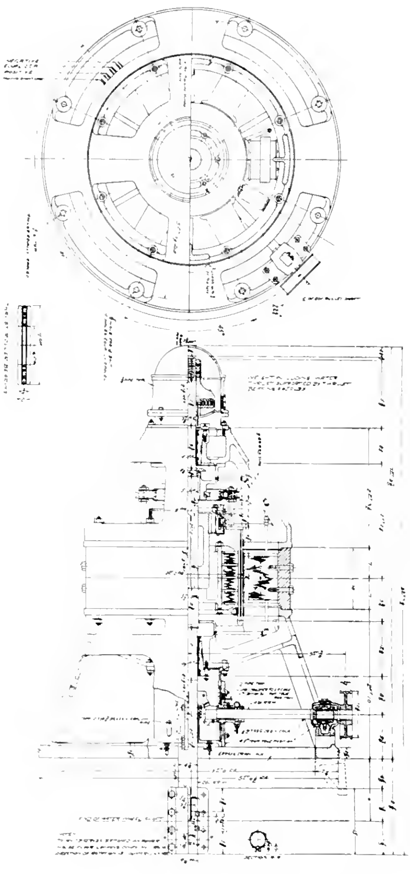


Fig. 21. Cross-section of Vertical-shaft Generator. Weight of armature, waterwheel, and waterthrust is supported on roller bearing on top of generator

head is too small for a turbine installation. High water during the spring floods required that the gas-electric power stations be located some distance from the locks, at a point above high water.

Gate Equipment

The lock gates are of the swing type and are operated through a spare carrying a rack engaging a pinion which is connected back to the motors through gearing. The motors are series wound and are of two sizes, viz., 7-h.p. and 10-h.p., and operate at 800 r.p.m. on 230-volt circuit. The upper gate motors are all 7-h.p., and for the most part the lower gate motors are 7-h.p., excepting in a few cases where 10-h.p. motors are used.

The control equipment consists of a contactor panel operated from a master switch, the control providing for automatic acceleration. An electrically reset overload relay and contactor for controlling the shunt wound solenoid brake are mounted on this panel, and also a contactor, operated from a limit switch, which throws in a section of resistance at the start and finish of the gate swing, thereby slowing down the speed of the gate at the moment of approaching the walls of the lock in opening, and when coming together against the miter sill in closing.

In the control system there is a geared type limit switch which automatically shuts off power when the gate is in the full open or full closed position. This limit switch also controls the signal lights, of which there are two, viz., one red, always showing when the gate is not entirely open, and the other green, showing only when the gate is entirely open.

As all the gate machinery is arranged for hand as well as motor operation, there is provided an electric interlock which opens the control circuit when the clutch coupling dividing the hand operated part of the machine from the motor-operated part is disconnected.

The wiring diagram, Fig. 30, shows the functions of the various parts of the control equipment. From this diagram it will be noted that there is a master switch for each control panel on each side of the lock so that any gate can be operated from either side of the lock.

Valve Equipment

The control of the valves is similar to the gate control, and is performed from a master switch, making use of a limit switch and electric interlock as in the case of the gates, with the exception that there are four signal lights, viz., one blue, showing when the valve is entirely closed, and three white lamps, showing when the valve is one-third, two-thirds, and full open. The valves are of

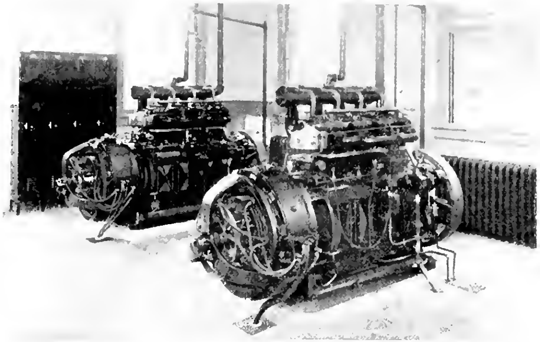


Fig. 22. Power House, Lock 12, Tribes Hill, N. Y. 25-kw., 560-r.p.m., 250-volt Gas-Electric Sets. This station is typical of stations having gas-electric sets, and building is partially heated by passing the cooling water from the engines through standard house type of hot-water heaters.

Fig. 23. Typical Power House Construction. All power houses are of concrete

Fig. 24. Typical View of Lock having its own Power Station

Fig. 25. Typical View of Lock Receiving Power from Adjacent Lock. The sheet iron cabinets shown in the wall enclose the gate valve, capstan motor, and control panels

three sizes, 5 ft. by 7 ft., 6 ft. by 8 ft. and 7 ft. by 9 ft., the two smaller valves being operated by 3-h.p. 1100-r.p.m. compound wound motors and the larger valve by a 7-h.p. 800-r.p.m. compound wound motor. Both motors are wound for 230 volts and are fitted with solenoid brakes. It will be noted from the illustrations that the electrical equipment for operating the gates and valves is enclosed in sheet iron cabinets to protect it from the weather. These cabinets are provided with a base, one section of which can be removed and the cabinet then rolled away from the electrical equipment, thus providing an easy means of getting at all parts for any repairs that may be required.

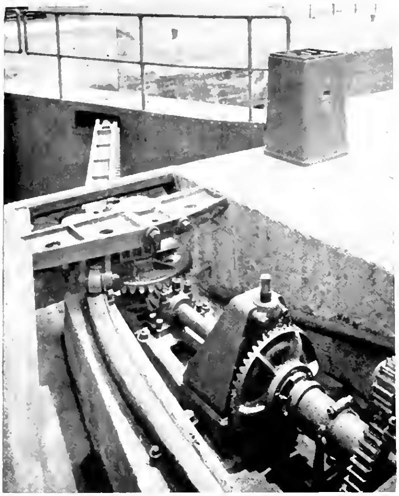


Fig. 26. Operating Stand Controlling Gate and Valve Motors, Lock-wall Type. A typical Lock-wall Type Gate Operating Machine

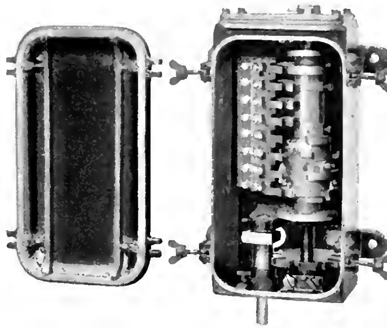


Fig. 29. Typical Limit Switch for Gates and Valve Equipments

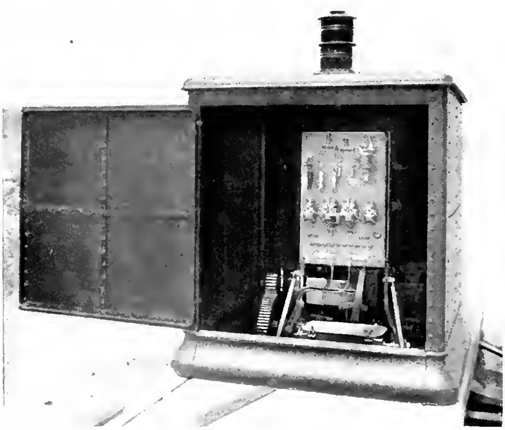


Fig. 27. Typical Control Panel and Cabinet; 7 and 10-h.p., 230-volt, Series Gate Motors, Lock-wall Type. Front view

Fig. 28. Rear View of the Control Panel and Cabinet shown in Fig. 27

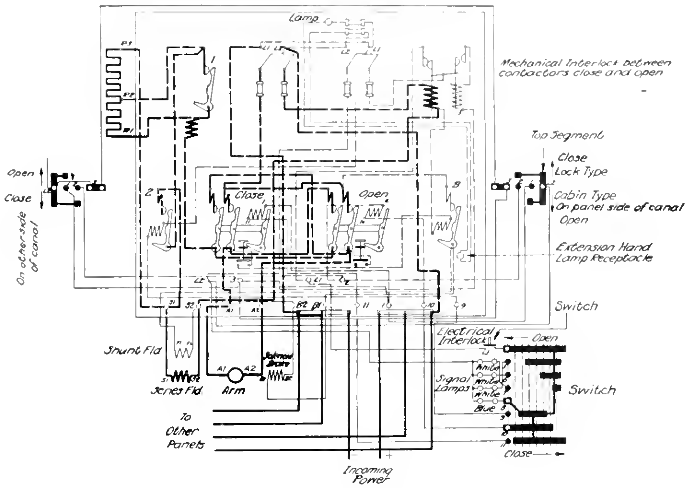


Fig. 30. Typical Wiring Diagram of Gate and Valve Equipments

An exception to the above arrangement of the electrical machinery is at Locks Nos. 8 to 15 on the Erie Canal, through the Mohawk River. This section is subject to very high water during the spring, and instead of the sheet iron cabinets, concrete houses (Fig. 32) are built at each end of the lock, and the electrical machinery is installed on the second floor, which is above the highest recorded high water mark. The up-stream end of the cabin is provided with a heavily reinforced concrete nose to withstand ice, logs, etc., during high floods.

The electrical equipment is controlled from the outside of the house, the master controller being set in a recess in the wall.

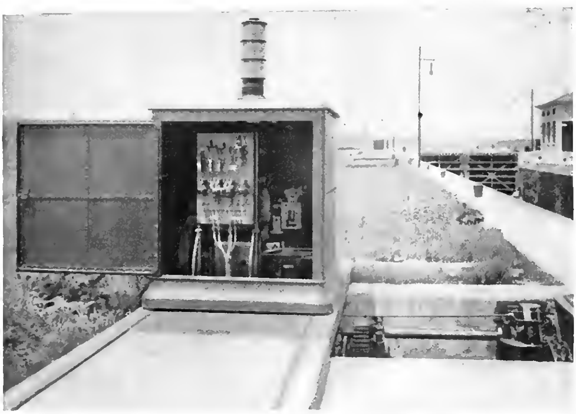


Fig. 31. Control Panel for 3-h.p. and 7-h.p., 230-volt, Compound-wound Valve Motors and Enclosing Cabinet. At the right is shown part of the valve machine. Typical view of the lock-wall type equipment

Capstans

At each lock there are provided two electrically operated capstans, one at each end, for pulling the boats through the locks.

The motors are of special design, made watertight because of their being installed in a recess in the lock walls, which at times is apt to contain water. They are 20-h.p., 550-r.p.m., 230-volt compound wound machines. The control is similar to the gate and valve control, except that the master switch is foot-operated. Pressing down on the foot


Fig. 32. Typical Concrete Operator's Cabin, Locks 8 to 15 inclusive, Erie Canal

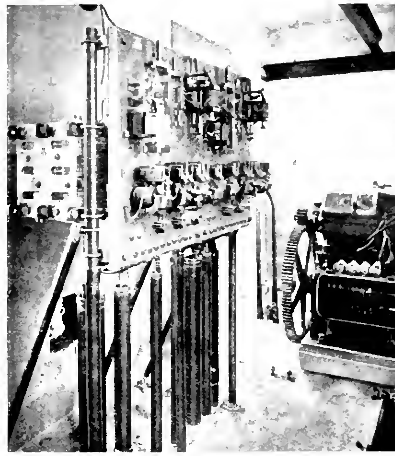


Fig. 33. Typical Operator's Cabin. Interior view showing motor control panels, Locks 8 to 15 inclusive, Erie Canal

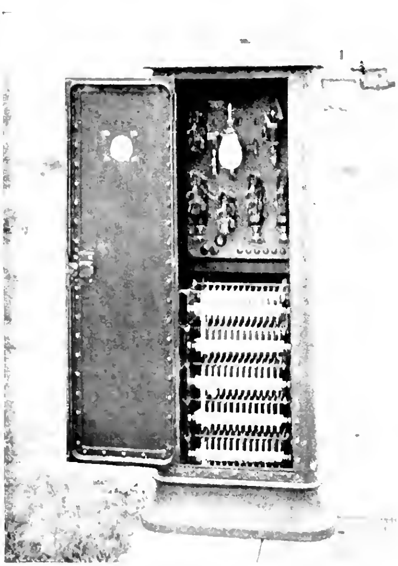


Fig. 34. Typical Control Panel for Lock-wall Type Capstan Motor shown in Fig. 36

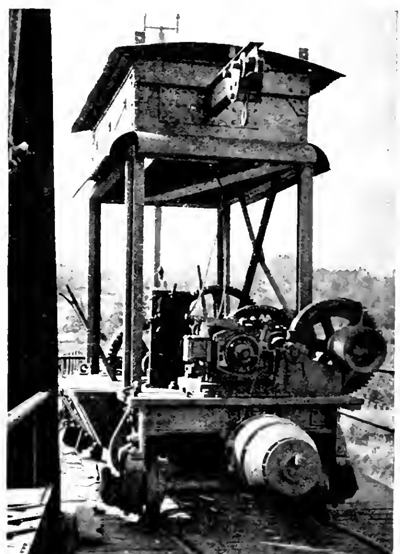


Fig. 35. Typical Electric Winch for raising and lowering the gates of movable dams; 12-h.p., 500-r.p.m., compound-wound motor and drum-type controller. When not in operation the equipment is enclosed with canvas curtains

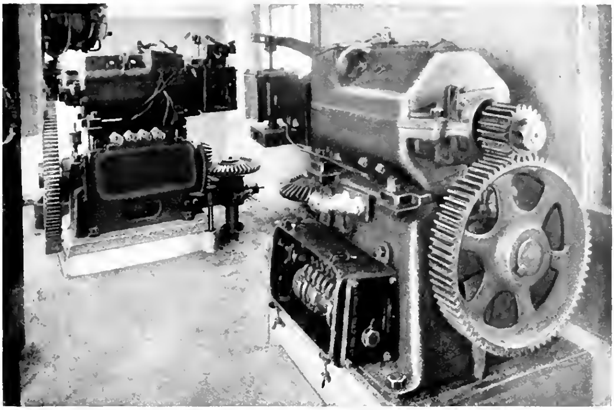


Fig. 36. Typical Operator's Cabin, interior view, showing a valve motor, Locks 8 to 15 inclusive, Erie Canal

pedal with the toe starts the motor up one step at a time; the resistance being so designed that the motor may operate continuously on any step. In this way the speed of the boat through the lock can be nicely regulated. Pressing on the foot pedal with the heel throws the master switch back to the starting position and stops the motor. This type of capstan is used at all the locks, with the exception of Locks Nos. 8 to 15 on the Erie, where the capstan is operated by a 20-h.p., 650-r.p.m., 230-volt mill-type motor, which is installed with the gate and valve motors in the concrete cabins. The master controller is hand-operated and located in a recess in the lock wall.

Movable Dam

After the season of navigation is ended the gates forming the movable dam are lifted up and suspended under the bridge, each movable dam being provided with two electric winches for raising the gates. Each winch is driven

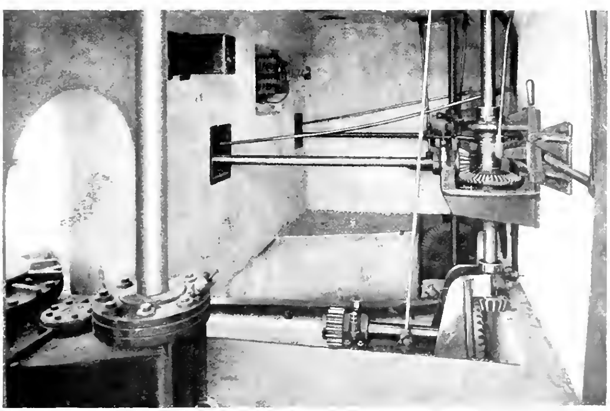


Fig. 37. Typical Operator's Cabin; basement view, Locks 8 to 15 inclusive, Erie Canal. The master control switches are seen projecting through the side of the wall

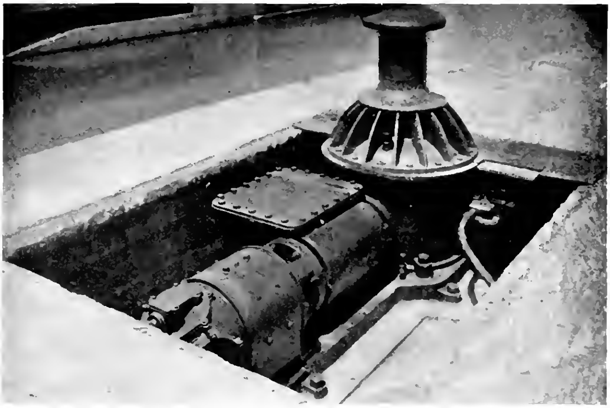


Fig. 38. Typical Lock-wall type, 20-h.p., 230-volt, compound-wound Capstan Motor and Capstan, showing foot-operated master controller mounted on the side of the Capstan

by a 12-h.p., 800-r.p.m. compound wound motor controlled by a drum controller having a circuit breaker for overload protection mounted on the back of the controller. The motor not only raises and lowers the gates, but through a clutch and gearing moves the car back and forth across the bridge.

Guard Gates

Fig. 40 shows the first one of a pair of guard gates at the head of the Waterford flight of locks, where the canal enters the Mohawk River. This type of gate has been used at several points along the canal where it is necessary to protect lower portions from a flood such as would occur in case of a break in a lower lock. For instance at this point Crescent dam holds back the water of the Mohawk River and only the lock gates at Lock No. 6 protect the rest of this flight of locks. Should a break in these gates occur all this water would flow out over the re-

Fig. 39. Locks 34-35, Erie Canal, Lockport, N. Y. New Barge Canal locks on the left, old canal locks on the right, power house in the center

Fig. 40. Guard Gate at the Head of the Waterford Flight of Locks; two 25-h.p., 600-r.p.m., 220-volt, three-phase, 60-cycle induction motors seen in the center. A bridge control equipment is in the operator's cabin on the right

Fig. 41. View of Locks 4, 5 and 6, Erie Canal, Waterford, N. Y., lighted by luminous arc lamps

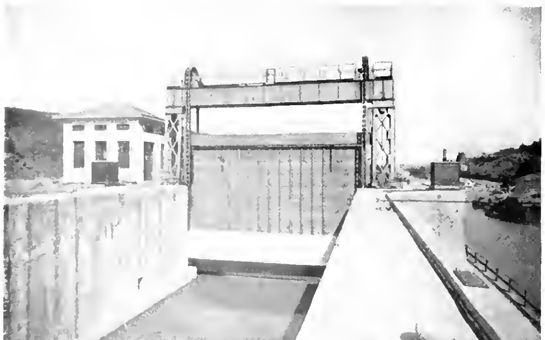


Fig. 42. Lower Gate, Lock 17, Little Falls, N. Y., Lift Type; the only lift lock gate on the canal; lift 40½ ft. At the time of construction, this was the largest lift lock ever built, operated by two 25 h.p. compound-wound direct-current motors

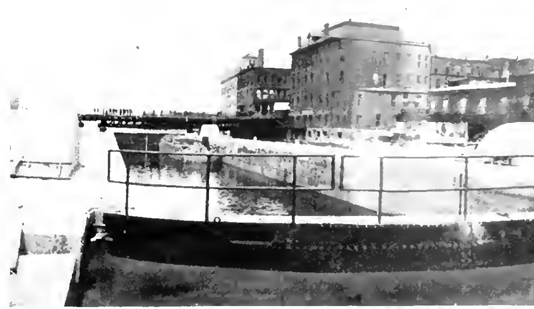


Fig. 43. Syphon Lock, Lock 8, Oswego Canal, Oswego, N. Y. The only lock of this type on the Barge Canal, and also the first to be built in this country, and the largest built employing the syphon principle

Fig. 44. View of Dam at Delta Reservoir showing Flight of Locks of the Relocated Black River Canal

Fig. 45. Barge Canal Terminal, Schenectady, N. Y. Typical of terminals along the canal. At a later date warehouses and loading and unloading machinery will be installed

Fig. 46. Navigation on the Old Canal

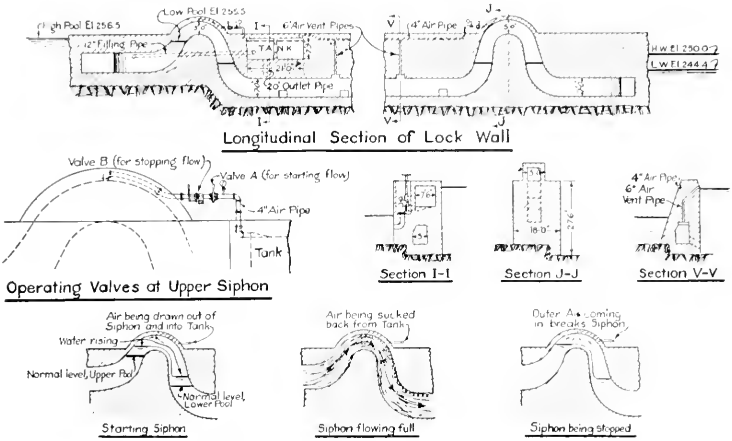


Fig. 47. Diagram showing the Method of Operating Syphon Lock shown in Fig. 42

The flow of water is started in the syphon by means of tanks. To perform an operation the tank is first filled with water, then the intake valve is closed and the outlet valve opened. There results a body of water suspended by its weight, but tending to escape into the lower pool, thus producing the necessary vacuum. On opening the air valve, air from the syphon rushes into the vacuum and water begins flowing over the crest in the neck

maining locks and flood the village of Waterford.

The electrical equipment of the gate consists of two 25-h.p., 600-r.p.m., 200-volt, three-phase, 40-cycle motors with solenoid brakes. The control is in duplicate mounted on separate panels. The motors operate in multiple, but one motor may be cut out and

Fig. 48. Formal opening of Barge Canal by Governor Whitman, May 15, 1915

the other will operate the gate alone. This gate is always kept closed except when boats are passing. The second guard gate is similar to the first, except that it is operated by two compound wound direct current motors, rated 30-h.p., 600-r.p.m., 220-volt, and fitted with solenoid brakes. The control apparatus consists of a contactor panel operated by four master switches, three of which are located on the gate superstructure and the fourth at Lock No. 6, a short distance away. This gate will normally be kept open, and closed only in case of an emergency.

The power stations are heated by 5-kw., 220-volt electric radiators and lighted by 100-watt Mazda lamps. The locks are lighted by 6.5-ampere magnetite arc lamps, from eight to twelve lamps being installed at each lock.

Noteworthy Structures

As a comparison to show the time saved by motor-operated locks, the following data were obtained from a test at Lock No. 7, Visschers Ferry, N. Y.

	Power	Hand
Opening gates	40 seconds	10 minutes
Opening valves	70 seconds	15 minutes
Fill lock	6 minutes	18 minutes
Empty lock	4.5 minutes	18 minutes
Time to lock boat through	20 minutes	45 minutes

The weight of each leaf of the upper gate is 45,000 lb.
The weight of each leaf of the lower gate is 97,000 lb.

It is estimated that the time saved in lockages, the increased speed of boats allowable, and the larger size of boats will make the capacity of the Barge Canal 25 times greater than that of the old canal.

There are 35 locks on the Erie branch. 11 locks on the Champlain branch, 7 locks on the Oswego branch and 4 locks on the Seneca and Cayuga Branch, a total of 57 locks. The electrical equipment of 50 of these is entirely General Electric, and at the remaining 7 locks the power station equipment is General Electric.

Summary

	No.	Total
Locks having power stations	45	....
Locks receiving power from adjacent locks	12	....
Vertical shaft waterwheel generators	52	2800 kw.
Horizontal shaft waterwheel generators	10	500 kw.
Motor-generator sets in substations	6	210 kw.
Gasolene-electric sets	22	550 kw.
Booster sets	5	75 kw.
Vertical shaft generator Crescent Dam power house	3	300 kw.
Power station switchboards	46	....
Switchboards at locks without power station	12	....
Gate motors	224	1604 h.p.
Valve motors	220	884 h.p.
Capstan motors	111	2220 h.p.
Motors for guard gates, guard locks, and lower gates Lock No. 17, Erie	18	386 h.p.
Winch motors—movable dams	16	192 h.p.
Governor pump motors	48	144 h.p.
Pump motors, cooling system, gas-electric stations	11	29 h.p.
Pump motors, vertical shaft generator oiling system	26	3¼ h.p.
Total	674	5462 h.p.
Motor control panels	565	
Operating stands	215	
Capstan master controllers	111	
Limit switches	454	
Electric interlocks	384	
Electric heaters	191	
Arc lamps	542	

Fig. 49. Navigation on the Barge Canal

THE ELECTRIC MOTOR AS AN ECONOMIC FACTOR IN INDUSTRIAL LIFE

By David B. Rushmore

Chief Engineer, Power and Mining Department, General Electric Company

The following article is composed of two main sections each arranged as a classification; the first treats of the various applications of power, and the second of the types of electric motors. Useful statistical data from census reports of industries are presented in tabular form for convenient reference. They are interesting for they disclose the phenomenally rapid growth of electric motor application in many fields, and are very valuable for they indicate the quantitative relation of the power item to the other cost items and the employee in classified manufactures. The remainder of the article is devoted to a textual classification of electric motors and their characteristics with regard to current, phase, frequency, voltage, capacity, speed, rating, design and economy. This article is based on a paper presented by the Author at the 1915 International Engineering Congress, San Francisco, Calif.—Editor.

INTRODUCTION

The electric motor as an economic factor can be truly seen only by viewing its proper place as a factor in modern industry, and in seeing modern industry as a part of the present-day activities and as the culmination of an historical growth.

The "dawn of history" may be said to have occurred with the development of articulate speech. Since then the progress of civilization has been accompanied by or has been the result of a number of distinct developments and inventions, amongst which are fire, the bow and arrow, pottery, the domestication of animals, the use of iron, the development of a written language, gun powder, the mariner's compass, paper and the printing press, the steam engine, spinning and weaving, the telegraph and telephone, and the inventions and developments too numerous for separate mention involved in our great activities of communication, transportation and manufacture.

In the development of a country, human activities progress along the line of exploration, hunting and fishing, mining, lumbering, agriculture and manufacturing.

The Age of Power

The general peaceful activities of human beings are in connection with the transformation of raw materials into the form of finished products suitable for ultimate consumption. This process of transforming raw materials is broadly known as manufacturing, and, taken in its widest sense, includes agriculture, in which the raw materials may be considered as seed, soil, fertilizer, moisture, light and heat.

In general, the real raw materials are relatively few in number, and, besides, those of agriculture are obtained from the deposits of natural resources. A relatively small amount of this is consumed in its original form, and the higher the development of civilization, the more extended becomes the process of transformation of these natural forms into a condition suitable for ultimate consumption.

From the elemental raw material to the final finished product, manufacturing processes stand in series like the bucket passers of the old fire brigade. The finished product of one process or industry becomes the raw material for the next. Energy is consumed at many points, both in transforming the material and also in the local transportation, and it is this which has made the period since the beginning of the last century distinctively an age of power.

Natural products in the shape of raw material being found in different parts of the earth, and consumption of these in many cases being approximately world-wide, there is associated with the processes concerned in transforming the raw material the great activity of transportation and distribution, in which the flow and transformation of commodities may be very well likened to the transmission and distribution of electric energy in a hydro-electric power system, the manufacturing processes corresponding to the transformation in the energy at the different substations and distributing points.

The power of a man working at his greatest physical capacity may be taken as approximately one-eighth of a horse power, the horse power itself being not the average output of a horse but the maximum output of a horse of unusual strength, and then only for a comparatively short period.

The present industrial age has grouped men very largely in cities, and in the ordinary daily life of man there is consumed in connection with each individual an amount of energy much larger than that represented by the muscular activity of this person. In the preparation of our food; in the heating and lighting of our homes; in the transportation systems, by railway, trolley and elevator;

TABLE I
SUMMARY OF MANUFACTURES

Industry	Census Year	No. of Establishments	Persons Engaged in Industry: Proprietors and Firm Members	Salaried Employees	Wage Earners (Average Number)	Total	Primary Horse Power	Capital	Salaries	Wages	Cost of Materials	Value of Products	Val. added by manuf'e (Val. of Products less cost of Materials)
								Expressed in thousands of dollars					
Agricultural implements	1909	640	465	9,213	50,551	60,229	100,601	256,281	10,140	28,609	60,307	146,329	86,022
	1904	648	496	7,199	47,394	55,089	89,738	196,741	7,573	25,003	48,281	112,007	63,726
	1899	715		10,046	46,582		70,646	157,708	8,363	22,541	43,945	101,207	57,262
Automobiles including bodies and parts	1909	743	405	9,233	75,721	85,359	75,550	173,837	9,479	48,694	131,646	249,202	117,556
	1904	178	103	1,181	12,049	13,333	10,109	23,084	1,257	7,159	13,151	30,034	16,883
	1899	57		268	2,241			5,769	295	1,321	1,804	4,748	2,944
Boots and shoes including cut stock and findings	1909	1,918	1,838	15,788	198,297	215,923	96,302	222,324	18,629	98,463	332,738	512,798	180,060
	1905	1,895	2,128	9,518	160,294	171,940	63,968	136,802	9,412	73,072	225,288	357,688	132,400
	1899	2,253		8,348	151,231		55,489	110,363	8,159	61,924	191,456	290,047	98,591
Boots and shoes, rubber	1909	22		1,287	17,612	18,899	25,903	43,905	1,415	8,544	29,577	49,721	20,144
	1904	22	2	822	18,991	19,815	26,084	39,412	874	8,867	32,000	70,065	38,065
	1899	22		483	14,391		25,017	33,668	597	6,427	22,683	41,090	18,407
Brass and bronze products	1909	1,021	828	3,395	40,618	45,441	106,120	109,319	5,540	23,677	99,228	149,989	50,761
	1904	813	784	3,600	33,168	36,952	69,494	77,438	7,778	17,666	65,653	102,407	36,754
	1899	695		1,813	27,166		47,257	51,120	2,297	13,599	61,189	88,654	27,465
Bread and other bakery products	1909	23,926	26,982	17,124	100,216	144,322	65,298	212,910	13,764	59,351	238,034	396,865	158,831
	1904	18,226	20,037	8,358	81,278	109,673	37,241	122,353	6,273	43,172	155,989	269,583	113,594
	1899	14,836		9,167	60,192		22,472	80,962	6,063	27,864	95,052	175,369	80,317
Brick and tile	1909	4,215	4,285	4,951	76,528	85,764	341,169	174,673	5,439	37,139	23,736	92,776	69,040
	1904	4,634	5,295	3,690	66,021	75,006	255,362	119,957	3,530	28,646	16,317	71,152	54,835
	1899	5,423		2,426	61,979		176,700	82,086	2,025	21,883	11,006	51,270	40,264
Cars and general shop construction and repairs by steam-railroad companies	1909	1,145	2	19,097	282,174	301,273	293,361	238,317	17,339	181,344	199,413	405,601	206,188
	1904	1,140		13,329	236,870	250,199	167,973	146,886	11,920	142,153	151,105	309,775	158,670
	1899	1,292		7,094	173,595		95,087	119,473	6,208	96,007	109,472	218,114	108,642
Cement	1909	135	17	2,719	26,775	29,511	371,799	187,398	3,653	15,320	29,344	63,205	33,861
	1904	129	26	1,383	17,478	18,887	149,604	85,759	1,858	8,814	12,215	29,873	17,658
Chemicals	1909	349	154	3,923	23,714	27,791	208,604	155,144	6,137	14,085	64,122	117,689	53,567
	1904	275	123	2,778	19,806	22,707	132,262	96,621	4,048	10,790	42,063	75,222	33,159
	1899	433		2,123	19,020		90,349	89,069	2,923	9,393	34,546	62,637	28,091
Copper, tin and sheet-iron products	1909	4,228	4,423	8,896	73,615	86,934	62,366	217,532	10,288	39,501	112,582	199,824	87,242
	1904	2,540	2,851	4,827	53,035	60,713	30,229	147,608	6,080	26,269	63,921	119,933	56,012
	1899	1,985		2,924	38,317		28,829	49,679	2,810	16,924	42,602	78,359	35,757
Cotton goods including cotton small wares	1909	1,324	377	8,514	378,880	387,771	1,296,517	822,238	14,412	132,859	371,009	628,392	257,382
	1904	1,154	432	6,981	315,874	323,287	986,604	613,111	10,238	96,206	286,255	450,468	164,213
	1899	1,055		4,902	302,861		795,834	467,240	7,350	86,690	176,552	339,200	162,648
Electrical machinery, apparatus, and supplies	1909	1,009	439	17,905	87,256	105,600	158,768	267,844	20,193	49,381	108,566	221,309	112,743
	1904	784	400	10,619	60,466	71,485	105,376	174,066	11,091	31,842	66,837	140,809	73,972
	1899	581		5,067	42,013		43,674	83,660	4,632	20,579	49,458	92,434	42,976
Fertilizers	1909	550	323	3,317	18,310	21,950	64,711	121,537	4,406	7,477	69,522	103,960	34,438
	1904	399	294	1,613	14,184	16,091	47,989	68,917	1,934	5,127	39,288	56,541	17,253
	1899	422		1,712	11,581		38,680	60,686	2,125	4,185	28,958	44,657	15,699
Flour-mill and grist-mill products	1909	11,691	14,570	12,031	39,453	66,054	853,584	349,152	12,517	21,464	767,576	883,584	116,008
	1904	10,051	13,098	7,415	39,110	59,623	775,318	265,117	7,352	19,822	619,971	713,033	93,062
	1899	9,476		5,522	32,226		670,719	189,281	5,258	16,285	428,117	501,396	73,279
Foundry and machine shop products	1909	13,253	9,851	74,623	531,011	615,485	869,305	1,514,332	93,795	321,521	540,011	1,228,475	688,464
	1904	10,765	9,370	49,406	443,409	502,185	606,165	1,034,135	59,703	246,573	367,412	880,514	513,102
	1899	11,046		34,286	426,985		443,085	790,741	39,318	219,870	363,036	798,454	435,418
Ice, manufactured	1909	2,004	1,066	3,927	16,114	21,107	317,789	118,641	3,868	9,779	11,317	42,953	31,636
	1904	1,320	746	2,332	10,101	13,179	191,660	66,592	2,001	5,549	6,011	23,790	17,779
	1899	775		1,531	6,880		100,421	38,020	1,226	3,403	3,312	13,781	10,469
Iron and steel blast furnaces	1909	208	48	4,584	38,429	43,061	1,173,422	487,581	6,525	24,607	320,638	391,429	70,791
	1904	190	26	2,231	35,078	37,335	773,278	236,146	2,891	18,935	178,942	231,823	52,881
	1899	223		1,757	39,241		497,272	143,159	2,304	18,484	131,504	206,757	75,253

Iron and steel, steel works and rolling mills	1909	446	47	20,639	240,076	260,742	2,160,978	1,604,735	26,191	163,201	657,501	985,723	328,222
	1904	415	64	14,330	207,562	221,956	1,649,299	700,182	17,860	122,492	441,204	673,965	232,761
	1899	445		7,454	183,249		1,100,801	430,232	9,433	102,336	390,895	597,212	206,317
Leather, tanned, curried and finished	1909	919	784	4,114	62,202	67,100	148,140	332,727	6,744	32,103	248,279	327,874	79,595
	1904	1,049	1,112	3,251	57,239	61,602	117,450	242,584	4,452	27,049	191,179	252,621	61,142
	1899	1,306		2,442	52,109		88,860	173,977	3,159	22,591	155,000	204,038	49,038
Lumber and timber products	1909	40,671	48,825	41,145	695,019	784,989	2,840,082	1,176,675	47,428	318,739	508,118	1,156,129	648,011
	1904	25,153	30,738	30,038	532,566	593,342	1,886,624	733,708	31,737	245,834	360,325	884,267	523,942
	1899	28,133		20,940	508,766		1,658,594	541,595	18,715	188,395	364,964	760,902	396,028
Paper and wood pulp	1909	777	250	5,245	75,978	81,473	1,304,265	409,348	9,510	40,805	165,442	267,657	102,215
	1904	761	309	3,778	65,964	70,051	1,093,708	277,444	6,097	32,019	111,252	188,715	77,463
	1899	763		2,935	49,646		762,118	167,568	4,501	20,746	70,530	127,326	56,796
Printing and publishing	1909	31,445	30,424	99,608	258,434	388,466	297,763	588,346	103,458	164,628	201,775	737,876	536,101
	1904	27,793	28,368	68,592	219,087	316,047	166,380	432,854	67,748	127,196	142,514	552,473	409,959
	1899	23,814		40,685	195,260		119,775	333,003	39,475	99,816	103,654	395,187	291,533
Slaughtering and meat-packing	1909	1,641	1,659	17,329	89,728	108,716	208,707	383,249	20,054	51,645	1,202,828	1,370,568	167,740
	1904	1,221	1,324	12,096	75,399	88,819	119,311	240,419	13,453	41,067	811,426	922,038	110,612
	1899	1,080		10,317	69,264		87,060	190,209	10,211	33,846	685,310	788,368	103,058
Smelting and refining, copper	1909	38	7	1,197	15,628	16,832	158,126	111,443	2,419	13,396	333,532	378,806	45,274
	1904	40	1	809	12,752	13,562	76,524	76,825	1,527	10,827	196,737	240,780	44,043
	1899	47		488	11,324		61,630	53,063	955	8,529	122,174	165,132	42,958
Woolen, worsted and felt goods, and wool hats	1909	985	732	5,722	168,722	175,176	362,209	430,579	10,097	72,427	282,878	435,979	153,101
	1904	1,074	958	4,593	146,755	152,306	288,969	314,081	6,781	57,073	204,613	319,348	114,735
	1899	1,281		3,808	130,697		244,825	265,730	5,574	46,812	153,930	248,798	91,868
Total all industries	1909	268,491	273,265	790,267	6,615,046	7,678,578	18,675,376	18,428,270	938,575	3,427,038	12,142,791	20,672,052	8,529,261
	1904	216,180	225,673	519,556	5,468,383	6,213,612	13,487,707	12,675,581	514,439	2,610,445	8,500,208	14,793,903	6,293,695
	1899	207,514		364,120	4,712,763		10,097,893	8,975,256	380,771	2,008,361	6,575,851	11,406,927	4,831,076

and in the power consumed in connection with our daily work, there is an expenditure of energy beyond the daily output of a man, and on this, to a large extent, rests the condition of civilization which we have today.

Thus we find the present highly developed civilization dependent upon the utilization of the stored energy in our natural resources or upon the energy from the sun, either directly or through water powers; and the utilization of this energy on a broad scale has been economically possible only by the use of electricity.

Advantages of the Electric Motor Drive

Electricity is the most convenient form in which to transmit and apply energy, and the electric motor is a means for transforming electrical to mechanical energy, and produces motion and torque at various speeds and in different directions. The advantages of the electric drive of machinery in general are:

An increased production for a given equipment, and an improved product.

A decreased power consumption and higher efficiency.

This is due to:

Centralized power supply.

Simplicity of power transmission and distribution.

Machinery may be conveniently located with reference to production rather than to the power transmitting system.

Changes can easily be made.

Reduced friction losses and, thus, increased efficiency.

Cleanliness and better light, due to absence of a large number of belts.

Less danger of accidents.

Better reliability of operation.

Wide choice of motors as to size, mechanical design and operating characteristics.

Perfect control, including readiness of starting and stopping and making close speed adjustments.

Remote and automatic control.

The operations may be closely studied by means of recording devices, and tests can readily be made.

Economy in time.

Ability to operate any portion of a factory at any time with a power consumption approximately proportional to the work done.

Statistical Data

In order to show the rapid increase in the use of electric power in our industries, Tables I to VII, based on census reports, have been prepared.

Table I gives a summary of the manufacturing industry, including the number of establishments, number of persons engaged in the industry and its various branches, the amount of primary power used, capital, salaries, wages, cost of materials, value of products and the value added by the manufacturing process. There are no figures available later than the 1909 census report, but an endeavor has been made to approximately estimate the amount of primary power used in the manufacturing industry at the present time and also the total horse power value of the electric motors used therein. These results are plotted in the curves, Fig. 1, and it may be safely assumed that the amount of primary power used is very close to twenty-five million horse power and that electric motors of a combined capacity of approximately ten or eleven million horse power are in use in the manufacturing industry alone.

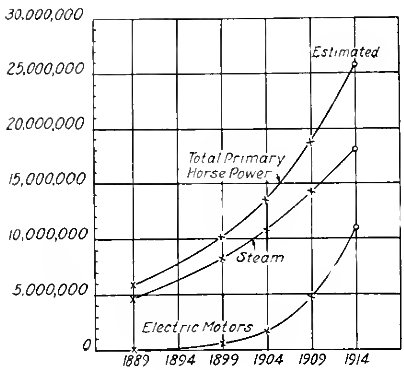


Fig. 1

Table II gives the horse power capacity of electric motors used in some of the leading manufacturing industries, as well as the whole industry for the years 1899–1904–1909. The horse power required per $1000 value of product and per person engaged in the industries is given in Table III.

Table IV gives the amount of primary power and electric motors used in the mining industry, while Table V gives some statistical data in regard to street and electric railways and shows how completely the old methods of drive have been superseded by the electric-motor drive.

Table VI gives the number of central stations in the country, their primary power and generator capacities. It also contains figures as to the number and horse power of stationary motors served, and the rapid increase in this field clearly illustrates the advantages of purchasing central-station power.

CLASSIFICATION OF MOTORS, AND FACTORS INVOLVED IN THEIR APPLICATION

Lacking standardization at the beginning entails the necessity for manufacturing varieties necessitated only by the conditions of existing systems and not by the intrinsic natural requirements. In the past, the electric motor has been adapted to the machine to be driven, but seldom is the reverse true, that the machine is adapted to the motor. While much work has been done towards a standardization of motor sizes, speeds, voltages and mechanical details, it is astonishing to note the thousands of varieties of motors which are being specified, and for which, of course, a large amount of special parts must be kept in stock by the manufacturers to meet reasonable deliveries; not to speak of the increased cost of the product.

The variety of electric-motor designs, from the standpoint of a large electric manufacturing company, is thus seen in the following general classification.

Current

This may be direct or alternating current, but the advantages of the latter are, as a rule, so many that it is almost always selected for industrial plants. If direct-current motors are required for a variable-speed service, motor-generator sets can readily be provided for the conversion.

Phases

These may be:

Single-phase.

Two-phase, three- or four-wire.

Three-phase, three- or four-wire, with grounded or ungrounded neutral.

Six-phase.

Frequencies

The following list gives the different frequencies for which motors have been designed: 15, 25, 30, 33, 40, 42, 50, 60, 62½, 66, 125, 133, 300. This latter frequency, 300, was used for a ball-bearing grinding motor operating at a speed of 18,000 r.p.m.

While 40 cycles might possibly have been the best frequency for general use, it did not become standard, and the choice is now between 25 and 60. The former has been used extensively for power work, but there is every indication that 60 cycles is gaining rapidly in favor, even for this class of service. One of its advantages is the greater number of motor speeds which is possible, as compared with the lower frequency.

Voltages

In motor design, over fifty special voltages are met with, distributed between 6 and 16,000.

For direct-current industrial motors, 115 and 230 volts have been adopted standard voltages. For small alternating-current motors, 110 and 220 volts are standard, while for larger sizes, 220, 440 and 550 volts have been adopted. In certain large instal-

TABLE II

ELECTRIC MOTORS IN LEADING MANUFACTURING INDUSTRIES

	HORSE POWER		
	1909	1904	1899
Agricultural implements	38,905	20,713	7,643
Automobiles	41,829	4,229	
Car and railroad repair shops	161,288	52,635	4,563
Cement	158,749	35,292	
Cotton goods	235,902	67,139	17,594
Electrical machinery	164,540	61,753	24,256
Foundry and machine shops	623,914	199,625	54,907
Iron and steel—blast furnaces	135,143	52,610	8,693
Iron and steel—rolling mills	716,609	254,258	64,658
Lumber and timber products	130,707	33,517	11,315
Paper and wood pulp	130,120	31,604	2,814
Printing and publishing	229,312	93,219	41,413
Total	4,817,140	1,592,475	492,936

TABLE III

POWER REQUIRED FOR MANUFACTURING BASED ON 1909 UNITED STATES CENSUS

	Horse Power Required per $1000 Production	Horse Power Used per Person Engaged in Industry
Agricultural implements	0.69	1.67
Automobiles	0.30	0.89
Boots and shoes	0.19	0.45
Brick and tile	3.68	4.00
Cement	5.90	12.60
Chemicals	1.78	7.50
Copper, tin and sheet-iron products	0.31	0.72
Cotton goods	2.07	3.35
Electrical machinery	0.72	1.50
Fertilizers	0.62	2.95
Flour and grist-mill products	0.97	12.90
Foundry and machine shops	0.71	1.41
Manufactured ice	7.40	15.05
Iron and steel—blast furnaces	3.00	27.30
Iron and steel—rolling mills	2.13	8.06
Leather—tanned, curried and finished	0.45	2.21
Lumber and timber	2.46	3.62
Paper and wood pulp	4.88	16.05
Printing and publishing	0.40	0.77
Packing houses	0.15	1.92
Copper smelting and refining	0.42	9.41
Woolen, worsted and felt goods	0.83	2.06
Total—all industries 1909	0.91	2.45
1904	0.91	2.17

lations, 660 volts are also used, the particular voltage to be selected being mainly governed by the most economical distributing pressure.

Capacities

It is almost impossible to tabulate all the different motor capacities which have been built or for which designs have been made. So, for example, are fractional horse power motors built in not less than sixteen different sizes varying from 1/200 h.p. to 3/4 h.p. There are forty-four different sizes between 1 and 100 h.p. and twenty-three sizes between 100 and 1000 h.p. Direct-current motors have been built in sizes up to 2000 h.p., and alternating-current motors are, at the present time, being built in sizes up to 7500 h.p., while sizes over twenty thousand horse power have been considered for the propulsion of ocean liners.

TABLE IV

POWER USED IN MINING

	1909 H.P.	1902 H.P.
Primary power		
Total	4,699,910	2,867,562
Steam power	3,840,923	2,432,963
Electric motors	723,727	
Horse power required per $1000 value of product	3.82	3.6
Horse power used per person engaged in industry	4.00	4.62

TABLE V

STREET AND ELECTRIC RAILWAYS

	1912 H.P.	1907 H.P.
Primary power		
Total	3,655,051	2,519,823
Steam power	3,169,554	2,368,183
Miles of track operated by		
Electricity	40,808	34,037
Cable	56	61
Animal power	57	136
Steam	76	105
Gasolene	66	40
Number of cars equipped with		
Electric motors	73,758	63,504
One motor	1,207	629
Two motors	45,996	45,660
Three motors	749	422
Four or more motors	25,806	16,793

TABLE VI

COMMERCIAL AND MUNICIPAL CENTRAL STATIONS

	1912	1907	1902
Number of stations	5,221	4,714	3,620
Primary horse power			
Total	7,528,648	4,098,188	1,845,048
Steam	4,946,532	2,693,273	1,394,395
Water	2,471,081	1,349,087	438,472
Gas	111,035	55,828	12,181
Kw. capacity of dynamos	5,134,689	2,709,225	1,212,235
Stationary electric motors served			
Total number	435,473	187,652	111,113
Total horse power	4,130,619	1,807,949	473,693
Average number per station	83	35	28
Average horse power per station	791	350	121
Average horse power per motor	9.5	9.9	4.3

Speeds

The speed of synchronous motors is fixed by the frequency of the supply circuit and the number of poles of the machine, the relation being expressed by the equation:

$$\text{Revolutions per minute} = \frac{\text{cycles} \times 120}{\text{number of poles}}$$

For induction motors, however, this condition does not hold true under load, as the speed then falls off somewhat, the percentage of decrease below synchronous speed being called the "slip." This slip of an induction motor, over the usual ranges of operation, varies directly with the load and the rotor resistance, and inversely as the square of the applied voltage.

There are hundreds of different speeds for which motors have been built—alternating-current motors from as low as 55 r.p.m. to as high as 18,000, and direct-current motors from 53.5 to 3450 revolutions per minute.

Speed Classification

Motors may, for convenience, be classified with reference to their speed characteristics as follows:

Constant Speed—Where the speed is constant or varies only slightly.

Adjustable Speed—Where the speed may be varied over a considerable range, but when once fixed, remains at this value, independent of the load changes.

Varying Speed—Where the speed changes with the load, usually decreasing as the load increases.

Multi-Speed—Where several distinct speeds may be obtained by changing the connections of the windings or by other means.

Classification According to Current and Operating Characteristics

- Direct Current
  - Series
  - Shunt
  - Compound
  - Differential
- Alternating Current
  - Synchronous
  - Induction
    - Phase-wound
    - Squirrel-cage
  - Synchronous-Induction
  - Commutator
    - Series-Characteristics
    - Shunt-Characteristics
    - Compound-Characteristics

Operating Characteristics

Series Motors: The torque increases faster than the current and is a maximum at minimum speed. The speed varies with the load, being high at light load and low at heavy load. The efficiency is high throughout a wide range of speed as well as load.

Shunt Motors: The torque is directly proportional to the armature current, irrespective of speed. Approximately constant speed for all reasonable variations of load. Efficiency high throughout a wide range of load, but only for a small range of speed.

Compound Motors: Combine the characteristics of series and shunt motors, having a powerful starting torque and an increasing torque with decreasing speed. Speed not extremely variable under load changes, thus avoiding the danger of excessive speed at light loads.

Differential Motors: The series and shunt windings oppose each other, and these motors have, therefore, poor starting qualities. Speed increases with increase of load, but they have no tendency to run at dangerously high speed. Used only rarely for special applications.

Synchronous Motors: The speed of a synchronous motor is constant, being fixed by the number of poles and the frequency of the applied voltage. The single-phase type is not self-starting and requires some auxiliary motor to bring it up to synchronous speed and into proper phase relation before it can be properly connected to the supply circuit. The polyphase type has a limited starting torque, unless special features are added to assist its inherent starting characteristics. They are, therefore, usually provided with amortisseur starting windings; and the starting torque, due to the currents in this winding, is proportional to the square of the current induced and to the resistance of the winding. A motor of large armature reaction and high-resistance starting winding will have a high starting torque. The amount of load that the motor will bring up to synchronism and pull in depends also on the starting winding; but in this respect, a low resistance amortisseur winding is required to get the best results or the least slip, and from this standpoint, high synchronizing torque is opposed to high starting torque, and vice versa. This factor is, however, not an especially difficult one to meet if the requirements are known beforehand, as it is seldom that the same motor will be called upon to start a heavy load and, at the same time, synchronize a heavy load.

The phase characteristics of a synchronous motor are of importance, as they show the variation in armature current for any given load with varying field excitation, and there is a certain field current at each load that causes a minimum current to flow. Any increase or decrease of field from this value increases the current and causes it to lead or lag in phase with respect to the line voltage.

Induction Motors, Phase-Wound: High starting torque with moderate starting current. Constant or variable-speed service, the latter being obtained by means of an adjustable resistance in the rotor circuit.

Induction Motors, Squirrel Cage: Constant-speed service with infrequent starting. Relatively small starting torque per ampere. By increasing the rotor resistance, thus decreasing the efficiency, it may, however, be built for high starting torque. Chief advantages are simplicity and durability.

Synchronous-Induction Motors: The same general construction as the wound rotor induction motor, the synchronous operation being obtained by exciting with low-voltage direct across one phase of the rotor winding. Better starting characteristics than the synchronous motor. The operation of the latter is, however, more stable under varying loads and fluctuating voltage, while it may be economically designed for power-factor improvements. Its cost is also lower.

A-C. Commutator Motors: The characteristics of these motors are such that with suitable control they can be used in place of corresponding types of direct-current motors.

Consideration of the factors involved in a motor application necessitates a careful study, not only of the conditions under which the motor is to operate, but also of the characteristics of the motor itself.

Load Conditions

A complete knowledge of the load condition is, of course, absolutely essential for the selection of a satisfactory motor equipment. It is best represented by a load diagram for a complete cycle of operation, and the frequency with which these cycles are repeated must also be given.

The manufacturing process and the load diagram should be carefully studied to ascertain if any part of the cycle can be varied with benefit. Arrangements may also be made so that intermittently-operated machines need not be operated simultaneously, thus giving a smoother load curve and allowing the use of a smaller motor to drive several intermittent machines. Future conditions such as an increase in the output and load, must be given consideration—also possible variations in the load caused by change of conditions, such as a decrease in head on a centrifugal pump, etc. Allowance must then be made in the motor size to take care of such contingencies.

The starting conditions should also be carefully studied. Even though the size of the motor may be sufficient for normal running, it may not be able to develop enough torque at starting, or the starting current may be excessive.

A study of the starting conditions involves the torque, horse power and time of acceleration. In many applications the "breaking away torque" is considerably higher than the running or accelerating torque, while in others the conditions may be such that the load increases as the motor comes up to speed.

Motor Rating and Limitations

There are various kinds of motor ratings, such as:

1. Continuous duty, where the load is practically constant over long periods of time.
2. Short-Time Rating:
   a. Cycle duty, in which a definite cycle repeats itself with more or less regularity, the machine stopping between each cycle.
   b. Varying-load duty, in which more or less definite cycles are repeated, but the motor runs continuously.

Among the limitations in the rating of motors, the following factors enter:

Mechanical strength
Insulation strength
Heating
Commutation
Regulation
Efficiency
Power-factor (a-c.)
Output
Torque (starting and maximum)

Mechanical Design

The operating as well as local conditions have a great bearing on the mechanical features of a motor; some of these mechanical features being listed below:

Types of Motors:

Horizontal or vertical; open; protected; semi-enclosed; totally-enclosed; enclosed, externally ventilated; enclosed, self-ventilated; water-cooled; moisture proof; splash or water proof; submergible; dust proof; high temperature proof; acid and alkali proof; explosion proof.

Bearings:
Types: Cylindrical, step, thrust, plate, ball, roller, pivot.
Materials: Cast iron, steel, gun metal, phosphor bronze, white alloys, lignum vitae and other hard woods.

Lubrications:
Oils—Vegetable, animal, mineral; greases; solids.

Methods of Application:
Compression grease cups; wick or siphon feed; oil pad pressed against the journal; oil rings or chains; centrifugal means; oil bath; gravity feed; forced feed.

Method of Drive:
Belt:
Various forms of leather; rubber; cast iron; wood or paper pulleys.
Gear:
Steel; cast iron; fabric.
Coupling:
Rigid; various forms of flexible.
Rope.
Chain.
Friction.
Accessories:
Bases, rails, foundation plates, number of bearings, belt tighteners, shaft extensions.

Special Types of Motors

The numerous special features which must be met for certain industries have made it desirable to design certain lines of motors which are particularly suited for these classes of service. Among these may be mentioned: Attrition mills, automobiles, blowers and fans, buffing and grinding, cement mills, coal cutters, compressors, cranes, dentistry, elevators, hoists, linotype machines, machine tools, oil wells, printing presses, pumps, railways, sewing machines, sugar centrifugals, textile mills, etc.

Control Equipment

The function of a control equipment is to regulate the speed and direction of the motors and to protect the machinery and operators against abnormal conditions, this being accomplished by certain definite systematic changes in the connections.

The speed variations of direct-current motors are usually accomplished by varying the armature or field circuits, or both, if the motors run separately, or by various groupings of motors in series and parallel, where the motors are in pairs, as is usual in railway practice.

The starting of squirrel-cage induction motors may be accomplished either by connecting the motors to compensator taps or, for small motors, by inserting resistance in the primary leads. For wound-rotor motors a resistance is inserted in the secondary circuit. Speed control of alternating-current motors may be accomplished by secondary resistance, pole-changing concatenation, brush shifting and dynamic regulation.

It is beyond the scope of this paper to discuss in detail all the numerous features entering into the selection of control equipments for the various classes of motors and service conditions, and only a brief outline of the points to be considered will be given in the following:

1. Functioning of Equipment.
   a. Personal or impersonal (automatic) pilot control.
      I. Personal control without any automatic aids or limitations.
      II. Personal control by aid of power-operated control devices, but without any automatic limits.
      III. Personal control, subject to automatic limitations of rate of change.
      IV. Personal control for a portion of the cycle and automatic control, irrespective of persons, for remainder of cycle.
      V. Complete automatic impersonal control.
   b. Requirements for driven machine.
      I. To control starting, retarding or reversing with reference to load or shocks imposed on driven machinery.
      II. To control speed or torque with reference to requirements of production.
      III. To start and stop one motion with respect to a related, but separately driven, motion.
   c. Requirements for motor and power circuit.
      I. Protection against injurious commutation.
      II. Limiting of mechanical shocks to motor.

III. Limiting of momentary load on line.
IV. Limiting of heating.
V. Conservatism of energy required for operation.

d. Protection against abnormal conditions.
I. Short circuits.
II. Momentary overloads on motor, line or driven machinery.
III. Time overloads on motor.
IV. Over speed
V. Failure of voltage.
VI. Emergency shut-down by other means—e.g. by hand from remote points; automatically, by breakage of machinery, etc.

2. Capacity.

a. Capacity of main circuit-changing parts.
I. To close on peak loads during acceleration.
II. To carry momentary running loads occurring after closing is completed.
III. To open under load.
IV. To carry sustained loads.

b. Capacity of rheostats or compensators.
I. Heat storage and dissipating capacity for making heaviest single start or reversal, or required number of starts or reversals in rapid succession.
II. Heat dissipating capacity to make required number of starts per hour or per day.
III. Capacity for prolonged operation at partial speed (rheostat only).
IV. Ability to withstand instantaneous load fluctuations without excessive mechanical stresses due to magnetic fields.
V. Ohms or voltage taps for limiting torque or current in-rush, as required.

3. Reliability and Convenience of Operation.

a. Certainty of opening of circuits.
b. Voltage range.
c. Interlocking for invariable sequence.
d. Interlocking to prevent short-circuits in making transitions.
e. Adjustment for adaptation to load conditions not precisely predetermined.

4. Local Conditions.

a. Atmospheric conditions, e.g., dust, humidity, etc.
b. Room temperature.
c. Stability of mounting, vibrations, etc.
d. Safety rules.
e. Underwriters' rules.
f. Class of labor used. Custom of the trade regarding inspection and repairs.

The subject of the life of the equipment has not been included in the above. Where conditions are severe, the life, capacity as in (2), and the reliability as in (3) are all dependent on one another.

Economy

In the consideration of the electric motor as an economic factor, the following points are also of interest in a comparison of the electric-motor versus other forms of drive, and afford a basis of comparison between motors of different characteristics:

The cost and value of efficiency, capacity, power-factor, starting and maximum torque, torque per ampere, weight per horse power, space per horse power, regulation, appearance, etc.

The cost and value of reliability and of duplication insurance.

The cost of insurance against failure of any part involving the loss, by interruption, of operations.

The cost of motor and controller as percentage cost of the entire equipment.

The cost of motor in terms of value of product.

The cost of energy in percentage cost of unit of product.

The influence of electric motors on the quality and quantity of product.

Cleanliness.

Safety insurance.

FIELDS OF MOTOR APPLICATION

Manufacture is defined by the Century Dictionary as "The operation of making goods or wares of any kind; the production of articles for use from raw or prepared materials by giving to these materials new forms, qualities, properties or combinations, whether by hand labor or machinery."

The principal industries and classes of service from the standpoint of the use of electric power are as follows:

Industries:

Agriculture, automobile, bakeries, boiler works, bottling works, box factories, breweries, brick factories, broom factories, building construction, candy factories, carpet and rug factories, cement, clothing, corn mills, cotton mills, cotton oil seed mills, creameries, dairies, dye works, flour mills, foundries, freight handling, glass factories, glove factories, hardware manufacture, harness factories, ice machines, irrigation, knitting factories, laundries, lumber mills, machine shops, mattress and spring factories, meat packing, mining, paint works, paper box factories, paper and pulp mills, piano factories, pipe mills, planing mills, porcelain factories, railways, refrigeration, rubber industry, shoe factories, shoe repairing, soap factories, spice factories, steel mills, stone quarries, stove factories, sugar industry, tanneries, textile mills, tile factories, tobacco factories, trunk factories, wagon factories, wall paper factories, woodworking factories, woolen and worsted mills.

Classes of Service:

Air compressors, blowers, coal cutters, concrete mixers, conveyors, cranes, crushers, dental appliances, dredges, elevators, exhausters, fans, hoists, ice cream freezers, lime kilns, locks, pumps, printing presses, rock drills, sewing machines, ship propulsion, towing machinery, turntables, vacuum cleaners, vehicles, washing machines.

OUTLINE OF AN INDUSTRY

All industries have certain common features which are of general interest. Amongst these are the following:

Description of the finished product.

Description of raw material.

Detailed description and explanation of the manufacturing process.

Description of equipment.

Power supply and energy consumption.

Labor.

Transportation of raw material, finished product, and during process of manufacture.

Location of raw material.

Location of centers for distribution and consumption of finished product.

Location of manufacturing plants.

Number of men employed in industry.

Exports and imports of raw material and finished product.

Further processes and work necessary on finished product to make it available for final consumption.

Capital invested in industry.

Gross sales.

Net profit.

Value added to raw material by process of manufacture.

Annual capital turn-over.

Output per man.

Capital invested per man.

Diagram of flow of material through factory.

Diagram of processes and items involved in cost estimate of product.

Diagram of ground floor plan of factory.

Curve of output of product over term of years.

Curve showing reduction in cost of product over term of years.

Photographs and drawings of machines utilized in process, showing location of motors and controllers.

Load curves for individual machines.

List of characteristics peculiar to each machine.

Data regarding the products and labor of each machine necessary for determining the kind and position of control.

Peculiar requirements of industry from the standpoint of the application of electric motors.

Special features required on motors, such as, for instance, those used in steel mills, mines and cement mills.

Starting requirements.

Effect of interruptions of power supply and precautions to be taken in connection therewith.

Requirements of process for speed variation and regulation.

Possibility of improvement in quality and quantity of product by use of electric motor.

Power requirements per unit of output

Capacity of station required.

Characteristics desirable in system of electric distribution.

HOW CITY PEOPLE TRAVEL

AN ANALYSIS OF TRAFFIC CONDITIONS IN DENVER, COLORADO

By Roger W. Toll

Chief Engineer, Denver Tramway Company

The author deals with an exhaustive analysis of traffic conditions in Denver in such a form that we believe both the methods of making the analysis and the results obtained will be most useful to street railways in other cities. The knowledge obtained in this way should be of material help in schedule making, etc. The relative popularity of different modes of travel is clearly brought out and much interesting data concerning the manufacture and increasing use of automobiles in America are given. The author originally published these results in the Tramway Bulletin, a paper issued by the Denver Tramway Company.—Editor.

Every street railway company engaged in furnishing transportation to a certain community is vitally interested in knowing how the people of that community travel and the extent to which other methods of transportation are employed to supplement the service rendered by the electric railway company.

The rapid increase in the use of automobiles is a factor of the greatest importance in the transportation field, but exact data as to the rate of this increase, the number of persons daily using this method of transportation, the relative importance of the different classes of vehicles and similar questions is usually difficult to obtain, and rough estimates are not satisfactory.

In order to obtain information as to the relative importance of the various methods of city transportation in Denver, a traffic investigation was conducted in May, 1914, and repeated in May, 1915, under the direction of Mr. John A. Beeler, vice-president and general manager of the Denver Tramway Company. The following is a description of the methods used and the results obtained, with comparative figures for the two years:

Dates of Investigation

It was desired to investigate traffic conditions on Sunday as well as on a week day, so the 1915 investigation covered two days—namely, Sunday, May 9th, and Tuesday, May 11th. The weather was good on both of these days, and the results obtained represent typical traffic conditions for this time of year. The month of May was selected for the traffic investigation, since it is intermediate between winter and summer and represents average traffic conditions as nearly as any one month of the year.

Boundaries of Assumed Business District

The basis of this investigation is a count of all persons and vehicles entering and leaving the business district of the city upon the dates selected.

The assumed boundaries of this business district are shown on the accompanying map, Fig. 1. The area of this district is 0.88 square miles. The total area of the City and County of Denver is 58.75 square miles so that the assumed business district is 1.5 per cent of the area of the entire city. The perimeter of this business district is 4.1 miles. The boundaries chosen include the greater part of the retail and wholesale districts of the city as well as a portion of the railroad terminal yards.

Classification of Traffic

All street traffic was grouped into the following classes:

- Passenger automobiles.
- Freight automobiles.
- Motorcycles.
- Bicycles.
- Passenger horsedrawn vehicles.
- Freight horsedrawn vehicles.
- Pedestrians.

Observers

The observations were taken under the direction of Mr. J. D. Rich of the engineering department, and the data collected were also compiled by him. Through the valued co-operation of Messrs. W. M. Casey, W. H. Seip and J. L. Adams of the transportation department, trainmen were secured as observers, and because of their interest in the work and conscientious attention to duty, the results obtained are accurate and reliable.

It was desired to make a complete count of all traffic entering and leaving the entire district in a single day, and as the number of available observers was limited, it was necessary to use a long shift. Thirty-nine men were on duty for a continuous eighteen-hour period from 6 a. m. until midnight. In order to provide for meals and short rests, a relief, consisting of four men, was maintained from 9 a. m. until midnight. Each relief man was assigned to a certain number of the observers, each of whom he relieved three times during the eighteen hours for a period of one-half hour.

Observations

Thirty-eight thoroughfares cross the assumed boundaries of the business district. In the case of a few streets with very light traffic one observer could record the traffic of two streets, but as a rule a man was stationed at each street entering the district, and owing to particularly heavy traffic, two simultaneous observers were placed at each of the four busiest locations, and by dividing the work reliable results were secured.

Number of Persons Inbound and Outbound

Table 1 shows a comparison of the Sunday and Tuesday traffic as to the total number of persons entering and leaving the business district, exclusive of street car traffic. This table shows the large increase of passenger automobile traffic on Sunday amounting to 41.6 per cent, also the decrease of freight traffic, both automobile and horsedrawn, amounting, respectively, to 77.7 per cent and 83.8 per cent. The great decrease in bicycle traffic, amounting to 59.3 per cent, shows that most bicycles are not used for pleasure, but primarily either for transportation to and from work or for business purposes. A large proportion of the bicycles are used by messenger boys and delivery boys.

Table 2 shows a comparison of the records obtained last year and this year relative to the total number of persons counted. An increase of 6.8 per cent is shown in the total number of persons entering and leaving the business district, exclusive of street car traffic. A considerable variation is to be expected from one day to another in the same month, due to weather and other conditions and, therefore, this increase should not be given too great weight in forming a general conclusion regarding the two years. However, a comparison of the results of the two days is very valuable. The total number of persons in passenger automobiles shows an increase of 51 per cent and the number of persons in freight automobiles increased 46 per cent. Much smaller gains are shown in the motorcycle traffic and bicycle traffic, while the horsedrawn traffic, both passenger and freight, and the pedestrians count have each decreased by a small percentage. The comparison, as a whole, shows a decided increase in automobile transportation.

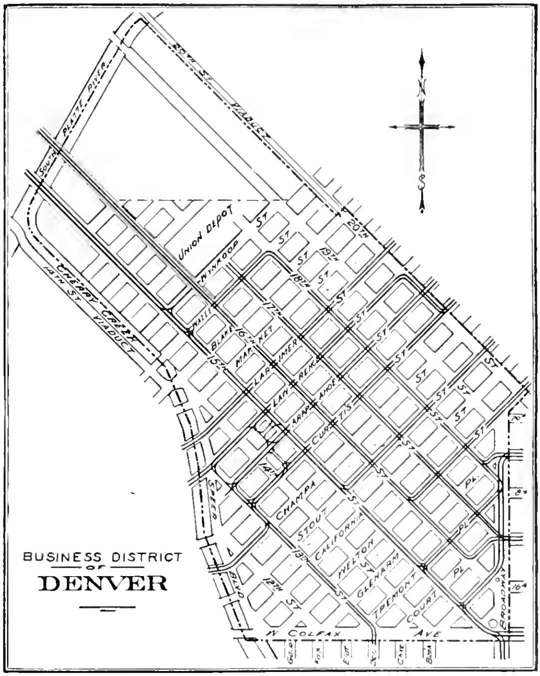


Fig. 1

Vehicles

The number of vehicles entering and leaving the business district was recorded, as well as the number of persons in the vehicles.

Table 3 shows a comparison of the totals of the vehicle count on Sunday, May 9, and Tuesday, May 11, together with the average number of persons carried by each class of vehicle.

A marked decrease in the use of freight vehicles, both motor and horsedrawn, is to be expected on Sunday. Table 3 shows the amount of this decrease, both numerically and in per cent. The large decrease in the use of bicycles, above referred to, is also noted.

The use of passenger horsedrawn vehicles also decreased on Sunday, showing that this class of transportation is used more for business purposes than pleasure.

The number of passenger automobile trips and motorcycle trips remained about the same, numerically, on Sunday as on the week day count, but it was very evident that their use on Sunday was largely for pleasure trips. This is also indicated by the increased number of passengers per vehicle on Sunday for both autos and motorcycles.

Table 4 gives a comparison between the vehicle counts obtained last year and this year. The total trips on Tuesday, May 11, this year show an increase of 12.7 per cent over the total trips of last year. The number of passenger automobile trips shows 38.8 per cent increase and the number of freight automobile trips shows an even greater percentage increase. Motorcycles and bicycles show small increases, but horsedrawn vehicles, both passenger and freight, show a decrease. These comparisons are closely analagous to the comparisons, for the two years, of the total number of persons, as shown in Table 2. In each class the number of passengers per vehicle is nearly the same for both years.

The passenger automobile is shown as the most numerous class of vehicle, with the bicycle in second place and the horsedrawn freight vehicle in third place. Last year the horsedrawn freight vehicle had first place, the bicycle second place and the passenger automobile third place.

Bicycles made nearly six times as many trips as motorcycles, a somewhat greater ratio than was shown last year, indicating that the use of the bicycle is holding its own as compared with the motorcycles. Passenger autos made more than six times as many trips as freight autos. Of the horsedrawn vehicle trips,

TABLE 1

COMPARISON OF SUNDAY AND WEEK DAY TRAVEL, 1915

Totals of Persons on Sunday, May 9, 1915, and Tuesday, May 11, 1915

Class	SUN., MAY 9, 1915		TUES., MAY 11, 1915		SUNDAY COMPARED WITH TUESDAY			
					Increase		Decrease	
	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent
Passenger automobiles	65,902	34.7	46,525	22.4	19,377	41.6		
Freight automobiles	1,219	0.6	5,453	2.9			4,234	77.7
Motorcycles	4,475	2.4	4,187	2.2	288	6.9		
Bicycles	8,544	4.5	20,951	10.1			12,407	59.3
Passenger horsedrawn vehicles	4,677	2.5	4,468	2.2	209	4.7		
Freight horsedrawn vehicles	3,752	1.9	23,122	11.1			19,370	83.8
Pedestrians	101,486	53.4	102,901	49.6			1,415	1.2
Total	190,055	100.0	207,607	100.0			17,552	8.5

TABLE 2

COMPARISON OF WEEK DAY TRAVEL, 1914-15

Totals of Persons on Tuesday, May 5, 1914, and Tuesday, May 11, 1915

Class	TUES., MAY 5, 1914		TUES., MAY 11, 1915		1915 COMPARED WITH 1914			
					Increase		Decrease	
	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent
Passenger automobiles	30,804	15.9	46,525	22.4	15,721	51.0		
Freight automobiles	3,735	1.9	5,453	2.9	1,718	46.0		
Motorcycles	3,923	2.0	4,187	2.2	264	6.7		
Bicycles	18,950	9.3	20,951	10.1	2,001	10.5		
Passenger horsedrawn vehicles	4,710	2.4	4,468	2.2			242	5.1
Freight horsedrawn vehicles	25,344	13.5	23,122	11.1			2,222	8.8
Pedestrians	106,990	55.0	102,901	49.6			4,089	3.8
Total	194,456	100.0	207,607	100.0	13,151	6.8		

86 per cent were for freight purposes, which is the same percentage as that of last year. Of the total vehicle trips, 31 per cent were for freight purposes, as against 35 per cent for last year. Contrary to last year's records, the automobile trips are in excess of the horsedrawn vehicle trips, being 37 per cent of the total number of vehicles, as compared with 30 per cent for the horsedrawn vehicles. Last year these percentages were exactly reversed.

Hourly Street Traffic Charts

Fig. 2 graphically shows the fluctuations in the number of persons entering and leaving the business district during each half-hour of the day for each method of transportation, on a week day, Tuesday, May 5, 1914, and the fluctuations on a typical Sunday will be found in Fig. 2.

The week day chart shows the peaks due to inbound traffic in the morning, outbound traffic in the late afternoon, and minor peaks at other times of the day. The afternoon peak is the largest of the day, and comes between 5 and 6:30 p. m. The morning and noon peaks are also prominent.

The Sunday chart shows the increased use of automobiles and the decreased use of bicycles and freight vehicles on that day. The passenger automobile peak was in the afternoon about 5 o'clock, but the travel was heavy all the afternoon. The greatest pedestrian travel was in the evening, from 7:30 to 8.

Car Traffic

The best statistics that are available for comparison with street traffic are the figures showing total passengers carried in the city, regardless of the business district. The car data include the street railway traffic of the entire city, while the street traffic data are confined to that crossing the boundaries of the business district. The combination of statis-

TABLE 3

COMPARISON OF SUNDAY AND WEEK DAY TRAVEL, 1915

Totals of Vehicle Trips on Sunday, May 9, 1915, and Tuesday, May 11, 1915

Class	Sunday, May 9 1915		Tuesday, May 11 1915		Sunday Compared with Tuesday: Increase		Sunday Compared with Tuesday: Decrease		Average No. of Persons per Vehicle	
	Vehicles	Per Cent	Vehicles	Per Cent	Vehicles	Per Cent	Vehicles	Per Cent	Sunday	Tuesday
Passenger auto	23,786	57.7	23,884	32.0	....	....	98	0.4	2.77	1.95
Freight auto	746	1.8	3,887	5.2	....	....	3,141	80.8	1.63	1.40
Motorcycle	3,318	8.0	3,616	4.9	....	....	298	8.2	1.35	1.16
Bicycle	8,143	19.8	20,891	28.0	....	....	12,748	61.1	1.05	1.00
Passenger horsedrawn vehicles	2,429	5.9	3,217	4.3	....	....	788	24.5	1.93	1.39
Freight horsedrawn vehicles	2,787	6.8	19,091	25.6	....	....	16,304	84.5	1.35	1.21
Total	41,209	100.0	74,591	100.0	....	....	33,382	44.8	2.15	1.40

TABLE 4

COMPARISON OF WEEK DAY TRAVEL, 1914-15

Totals of Vehicle Trips on Tuesday, May 5, 1914, and Tuesday, May 11, 1915

Class	Tuesday, May 5, 1914		Tuesday, May 11, 1915		1915 Compared with 1914: Increase		1915 Compared with 1914: Decrease		Average No. of Persons per Vehicle	
	Vehicles	Per Cent	Vehicles	Per Cent	Vehicles	Per Cent	Vehicles	Per Cent	May 5, 1914	May 11, 1915
Passenger auto	17,212	26.0	23,884	32.0	6,672	38.8	......	..	1.79	1.95
Freight auto	2,630	4.0	3,887	5.2	1,257	47.8	......	...	1.42	1.40
Motorcycle	3,452	5.2	3,616	4.9	164	4.8	......		1.14	1.16
Bicycle	18,667	28.2	20,891	28.0	2,224	11.9		...	1.01	1.00
Passenger horsedrawn vehicles	3,459	5.2	3,217	4.3	....		242	7.0	1.36	1.39
Freight horsedrawn vehicles	20,747	31.4	19,091	25.6	..		1,656	8.0	1.22	1.21
Total	66,167	100.0	74,591	100.0	8,424	12.7	......		1.47	1.40

tics showing the volume of these two classes of traffic, though not strictly comparable, gives interesting results.

As noted above, no observations were taken of the street traffic between the hours of midnight and 6 a.m. It is estimated that only 1 per cent of the total traffic for the twenty-four hours passes in and out of the business district during the six-hour period, so that the figures obtained for the street traffic represent

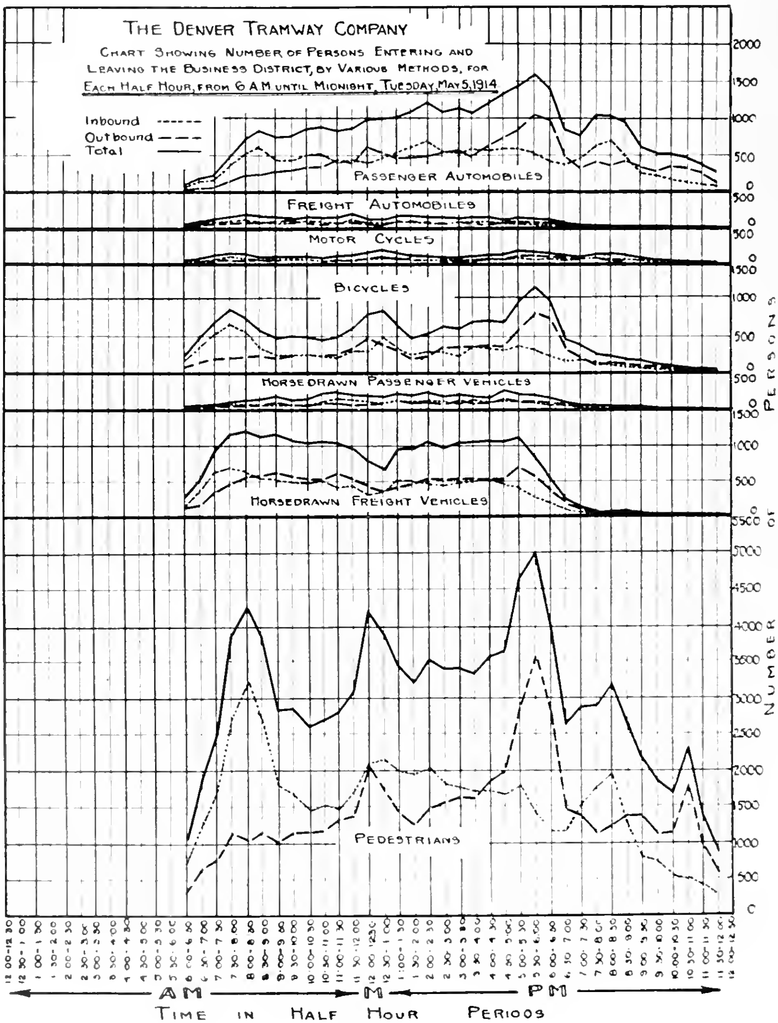


Fig. 2

99 per cent of the total for the twenty-four hour day.

The effect of weather conditions upon street traffic and car passengers is shown by some observations that were taken on two successive Sundays in May, the first being cold and windy and the second warm and mild. On the pleasant Sunday there was an increase of 11.1 per cent in the number of passengers carried on the street cars and an increase of

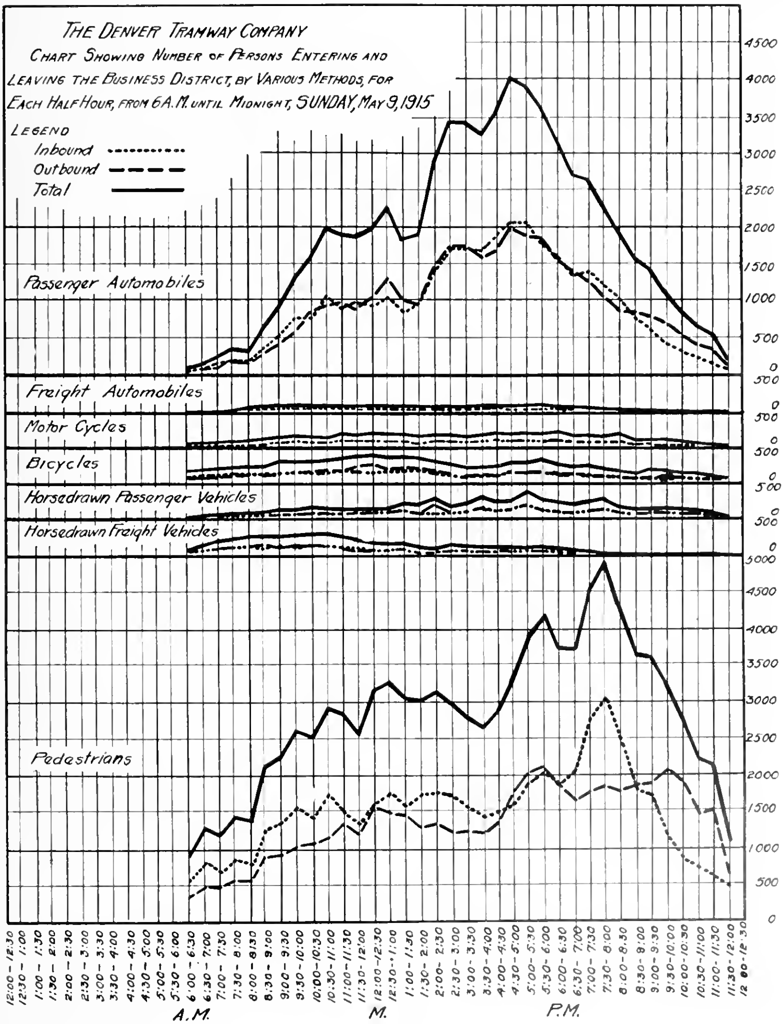


Fig. 3

32.6 per cent in the number of persons traveling by other methods. It therefore seems that while the weather has a decided effect upon Sunday street car travel, its effect upon other methods of travel is still more pronounced.

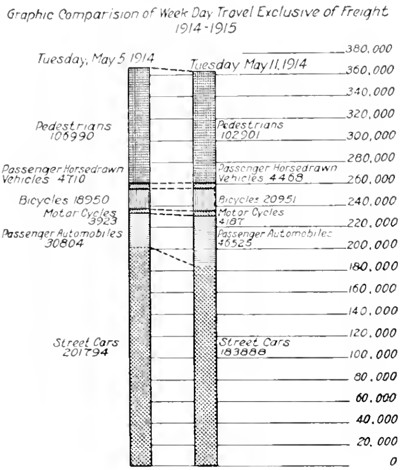


Fig. 4

Table 5 shows a comparison of the total traffic on Sunday, May 9, and Tuesday, May 11, of this year. The number of passengers carried by the cars in the entire city is combined with the total street traffic in and out of the business district. An interesting coincidence is seen in the fact that the total number of persons traveling on these two days is almost identical. With the population of Denver in the neighborhood of 200,000, the above total represents an average of one trip in and out of the business district per person per day.

Table 6 shows a similar combination and comparison for Tuesday, May 5, of last year, and Tuesday, May 11, of this year. As will be noted in this table, the total travel is 1.2 per cent less for 1915, as compared with 1914, the car travel on these two days showing a decrease of 8.9 per cent for 1915, and the total street traffic showing an increase of 6.8 per cent over the previous year.

Table 7 and Table 8 show the same comparisons as Table 5 and Table 6, respectively, but exclusive of freight traffic, both motor and horse drawn. Figure 4 gives a graphic comparison of all passenger traffic of a typical week day of last year, with corresponding traffic of this year.

The total number of persons carried on the street cars and in passenger automobiles on Tuesday, May 5, 1914, was 232,598. The passenger automobiles carried 13.2 per cent and the street cars carried 86.8 per cent of this number. On Tuesday, May 11, of this year, the total number of persons carried by these two methods of transportation was 230,413. The passenger automobiles carried 20.2 per cent and the street cars carried 79.8 per cent of this number. On Sunday, May 9, of this year, the total number of persons carried by these two methods was 266,097. The passenger automobiles carried 24.8 per cent and the street cars 75.2 per cent of this number.

The number of persons carried by the street cars, expressed as a multiple of the number of persons carried by passenger automobiles, is as follows:

Tuesday, May 5, 1914, cars carried 6.6 times as many as autos.

Tuesday, May 11, 1915, cars carried 3.9 times as many as autos.

Sunday, May 9, 1915, cars carried 3.1 times as many as autos.

Production and Use of Automobiles in the United States

Since the use of automobiles has such a vital connection with traffic conditions and the street railway industry, data on this subject have been collected from various sources. Most of the following data were obtained from "The Automobile," a periodical published in New York, and also from the National Automobile Chamber of Commerce, the U. S. Bureau of Census and the Ford Motor Company.

This rapid increase in the use and production of automobiles is shown graphically in Fig. 5.

The total number of automobiles produced during the past twelve years, as shown above, is 2,087,000. The number in use at the end of the year 1914, namely, 1,755,000, is 84 per cent of this amount. This result would be obtained by assuming that all automobiles in use at the beginning of the year 1903 have been scrapped, together with 332,000, or 16 per cent of the cars produced from 1903 to 1914, inclusive. The number of cars produced from 1910 to 1914, inclusive, a period of five years, was 1,740,000, which nearly equals the number in use at the end of the year 1914. This indicates the average life of an automobile as five or six years.

The following tables give the number of automobiles produced and in use in the United States, from 1903 to 1914, inclusive, a period of twelve years:

Year	Number of Automobiles Produced	Increase Over Previous Year	Per Cent Increase Over Previous Year
1903	11,000	......	......
1904	22,000	11,000	100
1905	25,000	3,000	14
1906	34,000	9,000	36
1907	44,000	10,000	29
1908	85,000	41,000	93
1909	126,000	41,000	48
1910	187,000	61,000	48
1911	210,000	23,000	12
1912	376,000	168,000	80
1913	450.000	72,000	19
1914	515,000	65,000	14

Year	Number of Automobiles in Use	Increase Over Previous Year	Per Cent Increase Over Previous Year
1903	40,000	......	......
1904	50,000	10,000	25
1905	80,000	30,000	60
1906	120,000	40,000	50
1907	180,000	60,000	50
1908	250,000	70,000	39
1909	350,000	100,000	40
1910	500,000	150,000	30
1911	677,000	177,000	35
1912	1,010,000	333,000	49
1913	1,254,000	244,000	24
1914	1,755,000	501,000	40

The total value of automobiles produced in the United States and the average value per auto for the same period are as follows:

Year	Value of Automobiles Produced	Value Per Automobile
1903	$12,650,000	$1,150.00
1904	30,000,000	1,380.00
1905	40,000,000	1,600.00
1906	62,900,000	1,850.00
1907	92,400,000	2,100.00
1908	107,800,000	1,270.00
1909	164,200,000	1,300.00
1910	215,500,000	1,150.00
1911	262,500,000	1,250.00
1912	378,000,000	1,000.00
1913	420,000,000	935.00
1914	485,000,000	940.00

The total number of Ford cars produced up to December 31, 1914, is approximately 645,000. The Ford Motor Company estimates that 90 per cent of all the cars they have ever built are still in service. This would give the number in use at the close of the year 1914

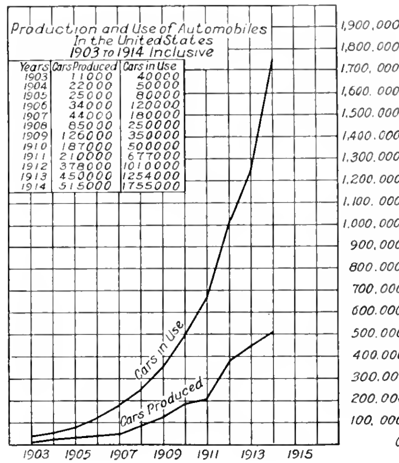


Fig. 5

as 580,000. The 90 per cent estimate allows the elimination of all cars produced prior to 1911. Therefore, of the total number of automobiles in use at the close of 1914, one-third were Ford cars. This proportion is increasing, since approximately one-half of the total cars produced in 1914 were Fords.

Production of Ford Cars by Years

Year Ending	Number of Cars Produced
Sept. 30, 1904	1,708
Sept. 30, 1905	1,695
Sept. 30, 1906	1,599
Sept. 30, 1907	6,759
Sept. 30, 1908	6,181
Sept. 30, 1909	10,660
Sept. 30, 1910	20,000
Sept. 30, 1911	35,000
Sept. 30, 1912	76,150
Sept. 30, 1913	167,400
Sept. 30, 1914	226,000
July 31, 1915 (ten months)	300,000+

The U. S. census has made investigations of the manufacture of automobiles for the years 1904 and 1909. Similar statistics for the year 1914 are now being collected, but it will be several months before these data are compiled.

The figures from the U. S. census contain much interesting information and are shown on page 14.

The difference between the imports and exports of automobiles in past years is not large enough to make any material difference between the number of automobiles manufactured and used in the United States.

Number of Automobiles in Use in Denver

The state law that went into effect on July 15, 1913, requires the registration, at the beginning of each year, of all automobiles and motorcycles. This registration must be made in the county where the auto is owned and taxed. The record of the total registration in Colorado at the close of the years 1913 and 1914 is shown on page 63.

These figures include automobiles registered on account of change of ownership, and are therefore somewhat greater than the number of automobiles in use at any one time.

The increase in the number of automobiles in use in the entire state is 35 per cent while the increase in Denver is 23 per cent, showing a more rapid increase out of the city than in Denver.

The figures for the entire United States show an increase of 40 per cent for the year 1914 over 1913, so that the use of automobiles in the entire country increased at a more rapid rate than in either Colorado or Denver.

TABLE 5

COMPARISON OF SUNDAY AND WEEK DAY TRAVEL, INCLUDING STREET CARS, 1915

Totals of Persons on Sunday, May 9, 1915, and Tuesday, May 11, 1915

Method of Transportation	SUN., MAY 9, 1915		TUES., MAY 11, 1915		SUNDAY COMPARED WITH TUESDAY			
					Increase		Decrease	
	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent
Street cars	201,005	51.4	183,888	46.9	17,117	9.3		
Passenger autos	65,902	16.8	46,525	11.9	19,377	41.6		
Freight autos	1,219	0.3	5,453	1.4			4,234	77.7
Motorcycles	4,475	1.1	4,187	1.1	288	6.9		
Bicycles	8,544	2.2	20,951	5.4			12,407	59.3
Passenger horsedrawn vehicles	4,677	1.2	4,468	1.1	209	4.7		
Freight horsedrawn vehicles	3,752	1.0	23,122	5.9			19,370	83.8
Pedestrians	101,486	26.0	102,901	26.3			1,415	1.2
Total	391,060	100.0	391,495	100.0			435	0.1

TABLE 6

COMPARISON OF WEEK DAY TRAVEL, INCLUDING STREET CARS, 1914–15

Totals of Persons on Tuesday, May 5, 1914, and Tuesday, May 11, 1915

Method of Transportation	TUES., MAY 5, 1915		TUES., MAY 11, 1915		1915 COMPARED WITH 1914			
					Increase		Decrease	
	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent
Street cars	201,794	50.9	183,888	46.9			17,906	8.9
Passenger autos	30,804	7.8	46,525	11.9	15,721	51.0		
Freight autos	3,735	0.9	5,453	1.4	1,718	46.0		
Motorcycles	3,923	1.0	4,187	1.1	264	6.7		
Bicycles	18,950	4.8	20,951	5.4	2,001	10.5		
Passenger horsedrawn vehicles	4,710	1.2	4,468	1.1			242	5.1
Freight horsedrawn vehicles	25,344	6.4	23,122	5.9			2,222	8.8
Pedestrians	106,990	27.0	102,901	26.3			4,089	3.8
Total	396,250	100.0	391,495	100.0			4,755	1.2

The registrations from the first of the year up to the date of the traffic investigation, for 1914 and 1915, respectively, are shown on page 67.

This shows that the rate of increase of automobiles in Denver for the first part of 1915, as compared with the same period in 1914, is more rapid than for the entire year 1914, compared with 1913. It also shows that more owners' automobile licenses had been issued

Class of Registration	1913	1914	Increase	Per Cent Increase
Owner's automobile licenses	13,135	17,756	4,621	35
Dealers' automobile licenses	489	677	188	38
Total automobile licenses	13,624	18,433	4,809	35
Motorcycle licenses	2,735	3,683	930	34

The record of total registration in Denver at the close of the years 1913 and 1914 is as follows:

Class of Registration	1913	1914	Increase	Per Cent Increase
Owners' automobile licenses	4,793	5,931	1,138	24
Dealers' automobile licenses	175	189	14	8
Total automobile licenses	4,968	6,120	1,152	23
Motorcycle licenses	1,013	1,313	300	30

TABLE 7

COMPARISON OF SUNDAY AND WEEK DAY TRAVEL, EXCLUSIVE OF FREIGHT, 1915

Totals of Persons on Sunday, May 9, 1915, and Tuesday, May 11, 1915

Method of Transportation	SUN., MAY 9, 1915		TUES., MAY 11, 1915		SUNDAY COMPARED WITH TUESDAY			
					Increase		Decrease	
	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent
Street cars	201,005	52.0	183,888	50.6	17,117	9.3	...	...
Passenger autos	65,902	17.1	46,525	12.8	19,377	41.6	...	...
Motorcycles	4,475	1.2	4,187	1.2	288	6.9	...	...
Bicycles	8,544	2.2	20,951	5.8	...	...	12,407	59.3
Passenger horsedrawn vehicles	4,677	1.2	4,468	1.2	209	4.7	...	...
Pedestrians	101,486	26.3	102,901	28.4	...	...	1,415	1.2
Total	286,089	100.0	362,920	100.0	23,169	6.4	...	...

TABLE 8

COMPARISON OF WEEK DAY TRAVEL, EXCLUSIVE OF FREIGHT, 1914–15

Totals of Persons on Tuesday, May 5, 1914, and Tuesday, May 11, 1915

Method of Transportation	TUES., MAY 5, 1914		TUES., MAY 11, 1915		1915 COMPARED WITH 1914			
					Increase		Decrease	
	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent	Persons	Per Cent
Street cars	201,794	54.9	183,888	50.6	...	...	17,906	8.9
Passenger autos	30,804	8.2	46,525	12.8	15,721	51.0	...	...
Motorcycles	3,923	1.2	4,187	1.2	264	6.7	...	...
Bicycles	18,950	5.2	20,951	5.8	2,001	10.5	...	...
Passenger horsedrawn vehicles	4,710	1.3	4,468	1.2	...	...	242	5.1
Pedestrians	106,990	29.2	102,901	28.4	...	...	4,089	3.8
Total	367,171	100.0	362,920	100.0	...	...	4,251	1.2

up to May 3, 1915, than during the entire year 1914.

It is assumed that the number of automobiles in use in Denver at the time of the traffic count was the same as the number registered by owners at that time, namely 6002. The vehicle count on Tuesday, May 11, showed the total number of automobile trips in and out of the city as 27,771. The percentage of trips made by freight automobiles was 14 per cent of the total automobile trips. Freight autos make more trips per day in and out of the business district than passenger automobiles do, and it is assumed that 7 per cent of the total autos are freight vehicles. This is consistent with the figures of the U. S. Census Bureau, that from 4 per cent to 7 per cent of the automobiles produced are for freight purposes. The number of passenger automobiles in use in Denver is then 93 per cent of 6000, or 5580. Roughly speaking, the average passenger automobile makes two round trips, or four single trips, per day, in and out of the business district, and carries two people per trip, making a total of eight passengers carried per day. The exact figures for Tuesday, May 11, are: Average number of single trips per day, 4.27; average number of passengers per trip, 1.95; average number of passengers carried per day, 8.35, as compared with 7.1 for last year. Both the number of trips per auto per day and the number of passengers carried have increased.

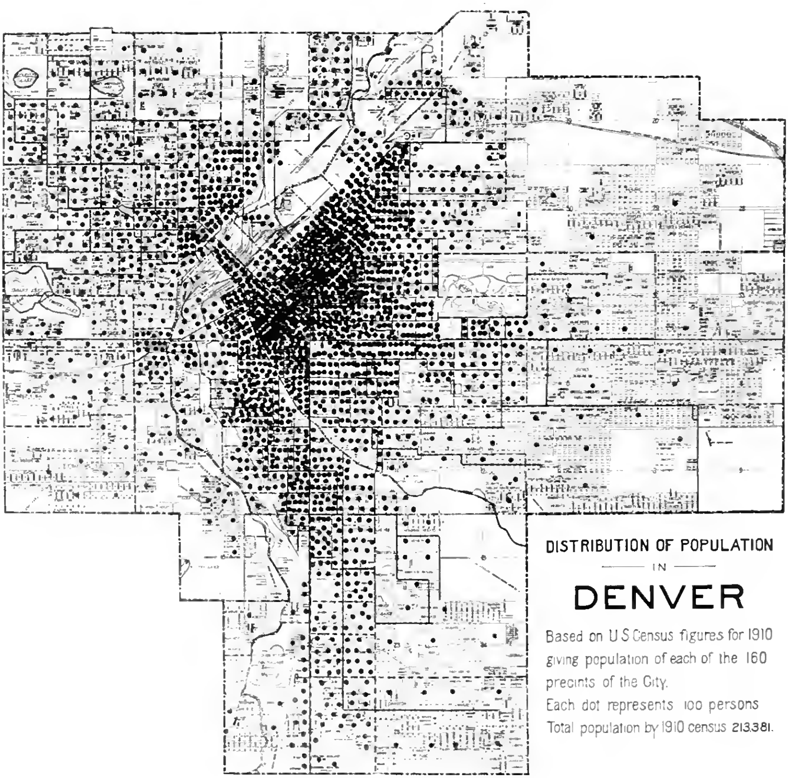


Fig. 6

If this average rate of 8.35 passengers carried per day is maintained through the year, an auto would carry 3000 passengers per year.

Assuming the population of the city at 200,000 and the number of passenger automobiles in use at 5580, there is an average of one auto for every thirty-six persons, or one to every eight families.

The State of Colorado, with 17,756 autos and a population of 799,024, has an average of one auto to forty-five persons. The United States, with 1,755,000 autos and a population of 91,972,266, has an average of one auto to fifty-two persons. This shows that there are more autos in proportion to population in Denver than in the state as a whole, and more in proportion to population in Colorado than in the United States as a whole. The more rapid rate of increase in the use of automobiles during 1914 as compared with 1913, for the United States and for Colorado, shows a tendency to meet the higher proportion that now exists in Denver.

Distribution of Population in Denver

The accompanying photographic reproduction, Fig. 6, shows geographically the distribution of the population in Denver, as derived from the U. S. census figures for 1910. These figures give the population of each of the several enumeration districts shown on the map. The total population of the city is given at 213,381. The entire area of the city was divided into sixteen wards, which were subdivided into 146 precincts, and some of

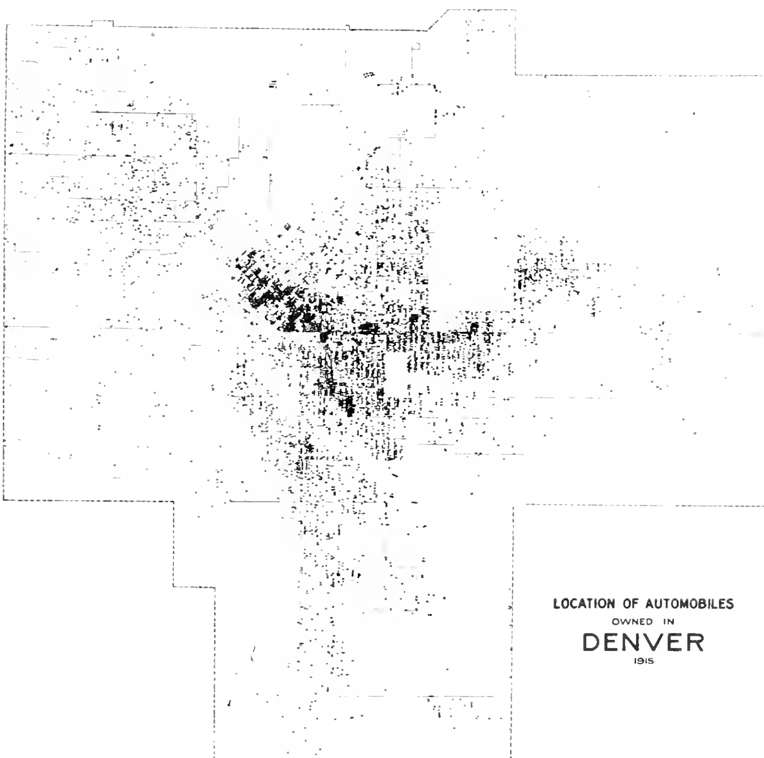


Fig. 7

these were again subdivided, making 160 census enumeration districts. These enumeration districts vary in size according to the density of the population. The boundaries of the various wards and precincts are shown on the map.

Each dot on the map represents 100 persons, so that the number of dots in each precinct represents the population to the nearest hundred persons. The dots are arbitrarily placed in each precinct, assuming uniform distribution, or in some cases according to the probable density of the population in the different sections of that precinct.

A comparison of this map with Fig. 7, showing location of automobiles, indicates

THE AUTOMOBILE INDUSTRY IN THE UNITED STATES

Statistics	1909	1904	Per Cent Increase
Number of automobile manufacturing establishments	265	121	119
Number of persons employed	58,142	11,246	417
Capital	$134,592,965	$20,535,247	565
Number of automobiles produced	126,593	21,692	484
Value of automobiles produced	$164,269,324	$23,751,234	592
Average value per automobile	1,300	1,100	...

The above figures do not include establishments manufacturing principally automobile bodies and parts.

CLASSIFICATION OF AUTOMOBILES PRODUCED, ACCORDING TO PROPELLING POWER

Propelling Power	1909	1904	Per Cent Increase
Gasoline automobiles produced	120,393	18,699	544
Electric automobiles produced	3,826	1,425	168
Steam automobiles produced	2,374	1,568	51
Total automobiles produced	126,593	21,692	484
Gasoline automobiles, per cent of total produced	95.1	86.2	
Electric automobiles, per cent of total produced	3.0	6.6	
Steam automobiles, per cent of total produced	1.9	7.2	
Total	100.0	100.0	

The increase in the proportion of gasoline automobiles is interesting.

CLASSIFICATION OF AUTOMOBILES PRODUCED, ACCORDING TO USE AND TYPE

Use and Type	1909	1904	Per Cent Increase
Pleasure and family vehicles—			
Touring cars	76,114	7,220	954
Runabouts	36,204	12,131	198
Other varieties	9,550	910	949
Total pleasure and family vehicles	121,868	20,261	501
Business vehicles—			
Delivery wagons	1,862	251	642
Trucks	1,366	160	754
Other varieties	1,497	1,020	47
Total business vehicles	4,725	1,431	230
Total vehicles produced	126,593	21,692	484
Pleasure vehicles, per cent of total produced	96	93	
Business vehicles, per cent of total produced	4	7	
Total	100	100	

that the distribution of automobiles is in general similar to the distribution of the population. There are a few exceptions to the general rule, for example: The district west of the Platt River in the central part of the city shows a dense population, but few automobiles. Park Hill and similar districts, on the other hand, show a large proportion of automobiles in relation to population, which may be partly accounted for by growth in these districts since 1910.

Location of Automobiles Owned in Denver

Fig. 7 shows the location of ownership of 5340 automobiles in Denver. It will be noted that the business district shows the most dense ownership, owing to the many machines owned by firms for business purposes, in either freight or passenger service. In the residence districts the most dense ownership is in the Capitol Hill region, from Broadway east to Madison street, and in the apartment house district along Colfax avenue. Park Hill and the district west and northwest of City Park also show a large number of machines. The automobiles owned along Broadway south of Cherry Creek, and also on the North Side, are numerous, but more scattered.

Of these 5340 autos, 1317, or 25 per cent, are Fords. As previously stated, the figures for the entire United States showed that 33 per cent of the cars in use are Fords.

Class of Registration	Jan. 1 to May 5 1914	Jan. 1 to May 3 1915	Increase	Per Cent Increase
Owners' automobile licenses	4,630	6,002	1,372	30
Dealers' automobile licenses	169	228	59	35
Total automobile licenses	4,799	6,230	1,431	30
Motorcycle licenses	927	944	17	18

ERRATA

December, 1915, number, page 1129; Growth of Current in Circuits of Negative Temperature Coefficient of Resistance

Equation (1) should read,

$$\frac{Edi}{[\lambda\delta\eta E-\lambda\delta\eta r_0(1+\alpha h_1)i-\alpha\lambda\delta r_0 Ei^2]i}=dt=\frac{Edi}{(a+bi+ci^2)i}$$

In the article the "i" was omitted after $(1+\alpha h_1)$ in the first member.

Equation (4) should read,

$$i=\frac{-b\mp\sqrt{b^2-4ac}}{2c}$$

In the article the denominator of the second member is "$2a$."

Equation (5) should read,

$$t=\frac{E}{2a}\log\frac{i^2}{a+bi+ci^2}-\frac{Eb}{2a}\left(\frac{1}{\sqrt{b^2-4ac}}\log\frac{2ci+b-\sqrt{b^2-4ac}}{2ci+b+\sqrt{b^2-4ac}}\right)+const.$$

In the article the denominator in the first term of the second member reads "$a+bi-ci^2$."

The expression in the last paragraph for the time required for the current to become indefinitely great is also incorrect. It should read,

$$\frac{E}{2a}\left[\log\frac{a+bp+cp^2}{cp^2}-\frac{b\pi}{\sqrt{4ac-b^2}}-\frac{2b\tan^{-1}}{\sqrt{4ac-b^2}}\,\frac{2cp+b}{\sqrt{4ac-b^2}}\right]$$

where p is the current at zero time as given by the quotient of the resistance of the conductor at zero time into the applied e.m.f.

POSITION LIGHT SIGNALS FOR RAILWAYS

By L. C. Porter

Edison Lamp Works, Harrison, N. J.

It is a recognized fact that the ordinary semaphore type of block signal may prove troublesome in operation under certain adverse weather conditions. To eliminate this detrimental effect on the block signal system, an all-electric signal device has been developed to replace the one employing the moving semaphore blade. The conception, development, operation, and a trial installation of this all-electric device, on the Pennsylvania Railroad, are described in the following article.—Editor.

One of the most important factors in the safe, efficient and economical operation of a railroad is the signal system. The ordinary block signals in common use today have proven very efficient, but they are still open to certain defects. Among these is trouble from ice and snow, and other mechanical troubles, due to the fairly large moving semaphore blade. The use of various colored lights at night is also liable to confusion, due either to trouble with the engineer's eyesight, or modification of the signal color by atmospheric conditions. Greater range than is offered by the present semaphore is also desirable.

Dr. William Churchill, of the Corning Glass Works, Corning, New York, and Mr. A. H. Rudd, Signal Engineer of the Pennsylvania Railroad, recently brought out the fact that the above difficulties might be largely reduced if the present semaphore blades were replaced by rows of bright lights, in positions corresponding to the various settings of the semaphore blades. Such a signal might be used both day and night. They therefore designed a system of lenses and mirrors to accomplish this result.

These signals have been installed under the direction of Mr. Rudd on the Pennsylvania Railroad between Overbrook Station, Philadelphia, and Paoli, Pa., in connection with the electrification of this part of the system. The signals consist of an opaque background, in front of which are mounted three rows of lenses to correspond with the three semaphore blade positions—"Stop," "Caution" and "Proceed;" thus, one row or another of lenses is always lighted. There are four lenses in each row, one being common to all three. Each signal has a sufficient number of rows of lights to be the equivalent of two semaphore arms.

Considerable difficulty was experienced in obtaining the right combination of light source, lens and reflector to give the desired results. This has, however, been successfully accomplished. The lens and mirror combination, taking light from a concentrated source at its focal point, gives a very brilliant signal. A problem was also met in working out a combination of a relation which, while

This eastbound train, near Ardmore, Pa., is just passing one of the new automatic electric block signals, which it has set at "Stop." On the adjoining eastbound track, the signal reads "Caution." It means that the 3500-foot block directly ahead is clear, but that there is a train on the next block. The direction to an engineman when the signal is set in the "Caution" position is "Proceed, prepare to stop at next signal."

The electric signal over the right-hand track reads "Stop." This means that the westbound train here shown, near Rosemont, Pa., has just entered a "block" of 3500 feet in length. The signal will remain at "Stop" until the train enters the next block, when it will go to "Caution" with the diagonal, instead of vertical, row of lights lighted on the upper half. On the adjoining westbound track, shown in the picture, the signal reads "Proceed," which means that at least three blocks ahead are clear. This picture gives a good view of the overhead conductors which will be used when the electric trains are operated.

giving sufficient intensity of illumination to permit the reading of the signals by daylight, would not hide the indication at night, owing to its excessive brilliancy, it being found that such excessive brilliancy at night destroyed the "indication." This also has been successfully taken care of by burning the lamps at lower voltage during the night, thus materially decreasing the candle-power.

The light source itself was a very difficult problem to solve. Special 12-volt 4-candle-power Mazda lamps have been developed by the Edison Lamp Works of the General Electric Company for this service. It has been found necessary to wind the filament of these lamps into a single helix approximately ¼ in. long and about ⅛ in. in diameter, mounted horizontally in the bulb. The bases have to be accurately placed on the lamp, so as to bring the long axis of the filament in a plane parallel to that of the rear face of the lens. It is absolutely necessary when installing the lamp to locate the filament at the exact focal point of the lens; otherwise, the beam of light therefrom would be reduced in intensity and thrown in directions other than down the track. To accomplish this it was necessary to develop a special sleeve to be soldered over the lamp base after being adjusted with a small optical telescope to get the exact length between the bottom of the sleeve and the lamp filament.

These signals can be easily seen even in the brightest sunlight for more than 4000 feet. At night, with full voltage on the lamps, it is possible to read large type by their light at a distance of 1000 feet. The glare, however, then becomes objectionable, so that for operation after dark the voltage on the lamps is reduced considerably.

Each signal protects a block of track 3500 feet in length. A train passing a signal will automatically set it at "Stop;" when the train reaches the next block, the first signal changes to "Caution." Another position of lights will show when two full blocks are clear, and a fourth position when three or more are unoccupied. An engineman will always receive notice of a possible stop at least 7000 feet in advance, and will receive two cautionary signals before approaching the "Stop" signal.

If this installation proves as successful as railway men expect, the new system will undoubtedly have wide application to signal work. Great credit is due to the men who have developed this system and brought about its successful application.

CHARACTERISTICS OF THE HIGH-RESISTANCE ROTOR, SQUIRREL-CAGE MOTOR FOR ELEVATOR SERVICE AND A COMPARISON WITH THE PHASE-WOUND ROTOR MACHINE

By R. H. McLain

Power and Mining Engineering Department, General Electric Company

Probably insufficient regard has been given to the suitability of the squirrel-cage motor for operating elevators. By analytically comparing the characteristics of the high-resistance rotor, squirrel-cage motor to those of the phase-wound motor, the author demonstrates that for certain types of elevators the former machine would be the better type of driving unit, all factors considered.—Editor.

For slow speed passenger and freight elevator work, where the elevator cage runs at less than 250 feet per minute, two kinds of polyphase induction motors are available: first, the wound rotor induction motor which is well known in all kinds of hoist work; second, the squirrel cage induction motor the rotor of which has a high enough resistance to cause it to give maximum torque at starting with high efficiency in starting current.

There are three vital factors concerned in applying a motor to an elevator: first, the motor must have sufficient starting torque to always start the elevator; second, there must be a good means of controlling the starting and stopping of the motor so as to make sufficiently accurate landings; third, the motors must not be overheated by the frequent recurrence of a typical duty cycle.

The fundamental difference between a motor with a wound rotor and a squirrel cage motor, as to starting torque, is that the wound rotor machine must be wound for a definite number of poles in the rotor, each of which produces a certain sector on it, whose magnetic path, under fully saturated conditions, is most favorable in one position only to a corresponding pole in the primary. The rotor pole and stator pole give their best starting torque results only when they are in this most favorable relative position; whereas the squirrel cage rotor is not wound for any definite number of poles and consequently produces as much starting torque in one rotor position as in another. This difference, caused by position, does not exist when the wound rotor motor is exerting normal starting torque, because the local reactance of the secondary windings is not sufficient in this case to disturb the flux paths. A squirrel cage motor of similar design in all respects except the rotor windings will exert more starting torque in any position than a wound rotor machine will exert in its most favorable position, because the whole periphery of the rotor is working without any distortion of its flux.

This difference may amount to something like 33 per cent in favor of the squirrel cage motor. Consequently, when built for the same maximum starting torque, a squirrel cage motor can be built in a smaller frame than a slip ring motor. The above difference of 33 per cent in starting torque must be discounted about 10 per cent on account of the full load running speed of the squirrel cage motor being about 10 per cent less than the wound rotor machine. The net difference when this is taken into account will be about 20 per cent in favor of the squirrel cage motor. Its rotor will be lighter, not only because of being smaller, but also because of the omission of extra weight of insulating material, slip rings, connections between phases, etc.

The wound rotor unit is very much more flexible in regard to control than is the squirrel cage motor, and for this reason has been used successfully on elevator car speeds as high as 250 feet a minute. The squirrel cage motor has been used successfully on elevator speeds as high as 150 feet a minute, but its most useful field is for speeds less than 100 feet per minute. The wound rotor machine can be made to exert at starting a moderate torque which is suitable for starting a light load without too much of a jerk, and an instant later to exert a maximum torque which can be used, as the case may be, either for starting a heavier load, which failed to start on the first point of the controller, or for accelerating the light load. It is this feature of smooth starting which enables the wound rotor machine to operate cars at as high as 250 feet per minute without causing the operator an undue amount of trouble in making his landings. Furthermore, after an elevator is installed, the starting and accelerating features of the wound rotor machine can be made either greater or less within certain limits so as to suit, in the best possible manner, the exact requirements of the elevator as determined by trial. The squirrel cage motor is not readily adaptable to any type of control which reduces its starting torque. It is most suitable for use when thrown directly on the line at starting. Consequently, it might jerk a light load unduly and will give the smoothest possible start only on full load. Practical experience has shown that this jerk does not become objectionable on speeds below 100 feet per minute. Since the wound rotor is much heavier than the squirrel cage, it will require a considerably heavier brake to stop it and will cause considerably greater wear on the brake surfaces. Since the mass of the rotor and brake wheel are moved at so much greater speed than any other parts of these elevators, they are the only important things to be considered in connection with power for starting and brake wheel wear for stopping. The starting efficiency of the wound rotor unit will be considerably less than for the squirrel cage rotor.

It is rare, if ever, that the heating characteristics of an induction motor for this work are of any importance in the ordinary sense of the word. If a motor is able to start the heaviest load, it will have a sufficient margin in regard to heating capacity for operating under usual load conditions. If a squirrel cage motor is started frequently, as might be the case were an attempt made to use it on elevators running at higher speeds than 100 or 150 feet per minute, it might be overheated, because during starting all of the losses that are absorbed in the external rheostat of a wound rotor machine are absorbed in the secondary winding of this motor. One other danger of overheating these motors would arise from choosing a motor which was too small to start its load. Such a motor might remain at standstill with full voltage applied long enough to cause it to burn up.

Another vital question to be considered is the effect of these motors on the power supply where the same source is used for lighting purposes. To illustrate this in the most general way, assume two cases: first, a case where the maximum load to be hoisted will demand the maximum starting torque of each motor; second, when, either on account of miscalculations or on account of the required torque being less than that produced by an available motor, a machine is selected somewhat too large for the maximum load which has to be started.

Under the first condition, the squirrel cage motor will make the best showing when maximum load is to be started, because it will exert a given maximum torque for less starting current than will the wound rotor unit. Also, since its rotating parts are so much lighter it will demand this maximum starting current for a smaller period of time. However, an elevator may not be called upon to start maximum load more than three or four times a week, and under small loads the controller of the wound rotor unit can be designed to demand far less than maximum starting current, while the squirrel cage motor will require maximum starting current every time. The only difference, so far as the squirrel cage motor is concerned in starting a heavy load or a light load, is that something like one-quarter to one-half of a second will be required for starting a heavy load, whereas about three-fourths as much time will be required for starting a light load. (See Appendix.)

In summarizing the above effects on lamps, it might be said that three or four times a week the slip ring motor will "wink" the lights worse than the squirrel cage motor. During the remainder of the week, the squirrel cage motor will "wink" the lights more than the slip ring motor, but considerably less than under the most severe conditions which happen three or four times a week. Where the elevator is so large that it actually taxes the voltage regulation of the line to the limit, it is probably fair to say that a wound rotor machine can be geared to operate an elevator to hoist a given load about 25 per cent faster than a squirrel cage motor without giving any more general dissatisfaction in regard to the lamps.

When the second condition mentioned above arises, the squirrel cage motor is at a greater disadvantage than the slip ring motor because the slip ring motor can be adjusted after being installed to suit the conditions of installation exactly, whereas the squirrel cage motor is not capable of any such adjustment, consequently, two factors must be carefully considered in this connection. Firstly, great care must be taken to select a squirrel cage motor of exactly the right size, neither too large nor too small for the work. Secondly, squirrel cage motors should be manufactured in a greater variety of ratings, so far as starting torque is concerned, than wound rotor units.

It will be seen from the above that the operating characteristics of a squirrel cage motor are, within proper limits of car speed, better than the operating characteristics of the slip ring motor in all respects except as to the "winking" of the lamps and in this respect are only slightly inferior. The first cost of a squirrel cage motor is less than of a wound rotor unit, and the control apparatus is so cheap and simple that it is almost negligible as compared to the wound motor machine. The cost of maintaining a squirrel cage installation is much less than a wound rotor installation, especially on account of the control apparatus. For these reasons, it is incumbent upon elevator builders to apply the squirrel cage motor in every case that conditions will permit, and it is incumbent upon power supply companies to make their rules in regard to starting current and power charges so as to favor the use of squirrel cage motors, except in those cases where the motor *actually* disturbs the lighting in its vicinity. A very small lighting company certainly cannot handle a large elevator installation, and it cannot handle quite as large an elevator installation equipped with squirrel cage motors as when equipped with wound rotor units. A large power company is under the same disadvantage as a small lighting company in certain outlying districts where the sizes of transformers and transmission lines are relatively small. In congested districts, the difference between a squirrel cage motor and a wound rotor machine is so small as to be absolutely negligible, and it is believed that it would be advantageous to power companies to divide their territory into two or more zones and make rules for each zone differ according to the actual physical conditions in regard to transformers and transmission lines in that zone. This would result undoubtedly in a greater use of small electric elevators and the elimination of many hydraulic elevators.

It is also highly important that manufacturers of motors, manufacturers of elevators and power companies combine in insisting that the squirrel cage motors used for elevator purposes have the best possible operating characteristics for this work. A discussion of these characteristics is given below.

The proper relation of the starting torque to the running torque or "full load" torque is determined actually by the characteristics of the elevator gear efficiencies and only very slightly by the motor characteristics. Several tests made by the writer, and tests recorded by others, indicate that many of these slow speed elevators require, under maximum load, 200 per cent as much torque to start the load as to hoist the load. The reasons for this excess torque requirement are that static friction of any two surfaces is greater than the running friction, and also, when worm gearing

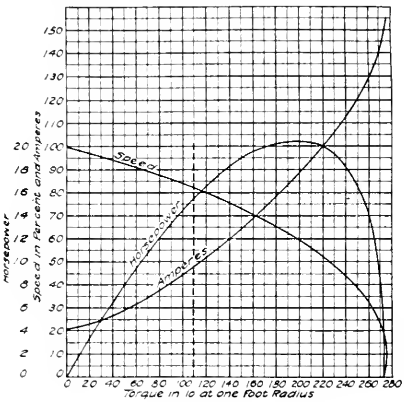


Fig. 1

is used, the oil is squeezed from between the worm and the gear at standstill. The above relation of starting to running torque is not necessarily correct, and may be expected to vary from 150 per cent, on high grade, high speed elevators, such as usually require wound rotor units to 300 per cent on low grade, very slow speed elevators, or elevators in a bad state of up-keep. In addition to the above facts, line voltage will frequently vary as much as 10 per cent, thereby causing a reduction in starting torque of 20 per cent. A very good rule, to cover these variations in conditions and one which practical experience seems to justify, is to make the starting torque 250 per cent of the torque required to hoist maximum load. The motor should be able to exert this starting torque with the least possible disturbance to the line voltage consistent with good operating characteristics of the motor.

The starting amperes of an ordinary high efficiency, low resistance rotor, squirrel cage motor are entirely too high to be suitable for elevator work. Such a squirrel cage motor can be made suitable by increasing the internal rotor resistance sufficiently. The more resistance used, the more starting torque per ampere will be obtained, until a certain limit is reached, and for purposes of determining what amount of internal resistance is proper to use, two cases are considered below.

First, as in Fig. 1, which shows the speed-torque-current-horsepower curves of a certain motor, where the internal resistance is made just large enough to cause the motor to exert maximum torque at starting when the rotor is heated to the temperature which it would attain when run for one-half hour at 40 per cent of this starting torque.

Second, as in Fig. 2, which shows the speed-torque-current-horsepower curves of the same motor with a new rotor having higher internal resistance just sufficient to cause it to exert the greatest starting torque per ampere.

At a running torque of 109 lb. in Fig. 1, we find the horse power exerted to be 15.3. This motor will exert 273 lb. starting torque with 155 amp. or 1.76 lb. per ampere. It will exert 15.3 h.p. running with 155 amperes starting current or 0.99 h.p. per starting ampere.

In Fig. 2 at a running torque of 60 lb., the horse power is 6.67. This motor will exert 2.34 lb. starting torque per starting ampere, and it will exert 1.04 running horse power per starting ampere.

At first glance it would seem that Fig. 2 makes a superior motor because it exerts more torque per ampere at starting than Fig. 1 in the ratio of 2.34: 1.76. However, this is not true at all, because if a 15.3-h.p. motor is required, and a motor with rotor designed as in Fig. 2 were used, it would have to be larger

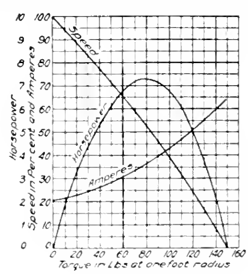


Fig. 2

than the motor in Fig. 1, in the ratio of 15.3: 6.67, and if its power-factor and other characteristics were identical to the characteristics shown in Fig. 2, this motor would require $\frac{0.99}{1.04} \times 155$ or $147\frac{1}{2}$ amperes to start the load.

However, in such a large motor, the power-factor conditions would be worse because more iron and more air gap would have to be magnetized. A greater flywheel would have to be started. The first cost of the motor would be greater. Furthermore, the slip of this motor would be 35 per cent as compared to a slip of 18 per cent in Fig. 1, thus giving much poorer speed regulation and poorer running efficiency; consequently, a feature of design which might seem advantageous is really disadvantageous in all respects.

The conclusions reached in the above paragraphs would be altered if full load torque were considered to be any other than 40 per cent of starting torque. A smaller value for full load torque would allow the motor in Fig. 2 to appear more favorably; and a larger value, less favorably. Consequently it is of some importance to decide in each installation the relation of starting to full load running torque.

The above fundamental facts of design can be entirely lost track of if these motors are designed primarily to meet some central station rules and regulations which have been enforced up to the present time, rather than to meet the fundamental conditions of service.

One of the main objects of this article is to point out some of the fallacies which might be encountered in drawing up specifications for these motors.

First: The method of testing for starting torque and starting current should be clearly understood. As pointed out above, Fig. 1 is made on the basis of keeping the temperature of the rotor the same as would be caused by a full load heat run for one-half hour throughout the whole length of the speed torque curve, and this curve shows that 273 lb. are obtained at starting with an expenditure of 155 amperes. Great care must be exerted on the test floor to keep from deceiving oneself in regard to the starting amperes. If this motor were connected to full voltage and kept at standstill, it would require only about seven seconds for the rotor to attain an extra temperature rise of 60 deg. C. under which conditions the motor would exert 268 lb. with 135 amperes. Fig. 1 shows $\frac{273}{155}$ or 1.76 lb. per ampere. However, with the rotor hot the motor would exert $\frac{268}{135}$ or 1.99 lb. per ampere. This merely goes to show that an apparent improvement of $\frac{1.99}{1.76}$ or 13 per cent could be shown by using improper testing methods. The only accurate way to test one of these motors is to determine by several trials the exact starting torque which it will exert, and lock it against a spring balance whose reading will be this value of torque. Then allow the motor to cool down to operating temperature and then take a reading of starting current, by means of an oscillograph, when it is suddenly connected to full voltage. This method is impractical for commercial purposes and might better be supplanted by calculated results based on actual impedance and core loss tests and checked by starting tests made at reduced voltage, under which conditions the heating of the rotor is insufficient to greatly modify accurate results.

Another suggestion for testing is to determine by several tests the starting torque of the motor. These tests can be made fairly well regardless of temperature because starting torque does not vary so much with temperature as does starting current. Then determine the starting current by taking the reading of a dead-beat ammeter in the line when the motor is suddenly connected to full voltage and allowed to start under no-load conditions. The reading of the dead-beat ammeter would not be the true instantaneous starting current of the motor, but it would be a measure of the disturbance which the motor would produce on the lighting system. Under this method of testing, a motor, having a very light rotor, would start up much quicker than a motor with a heavy rotor, and consequently would cause a smaller swing on the dead-beat ammeter. This is as it should be and shows the advantage of a motor which has the proper characteristics.

Second: It will not do to specify that the starting current should be, for example, 200 per cent of full load current. This specification is not clear in the first place as to what constitutes full load, and on this account may be entirely misleading. In the second place, a motor with a very poor and undesirable power-factor would meet this specification and be inferior to a motor with a good power-factor and efficiency which did not meet it. A numerical example of this would be a bad motor, whose full load current was 50 amperes and starting current 100, as compared with a good motor, whose full load amperes would be 30 and starting 90. Each motor might exert the same starting torque in pounds, yet the good motor would fail to meet the specifications.

Third: It will not do to specify that starting torque per ampere shall be some definite value, because this would lead to a motor having the poor characteristics already pointed out when comparing Figs. 1 and 2, and would not enable a given elevator, guaranteed for a certain speed in feet per minute, under full load conditions, to be started with as small a current as otherwise would be obtained.

Fourth: Having eliminated several of the undesirable methods of specifying and describing these motors, the author proposes that these motors be specified to have the greatest running horse power (the running horse power being that which corresponds to 40 per cent of starting torque) per starting ampere. This specification encourages an endeavor to make a good, efficient motor, and also ensures that the greatest number of pounds can be hoisted in an elevator cage at a specified speed with the least current demand from the line.

APPENDIX

Fig. 3 has been prepared to show how quickly a particular squirrel cage motor will start up under various conditions of load. Curves are plotted with amperes line and per cent synchronous speed as ordinates, and seconds as abscissæ. Curves A show the current and speed curves when the motor is being started up under maximum load. Curves B show the current and speed when the motor is being started up in a lowering direction with no load in the cage. Curves C show the speed torque curves of the motor when there is a load in the cage just sufficient to balance the counterweight and to overcome the friction of the machinery, thereby requiring the motor to do no work at all after it has accelerated the various parts of the system.

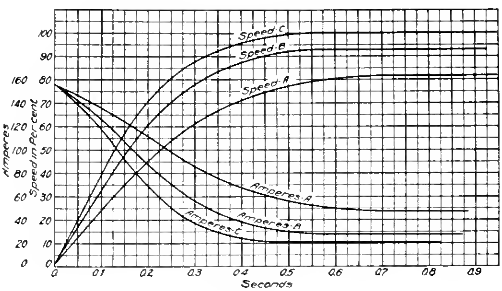


Fig. 3

The following data are used:

15.3-h.p. 738-r.p.m. motor in Fig. 1.

WR^2 of armature in pounds at one foot radius = 14.

WR^2 of coupling in pounds at one foot radius = 5.

Weight of cage = 2000 lb.

Weight of maximum load in cage = 3600 lb.

Weight of counterweight = 3080 lb.

Weight of drum = 1000 lb.

Full load hoisting speed = 100 ft. per minute.

Overall efficiency of elevator machine = 50 per cent.

Calculations

Total weight of cage, load, counterweight and drum = 9680.

Weight at one foot radius on armature (running at 738 r.p.m.) which is equivalent to 9680 lb. running at 100 ft. p.m. equals

$$\frac{9680 \times 100^2}{(738 \times 2\pi)^2} = 4.52 \text{ lb.}$$

Horse power to hoist load =

$$\frac{(3600+2000-3080)\times 100}{33000 \times 0.50} = 15.3 \text{ h.p.}$$

15.3 h.p. corresponds to 109 lb. ft. torque in Fig. 1.

Total mass to be accelerated, expressing in lb. at one foot radius on armature = 14 + 5 + 4.52 = 23.52.

Torque required to accelerate 23.52 lb. at one foot to 900 r.p.m. in one second =

$$\frac{900 \times 23.52}{308} = 68.7 \text{ lb. ft.}$$

Torque to lower empty cage =

$$\frac{3080-2000}{(3600+200)-3080} \times 109 = 48 \text{ lb. ft.}$$

From the above data and calculations the curves in Fig. 3 are plotted by using the step by step integration process.

POWER EQUIPMENT FOR ALTERNATING-CURRENT SIGNALLING AT INTERLOCKING PLANTS

By Harry M. Jacobs

Signal Accessories Department, General Electric Company

A prime factor in the design of an electric signal installation is the degree of continuity of service that will be required by the particular section of the railway line which that signal equipment controls. For practical consideration, the author classifies continuity requirements into three degrees. Following this introduction is a general description of each equipment that will be necessary to fill each of these requirements; after which is a detailed description of recent alternating-current signal installations and their operation on the N. Y., N. H. & H. R. R.—Editor.

Continuity of service is the prime consideration in any railway signal system. Direct-current systems rely upon either primary or storage batteries, but alternating-current systems must depend upon the reliability of the source of supply. This is most important at interlocking plants for these govern train movements into and out of stations and at junctions and yards.

Until very recently, the power equipment used in connection with an alternating-current interlocking plant embraced a storage battery and charging apparatus for operating some part of the interlocking mechanism. The two electric interlocking plants recently placed in service at Pawtucket, R. I., on the New York, New Haven & Hartford Railroad, are the first plants to use alternating current exclusively for the operation of all units, and, from an economic standpoint, the results of this latest development in the alternating-current system of signalling have been especially gratifying.

The fact that this new type of interlocking plant relies solely upon the continuity of the alternating-current service does not necessarily mean that the service must never be interrupted, for traffic and operating conditions are the prime governing factors in the degree of continuity required. From this standpoint three conditions are apparent:

(1) That of an interlocking plant which is located on the line at a point where the traffic conditions are such that one may well trust the electric service for maintaining continuity of traffic, that is, the probable delay resulting from a loss of power will not be a serious matter.

(2) That of an interlocking plant at a junction or at some important point where the traffic conditions are such that the continuity of the signal service must be practically perfect—the absence of energy from the signal system not to exceed one minute duration.

(3) That of an interlocking plant located at a point where the continuity of service must be absolutely perfect, such as, a plant for a large terminal or a junction point where fast and frequent service demands perfect operation.

Fig. 1. An Express Train passing the Boston Switch—Central Falls Signal Tower, N. Y., N. H. & H. R. R., Pawtucket, R. I.

Each of these conditions requires different treatment in selecting the proper power equipment for operating an all alternating-current interlocking plant. The power equipment for a plant of the first character need be only a transformer. An interlocking station of the second class requires a stand-by motor-generator set drawing power from a storage battery and also such automatic switching equipment as is necessary, upon failure of the prime source, to start the set from rest and to supply power to the signal system with the least possible delay. An interlocking plant of the third class (wherein continuity of service must be absolutely perfect) requires duplicate motor-generator sets, a large storage battery, and an automatic switching equipment so arranged that upon the failure of the commercial supply the alternating-current generator of the active set will supply power to the signal system without interruption. These sets may consist of a direct-current machine floating on a storage battery, an alternating-current machine for supplying the signal system, either self-excited or excited from a direct-connected exciter and an induction motor. Under some conditions the induction motor may be omitted and the alternating-current machine be designed to act as a generator or as a synchronous motor; in such a case the signal system is to be supplied directly from the commercial line but the switching equipment must be arranged so that on a failure of the commercial supply the commercial line will be cut off and the signal system be supplied from the alternating-current machine without interruption.

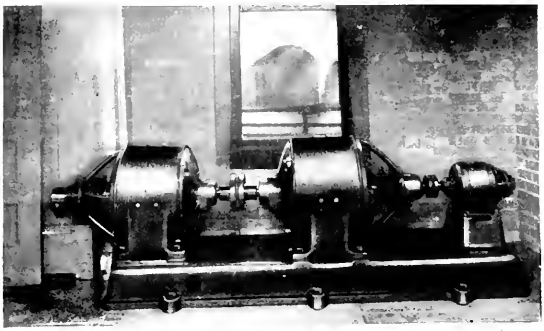


Fig. 2. Motor Generator Set, Boston Switch—Central Falls Signal Tower, N. Y., N. H. & H. R. R., Pawtucket, R. I.

The commercial power available at Pawtucket, R. I., is very reliable, but, to guard against a continued interruption due to a possible feeder fault, two feeders are run each through different streets of the city to an automatic oil switch from which the signaled territory including the two interlocking plants is fed. This practically eliminates supply feeder trouble.

The interlocking plant at Woodlawn is located approximately one mile from the passenger station in the direction of Providence and controls movements on the main tracks. The traffic conditions at this point place the plant in the forementioned first class and the power equipment consists of only two duplicate transformers stepping down from 2200 to 110 volts.

The interlocking plant at Boston Switch—Central Falls is located approximately one mile east of the passenger station at the junction of the tracks to Valley Falls and Newport Road (the main line to Worcester and Boston). The local traffic conditions place this plant in the second class, that is, the signal service must be practically perfect. This requires an infallible auxiliary source of alternating-current power that will be automatically cut into service in the shortest possible time after a failure of the commercial supply. The necessary power equipment consists of an alternating-current generator of sufficient capacity to clear all the signals (approximately 60 per cent overload for 20 seconds), a means for exciting the generator, a direct-current motor for driving the generator, a storage battery for supplying power to the motor, and a switchboard. The functions of this switchboard are the distribution of the commercial supply power, the control of the motor-generator set and, upon failure of the commercial supply, the opening of the supply circuit and the providing of a means for automatically starting the set from the battery, bringing the generator to normal voltage and frequency and connecting it to the signal mains, and in addition upon resumption of the commercial supply to shut down the set and reconnect the signal supply to the commercial supply. Means must also be provided for charging the storage battery from the commercial supply.

By utilizing the motor-generator set electrically reversed—alternating-current machine as a synchronous motor and direct-current machine as a generator—a separate equipment for charging the storage battery is eliminated but this necessarily complicates the control equipment.

The three-unit motor-generator set illustrated in Fig. 2 consists of (1) a 6 h.p. direct-current shunt-wound machine operating between 110 and 155 volts as a generator for charging the storage battery or between 110 and 80 volts as a motor, (2) a single-phase 120-volt alternating-current machine capable of normally delivering as a generator 5 kv-a. at 0.74 p-f. with a 3 kv-a. intermittent overload capacity for short duration, and of sufficient capacity as a synchronous motor to drive the generator when delivering 50 amperes, 155 volts maximum to the storage battery, and (3) a 125-volt exciter capable of delivering 250 watts (for indicating lamps) in excess of the required excitation for the alternating-current machine.

The switchboard consists of two natural black oil finished slate panels 76 in. high, each of two sections mounted on pipe supports, one to control the direct-current machine and the other the alternating-current machine and commercial line. With the exception of two relays mounted back of the board the automatic equipment, consisting of direct-current motor, automatic starter, alternating-current contactors, and control relays, is mounted on the sub-panels.

Under normal conditions the interlocking circuits are supplied from the commercial source and the set is idle. On failure of the supply, the control relays fall by gravity and de-energize the alternating-current line contactors at the same time energizing the starting equipment for the direct-current machine. After the set has attained a speed such that the voltage on the alternating-current machine is sufficient to energize the alternating-current machine contactor, the machine is connected to the signal bus and supplies the interlocking system. The speed is held constant by means of a centrifugal switch on the shaft acting on the direct-current motor field rheostat. When the commercial supply returns, the control relays become energized and thereby the contactors on both the direct-current and the alternating-current machines are opened, after which the alternating-current contactor is closed, restoring normal operation to the interlocking plant from the commercial supply and shutting down the set.

Normal and reverse operation of the set necessarily require different field excitation on both machines for each function. This is taken care of by two field rheostats for each machine, each pair being connected in series, and by means of a four-disk low-voltage relay one rheostat for each machine is short circuited for both the energized and de-energized position of the relay. All the rhostats are mounted back of the switchboard; the two that control the set while supplying emergency alternating-current power require very little adjustment as the load is practically constant, therefore to avoid confusing the operator these are controlled from the back of the board.

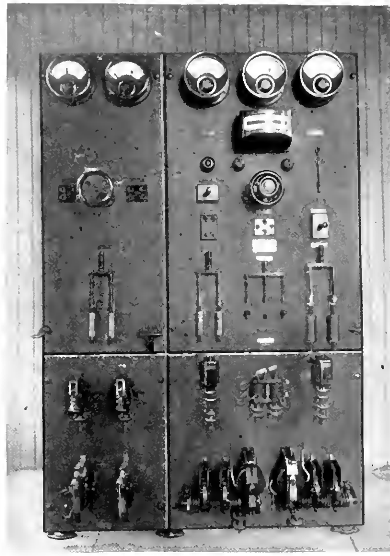


Fig. 3. Switchboard, Boston Switch—Central Falls Signal Tower, N. Y., N. H. & H. R. R., Pawtucket, R. I.

Should a failure of commercial power occur while the storage battery is being charged, the voltage of the alternating-current machine will tend to hold up the low-voltage control relay and rheostat control relay and prevent the opening of the alternating-current line contactor and the interchanging of the field rheostats, so that the set will run at low speed. To guard against this condition a direct-current reverse-current relay, operated by reversal of current from the battery, energizes a shunt-trip relay to open the coil circuits of the alternating-current line contactor and the two low-voltage relays. This interchanges the rheostats and supplies emergency alternating-current power from the set as before described.

It is obviously impossible, without going into unnecessary complications, to automatically synchronize the set with the commercial supply after an interruption. Therefore, to prevent the line contactor from closing as soon as the commercial supply is again available, a "last-position" relay is introduced to open the coil circuits of the line contactor and of the field rheostat control relay immediately after an interruption occurs during charging. This relay is energized from the storage battery through a disk contact on the main low-voltage control relay and through one blade of the main triple-pole double-throw control switch in the "down" position. The operator will be advised when the commercial power is again available by an alternating-current alarm actuated through contacts of the "last position" relay.

commercial source; the alternating-current line contactor is energized through the upper disk making contact when the relay is energized. When the switch is up and the relay becomes de-energized, the two direct-current line contactors are energized through the bottom disk and one blade of the switch, and the alternating-current contactors are energized from the machine (after the voltage has built up to the pick up point) through the third disk and another blade of the switch. It is thus impossible to start the set when the switch is in the "up" position by any means other than by de-energizing the control

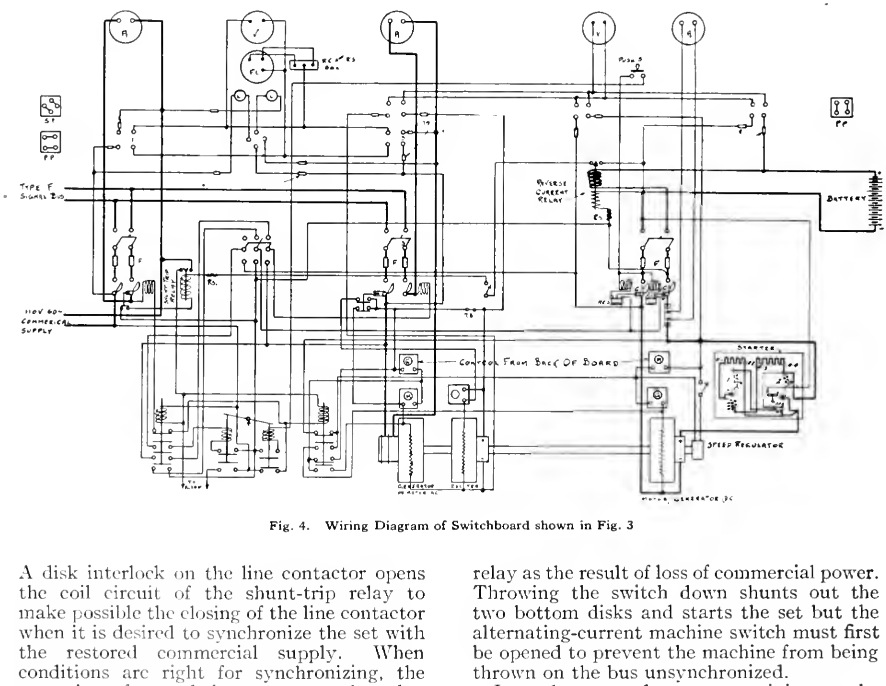


Fig. 4. Wiring Diagram of Switchboard shown in Fig. 3

A disk interlock on the line contactor opens the coil circuit of the shunt-trip relay to make possible the closing of the line contactor when it is desired to synchronize the set with the restored commercial supply. When conditions are right for synchronizing, the operation of a push button resets the relay and thus restores energy to the alternating-current contactor and the field rheostat control relay. The set then automatically picks up the charge as before the interruption.

The triple-pole double-throw lever switch and the four-disk low-voltage alternating-current control relay are the heart of the control system. The relay is energized from the relay as the result of loss of commercial power. Throwing the switch down shunts out the two bottom disks and starts the set but the alternating-current machine switch must first be opened to prevent the machine from being thrown on the bus unsynchronized.

In order to reduce to a minimum the interval of time from the loss of power to the energizing of the signal bus from the set, two disk contacts on the alternating-current machine contactor short circuit the exciter rheostat and the machine rheostat when the contactor is open. By actual tests this interval has been shown to be only 13 to 15 seconds; approximately 5 seconds are required to "clear" a signal so that the total interruption from a traffic standpoint can be only 20 seconds.

When it is desired to charge the battery the operator will open the alternating-current machine switch, strengthen the direct-current machine field with the rheostat controlled from the front of the board, and throw the triple-pole double-throw control switch "down." The set will immediately start and the voltage on the alternating-current machine will build up. The frequency and the voltage should be adjusted to correspond with those of the commercial line, and synchronizing is accomplished across the machine switch. Further strengthening of the direct-current machine field will increase the charging current to the battery. Any desired charging current can be maintained without affecting the automatic operation should a failure of commercial power occur.

Such an equipment as has been described is not restricted to the railway signal field alone, but is applicable to any case where more than a momentary interruption in service would be serious.

PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

Part XV (Nos. 66 to 68 inc.)

By E. C. Parham

Construction Department, General Electric Company

(66) GENERATOR-VOLTAGE WAS LOW

At any particular speed and load, the highest voltage obtainable from a generator is that which is given when all the resistance of the field rheostat is cut out; in other words, when the field rheostat is short-circuited. In those installations where the generator voltage is regulated by hand, the field rheostat is turned in one direction or the other until the desired voltage is obtained. In this case, the active resistance of the field rheostat is changed to a value that remains fixed until the next occasion arises for changing the voltage; i.e., the effective rheostat resistance can be considered to be *permanently* changed. Aside from the labor involved, just as good regulation could be obtained by means of two wires so connected that when touched together they will short-circuit the rheostat. With, first, the "permanent" resistance of the rheostat adjusted to a value such that the voltage of the generator would be too low when the short-circuiting wires were held apart, and, second, on holding the short-circuiting wires together (thereby short-circuiting the rheostat) the voltage would soon become too high, it is conceivable that, third, by observing the voltmeter for guidance and by alternately and continually pulling the short-circuiting wires apart and touching them together, the tendencies of the voltage to rise and to fall could be controlled so as to keep the voltage constant. In such a case, the resistance of the field rheostat would alternately be all out and all in: the total resistance of the rheostat would be *temporarily* changed, as opposed to *permanently* changed, which latter occurs in the case of manual control of the rheostat. The alternate tapping of the wires together and pulling of them apart is the exact function of the generator automatic voltage regulator. When the generator voltage tends to rise, the regulator contacts open the shunt circuit across the rheostat; this results in cutting all the rheostat resistance in, thereby lowering the voltage. When the voltage tends to lower, the regulator contacts close the shunt circuit across the rheostat; this results in cutting out all the resistance, thereby increasing the voltage. Manifestly, the maximum voltage obtainable occurs when the regulator holds the short-circuiting contacts together.

An operator once complained that his regulator would not regulate properly though the device itself seemed to be in perfect order. An inspector determined that there was nothing wrong with the regulator and that there was nothing wrong with the generator *per se*. He further determined that the whole trouble was that the load and steam pressure conditions were such that the generator speed was abnormally low at times. Near full load the speed was so low that normal voltage could not be maintained, even if the regulator contacts were held permanently together.

The source of trouble was suggested by the facts that the engine speed variations could be heard and that regulation was satisfactory at the lighter loads.

(67) END-PLAY VARIATIONS

The principal purpose of having end-play in the armature of a motor or of a generator is to keep the brushes from tracking in the same path and thereby wearing a groove in the commutator or in the collector rings as the case may be. To prevent such wearing of grooves, the armature end-thrust clearances are so disposed that when the armature is running in its normal zone, which is governed by the pull of the pole-pieces on the armature core, the thrust clearances at the two bearings are equal. Assuming the correct gear or pulley alignment to the connected load, the armature will never run sideways far enough to knock the bearing on either side; because when it has run over a certain distance, the field will pull it back toward and past the magnetic center. The same action will then be repeated but in the opposite direction. If, however, the end-thrust is unequally distributed for any reason, or if the machine as a whole is not level, knocking will occur which in the case of small, high-speed machines may take the form of serious vibrations that are likely to pound down the bearing linings.

Four motors of fractional horse power, which were direct connected to tool grinding wheels, were installed by the purchaser. Three of the outfits gave entire satisfaction, but the fourth one vibrated so badly that it shook the whole supporting structure. The rotating elements of two of the units were then interchanged and the vibrations remained with the same rotor. Spinning the rotating element of the troublesome machine in a high-speed lathe proved the shaft to be perfectly straight. Close inspection disclosed that the end-play was not distributed on the faulty outfit in the same manner as on the faultless ones.

All vibration was eliminated by loosening the thrust collar so that the rotor when running could center itself, then starting the motor and letting it slow and stop, and then tightening the collar.

(68) FREQUENCY WAS HIGH

The lower the frequency of an alternating current supply circuit, the larger the percentage of the normal frequency will be a given amount of frequency variation; thus, a variation of 2½ cycles would be a 10 per cent variation on a 25-cycle circuit, a 6 per cent variation on a 40-cycle circuit, and a 4 per cent variation on a 60-cycle circuit.

In the factory adjustment of continuous current compound-wound engine-driven generators, it is sometimes the practice in compounding to allow a small margin that represents a difference between the rated engine speed and the speed at which it is estimated that the engine actually will turn at full load. Occasionally, it may happen that the no-load engine speed is slightly above rated value, so that the full-load speed does not lower to the value for which the connected generator was compounded. In such cases the compounding of the generator may require a slight readjustment of either the series-field compounding shunt or the shift of the brushes.

When the generator is to be driven by a synchronous motor, no allowance need be made, because the speed will be governed by the frequency of the supply circuit; and if that frequency is normal the speed of the direct-connected generator will also be normal. When an induction motor is the driving agent, the slip of the rotor necessarily will reduce the generator speed; but as the outfit is tested at rated frequency the compounding is automatically taken care of.

Without giving any other details, an operator stated that his generator voltage was too high at full load. The matter was investigated and the generator was found to be direct connected to an induction motor. As the inspector did not suspect any unusual condition, he simply changed the series-field compounding shunt to give the desired full-load voltage and everything was satisfactory.

It afterward developed, however, that the high full-load voltage had been caused by the Power Company maintaining its frequency at 62½ cycles instead of at 60 cycles. The generator when ordinarily compounded had been driven by its motor running on a 60-cycle circuit; therefore the motor when operating on this 62½-cycle circuit was, in effect, operating without slip on a 60-cycle circuit. Consequently, the generator was being driven at a speed greater than the 60-cycle-minus-slip speed at which it had been compounded.

ELECTRICITY IN THE MANUFACTURE OF THE POCKET KNIFE

By F. A. Buttrick

Power and Mining Department, General Electric Company

Years ago, many small factories were built adjacent to rivers, which were frequently small, because waterwheels would supply at small cost the power needed for operating at that date and still have a small excess for later growth. The size of many of these factories has far outgrown the original power supply, and it has been necessary for their managements to provide new sources. The company whose equipment is described in this article is but one of the many that have turned to electricity as the cleanest and most dependable form of power. In the article is given a detailed description of the steps in the manufacture of a pocket knife and lists of the pieces of electrical apparatus used in this particular factory.—Editor.

The manufacture of pocket cutlery on a commercial scale in this country dates back to the early part of the last century, at which time the work was done by hand. When machine tools, such as drop hammers, etc., were introduced there was evolved a very profitable industry on a large scale.

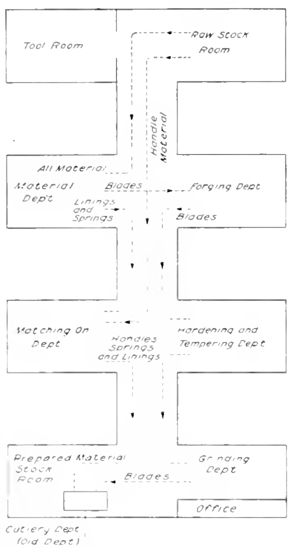


Fig. 1. Layout of the Walden Factory Building for Manufacturing Pocket Knives

A number of old existing knife factories are located where they are able to secure water power for only part of the year; and as the business of these factories continued to grow—with no regard for the dry season—the progressive companies turned to the electric motor as the best solution of the production problem.

A splendid example of progress along these lines is that of the Walden Knife Company, located on the Walkill River, at Walden, N. Y. This company was formed in 1871 for the manufacture of pocket cutlery and like many others obtained its power from waterwheels. Two years ago the increase in its business necessitated a substantial addition to the original plant and electric motor-driven machinery was decided upon for the new addition, since greater production and a safe and clean equipment was desired.

This new addition is a one-story structure with a hexagonal roof, amply supplied with skylights, and giving splendid daylight lighting. It is built on the unit plan as will be seen from Fig. 1; and it is comprised of a raw-stock room, tool room, material department, forging department, hardening and tempering department, matching-on department, grinding department, prepared material stock room and office.

Before describing the processes carried on in the foregoing departments, a brief definition of the various knife parts will be furnished.

Handle (wood, pearl, bone, silver, etc.).

Linings (brass or german silver, separating blades and supporting handle).

Bolsters (iron, placed on the ends of linings).

Springs (steel).

Blades (steel).

Raw-Stock Room

All raw material is delivered to this department which stock consists of blade steel, spring steel, bolster iron, brass, german silver, etc.

A perpetual card inventory is kept of the quantity of each class of material incoming and outgoing, from which a yearly graphic chart is plotted showing at a glance the consumption of the various materials.

Tool Room

The tool room, or more properly the machine shop and die room, is completely equipped to set up all new machines before being put into productive service, to make all repairs on machinery, and to make all dies and tools necessary for the manufacture of cutlery. In addition to the following motor-driven machinery, there is a die tempering furnace.

Material Department

All material necessary to make up the finished knife, with the exception of the handle material, is sent from the raw-stock room to the material department. Here the "bolsters" are blanked out, drop forged to shape, and matched on to the lining material, after which the "scales" (this combination of linings and bolsters) are blanked out to the shape of the knife. The springs are stamped out, tumbled, and flattened, and are then sent to the matching-on department. The linings are then pierced to receive the handle rivets and hinge pins and are sent to the matching-on department. Pocket knife blades are stamped out and tumbled, after which they are sent to the forging department.

Matching-on Room

The handle material makes its appearance in the matching-on room where it is matched to the metal "scales" received from the material department. Next, the coverings or handle materials are drilled, and last they are riveted to the "scales." The springs are also drilled, all drilling being done to template. All of these parts are then sent to the prepared material stock room.

Forging Department

The blades are sent from the material room to the forging department where they are heat treated, drawn out, nail marked and straightened. The forging of the pen knife blades is done to templates of brass. (In this department also screw drivers and blades for butcher knives and draw knives are drawn out.) All parts are then sent to the hardening and tempering department.

Hardening and Tempering Department

Next comes the important factor in the manufacture of cutlery—hardening and tempering. At this point a brief description of the fuel oil system will be of interest. In this plant the heat treatment of steel blades and springs is accomplished by means of a system adapted to either light or heavy fuel oils. All oil pipes are laid in trenches having metal covers, thus rendering any part of the system accessible for repairs or additions.

An Ingersoll-Rand compressor driven by a 35-h.p., 900-r.p.m., wound-rotor motor supplies the compressed air for the system. One air line runs direct to the furnaces from the air reservoir and a second to an air-driven oil pump which in turn supplies the furnaces with oil. It will thus be seen that if the air system fails the fuel system also fails, which reduces the fire risk.

As the pocket knife blades are received from the forging department, the next steps in the process are as follows:

1st. "Choiling" the blades. (This consists of putting a small fillet in the cutting edge of the blade at the shoulder end.)

EQUIPMENT OF TOOL ROOM

Machine Tool	Drive	Motor
Prentice Bros. 30-in. lathe	Individual	7½-h.p., 1200-r.p.m.—belted
B. & S. Cutler reamer grinder	Individual	¾-h.p., 1200-r.p.m.—geared
2-in. radial drill	Individual	2 -h.p., 1200-r.p.m.—geared
B. & S. Universal milling machine	Individual	5 -h.p., 1200-r.p.m.—chain
Whitcomb 24-in. planer	Individual	5 -h.p., 900-r.p.m.—belted
Water circulating pump (heating system)	Individual	30 -h.p., 1200-r.p.m.—direct-connected
Diamond auto surface grinder	Group	7½-h.p., 1200-r.p.m.—belted
Hess No. 7 file cutting machine		
P. & W. No. 1 turret lathe		
8-in. engine lathe		
Die filing and sawing machine		
B. C. Ames bench lathe		
Steptoe 14-in. shaper		
Racine high-speed hack saw		
12-in. shaper		
Single spindle drill press		

(All motors are of the squirrel-cage rotor type.)

EQUIPMENT OF MATERIAL DEPARTMENT

Machine Tool	Drive	Motor
8 Punch presses and 1 shear	Group	5 -h.p., 1200-r.p.m.—belted
1 Bliss power press	Individual	5 -h.p., 1200-r.p.m.—belted
1 Bliss power press	Individual	5 -h.p., 600-r.p.m.—geared
3 Hand drop hammers	Group	5 -h.p., 600-r.p.m.—belted
4 Hand drop hammers	Group	5 -h.p., 600-r.p.m.—belted
2 Punch presses	Individual	½-h.p., 1200-r.p.m.—belted
Rotary shears 2 Tumblers 1 Emery grinder 1 Clipping machine	Group	3 -h.p., 1200-r.p.m.—belted

(All motors are of the squirrel-cage rotor type.)

EQUIPMENT OF MATCHING-ON ROOM

Machine Tool	Drive	Motor
15 Drill presses 3 Matching machines 2 Grinders 2 Pairs of cutters 2 Milling machines 2 Boring out machines 1 5-spindle drill 1 Tumbler	Group	7½-h.p., 1200-r.p.m.—belted
1 4-spindle drill	Individual	2 -h.p., 1200-r.p.m.—belted
2 Riveting-on machines 2 Pinning-on machines	Group	2 -h.p., 1200-r.p.m.—belted

(All motors are of the squirrel-cage rotor type.)

EQUIPMENT OF FORGING DEPARTMENT

Machine Tool	Drive	Motor
3 Hand drop hammers	Group	5 -h.p., 1200-r.p.m.—belted
3 Hand drop hammers	Group	5 -h.p., 1200-r.p.m.—belted
4 Hand drop hammers	Group	5 -h.p., 1200-r.p.m.—belted
2 500-lb. drop hammers 1 Power press	Group	7½-h.p., 1200-r.p.m.—belted
2 Bradley trip hammers	Group	5 -h.p., 1200-r.p.m.—belted

(All motors are of the squirrel-cage rotor type.)

EQUIPMENT OF GRINDING DEPARTMENT

Machine Tool	Drive	Motor
8 Hemming Bros. blade grinding machines	Group 1*	7½-h.p., 1200-r.p.m.—belted†
8 Hemming Bros. blade grinding machines	Group 2*	10 -h.p., 1200-r.p.m.—belted†
8 Hemming Bros. blade grinding machines	Group 3*	15 -h.p., 1200-r.p.m.—belted†
6 Hemming Bros. blade grinding machines	Group 4*	20 -h.p., 1200-r.p.m.—belted†
5 72-in. butcher knife grinding stones	Group	25 -h.p., 900-r.p.m.—belted‡
4 48-in. grinding stones	Individual	5 -h.p., 1200-r.p.m.§
5 Swaging machines with 12-in. dia. by 2½-in. face stone	Group	7½-h.p., 1200-r.p.m.—belted†
1 Grinding machine	Individual	2 -h.p., 1200-r.p.m.—belted†
1 Gould's "Pyramid" pump for supplying water to grinding stones	Individual	1 -h.p., 1200-r.p.m.—geared†

* Various sizes of blades necessitate larger motors for Groups 2, 3 and 4 than for Group 1.
† All of these motors are of the squirrel-cage rotor type.
‡ This motor is of the type using an internal starting resistance which is later short circuited by a mechanical switch.
§ This motor is of the squirrel-cage rotor type and has silver soldered end connections.


Fig. 2. Tool Room


Fig. 3. Material Department

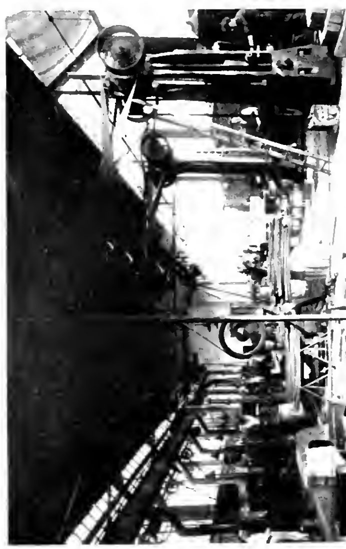


Fig. 4. Forging Room

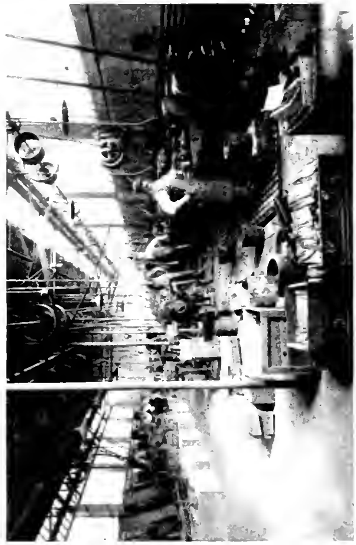


Fig. 5. Grinding Room

Views in the Walden Knife Factory showing Electric Drive

2nd. Shaping the blades and laying in the "tangs" or shoulder.

3rd. Hardening and tempering.

All blades are heated in oil-heated lead baths, the temperatures of which are kept at from 1350 deg. F. to 1450 deg. F. by pyrometers, depending upon the condition of the steel.

The pocket knife blades are hardened in a brine solution and are then tempered in a revolving oven heated by fuel oil. The temper of the butcher knife blade is drawn in an oil bath. These blades are then placed on a warming sand plate and straightened. All blades are later sent to the grinding department.

EQUIPMENT OF HARDENING AND TEMPERING DEPARTMENT

Machine Tool	Drive	Motor
Choiling machine........	Individual	½-h.p., 1200-r.p.m.—belted
7-blade shaping machines.......		
Am. Gas blade tempering machine.	Group	10-h.p., 1200-r.p.m.—belted
4 Hand grinders 30-in..........		
30-in. Buffalo forge blower for exhaust for 9 hardening furnaces.....................	Individual	3-h.p., 1200-r.p.m.—belted

Grinding Department

All blades are machine ground to a rough edge in Hemming Bros. grinders. The blades are placed in a clamping device which carries one side of the blade to the side of the wet wheel, automatically applying the necessary pressure to insure the proper amount of grinding. The clamping device then returns to its first position and the operator removes the blade and places it in a second machine which grinds the opposite side in the same manner. The next operation consists of "swaging" the pocket knife blades, which is the process of slightly beveling the top edge of the blade beginning at the point and running back about ¾ of its length, thus giving the desired smoothness to that part of the blade. The butcher knife blades are hand ground to a cutting edge on large wet wheels; and these with the pocket knife blades are thoroughly limed to prevent rusting, after which they go to the prepared material stock room.

This operation brings all the knife parts to the prepared material stock room. Here all orders are received and the requisite number of parts is turned over to the cutlery department, located in the older buildings.

Before leaving the manufacturing department, it may be interesting to note the system which is used for following the different jobs through the shop. A large board, similar to a broker's quotation board, has been erected, and on it each job is represented by a white card about 2 in. by 2½ in. The names of the departments are located in the left-hand column and ample space is allowed at the right for several tickets. The foreman of each department locates the job on the board immediately it is received in his department. Reference to the board previous to his own indicates to any foreman what to expect and thereby eliminates unnecessary consultation with the factory head.

As has been stated, the material parts for an order are turned over to the cutlery department for assembly and finishing. Briefly, the processes consist of assembling the blades, handles, and springs, the springs being hardened and tempered in this department in a manner similar to that of the blades. They are then inspected and go to the blade finishing department. Here they are reinspected, the trade mark etched on, the final edge put on, and are cleaned and boxed, then sent to the shipping department.

Current for the motors for the new plant is supplied by the local lighting company at two-phase, 60-cycle, 2300 volts stepped down to 240 volts. In addition to the motor equipment described there was subsequently installed a 75-kv-a. belt-driven alternator which is driven by one of the old waterwheels. This unit is used for supplying the lights and some of the power at night.

The present capacity of the Walden Knife Company is 500 dozen finished pocket knives per day; and the variations in its product amount to more than a thousand different styles.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

NOTES ON THE PROTECTION OF THE EYE FROM DANGEROUS RADIATIONS

It is well known that the light of the iron arc and the quartz mercury lamp are especially rich in ultra-violet rays and the powerful electric flame used in the process of arc welding is therefore a serious menace to the eyesight of the operator, unless sufficient protection is provided to subdue the glare of the visible light and absorb the invisible and destructive ultra-violet radiation. As ordinary clear glass of reasonable thickness, say 3 or 4 mm, is practically opaque to these dangerous invisible rays, their effects can be easily avoided if simple precautions are observed.

The intense visible glare that is produced by the electric arc, between carbon or iron terminals, must be screened down to a safe limit by colored glass, and it is here that careful discrimination is necessary in order that the operator may secure the clearest definition of his work with the least amount of glare.

To the ordinary normal eye the tints produced by combinations of red, orange, yellow and green show a better definition of details than combinations including blue and violet, and this is based on the scientific fact that the eye is more sensitive to the light waves at the red end of the spectrum than it is to those at the violet end, the maximum degree of sensitiveness being usually found in the central yellow and green rays.

A careful study has been made of various safety glasses of American and foreign manufacture and it has been found that those glasses which are of a cloudy orange tint, a little inclined to green, appear to give the best general results. Operators when using the iron or carbon electric arc usually wear masks made of thin sheet aluminum or vulcanized pressboard, furnished with round or rectangular glass windows, so constructed that the glasses can be readily changed to suit the character of the work in hand. Dark colored safety glasses especially made for the purposes have recently come into use, but previous to this thin plates of ordinary flashed ruby glass and emerald green glass, stacked up alternately to the required color density, were employed, and, owing to the present high price of the special safety glasses above referred to, these combinations have not as yet been entirely superseded. Combinations of ruby and blue glass have also been employed, but, for reasons already stated, blue glass should always be avoided and green used in its place.

The masks above referred to are necessary to shield the face and neck of the operators from the sunburn effects of the intense visible and invisible rays generated by the electric arc. Besides the ultra-violet, these invisible rays contain a plentiful amount of infra-red or heat rays, the effects of which would also be dangerous to the operators' eyes if they were not largely filtered out by the dark colored glass in the mask window. The heat absorbed by the glass gradually warms it up so that under extremely severe conditions it may in itself become uncomfortably hot. In this case the sense of feeling will give sufficient warning to the operator before danger is incurred.

Operators who perform welding operations with oxy-acetyline and oxy-hydrogen flames generally wear goggles fitted with light colored safety lenses, instead of masks, as the dangerous rays from these flames are very much weaker than those from the iron arc, and less protection is required. In all work where the operators' eyes are constantly used near a source of heat and light it is wise to shield the eyes with clear or colored glass suitable to the work. As an example of the danger often unconsciously incurred by ignorance, the well known fact may be cited that glass workers who use their unprotected eyes in proximity to very hot flames of weak luminous intensity are extremely subject to cataract. This disease could probably be entirely avoided by wearing properly constructed spectacles or goggles.

There is no sharp line of demarcation between the infra-red, the visible and the ultra-violet rays as they merge gradually into each other as do the different colors in the visible (continuous) spectrum. The limit of perception of red to the average eye occurs at a wave length of about 6700 Ånstrom units ($1\ AU = 10^{-8} cm.$) although waves as long as 8000 *AU* have occasionally been seen by persons with very acute vision. At the other end of the visible spectrum, to the average eye, the violet merges into darkness at a wave length of about 3900 *AU*, although the extreme limit of very acute vision is sometimes extended to 3600 *AU*, where the ultra-violet spectrum may be said to begin.

Harmful ultra-violet radiation probably begins at a wave length of about 3400 *AU*, but as flint glass, such as spectacle lenses are usually made of, ceases to transmit at a wave length of about 3380 *AU*, there is little or no danger to be feared from ultra-violet light where ordinary spectacles or eye-glasses are worn. It must, however, be carefully remembered that the so-called "pebble" lenses afford no protection against ultra-violet radiation. These lenses are made of natural crystallized quartz, or as it is commonly termed, "rock crystal," which unlike glass is transparent to these rays.

From the above brief notes it will be seen that by the exercise of a little intelligent caution all harmful effects from dangerous radiations may be avoided.

W. S. Andrews.

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.

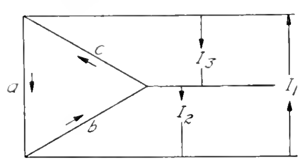
TRANSFORMER: LOADS FROM DELTA-CONNECTED SECONDARY

(158) **If unequal loads are drawn from the different phases of a delta-connected transformer secondary, how will the currents divide in the windings of each phase?**

General

The distribution of currents in a delta-connected secondary will be the same whether the primary be delta connected or Y connected. It will also be the same in a three-phase transformer or in three single-phase transformers. The assumption will be made that the load is at unity power-factor and if three single-phase transformers are used that all these will be exactly alike. Power-factors less than unity and transformers of unlike capacity are covered by other discussions.

It will usually be sufficiently accurate to draw the vector diagram and scale the resultant currents. If greater accuracy is required, the various solutions should be made analytically.



(158) **Fig. 1**

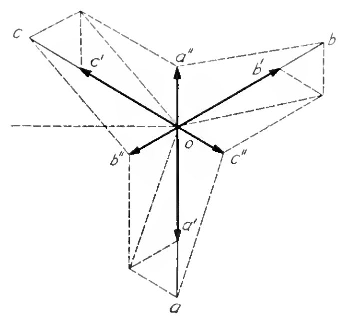
Fig. 1 shows the secondary connections. The symbols a, b, and c indicate the currents flowing in the winding of each phase, and I_1, I_2, and I_3 indicate the currents flowing in the load across the different phases. The primary windings and line currents are not shown.

When current is drawn from the terminals of one phase it will flow in the windings of all three phases, dividing among them inversely as the impedances of the parallel paths, i.e., two-thirds will flow in the single winding between the terminals and one-third will flow in the two windings that are in series between the terminals.

When currents are drawn from the terminals of more than one phase, each current will divide the same as if it were independent and single-phase, and the total current in each winding will be the vector sum of these currents.

Three Phases Equally Loaded

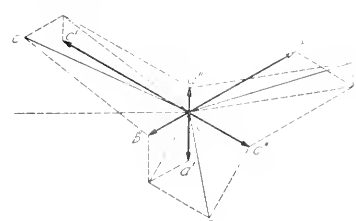
See Fig. 2. Draw oa' equal to $\frac{2}{3}$ of the load on phase A and oa'' equal to $\frac{1}{3}$ of the load on phase A. Draw $b'b''$ and $c'c''$ in a similar manner, 120 degrees apart. The currents oa, ob, and oc, in the windings of the respective phases, are obtained by drawing the "parallelograms of forces."



(158) **Fig. 2**

Three Phases Unequally Loaded

See Fig. 3. This diagram is constructed in the same manner as was Fig. 2. Note that the currents in the windings having the heavier loads are less than the respective currents at the loads and that the current in the winding having the least load is greater than the corresponding current at the load.

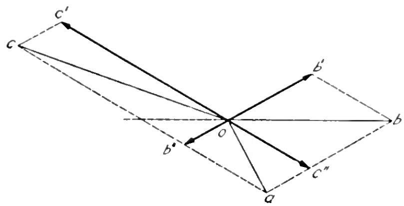


(158) **Fig. 3**

The currents in the windings are out of phase with the currents at the loads, and the kilovolt-ampere value is greater than the kilowatt value.

Two Phases Unequally Loaded, One Phase Not Loaded

See Fig. 4. This diagram is also constructed in the same manner as was Fig. 2. Note that the currents in the windings on the loaded circuits are less than the respective currents at the loads and



(158) **Fig. 4**

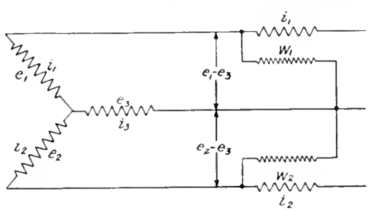
that the winding on the unloaded circuit carries current. As in Fig. 3, the currents in the windings are out of phase with the currents at the loads and the kilovolt-ampere value is greater than the kilowatt value.

W.P.W

WATTMETERS: UNEQUAL READINGS ON THREE-PHASE POWER

(159) When measuring the power input to a three-phase induction motor by means of the two-wattmeter method why do the two meters give unequal readings?

The phenemenon noted is caused by the phase displacement between the currents in the series and shunt coils of one meter differing from that in the other meter. Fig. 1 is a diagrammatic representation of the connections of the motor and the two wattmeters with the instantaneous values of voltage and current indicated. The difference in the amount of the phase displacements referred to will be evidenced clearly by referring to Fig. 2.

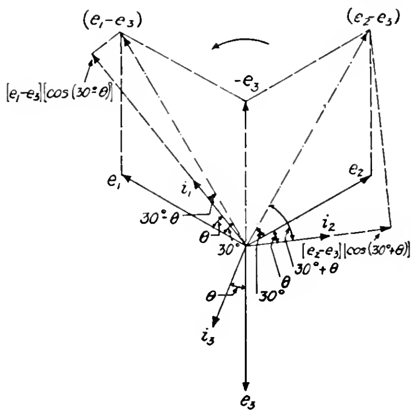


(159) **Fig. 1**

Here the full line vectors i_1, i_2, and i_3 represent the line currents and i_1 and i_2 are also the currents in the series coils of the meters. Also the full line vectors e_1, e_2, and e_3 represent the line-to-neutral voltages. The angle of lag, θ, appears between the current and voltage vectors. The vector representing (e_1-e_3), which is the voltage impressed on the potential coil of W_1 is located in Fig. 2 by drawing in $-e_3$ equal and opposite to e_3 and adding it vectorially to e_1. The vector (e_2-e_3), the voltage on the potential coil of W_2 is located in the corresponding manner. It will be observed that for balanced voltage, that is, $e_1=e_2=e_3$, the angles between (e_1-e_3) and e_1 and (e_2-e_3) and e_2 are 30° each. It will then be seen that the angle between (e_1-e_3) and i_1 is $30°-\theta$, which is the phase displacement between the series and potential coils of W_1 for a line power-factor of cos θ. Likewise the phase displacement angle between (e_2-e_3) and i_2 is $30°+\theta$.

Wattmeters are constructed to measure true power only, therefore W_1 indicates $i_1\times(e_1-e_3)$ $\times$(the cos of the internal phase angle displacement existing in it) and W_2 indicates $i_2\times(e_2-e_3)\times$(the cos of the internal phase angle displacement existing in it). Thus, W_1 indicates $i_1\times(e_1-e_3)\times\cos(30°-\theta)$ and W_2 indicates $i_2\times(e_2-e_3)\times\cos(30°+\theta)$. Although $i_1\times(e_1-e_3)$ equals $i_2\times(e_2-e_3)$ for balanced load and balanced voltages it is obvious that the meters will not register equal values for a power-factor of cos θ because the additional factors cos $(30°-\theta)$ and cos $(30°+\theta)$ are unequal.

If the line instead of operating at power-factor cos θ, were furnishing power at unity power-factor, cos θ would be 1 and θ would be zero. Under these



(159) **Fig. 2**

conditions the phase displacements in the two meters, cos $(30°-\theta)$ and cos $(30°+\theta)$, would be equal (actually cos 30°) and the two meters would read alike.

E.C.S.

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE Editor, JOHN R. HEWETT Associate Editor, B. M. EOFF Assistant Editor, E. C. SANDERS

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CONTENTS

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A TYPICAL VIEW OF THE WATER FRONT ALONG THE WEST SIDE OF NEW YORK

Where the Trans-Atlantic, South American, Coastwise, River and Ferry boats dock to be met by hurrying crowds, laborers, drays and the apparent confusion of mingled incoming and outgoing freight of a thousand kinds. There is a well-defined modern trend toward the systematic use of machinery to mitigate these inefficient conditions in terminals. (See page 127)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

In our last issue we gave a review of the progress made in the electrical industry during 1915, and in this issue we show some of the scientific advances, mostly in the realm of chemistry, made during the same period; we hope also in an early subsequent issue to deal with the progress made in physics.

We are constantly calling attention in these columns to the imperative necessity of a widespread and thoroughgoing recognition of the ever increasingly important part that industrial research is to play in all future industrial progress. The advancement made in those industries that have paid due attention to organizing research work is as astonishing as it has been gratifying.

In the past the foundations of our modern industries were laid by the immortal genius of such men as Newton, Maxwell, Kelvin, Hertz, and those others who propounded the laws of nature and gave us orderly scientific thoughts from an obscure muddle of isolated, only partially understood, facts. The debt we owe such men can never be even estimated, and the success of those who have commercialized the work that they have made it possible to accomplish must be traced back to their genius, if credit is to be given where credit is due. It must also, on the other hand, be acknowledged that mankind would never have benefited by this work to the same extent that it has without the courage and perseverance of those who have developed the commercial product.

We are entering a new stage in our industrial and economic life where advancements will depend more and more each year upon the results of organized research work. These results will very largely depend upon the organization of brains that, if left to their own initiative, without the co-operation of others, might prove unproductive.

In recognition of these facts modern industry is reversing the older order of things and is setting out for itself to make scientific investigations, each industry making such investigations as are shown to be relevant to its progress. Scientific investigations as made by the industries are not to be haphazard, but are to be made along more or less definite lines, for useful purposes: the results will largely depend upon the organization—the proper co-operation between the director and the directed.

The results obtained by such definite research work are likely to be of more immediately intrinsic value than those arrived at by purely academical investigations, but at the same time the enormous value of academical work must never be lost sight of, as the most valuable results are always possible from investigations that at first lend no promise of bearing commercial fruit. Industrial research work aims at assisting developments—academical scientific research may lead to invention and discovery.

A very great deal of purely academical work has been done in the realm of physics, but up to the present time industrial research has rather neglected this field for those that seem to promise more immediate results, such as chemistry, etc. We believe that there are many industries that could profit by organizing physical research work, as there is little doubt that there are enormous possibilities in this direction. To cite only one instance, any future increase in the efficiency of artificial light is likely to depend upon the investigations of the industrial physicist.

SOME SCIENTIFIC ADVANCES DURING 1915

By Helen R. Hosmer

Research Laboratory, General Electric Company

The writer makes an interesting review of the advancements in the field of chemistry, and also notes some of the technical progress accomplished during 1915. We hope in a subsequent issue to publish an account of the progress made in Physics during the same period. These articles, together with that published in our January issue on "Developments in the Electrical Industry During 1915," should enable our readers to form an intelligent idea of the progress made in these interesting fields of activity.—Editor.

Science does not always progress by clear and logical steps, and frequently her most fruitful discoveries fail to receive instant recognition. More often her building is in the way of a fragment aimlessly added here and there as fickle fancy may direct to the master picture puzzle which she is slowly piecing, and yet what appears a fragment, now idly cast upon the board, may prove tomorrow the part so necessary for the completion of some half-forgotten design. A review of the events of any one year made before lapse of time has lent perspective can hardly fail to omit important points, and to put unnecessary emphasis upon others. These notes can therefore merely present a few of the occurrences of interest in one or two fields during 1915, and it must be frankly admitted that the choice is undoubtedly biased in favor of those things which are near at hand, and familiar in their details and bearing. The appearance of prejudice is further accentuated by the fact that, as might be expected, the warring nations and their near neighbors are neither in the mood nor condition to forward investigation, and their output of published material has been very much curtailed. It is probable that in Germany, at least, there is much research of an intensive sort in progress which can not be revealed at present. Rumor has mentioned a number of accomplishments sufficiently startling, such as the manufacture of explosives without cotton, and of an edible flour from sawdust. Details are, however, lacking.

Chemistry

In the field of pure chemistry there have appeared several papers of considerable interest.

Richards[1] has continued his work upon compressibilities by a determination of the values for seven metals, of which two, tantalum and tungsten, had not been previously studied. The compressibility of mercury, which is of especial importance, because it is used as a standard of reference for all other values determined, was re-determined by reference to the new absolute value for iron recently obtained by Bridgman. Tungsten was found to have the smallest compressibility of any substance yet measured with a value of 0.28×10^{-6} megabars.

In a later paper[2] is given a general discussion of the degree of accuracy of the determined values for the 38 elements, which have been carefully studied and re-calculated in accordance with the recent very carefully determined value for mercury. The values agree very well with those determined by Grüneisen in accordance with his theory of elasticity. The relation of compressibility to other properties is discussed. The compressibilities of liquids may not be compared with those of solids, since several which have been investigated in the solid, and also in the supercooled condition, have shown a value two or three fold greater in the liquid than in the solid state. For this reason, those elements whose compressibilities have been determined in the former state have been omitted from consideration. Curves plotting compressibilities of the solid elements against atomic weights show a rather close parallelism to the atomic volumes curve, and also to the curves for reciprocals of melting-points and coefficients of expansion which suggests some fundamental relation of the four properties.

A number of generalizations may be deduced.

Compressibility increases as the melting point becomes lower, decreases as the density increases, and is proportional to the atomic volume for only such elements as have at once nearly equal densities and melting temperatures. Substances melting very near the temperature of experimentation have abnormally high compressibilities.

An approximate empirical formula expressing these relations has been attempted, but is only qualitatively correct in its present form. It does, nevertheless, indicate tendencies such as would be predicted from the theory of compressible atoms.

Langmuir[3], while continuing work upon the effect of introduced gases upon metal filaments in evacuated bulbs, has developed certain new views in regard to heterogeneous reactions and the phenomena of absorption. Conditions are so simplified at very low pressures by the elimination of subsidiary effects due to convection and conduction of heat, diffusion phenomena and secondary reactions due to collision of molecules, that the behavior of the individual molecule is unmasked, and the atomic and molecular nature of matter becomes constantly more apparent. Application of the statistical method, along lines indicated by the kinetic theory of gases, to the problems of chemistry gives a method of attack offering wonderful opportunities which have as yet been little utilized by the chemist. Advances in this direction have hitherto been mainly due to the physicist, energy relations absorbing the attention of the physical chemist. The work of Strutt on active (atomic) nitrogen, and of J. J. Thomson on positive rays, are examples of recent applications of the statistical method.

Langmuir's work consisted in studying the velocity and nature of reactions between filaments of carbon, molybdenum, platinum, iron, palladium and other metals at various temperatures, and low pressures of oxygen, nitrogen, hydrogen, carbon dioxide, chlorine, bromine, iodine, methane, cyanogen, hydrochloric acid, argon, phosphine, and vapors of mercury, phosphorus pentoxide, sulphur, etc. Combination occurs under suitable conditions between each of these gases and tungsten.

Reactions of four different types are exemplified, i.e.; attack on filament by gas, reaction between vapor from filament and gas, catalytic action of filament upon gas, and reactions due to electrical discharges through the gas. The data from these experiments afforded material for a study of the mechanism of reaction and nature of products for each individual case, as well as evidence for certain general deductions.

Previous experiments on the electron emission from heated tungsten wires in high vacuum have pointed very directly to the existence upon the surface of the metal of a layer of gas one molecule deep. This evidence has been strikingly corroborated in this later investigation. The rate of reaction seems to be limited, not by the rate of diffusion through an adsorbed layer, but by the rate at which the metal becomes exposed by the evaporation of single molecules. In certain cases, as that of carbon and oxygen, the adsorbed layer appears to be chemically combined, and extremely stable. Always the velocity of reaction depends upon the rate at which the molecules involved come into contact with each other, and so involves all such physical factors as affect this latter action, such as the rate at which gas molecules may collide with each other or strike that part of a filament which is in condition to react.

For the only cases in which such purely physical factors were not involved, the temperature coefficient of velocity was strongly negative. The positive coefficient of the other cases was due to the increase in rate of evaporation of filaments, or adsorbed materials with temperature, a physical factor of sufficient magnitude to mask the probably negative coefficient of the true reaction. There is reason to believe that the same principles apply to reactions at high pressures, and between solids and liquids.

A study of the merits and practicability of cobalt plating, made by Kalmus, Harper and Savell[4], has yielded interesting results. Cobalt offers a number of very considerable advantages over nickel, not only in regard to the properties of the plate produced, but also because the nature of its salts facilitates the processes of production.

The greater solubility of cobalt metal renders unnecessary the presence of iron in the anode, and the plate produced is therefore purer. This is probably one reason for the better resistance to corrosion which it exhibits. The greater solubility of its salts makes it possible to use more concentrated baths, and, further, in all cases tested, the cobalt solutions have had a higher conductivity than the corresponding solutions of nickel. These facts make possible a much more rapid deposition of metal, and to this saving in time is added the consequent advantage of much increased hardness of the plate.

Comparative tests were made with a series of salts, of both cobalt and nickel, and these advantages were found to hold for almost all in a greater or less degree. The two best solutions of those tested were a cobalt ammonium sulphate, and a cobalt sulphate containing sodium chloride and boric acid. Plates made from these solutions, under conditions identical with those existing in nickel-plating practice, are satisfactory in every way, and can be obtained in one-fourth and one-fifteenth the times respectively required by the fastest satisfactory nickel solutions.

With the second solution, a plate capable of withstanding the usual commercial tests for nickel plate can be deposited in one minute, against one hour required for nickel. The weight of metal used is about one-fourth that of nickel. Massive deposits are also far superior to those of nickel, as there is less tendency to distortion, and the detail is hard, sharp and tough. Tests under commercial conditions indicate the possibility of great economy in methods of production, and have shown that the product is decidedly superior to nickel in wearing qualities.

The production of zinc electrolytically is an advance of especial importance to the metallurgical industry and one first coming into prominence during 1915. The application of this method has been very rapid and plants requiring 10,000 kilowatts for operation are already installed or under contract. There is already in sight further development which will take 30,000 kilowatts more and the expectations of the next five years reach 100,000 to 150,000 kilowatts. The power requirement per ton of zinc is from 150 to 160 kilowatts.

The rapidly increasing use of gasoline as fuel for internal combustion engines, with the consequent increase in price, has given a special interest to the investigation of new sources and methods of producing it by the breaking down of more complex hydrocarbons.

Rittman[5] has studied the decomposition of petroleum with the idea of defining the conditions and character of the so-called "cracking" reactions long applied to petroleum. With this accomplished he has experimented with cracking in the vapor phase, which offers considerable advantages both in ease and safety of operation, and in the nature of the products. Applying the method to some of the less commercially valuable oils which were lacking in low boiling constituents, he found it possible to produce, with proper temperature and pressure regulation, something like a 16 per cent increase in the gasoline yield from an oil ordinarily giving upon distillation about 5 per cent. He also found that with higher temperatures it was possible to increase the content of aromatic hydrocarbons by about 8 per cent.

These results seem to indicate the possibility of so handling cheap oils as to obtain from them products of considerable value either as fuel or in the manufacture of dyes and other coal tar products.

McAfee[6] has published the details of his process for splitting high boiling petroleum oils into low boiling oils by distillation in the presence of aluminum chloride as a catalyzer. This substitutes for the dangerous and unsatisfactory cracking processes a method by which, with proper adjustment of the condenser temperature, high boiling oils containing unsaturated compounds can be broken down into clear, white, non-offensive, saturated products. The reaction takes place at ordinary pressures, and there is little gas given off, or carbon deposited. The process may be regulated to produce greater or smaller proportions of gasoline. In practice it is so adjusted as to leave the paraffins and lubricating oils after removing the gas oil friction as low boiling hydrocarbons.

Technical Advances

Applied chemistry has undergone a very considerable territorial expansion during the year and a half since the outbreak of war with its attendant cutting off of supplies of many materials essential to industry. Germany, with her wonderful co-ordination between education, science, industry, and the state had all too easily monopolized certain lines of production whose vital importance to whole industries, and even to national well being has been sharply revealed in ways that the most indifferent cannot fail to read. The inception of such industries in countries where they have not previously existed constitutes a very real advance in the interests of humanity.

It is of interest then to note a few of the respects in which it is to be hoped that America in the near future may again declare her independence of Europe.

Among the most insistent cries for help that followed the closing of German ports was that of the textile[9] manufacturers, who saw approaching disaster in the cutting off of the 85 per cent[10] of their dye materials which had come from abroad. This very real danger seems now to have been warded off by the prompt response of chemical manufacturers, both in the way of extension of existing factories, and the establishing of new. Within a year the American production of synthetic dyes has been nearly trebled, and the output of natural dyes greatly extended. By rigid economy in the use of materials, it will probably be possible to weather the present crisis. With careful attention to the details of manufacture and organization, it is possible that another five years may see America producing the bulk of its own consumption in artificial dyestuffs.

Toluol, benzol, and aniline, necessary intermediates for dye manufacture, are being put out by the Standard Oil Company, the Benzol Products Company and other concerns, in large quantities. Edison, within a few months after the outbreak of war, had in operation a plant for making synthetic phenol and aniline on a large scale. He is now turning out 6000 lb. per day of the latter.

Laboratory porcelain and glassware adapted to specific purposes is being put on the market by various producers. The merit of some of these products may yet need confirmation, but the idea is started, and research can accomplish the rest. England[11], who found herself especially hard hit in this regard, has also made a beginning at producing her own, by investigating and publishing the formulæ for glasses suited to various uses. Optical glass is also being made in America for the first time. It is expected that Bausch & Lomb will hereafter be able to supply our needs without recourse to importation.

America has long been dependent upon Germany for the supply of all its potash, and the situation would have already become very serious, were it not for the large quantities held in storage at the beginning of the war. A small supply should be available shortly from the treatment of Utah alunite. A plant[12] is nearly completed, which is expected to produce 20 tons of potassium sulphate per day. Processes[13] have also been worked out for the extraction of potash salts from the Searles Lake brines, and plants designed to produce 100 tons daily are under construction. These should be in operation early this year. Experimental work is also being done upon the utilization of the kelps of the Pacific Coast.

Another substance, of importance in the manufacture of war munitions, for which the world has depended largely on Germany in the past, is the metal magnesium. A process of production has been worked up by Mr. Dantsizen of the Research Laboratory, and has been in operation on a small, but increasing commercial scale, for nearly six months. There seems to be an important future for this metal as a constituent of light alloys, and there is no doubt that America will be able to economically supply her own demand even against foreign competition.

Probably not the least valuable of the advances in applied chemistry is the impetus to effort given by the clear demonstration, staged, to our good fortune, across the water, of the fact that systematic study rather than genius brings the solution of the problems of existence, and research in one form or another is the key to evolution in the human race.

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THE UNWATERING OF THE DOWN TOWN MINING DISTRICT OF LEADVILLE

By W. H. Horton, Jr.

General Electric Company, Denver, Colo.

The author describes one of the most interesting and difficult pumping propositions ever undertaken, giving such details as will enable the reader to understand the work. The equipment is described. The introduction of electric pumps enabled the work to be carried to a successful conclusion. In an appendix the author gives most valuable statistical data which should be of much use to others interested in such undertakings. The comparisons of costs for steam and electric operation speak for themselves.—Editor.

The unwatering of the Down Town section of the Leadville Mining District by the Down Town Mines Company, by means of electrically driven pumps, is the largest undertaking of its kind in the mining history of this continent. In view of the fact that 17 years ago, when this district had been worked to a depth of only 540 ft., it was unwatered by means of steam equipment and that the Down Town Mines Company have already unwatered this same district to a considerably lower depth than this, it is interesting to give a comparison of the equipment and cost of the two methods. But first a brief description and history of the district will give a clearer conception of the undertaking.

The Down Town District of Leadville, as its name implies, is that portion of the Leadville Mining District on which the city of Leadville is built, and embraces an area about 2½ miles long ,and 1½ miles wide, containing some 30 miles of underground workings. A cross section showing the formation under the surface is shown in Fig. 3, and was taken on a line at about "AA" shown in Fig. 2.

Fig. 1. Surface Plant of the Penrose Shaft

It will be noticed that there are several faults or slippage planes with the various strata duplicated on each side but at a different elevation and with a different slope. Thus it is seen that the Carbonate Hill fault separates the Down Town drainage area from the other drainage areas because of the different direction of the slope of the strata on the two sides of this fault. A cross section taken at right angles to this would show these strata as having an inverted bow shape; the lowest part of the bow being about at the Penrose shaft.

During the strike of the mine workers in 1896–7, when, of course, these mines were producing no revenue, this entire district was allowed to flood, because of the high cost of keeping the pumps running.

Early in 1898 the Leadville Home Mining Company was formed which acquired a lease on the Penrose property, and bought the Penrose surface and underground equipment. They, together with six other companies, formed a pumping association for unwatering this district with steam pumps. Each company turned over its equipment to the pump association, who then assumed entire charge of the unwatering operations and who assessed each member their portion of the operating cost as well as their portion of the cost of equipment which the Pump Association found necessary to purchase.

Active pumping began on October 10, 1898, and ended about July 25, 1899, covering a period of 9½ months.

The Pump Association was discontinued on the first of October, 1899, only to be again organized a few months later in order to justly apportion the cost of operating the permanent pumping equipments among the several mines then operating in this district.

The district was then worked for several years by many different companies, but allowed to fill again when the price of metals in 1907–8 fell to such a low point that further operations were unprofitable. During the period from 1898 to 1907 the Penrose shaft was sunk to its present depth of 875 ft. Later, better smelting processes giving a greater incentive, large deposits of zinc mostly in the form of zinc carbonates were found in adjacent properties which were operating. Also, evidences of large deposits were found in the Down Town district. In 1914-15, the Down Mines Company was organized and acquired 20-

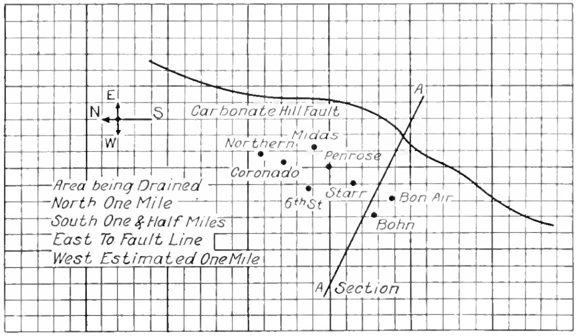

Fig. 2. A Sketch of the Drainage Area of the Down Town District, showing the Relative Position of the Various Shafts Located Therein

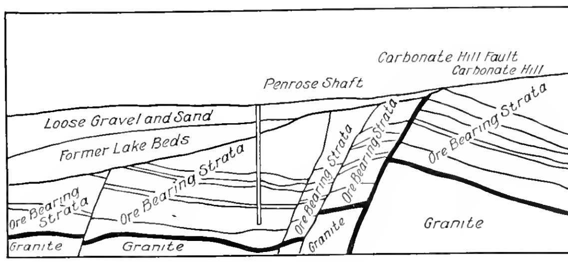

Fig. 3. A Cross Section of the Drainage Area of the Down Town District

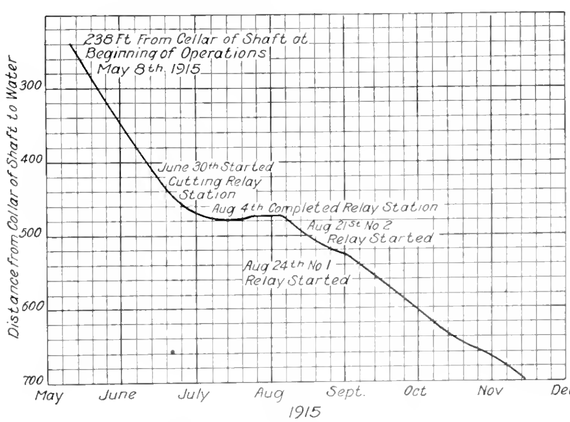

Fig. 4. Progress Curve of the Pumps in the Penrose Shaft

year leases on the various properties in this district as well as perpetual pumping contracts. So, on May 8, 1915, active operations on the second unwatering began, but this time by means of electrically driven unwatering pumps.

The entire operations are now confined to the Penrose shaft, which has three compartments. The two outside compartments are used for the unwatering pumps, and are each 3 ft. 4 in. between the guides and 4 ft. 6 in. long, and 5 ft. 6 in. long respectively. See Fig. 8. On September 7, 1915, these pumps reached the 540-ft. level, but, of course, continued on down and to date are at the 700-ft. level.

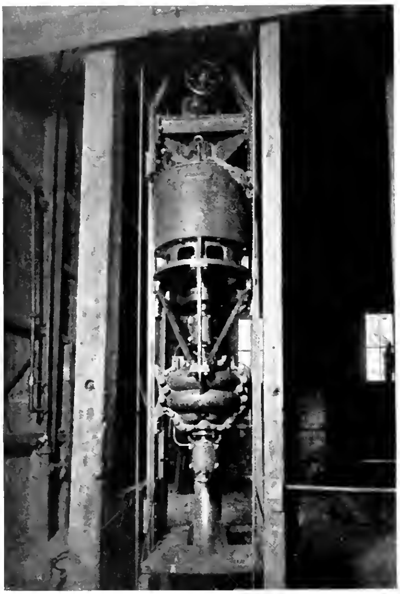

Fig. 5. The Unwatering Pump Ready to be Lowered for Service

Fig. 6. This same pump in operation just opposite the Relay Pump Station at the 470-ft. level

Before comparing the costs of the two methods of unwatering a brief description of the present equipment would be in order. There is a total of four duplicate pumps—two of these pumps are arranged for suspension in the shaft and the other two are used to relay the water after the first two reached a head of more than 425 ft.

These pumps were furnished by the Providence Engineering Works of Providence, R. I., and are two-stage centrifugal pumps, approximately 2 ft. 4 in. in diameter, designed for 2000 gallons per minute, each at 425-ft. head. The curves in Fig. 9 show the operation of these pumps while under test. The pumps were run during this test at 1760 r.p.m., while in actual operation they revolve at 1810 r.p.m., and therefore throw considerably more water than the curves indicate.

A study of these curves will show at once that these pumps are of a unique design and specially adapted to the varying head encountered in the process of lowering the water in the shaft, and that full advantage of the smaller power demand at the lower heads can be obtained.

The motors were furnished by the General Electric Company, and are each 300 h.p.

three-phase, $61\frac{1}{2}$ cycles, 550 volts, open vertical squirrel cage induction motors, making 1810 r.p.m. at full load.

The pumps and motors are mounted on the same channel iron frame and their shafts are connected by a flexible pin coupling. Each pump and motor carries its own revolving weight—the motor by means of an oil lubricated ball thrust bearing of the "SKF" type, and the pump by means of a lignum vitae water lubricated marine thrust bearing. The guide bearings of the motor are of hard babbitt, and oil lubricated, while those of the pump are the lignum vitae and water lubricated. Thus it is seen that the pump end of each unit is capable of being submerged. The pumps are primed by submerging the first stage. The total weight of each pumping unit is about 16,000 lb.

The unwatering units are hung in the compartments by $\frac{7}{8}$-in. "Hercules" steel cable in the manner shown in Fig. 7, which gives a three-rope block and tackle arrangement. The only other support for these units is through the shoes on the channel iron frame which ride on the guides in the manner of the usual mine cage. These shoes are not shown in Fig. 8, but can be seen projecting from the channel iron frame on the left in Fig. 5.

After the unwatering pumps reached a depth equal to a head of 425 ft., the station, or relay pumps, were put in operation. The discharge from the unwatering pumps is connected direct to the suction of the relay pumps with no sump between. The relay pumps are mounted in the same manner as the unwatering pumps, but have a heavy cast iron base, which holds the channel iron supporting framework rigid in an upright position.

The electric cable which supplies the power to the pump motors is wire armored and supported by clamps. The cable for the unwatering units is lowered by hand winches as fast as the pumps are lowered. The cables for the relay units are installed permanently in the shaft.

The water columns consist of 20-ft. lengths of 10-in. steel pipe, with bolted flange joints and each section is supported from the shaft. Connection is made to the unwatering pumps through a slip joint that is capable of a 20-ft. extension. As each additional length of pipe is necessary it is inserted at the lower end of the column, next to the slip joint, and secured to the shaft with cross timbers or stulls.

The steam winches shown in the background of Fig. 12 are used for lowering and hoisting the unwatering units. These winches have a worm gear reduction which holds the drums in any given position, without the use

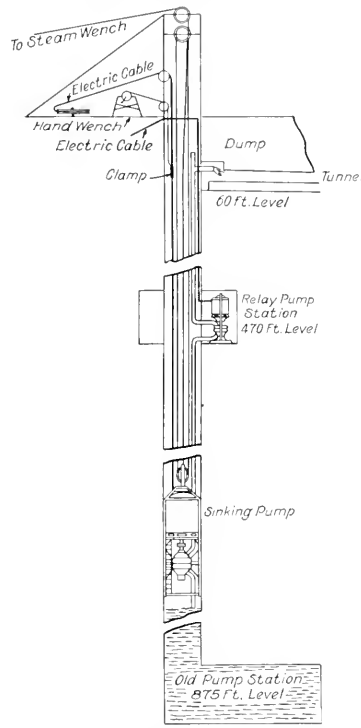

Fig. 7. Sketch showing the method of suspending the unwatering pumps and of connecting the pipe between these pumps and the relay pumps

of brakes. Steam is used for these winches in preference to electric power because of the necessity of raising the unwatering units in case of an interruption of the power supply.

The main hoist which operates the cage in the center compartment, and is used for lowering supplies, etc., as well as in the retimbering operations which are necessary when a poor portion of the shaft is encountered, is an old steam hoist converted to electric drive. A 175-h.p. hoist motor, controlled through a contactor panel, is used for this purpose. The method of connecting this motor to the hoist consists of gearing a crank disk to the motor and then connecting this disk to the crank disk of the hoist by means of a very short link. Power is supplied to the electrical equipment by the Colorado Power Company at 550 volts, three-phase and 61½ cycles. Steam is supplied from a 100-h.p. boiler placed at the side of the hoist room and fired by the hoist men at infrequent intervals.

Coming now to the comparison of the costs of the two methods of unwatering. Since the first unwatering only went to a depth of 540 ft., the costs of the Down Town Mines Company as shown, unless otherwise noted,

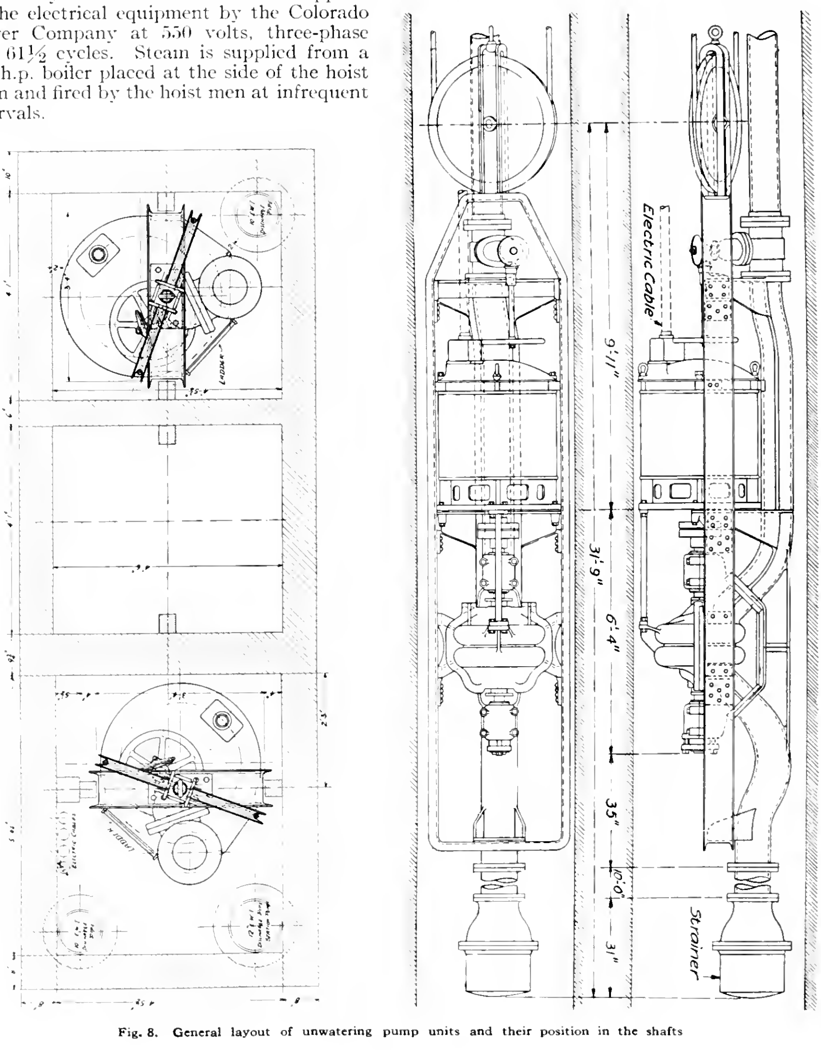

Fig. 8. General layout of unwatering pump units and their position in the shafts

include only those expenses incurred before Sept. 8th, at which time the 540-ft. level was reached.

The tables in the appendix give detailed information as to the equipment and costs for both the Pump Association and the Down Town Mines Company. The relative costs of the two methods can be summarized approximately as follows:

	Steam Unwatering	Electric Unwatering
Investment in plant equipment	$174,286.13	$80,000.00
Operation expenses:		
Pay roll	52,424.67	15,120.00
Fuel or power costs	57,930.42	13,287.63
Overhead supplies and miscellaneous	31,456.58	20,000.00
Total	$316,097.80	$128,407.63

The figures in the above table speak for themselves, but in conclusion further attention is called to the following facts, which, with the exception of the sixth item are all based on a study of the actual figures exclusive of any assumed figures:

First: The pay roll expenditure for the electric unwatering is less than 30 per cent of the corresponding steam unwatering cost.

Second: The total power and fuel cost of the electric unwatering is less than 25 per cent of the fuel cost for the steam unwatering.

Third: From a study of the vouchers it is at once evident that the cost of repairs and supplies for the electric unwatering is but a very small fraction of the same items for the steam unwatering. This fact is forcibly impressed upon one by the following statement made by the manager of the local machine shop, who had charge of all the repair work during the steam unwatering period:

"During the steam unwatering period, I had two of our machinists working all the time on repairs for the steam equipment and at times there were a total of ten."

To date there has been spent by the Down Town Mines Company since regular operations began less than $400 on machine shop repairs.

Fourth: The time of unwatering by electricity is about 40 per cent of that required by steam.

Fifth: Deducting the machinery account investments from the totals as given in Table VII, we find that the total operating cost for the electric method of unwatering is less than 35 per cent of the corresponding cost by the steam method.

Sixth: The machinery accounts as given show that the Plant Equipment investment for the electric method is less than 50 per cent of the corresponding steam cost.

Seventh: There are some further advantages in favor of the electric unwatering method such as greater safety for the men. There has not been a single accident at the Penrose shaft to date. Also the rubber clothing of the men lasts a much longer time, and this is no small item.

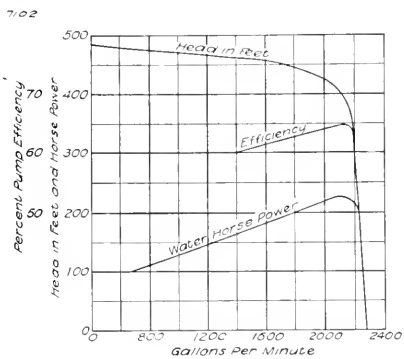

Fig. 9. Test Curves of the Pumps

The management of this property is very pleased with the showing that the electric unwatering equipment has made for itself.

APPENDIX

The figures used in the following tables were obtained from the following sources, with the exception of those noted.

The Pump Association costs were obtained from their monthly vouchers and the August

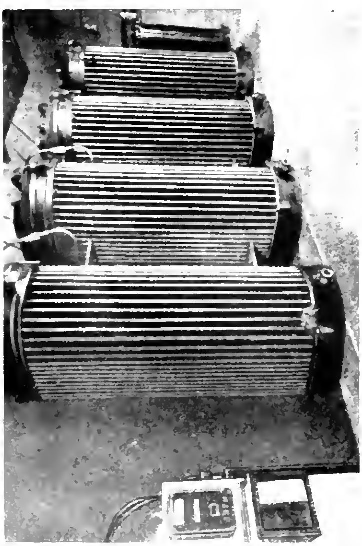

Fig. 10 Four 300 kv-a., 6600/550 v. Transformers

Fig. 11. Switchboard for Controlling Four 300 h.p. Pump Motors and One 175 h.p. Hoist Motor

Fig. 12. The Hoist Room of the Penrose Shaft

Fig. 13. Landing Floor of Three Compartment Penrose Shaft. Two Thousand Gallon per Minute Sinking Pump working in the right-hand compartment, Companion Pump about to be lowered in the left-hand compartment. Hoisting Cage in center. Coiled Electric Power Cables for Pump Motors shown in right and left foreground

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Figs. 14, 15, 16, 17 Various Views of the Creek Formed by the Discharge of the Pumps in the Penrose Shaft

TABLE I

LIST OF EQUIPMENT

	1898-9 Steam	1915 Electric
Number of shafts operated for pumping	6	1
Number of pumps operated	8	4
Number of bailers operated	3	0
Number of boiler plants operated	5	1
Number of boilers operated	19	1
Number of hoists operated	5	1
Number of steam wrenches operated	8	3
Number of hand wrenches operated	unknown	2

TABLE II

MISCELLANEOUS INFORMATION

	1898-9 Steam	1915 Electric
Length of operations in months	9½	4
Gallons of water per minute lifted	2800 estimated	3600 to 4600
Feet gained per day average	1.03	2.5
Total depth in feet	540	540 to Sept. 7th
Depth unwatered in feet	302	302 to Sept. 7th

TABLE III

LABOR

	1898-9 Steam	1915 Electric
Number of hoist men	15	3
Number of firemen	21	0
Number of topmen	12	3
Number of men in pipe gang	5	4
Number of pump men	24	12
Number of miscellaneous and supervision	12 to 20	7
Average payroll per month not including miscellaneous and supervision	$5518.00 from the Pump Assn. Vouchers	
Average payroll per month, total		$3360.00

TABLE IV

MACHINERY AND EQUIPMENT ACCOUNTS OF THE DOWN TOWN MINES COMPANY

Boilers, steam piping, fire pumps, etc.	$3,500.00
Equipment to handle the water column	700.00
Equipment to handle the electric cable	1,800.00
Equipment to handle the unwatering pumps	6,000 00
Unwatering and relay pumps*	15,000.00
Water pipe	3,000.00
Electric cable and wire	4,500.00
Miscellaneous tools, cars, cages, etc.	2,000.00
Supplies, repairs, and cost of putting equipment in operating condition	6,500.00
Hoist and motor	5,000.00
Total machinery account	$50,000.00

* Includes cost of excavating station.

TABLE V

EXTRACTS FROM THE STATEMENT OF THE PUMP ASSOCIATION FOR AUGUST 1, 1899

Weldon Mining Company,		
1/4 assessment	$39,652.30	$43,529.41
2/7 delinquency	3,877.11	
Leadville Home Mining Co.,		
1/4 assessment	39,652.30	
2/7 delinquency	3,877.11	43,529.41
Bohn Mining Company,		
1/8 assessment	19,826.15	
1/7 delinquency	1,938.56	21,764.71
Leadville Basin Leasing Co.,		
1/8 assessment	19,826.15	
1/7 delinquency	1,938.56	21,764.71
Coronado Mining Company,		
1/8 assessment	19,826.15	
1/7 delinquency	1,938.56	21,764.71
Leadville Mines Leasing Co.,		
1/16 assessment, paid only	4,575.92	
Owed	5,337.15	4,575.92
Bison Mining Company,		
1/16 assessment, paid only	781.25	
Owed	9,131.83	781.25
Total expended by Pump Association to August 1, 1899		$157,710.12

The difference between the total pump association expenditure, as shown in Table VI, and that given above is accounted for by the slow payment of bills due at August 1, but not paid until further payments of assessments we-e made by its members.

TABLE VI

	TOTAL COSTS AS FAR AS THERE IS RECORD OF SAME		
	Pump Association	Leadville Home Mining Co.	Down Town Mines Company
Total pay roll	$52,424.67		$15,120.00
Total fuel account	57,930.67		700.00
Total power account			12,587.63 to Sept. 7th incl.
Total supplies, miscellaneous	31,456.58		20,000.00
Total machinery account	35,188.33	$34,774.45	50,000.00
Total	$177,000.00	$34,774.45	$98,408.63

TABLE VII

	TOTAL COST FOR UNWATERING ON THE BASIS OF EQUAL TONNAGE OUTPUT	
	1898-9 Steam	1915 Electric
Down Town Mines Co. cost to Sept. 7th as shown in Table VI		$98,408.63
Cost of permanent station equip. to be at bottom of shaft		10,000.00
Cost of putting additional shafts in running order to get out equal tonnage		20,000.00
Pump Association	$177,000.00	
Leadville Home Mining Co.	34,774.45	
Estimated cost of the other companies for their plant equipment	104,323.35	
Total	$316,097.80	$128,408.63

1, 1899, statement of the association to its members as well as the final statement on October 1, 1899.

The costs of the Leadville Home Mining Company were obtained from their cash book covering this period as well as from the minutes of their directors' meetings.

The estimates of the operating force and equipment of the Pump Association are based on information obtained from men who worked on the pipe gang during this time. [The pipe gang consists of the men who install the piping, etc., in the shaft as the additional lengths are necessary. The Down Town Mines Company pipe gang have installed a 20-ft. length of 10-in. pipe, removing the necessary bolts and lowering the slip joint, and then putting in the necessary bolts, with the pump shut down in a total of 9 minutes and 15 seconds.] These estimates are checked where feasible by reference to the Pump Association vouchers.

The figures for the Down Town Mines Company's costs were furnished by Ex-Governor Jesse F. McDonald, Manager of the Down Town Mines Company.

Tables I, II, III, and IV give a general idea of the equipment and operating force, which need no comments.

Table V shows the payments made by each member of the Pump Association up to August 1, 1899, and it is shown here that the Leadville Home Mining Company paid one-fourth of the total assessment to this data.

Now, a study of the Pump Association vouchers shows no expenditures for any surface plant or other permanent equipment beyond that for five unwatering pumps and their necessary auxiliary equipment. Thus there has been accounted for in Table VI only the surface plant of the Leadville Home Mining Company. The records of the operations of the associated companies are not available and, therefore, some assumptions must be made to arrive at this missing figure.

Since the Leadville Home Mining Company paid about one-fourth of the Pump Association cost, it is assumed that the total plant equipment not accounted for is proportional to the amounts that these companies paid the Pump Association. Table VII is based on this assumption. To be sure this is open to criticism but no better method of arriving at this cost presents itself at this late date.

There is still a further possible criticism that the associated companies had considerable plant equipment available, at no additional cost to them, for use in their regular mining operations which began immediately after the unwatering period. Ex-Governor Jesse F. McDonald, Manager of the Down Town Mines Company, has given considerable study to the output of the associated mines and has arrived at the following conclusions:

"It would require an expenditure by the Down Town Mines Company of less than $20,000 to put enough additional shafts into operation to bring the future tonnage of the Down Town Mines Company to a figure equal to the combined tonnage of the associated companies. Further, the permanent plant required for caring for the water after the unwatering period will cost less than $10,000."*

For the above reasons, these costs have been included in the totals as given in Table VII. Also, it is well to bear in mind that the machinery account of the Down Town Mines Company would have been considerably less had this equipment been built with a view of only going to the 540-ft. level.

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* This pumping equipment has already been contracted for by the Down Town Mines Company.

LIGHT AND LIGHTING

By Edward P. Hyde

Director of the Nela Research Laboratory, National Lamp Works of General Electric Company

There has always been considerable confusion concerning the definition of the term "Light" and also, but perhaps to a somewhat lesser degree, about the term "Lighting." The author, who is so thoroughly competent to speak with authority, outlines the connotations of these terms and shows the inter-relations and the inter-dependence of the science of light and the science and art of lighting.—Editor.

"Light and lighting," though of identical origin connote widely different ideas. It is my purpose in this article to outline the distinguishing connotations of these two terms, and to point out the inter-relations and the inter-dependence of the sciences of light and the science and art of lighting.

There is still some degree of academic confusion regarding the precise significance of the term "light." Light is primarily a sensation, and there are those who restrict the use of the term to the expression of the idea of visual sensation. On the other hand the term is commonly used by extension to connote the physical phenomena which under ordinary circumstances precede and cause the sensation of vision; indeed it is frequently found that the term is employed principally to denote those physical phenomena antecedent to vision and productive of it. The term may be used to include the entire gamut from those esoteric phenomena which obtain in the surface or body of a radiating source to the subjective phenomena associated with the impingence of radiation on the retina of the eye. I shall have in mind in this paper the most general meaning of the term, thus including in the sciences of light the physical science of emission and radiation, and the sciences of physiology and psychology in so far as they have to do with the process of vision, or are concerned with the effect of radiant energy on living tissue. Moreover the term "light" in its physical significance will be understood to include all radiant energy,—not only that within the region of the spectrum corresponding to the single octave of frequency of vibration which is capable of exciting the human retina in the visual sensation, but also all that radiant energy which lies beyond the red limit of vision, and that ordinarily lesser quantity of radiant energy which lies beyond the violet end of the visible spectrum. To speak of "ultra-violet light" may be a linguistic abortion, but common usage and simplicity of terminology adequately justify it.

The term "lighting" connotes an entirely different group of ideas. Light is the principal tool of lighting, but in employing the latter term there is usually in mind the use and application of light sources and illuminating accessories in accomplishing the illumination of objects. Lighting is both a science and an art. As a science it rests upon all the sciences of light and includes in addition that classified knowledge of the utilization of light sources, shades and reflectors and other accessories in accomplishing a given illumination effect. The art of lighting is the application of this knowledge in the design and installation of a system which will conform to the requirements set forth in the science of lighting and will commend itself to the aesthetic sense.

Let us consider briefly now the inter-relation and inter-dependence of the sciences of light and the science and art of lighting. How fascinating it would be if we could achieve the true perspective over the illimitable past and could mark accurately the progress of our knowledge regarding light! From the earliest times when the pine torch constituted the only artificial light source of a simple civilization down to the present era of "white ways" there has been a constant, steady progress, though it would seem that the rate of progress has been subject to a constant acceleration. Civilization has incessantly demanded more light and more efficient light, and science has paved the way for the satisfaction of this demand. The science of light, born when the mind of man first contemplated the wonderful phenomena of his environment remained but a sickly infant until it was nourished by the contributions of the investigators of the seventeenth century. Since that time its growth has been phenomenal, and yet, even at the present time, its wonderful development shows no abatement. We know much regarding the laws of radiation and the radiating properties of different forms of matter, and yet the most efficient light source which we have been able to produce has less than one-tenth the efficiency which is theoretically obtainable. We have learned much of the phenomena of vision and yet even now there is no generally accepted theory which will account for all the observed phenomena of vision. We know that ultra-violet light in excessive quantities will kill certain micro-organisms, will accelerate the formation of cataract in certain conditions of abnormal nutrition, will produce inflammation of the cornea of the eye and will cause inflammation of the skin, and yet we know little of those insistent causes which are accountable for the almost universal defects in vision, of those sources of eye strain to which we are all subject, and to which many of us partly succumb. We know that certain extreme conditions of illumination are inhibitive of mental efficiency, and yet we know practically nothing at all of the correspondence between visual field and mental state. The sciences of light have made mighty strides but measured even in terms of the possible accomplishments which we, with our limited horizon, may foresee, they have made only a beginning toward the goal of complete knowledge.

The science of lighting is even more undeveloped. Millions of dollars of capital, and the brains of many men have been invested in the development of the lighting industry, and yet it has only been within the last decade that a consistent study of the science of lighting has been undertaken. The United States Illuminating Engineering Society will soon celebrate its tenth anniversary, and this Society inspired the first organized efforts to develop the science and art of lighting. More recently similar societies have been organized in England and Germany and two years ago the International Commission on Illumination was formed, all of these bodies having as their object the development of the science of lighting and its application to practical ends. But although conspicuous progress is being made, the science and art of lighting are still relatively in their infancy.

As I have stated already the science of lighting rests primarily on the sciences of light, and it is therefore necessary to foster these sciences if the largest development of lighting is to be expected. The entire electrical industry of the present day owes its existence to the scientific researches of Faraday, Henry, Maxwell, Hertz, and others. Notwithstanding the fact that the newspapers raise into prominence as the most immediate and therefore the most important factor in the avoidance of a greater maritime disaster the wireless operator on the ship, yet wireless telegraphy owes its existence to the mathematical investigations of Clerk Maxwell and the brilliant experiments of Heinrich Hertz. The world never hears these names, and the general public, particularly the American public, has been markedly deficient in its appreciation of the ultimate practical value of the pure sciences, but it is a favorable sign that the large industries of the United States are coming to a better appreciation of the importance of research laboratories, both for the immediate development of the industries and for the advancement of the pure sciences on which the industries ultimately depend. The industrial chemist is received now as a vital unit in the great industrial scheme, and perhaps I may be pardoned for expressing the hope that soon, through a better understanding on the part of both the industries and the universities, the industrial physicist may also come into his own.

It is futile to attempt to prophesy or speculate on the possible accomplishments of the sciences of light in the furtherance of lighting practice, but it is not impossible that the day may come when we shall have, not half-watt lamps, but one-tenth watt lamps. We now have lamps that shed upon objects light of the same quality as that of daylight in any of its variations, and the time may come when we shall know what qualities, what intensities and what distributions of light shall be best suited to any given conditions, and shall be able to produce these results in the most efficient way, and at the same time to conserve the eyesight of the race.

We have many senses, but the strongly dominant sense over all the others is that of sight. When the sense of sight is dimmed then oftentimes the other senses become more acute, but so long as the visual sense is normal it usually overrides all our other senses and serves as premier in our sensory cabinet. When the eye is darkened and there is no light we hear sounds that escape unnoticed when the mind is concerned with the material provided by the sense of sight. I have difficulty in following an address, or in listening to complex music when my eyes are open because of the dominating insistence of the visual sensations. The importance of the roll which vision plays in the scheme of life can scarcely be emphasized too strongly.

And so it is necessary that the value which attaches to the furtherance of all those sciences which are concerned with vision in any of its manifold aspects should be duly appreciated if the science and the art of lighting are to progress in a manner commensurate with their importance.

RURAL DEVELOPMENT OF TRANSMISSION LINES IN EASTERN PENNSYLVANIA

By Joseph W. Price

General Electric Company, Philadelphia

The author presents valuable data on the experience of two power companies in the development of rural loads. As these data are specific they should be of much value to other companies. It is shown that both the power companies and farmers have displayed a commendable spirit of co-operation which is essential if these important developments, on which the future prosperity of the country will so largely depend, are to succeed.
—Editor.

For obvious reasons, the names of the companies that have kindly furnished the data for this article are not given. They permit the information to be published, however, for what it may be worth to contemporary companies.

For our purpose, central stations may be divided into three classes. The first class is that which is distinctly a part of the big city—the station which started years ago and whose business has been so far ahead of it that up to the present time it has been impossible to give attention to any but customers within the city boundaries, or at most a few outlying suburbanites. This class of station does not interest us in the present article.

The second class of station is that which has assumed fair proportions, principally on account of being located in an industrial center of reasonable size and which has grown along with that center, at the same time branching out here and there as business seemed to warrant, or as the pioneer idea found temporary favor. Such a station is herein designated as Company No. 1.

The third class of station is that which has been installed in a small community having little or no manufactures, making the station practically dependent upon farms and farmers for its existence. This type is well exemplified in Company No. 2.

COMPANY No. 1

This company has acquired its rural customers incidentally, as it were, and is frank to say that up to the present time it has not established any definite policy for acquiring the rural load. Recent investigation into what this load consisted of brought out interesting and valuable data. The result will undoubtedly be the establishing of a definite policy for the acquiring of farm loads at a fair profit. This does not mean that the load thus far obtained has not shown a profit, but from a monetary viewpoint the company has just about broken even. It is pointed out that the company has heretofore taken farmers on its lines upon the same basis as a city customer, so far as running lines are concerned, except in a few special cases. If under such conditions, the income from these rural customers allows the company to break anywhere near even, it is fair to assume that if it had made charges for lines and transformers (as other companies do) then the result would show the undertaking to be a paying proposition.

In presenting this article, the first desire was to show the cost of the line construction, of maintenance and general overhead charges. These data were not available for several reasons:

1. The majority of the farms are connected to lines which could not properly be charged against them, as they were originally put up for connecting towns or to supply some large industrial plant. The fortunate farmers close enough to the line were taken on incidentally. In fact, one of the most satisfactory farm loads is connected to a line which was run from one plant to another as a tie line. There are, at the time this is written, 125 farm customers. Only 12 miles of special lines have been put up. These 12 miles are made up of small sections here and there averaging from ¼ to ½ mile in length.

2. A number of the farm customers were inherited en masse, when lines formerly owned by separate companies were merged with the present company, and statistics of the costs of these lines are not at hand.

3. As previously mentioned, it was not until very recently that particular attention has been given to the farm load, so that up to this time no careful statistics have been kept

Of the 125 farmers above mentioned there are, to date, thirty users of power. All are users of light A conservative average yearly revenue for the 95 customers who use current for light only is given as $18 per year, or a total of $1710. In some cases, on large farms, there are two separate lighting circuits, one for house and nearby buildings and one for barn, stables and outbuildings. Separate meters are used for each circuit and a separate meter is also used for the power circuit.

To place before the reader in concrete form the data accumulated concerning the 30 farms using power, Table I has been prepared.

This company has a uniform lighting rate of 12½ cents (less 20 per cent for prompt payment) and a power rate of 5 cents per kw-hr. (less 10 per cent for prompt payment). This very reasonable power rate is given to the farmer the same as to the city user, and in the case of farmers No. 1 and No. 5, the rates based on quantity consumption are 3½ cents and 2½ cents net, respectively. The monthly minimum is $1. One (No. 24) has a line connected up and motor installed but has the meter taken out for 9 or 10 months of the year, simply using the motor in August and September. This, of course, is very liberal treatment and certainly not a paying one for the power company so far as direct revenue from this particular power line is concerned. There is, however, some advantage gained from an advertising standpoint.

The following is a list of the various farm machines which are driven by the motors shown in Table I:

Farm No. 1 also drives a small generator for battery charging.

Farm No. 5 also has a small motor-generator set installed for battery charging. It will be noticed that Farm No. 5 is the largest single user of electricity shown in the table. This is explained by the fact that, in addition to operating a general farming business, this farmer also operates an ice making plant. His nearby brother farmers are thus kept supplied with this much needed commodity during the summer months.

TABLE I. REVENUE FROM THE THIRTY POWER CUSTOMERS OF COMPANY NO. 1

Farm No.	Size Acres	No. of Motors	H.P.	No. of Meters	Revenue Power Only: Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Total	Ave. Monthly	Ave. per H.P.	Revenue Lights Only	Yearly Revenue Total Power and Light
1	160	3	38	2	19.84	29.05	24.92	28.49	23.52	32.06	39.13	43.19	37.66	28.07	19.95	20.75	346.63	28.88	9.12	24.00 est.	370.63
2		1	10	2	1.17	1.35	1.66	1.00	1.03	1.00	1.00	1.00	1.00	1.00	1.48	1.44	14.13	1.17	1.41	none	14.13
3	84	2	18	2	2.12	1.89	3.29	3.51	2.52	1.00	1.00	1.00	1.00	1.00	1.00	4.05	23.38	1.95	1.30	18.00 est.	41.38
4	44	2	17	2	4.68	3.20	3.74	3.02	3.96	2.84	1.17	1.00	1.00	2.30	2.39	5.22	34.52	2.87	2.03	18.00 est.	52.52
5	78	3	45	2	53.50	44.50	47.25	48.75	50.75	47.50	58.25	74.50	54.25	49.25	46.25	43.50	618.25	51.52	13.74	24.00 est.	642.25
6	76	1	5	2	1.98	1.44	1.44	1.62	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	14.48	1.20	2.89	18.00 est.	32.48
7	85	3	14	2	3.01	3.33	2.79	5.80	2.97	2.29	1.00	1.39	1.17	3.01	1.00	2.07	29.83	2.49	2.13	18.00 est.	47.83
8	120	1	1	1	3.40	3.70	3.20	3.50	4.10	3.50	3.80	3.70	3.90	5.00	6.40	4.20	48.40	4.33	3.22	none	48.40
9	190	1	3	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12.00	1.00	4.00	53.30 actual	65.30
10	43	1	10	2	6.53	6.57	4.91	6.12	3.69	2.12	1.89	1.44	5.58	1.71	5.31	7.70	53.57	4.46	5.35	18.00 est.	71.57
11	100	1	15	2	3.69	2.30	2.57	2.52	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.40	19.48	1.64	1.29	23.00	42.48
12	110	1	15	2	6.39	8.06	9.18	3.92	1.40	1.00	1.00	1.00	1.00	1.00	1.00	2.88	37.83	3.15	2.52	19.70	57.53
13		3	3¼	2	1.00	1.00	1.00	1.00	1.00	2.16	1.93	2.25	2.07	2.29	2.83	2.16	20.69	1.72	6.30	16.00	36.69
14	70	1	2	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12.00	1.00	6.00	13.80	25.80
15	70	2	17	3	1.35	1.00	1.12	1.00	.35	1.71	1.00	1.00	1.00	1.00	1.00	1.21	12.74	1.06	.75	48.80	61.54
16	130	1	1	2	2.40	1.80	1.60	1.60	1.00	1.10	1.00	1.00	1.40	1.60	1.70	2.20	18.40	1.53	18.40	190.10	208.50
17	100	2	8	2	2.07	1.48	1.89	1.12	1.00	1.00	1.00	1.00	1.00	1.00	2.07	2.25	16.88	1.40	2.11	16.60	33.48
18	75	1	2	2	1.00	1.00	1.00	1.03	1.35	1.26	1.03	1.35	1.26	1.39	1.12	1.00	13.79	1.15	6.89	46.20	59.99
19	90	1	15	2							.66	1.70	1.00	3.70	2.50	3.40	25.92	2.16	1.72	24.24	50.16
20	80	1	15	2							.66	4.22	1.00	1.00	1.00	1.00	17.76	1.49	1.18	14.06	31.82
21	132	1	15	2							.66	.77	1.00	1.00	1.00	1.00	10.86	.90	.72	15.06	25.92
22	150	1	15	2							.66	.67	1.00	1.00	1.66	2.74	15.46	1.12	1.03	18.86	34.32
23	120	1	15	2								1.00	1.35	2.61	7.02	8.68	41.32	3.44	2.75	18.00 est.	59.32
24	75	1	15	2								1.80	12.46			1.00	15.26	1.27	1.01	18.00	33.26
25	73	3	16⅙	2										2.47	4.50	5.67	22.40	1.86	1.32	25.00 est.	47.40
26	220	1	5	3											4.00	3.60	25.00	2.08	5.00	45.00 est.	70.00
27	73	1	15	2	New	custom	er						Bills es	timated		2.29	25.00	2.08	1.06	25.00 est.	50.00
28	54	1	7½	2	New	custom	er						Bills es	timated			15.00	1.25	2.00	18.00 est.	33.00
29	122	1	20	2	New	custom	er						Bills es	timated			24.00	2.00	1.12	18.00 est.	42.00
30	100	1	20	2	New	custom	er						Bills es	timated			24.00	2.00	1.12	18.00 est.	42.00
TOTAL		44	412														1608.98			822.72	2431.70

This is a good example not only for other central stations, but for isolated farm communities as well.

TABLE II

Name of Machine	No. Machines Installed	Per Cent of Farmers Using Each Machine
Bottle washer	4	13⅓
Butter churn	3	10
Cob grinder	1	3⅓
Corn sheller	10	30
Cream separator	1	3⅓
Fan mill	2	6⅔
Feed chopper	21	70
Fodder shredder	12	40
Grindstone	1	3⅓
Hay baler	1	3⅓
Hay hoist	2	6⅔
Meat chopper	1	3⅓
Milking machine	1	3⅓
Pumping	7	23⅓
Refrigerating	1	3⅓
Root cutter	1	3⅓
Saw (wood)	6	20
Saw (rip)	1	3⅓
Sewing machine	1	3⅓
Thresher	11	36⅔
Washing machine	6	6⅔

Farmer No. 9 and farmer No. 16 are gentlemen farmers with large main dwellings as well as a number of smaller buildings, all electrically lighted. Light is lavishly used and both parties say they are well satisfied with the amount of their bills.

Attention is called to Farm No. 27; the owner of the farm has been operating his own plant driven by a gasolene engine and was induced to change over to the central station service. He has been on the lines for only a few months but is very much pleased and claims his present cost for power is only half of what it was under the former system. Company No. 1 states that this is not an unusual experience among its customers.

The total connected farm power load is 412 h.p. or 307.35 kw.

The total farm lighting load is 125 kw.

The total load is 432.35 kw.

The average connected load per rural customer is 3.46 kw.

Total yearly kw-hr. for power......26,940
Total yearly kw-hr. for light........28,150

Total yearly kw-hr for power and light..........................55,090
Total revenue..................$4,142.00
Average income per kw-hr....... ..$ .075

From Table I it will be seen that the average horse power installed is 13.7.

The average yearly revenue per *power* customer is $81.06.

This includes the income for lighting for the same customers.

The average yearly income per customer on the basis of 125 customers, including all power and light used, is $33.17.

The average monthly income is $2.76.

One writer in the West has stated that a rural customer is not a paying proposition until he averages nearly $3 per month. From all the data obtainable in the present case, $2.76 per month is the average minimum revenue per customer and a fair profit does not show until the figure is close to $3

COMPANY No. 2

This company owns and operates two water power plants and has an agreement at the present time with Company No. 1 for emergency current.

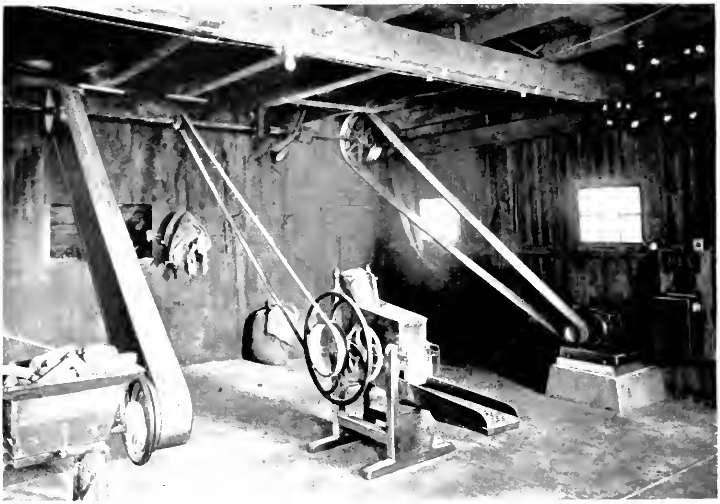
Some of the present officers became interested in a local telephone company, the lines of which they constructed with great pains, using the same poles that belonged to the power company. This telephone company was later taken over by the Bell system and one of the stipulations of the merger was that the power company should have the privilege of continuing and extending its lines on the poles of the telephone company in this section. It will readily be seen how impossible it is to charge up to the farmers the entire 32 miles of lines of this company. As a matter of fact, since it began operating, seven years ago, there have been constructed only 4¼ miles of pole lines and this has been done to accommodate seven customers. These 4¼ miles were installed as follows:

2 miles for 3 customers
1½ miles for 3 customers
¾ mile for 1 customer

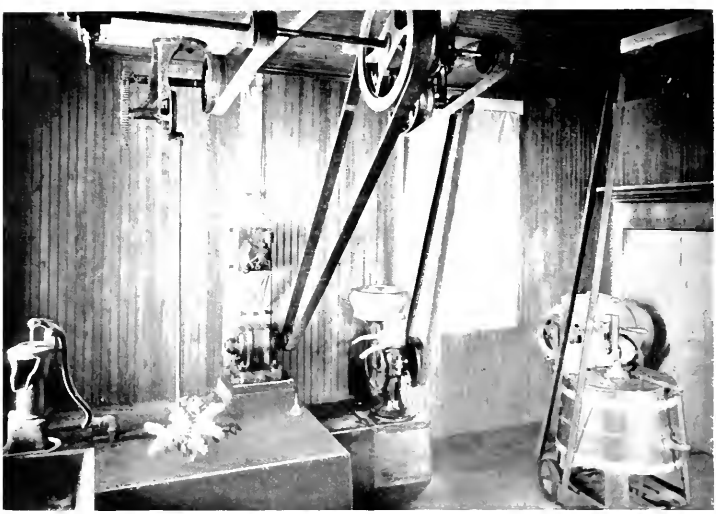
It is fully expected, however that many more customers will be put on these lines very shortly.

Current is also furnished for street and road lighting in the several boroughs through which the lines are run.

From the outset, the company realized that the load would consist principally of farms; that to make a success of its enterprise, it must make a fair profit; that the farmers wanted electricity and were willing to pay a just and reasonable rate for it. Therefore, the company arranged a special contract for farm customers and when submitting this contract to prospects, pointed

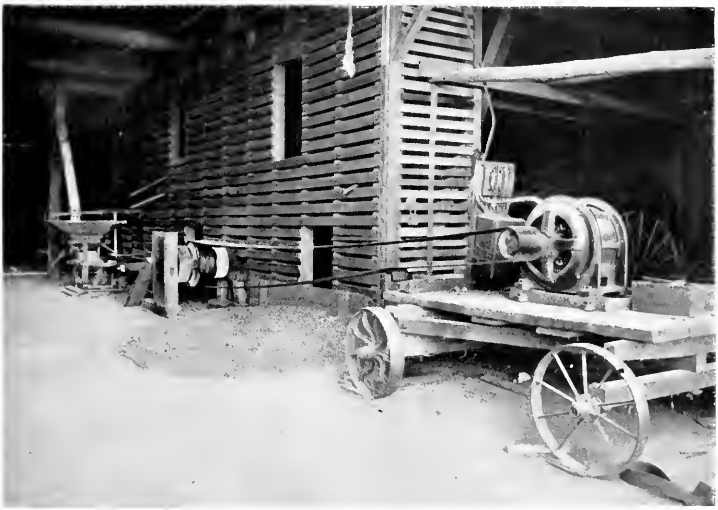


A 10-h.p., 1200-r p.m., 220-volt, Three-phase Induction Motor Operating a Corn Sheller and a Grinder



A 1-h p , 1800-r p m , 220-volt, Single-phase Induction Motor Driving a Pump, a Cream Separator, a Washing Machine and a Butter Churn out that farmers living in scattered communities could hardly expect to obtain first class electric service at city rates, without sharing part or all of the cost of the line, if conditions warranted.

This contract provided that any service connections beyond 100 feet should be paid for by the customer unless business warranted the power company assuming the cost. Several changes were made in the original contract until it now provides that where the prospective business is not sufficient to warrant an extension at the company's expense, such extension will be installed by the company but the customer guarantees revenues within two years to cover the cost of the extension. The customer must pay for and maintain his own transformer and disconnecting switch. The idea of this is that the farm load is very intermittent and the load occasioned by the core loss in the idle transformers would be considerable. The disconnecting switch is conveniently mounted and the customer keeps this open when not using current, thus reducing the load on the station and protecting his transformer.



A 25-h.p., 1200-r.p.m., 220-volt, Induction Motor Driving a Corn Chopper and a Cob Breaker. Portability is secured by mounting the motor on a truck

The base rate for lighting is $12\frac{1}{2}$ cents per kw-hr. with a discount of 10 per cent for prompt payment. Further discounts are available for large bills amounting to $5 and over.

The minimum charge for 1 to 15 lamps installed is $1.12 per month; for 16 lamps or more $1.38 per month, subject to 10 per cent discount for prompt payment. Motors 1 h.p. and smaller are classed as lighting.

Cooking, heating, charging batteries and general motor service in excess of 1 h.p. are classed as power. The rates for power are as follows:

Less than 20 kw-hr. per month	$0.08 per kw-hr.
From 20 to 40 kw-hr. per month	.07 per kw-hr.
From 40 to 60 kw-hr. per month	.06 per kw-hr.
From 60 to 100 kw-hr. per month	.055 per kw-hr.
From 100 to 200 kw-hr. per month	.05 per kw-hr.
From 200 to 400 kw-hr. per month	.045 per kw-hr.

Minimum charge

1 to 6-h.p. motor	$1.12 per month	or equivalent.
6 to 16-h.p. motor	2.22 per month	
16 to 31-h.p. motor	3.33 per month	

Prompt payment discount of 10 per cent is allowed.

There are forty farm customers on the lines of this company. Thirty of these use both light and power. The total motor load on the station is 325 h.p. of which 225 h.p. is distributed among these thirty customers, averaging 7½ h.p. each. This load would be 300 h.p. and the average 10 h.p. each, but for the fact that in the early stages of its work, the company permitted the installation of a number of 5-h.p. and 7½-h.p motors for general farm use. Later they adopted a standard of 10 h p. which they now try to maintain.

Table III, covering six representative customers, gives an idea of the total farm business. The writer is assured that these are not a specially selected few but that all their farm customers will run about the same.

On the basis of the six representative farms the average yearly revenue, for both light and power per customer, is $72.25 or $6 00 per month.

stations in so far as indicating that the farm load has its own special features and must be handled accordingly.

There is a question as to the size of motor to recommend for general farm purposes. The tendency is to keep the horse power rating down, making the farmer operate his machines at lighter loads but for longer periods, instead of trying to cram all his work through the machine at one time. This point is quite ably expressed by Mr. Alexander R. Holliday in his paper on "Rural Electrical Development in Indiana":

"It is quite important that the farmer be trained to use a small motor long hours, instead of a large one a few hours. Rates should take into account the load factor. Many machines, even thrashing machines, can be made in small sizes. The chief reason for large machines has been that the labor cost on power was the same, regardless of size. The electric motor takes away the reason."

TABLE III

Farm No.	No. of Meters	Total h.p.	Yearly Revenue Power	Average Per Month	Average Per h.p.	Yearly Light	Revenue Total
1	2	5	$33.74	$2.73	$.675	$20.45	$54.19
2	2	10	76.14	6.34	7.61	24.18	100.32
3	2	10	52.24	4.35	5.22	*40.28	92.52
4	2	10	45.02	3.75	4.50	*25.79	70.81
5	2	10	44.14	3.68	4.41	13.66	57.80
6	2	10	45.87	3.82	4.58	12.00	57.87

* This amount includes cost of current used by 1-h.p. motor also installed.

For forty farms, therefore, the total would be $2890.00.

The total average income per horse power (above 1 h.p sizes) installed on the thirty farms is $5.51.

The total income for power (above 1 h.p.) alone would be $1239.75.

The farms on the lines of Company No. 2 are of the same class as those of Company No. 1—in fact some of the farms on the separate lines adjoin each other. Three farms on No. 2 have their motors mounted on portable trucks. There are also about 200 flatirons, 100 vacuum cleaners and 50 washing machines, besides a large number of the different types of heating devices, distributed among the farm customers on the lines of No. 2.

CONCLUSION

The experiences of these two stations should be of assistance to other central stations in so far as indicating that the farm load has its own special features and must be handled accordingly.

The 15-h.p. motor seems to be the favorite with the 10-h.p. a close second but, as education progresses, this latter size will doubtless become the most popular.

Another point which should be borne in mind is that, while a customer may start out using current for light only, and the revenue at first may be lower than the required average, experience shows it to be a question of but a short time before this customer adds new devices and takes power for driving his machines.

Attention is called to the fact that none of these customers employ irrigation. If electricity on the farm can be made to pay without irrigation, certainly it should pay in those localities where irrigation is needed.

THE BRUSH-SHIFTING POLYPHASE SERIES MOTOR

PART I

By W. C. K. Altes

Induction Motor Engineering Department, General Electric Company

This article is the first of a series on the brush-shifting polyphase series motor, which is a machine having a wide range of speed and an efficiency that is high at low as well as at normal speed. This installment details the theory of both the single-phase and polyphase series motors, trignometric relations only being used in the derivations. The second installment will deal with the characteristics, applications, testing and installing of these motors.—Editor.

The growing demand for an alternating current motor the speed of which can be regulated over a large range with small increments, without the considerable loss of energy incurred by the application of the induction motor with polar wound armature and secondary resistance control, has led to the development of the brush-shifting single-phase and polyphase motors.

This article will deal with the brush-shifting polyphase series motor.

Theory of Operation

In Fig. 1 we have shown a machine consisting of a stator S built up of punchings, and a rotor R also made up of punchings. The rotor is mounted in bearings. Stator and rotor are provided with coils, connected in series with each other, through which a current flows derived from a d-c. source of supply. We assume that the coil on the rotor has more turns than the coil on the stator.

In Fig. 2 we have represented the magnetomotive force of the stator ampere turns by a vector $MMFS$ and that of the rotor ampere turns by a vector $MMFR$, the combination of which gives as resultant $MMFF$ which

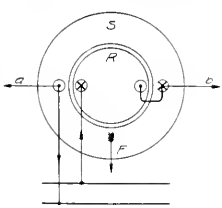


Fig. 1

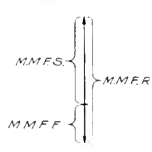


Fig. 2

excites the field flux F. The direction of this field flux has been shown in Fig. 1 by an arrow. In accordance with Laplace's law a pull is exerted on each side of the rotor coil due to the repulsion between the current in the coil and the magnetic field, which pull has been represented by the arrows a and b However, this pull does not give rise to a torque when the rotor is standing in the position shown in Fig. 1, the two forces being

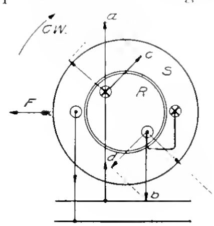


Fig. 3

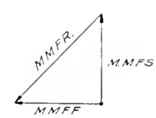


Fig. 4

equal and opposite and working along the same line.

In Fig. 3 we have shown the rotor in a different position. The direction of the field flux, again marked by an arrow, has been obtained by the aid of the vector diagram of the magnetomotive forces shown in Fig. 4. We assume that the current is kept constant, and that the iron is of such proportions that we are independent of the saturation, so that the flux is proportional to the magnetomotive force. The vectors a and b of Fig. 3 again represent the pull on both sides of the coil. This pull is proportional to the current in the coil, the number of turns of the coil, and the field flux. The components c and d of the vectors a and b along the axis of the rotor coil will exert a torque that tends to turn the rotor clockwise.

In Fig. 5 we have represented the vector a by CE; the component exerting the torque is then equal to CF. We further have drawn OD perpendicular to CG, the latter corresponding to $MMFR$ of Fig. 4. CE is always perpendicular to OC and $\triangle CEF$ and $\triangle ODC$ are similar. Hence DO will be proportional to CF, i.e., proportional to the torque, if we keep the current constant, in which case only the flux changes. We can therefore always resolve the flux into two components, one of which is perpendicular to the axis of the rotor windings and determines the torque, the other of which follows the axis of the coil and does not exert any torque. In the following we will call the total field flux F, the component exerting the torque Ft, and the other component Fc. If we now let the rotor turn, the angle OGC will increase, the end C of the magnetomotive force vector $MMFF$ will move on the field circle and the end D of the torque vector on the torque circle (see Fig. 6). The torque will vary proportionally to the sine of the angle OGC, as shown in Fig. 7. There are two positions in which the torque is zero, i.e., for $\angle OGC = 0$ and $\angle OGC = 180$. In both positions the component Ft of the field flux perpendicular to the axis of the rotor winding is zero. The field circle corresponds to the actual flux existing in the motor; the torque circle not only gives the torque but also represents the component Ft of the field flux. As soon as we do not limit ourselves to the theoretical assumption that the iron does not saturate, on which is based the proportionality between the magnetomotive force and flux, the total flux will no longer be determined by the field circle, but by a line lying inside this circle, every point of which can be determined by means of the saturation curve. The torque circle, representing both the torque and the component Ft of the flux for different rotor positions, will be changed into a similar line.

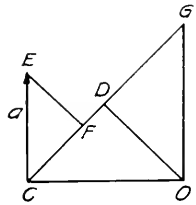


Fig. 5

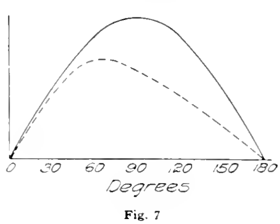


Fig. 7

In Fig. 7 we have shown by a dotted line the torque position curve when the saturation is taken into account, and a constant current is maintained.

In Fig. 8 we have shown the same diagram as in Fig. 6, only with $MMFR < MMFS$, i.e., a smaller number of turns in the rotor than in the stator coil. The two circles intersect in two points. The point CD shown in Fig. 8 is of special interest, since at this point the total field flux is perpendicular to the axis of the rotor winding, and F and Ft are the same. In this particular position of the rotor the same torque can be obtained with less kv-a. than when the rotor coil has more turns than the stator coil. We have further shown in Fig. 8 by dotted lines the torque OD', in which case the angle OGC' is large, resulting again in only a small component of the field flux being effective.

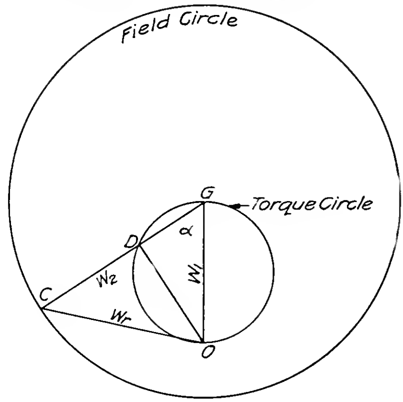


Fig. 6

Fig. 9 and Fig. 10 are the same as Fig. 3 and Fig. 4, only we have turned the rotor 45 degrees counter-clockwise instead of clockwise from the position of Fig. 1. It is apparent that with the rotor in this position a torque will be exerted that tends to shift it counter-clockwise. The rotor position of Fig. 1 is usually called "live neutral," and is characterized by the fact that if the rotor is displaced from this position a torque is exerted that tends to increase the displacement. The other rotor position, in which no torque is exerted and which lies 180 degrees from the live neutral, is often called the "dead neutral." It is characterized by the fact that if the rotor is displaced from it a torque tending to decrease the displacement is exerted.

Instead of equipping rotor and stator each with a single coil, we can use a distributed winding covering either a part or the entire circumference. It can easily be proved that this distributed winding is identical in its effect to a single coil winding, the number of turns of which is equal to the effective number of turns of the distributed winding and which is located in such a manner that its axis is the same as that of the distributed winding. In Fig. 11 distributed windings S and R on both stator and rotor have been shown. Instead of stator and rotor being connected directly in series, the rotor winding has been connected to a commutator and the current is supplied

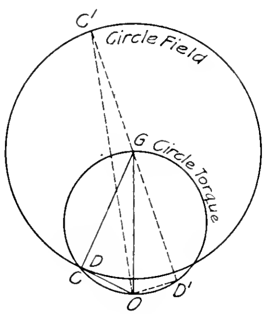


Fig. 8

to it over brushes sliding on this commutator. If we now hold the rotor in position and shift the brushes, then we shift the axis of the rotor winding in the same way as was previously done by shifting the rotor, and the variation of the torque for different brush positions can be determined in the same way as has been explained for different rotor positions.

We can also let the rotor rotate at a certain speed without affecting the relation of torque and brush position, provided we keep the brushes stationary and the current in the windings unchanged. In order to keep the current the same for different speeds, it will be necessary to vary the voltage since, due to the rotation of the rotor winding through the magnetic field, a counter e.m.f. is induced which must be balanced by the applied voltage. This counter e.m.f. will be proportional to the speed, the number of rotor turns, and the component Ft of the flux.

The theory developed above must be applicable to the d-c. series motor. We therefore have shown such a motor in Fig. 12, and the vector diagram of the magnetomotive forces

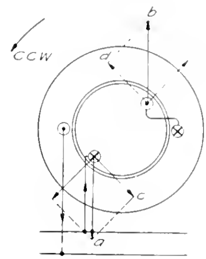


Fig. 9

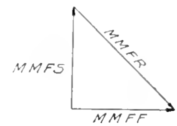


Fig. 10

in Fig. 12a. $MMFS$ corresponds to the magnetomotive force excited by the field coil; $MMFR$ to that of the armature winding, the axis of which is shifted over an angle of 90 degrees clockwise from the live neutral position.

If we had a smooth core stator instead of the salient poles used on most d-c. machines,

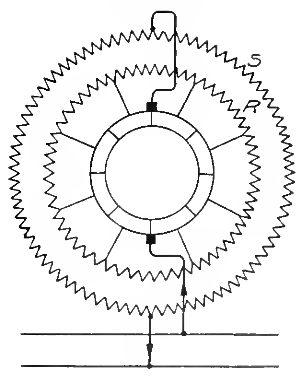


Fig. 11

a resultant magnetomotive force $MMFF$ would yield a total flux the component, Ft perpendicular to $MMFR$, of which would only contribute to the torque and the counter e.m.f. The component Fc of the total flux along the axis of the armature winding would not generate any voltage in the armature circuit between the brushes, since these voltages would be equal and opposite. The maximum voltage resulting from this component would be generated in the coils short circuited by the brushes, which would cause

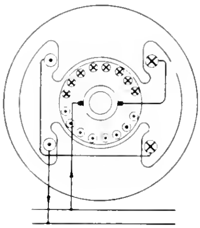


Fig. 12

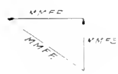


Fig. 12a

sparking. It is therefore the general practice to design the iron path of the stator in such a way that a large local air gap at this point of the circumference suppresses the flux yielded by *MMFR*. Remembering what has been stated above in regard to the direction of rotation depending on the direction of shift from the live neutral it is clear that a motor, the circuits of which have been connected in series relation as in Fig. 12, will run clockwise. Hence after having once obtained a thorough understanding of the torque relation of the arrangement covered by Fig. 1 and Fig. 3, it is a simple matter to predetermine the direction of rotation of a d-c. series motor as soon as we know the way in which armature and field have been connected in series.

So far we have drawn our conclusions under the assumption that direct current is used. As the circuits under consideration are connected in series it is clear that the same laws will apply in case the current pulsates or alternates; only, we will get a pulsating instead of a continuous torque and the counter e.m.f. induced by rotation will follow the same fluctuations as the current which we apply. In addition thereto if we have an alternating current in those parts of the circuit which allow the current to build up an alternating flux, voltages will be induced lagging 90 degrees in timephase behind the current. Taking the motor shown in Fig. 11, to which we can apply the diagram of Fig. 6, it is clear that the resultant magnetomotive force *MMFF*, the direction of which coincides with the axis of the resultant turns, will excite an alternating flux which induces a voltage lagging 90 degrees behind the current. Hence a larger voltage will be required to drive the current through the windings than would be required if direct current were used. This out-of-phase voltage will be proportional to the frequency of alternation, the number of resultant turns, and the flux. If we call the angle of brush shift corresponding to angle *OGC* of Fig. 6, α; the number of stator turns, w_1; the number of rotor turns, w_2; and the ratio of rotor to stator turns $c=\frac{w_2}{w_1}$, then the resultant turns w_r will be equal to

$w_r = w_1 \sqrt{1-2c\cos\alpha+c^2}$ which follows from Fig. 6, or $w_r = v \times w_1$ in which

$$v=\sqrt{1-2c\cos\alpha+c^2}$$

In Fig. 13 several curves for different values of c have been drawn with the angle of brush shift α as abcissæ and v as ordinates.

Suppose now that we know from test or calculation the saturation curve for the stator winding S, having w_1 turns; further, that we have determined for a certain brush position and over compensation, c, the factor v with the aid of the curve given in Fig. 13. If then a

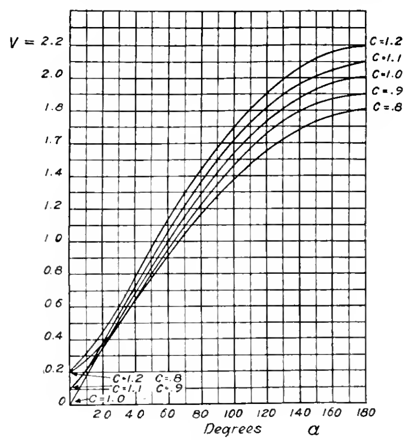


Fig. 13

current I is flowing through the motor, the ampere turns yielding the total field flux F in the motor will be equal to Ivw_1. The saturation curve of Fig. 14 applies to a winding wound on the same core but having w_1 instead of vw_1 turns. If we take from this saturation curve the voltage E induced with vI amp. and multiply this voltage by v, we will obtain the voltage Ew induced in the resultant turns w_r of the motor. In order to find the rotation voltage E_R we first have to determine the component Ft of the flux perpendicular to the axis of the rotor winding. This can be done by the aid of Fig. 6. We know that

$$\frac{OC}{OD}=\frac{F}{Ft}$$

Further

$$OG=\frac{OC}{v} \text{ and } OD=OG\ sin\ \alpha=OC\frac{sin\ \alpha}{v}$$

Hence

$$Ft=F\ \frac{sin\ \alpha}{v}$$

The total field flux F induces by alternation in a winding with w_1 turns E volts; hence the voltage in the rotor winding induced in cw_1 turns with a frequency of rotation fr and a flux equal to

$$\frac{sin\ \alpha}{v}\times F$$

will be

$$E_R=E\frac{c\ sin\ \alpha}{v}\times\frac{f_r}{f_1}=E\frac{c\ sin\ \alpha}{v}(1-s)$$

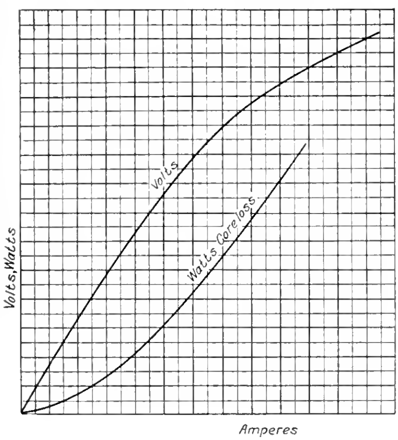


Fig. 14

The leakage reactance drop Ix lags 90 degrees behind the current and can be added to Ew.

The resistance drop Ir and the brush drop e_b, which are directly opposite to the current, can be added to E_R. We further can add to E_R a watt component e_c which, multiplied by the current, gives the core loss. The core loss can be taken from Fig. 14 by taking the core loss obtained with a current equal to vI.

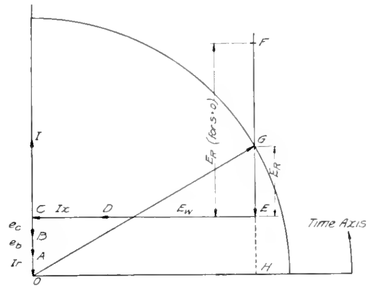


Fig. 15

After we have thus analyzed all the voltages which appear in our motor circuit both in value and timephase, it is not difficult to draw a diagram from which we can accurately predetermine the characteristics of the motor.

This diagram is shown in Fig. 15. Our problem is to find the speed, torque, output, input, efficiency and power-factor for a certain brush position α, current I, and applied line voltage E_l.

Taking two perpendicular coordinates we make

$OA=Ir$ (the total resistance drop.)
$AB=e_b$ (the brush drop)
$BC=e_c$ (core loss divided by the current)
$CD=Ix$ (the total leakage reactance drop)
$DE=E_w$
$EF=E_R$

We describe with the applied voltage E_l as radius from O as center a circle which interesects EF in G, and thus find the rotation voltage that can be generated.

The frequency of rotation will be $fr=f\ \frac{EG}{EF}$ and the speed of the motor is known.

The torque of the motor in synchronous watts equals $I\times EF$. If we subtract from this the bearing and brush friction-torque then we find the torque which appears at the shaft. The electrical output in watts equals $I\times EG$. If we subtract from this the friction and windage losses then we find the mechanical output in watts.

The input equals $I \times GH$

The efficiency equals $\frac{\text{output}}{\text{input}}$

The power-factor is the cosine of the angle between I and OG or $PF = \frac{HG}{OG}$

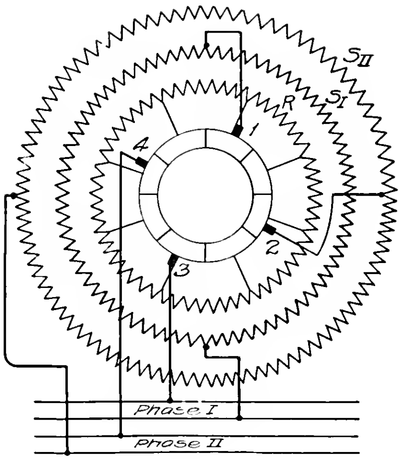


Fig. 16

This diagram, Fig. 15, can be repeated for different currents and brush shifts.

The calculation can also be made without a diagram by proceeding as follows:

For a given brush position we first determine $Ix + E_w$ and find $HG = \sqrt{E_t^2 - (Ix + E_w)^2}$. From this we subtract $(I_r + e_b + e_c)$ and find EG. We further calculate $EF = E \frac{c}{v} \sin\alpha$ and the other values are determined in the same way as explained above.

The principal disadvantage of this type of single-phase motor is the difficulty in obtaining good commutation.

For the d-c. series motor of Fig. 12 we have already explained that in the coils short-circuited by the brushes a voltage is induced by rotation through the component Fc of the field flux. This voltage increases proportionally to the speed and is in timephase with the current. The component Ft of the field flux induces by alternation a voltage between the brushes proportional to the line frequency and independent of the speed and lagging 90 degrees in timephase behind the current. It is only possible to obtain satisfactory commutation by designing a motor of larger dimensions than is required for other types of single-phase motors, such as the repulsion motor and compensated repulsion motor. Therefore we will not go any further into an examination of its characteristics, but we will show how both its characteristics and its commutation can be improved by building it quarter-phase.

In Fig. 16 we have shown the same motor as in Fig. 11. The brushes have been shifted clockwise from the live neutral over an angle α. We have put four brushes on the commutator instead of two and added another stator winding so that we can have two circuits in space quadrature. The diagram of the magnetomotive forces has been shown in Fig. 17 under the assumption that the effective value of the current is the same in both phases, and that rotor and stator have an equal number of turns. As the resultant magnetomotive forces $MMFF_1$ and $MMFF_2$ are perpendicular to each other no voltage will appear at the terminals of phase 2 if phase 1 is connected to an alternating source of supply. The resultant number of turns of each circuit is non-inductive with respect to the other as far as induction by alternation of the flux interlinked with either circuit is concerned. Each circuit is connected to a different phase of a quarter-phase source of supply so that the currents differ 90 degrees in timephase. Again the torque for phase 1 is proportional to the ampere turns of the armature winding, and the component Ft of the field flux which has the same direction as the vector OD. The component Fc of the field flux yielded by $MMFF_2$ of phase 2, in the direction of $C''D''$ is also perpendicular in space to the axis of the armature winding of phase 1, but does not exert any torque, since this component is 90 degrees out of timephase with the current in phase 1. Hence the torque for each phase can be determined in the same way as has been shown for the single-phase motor and the torque of the motor is the sum of the torque exerted by both phases, i.e., 2 IE_R measured in synchronous watts.

When the motor is running in either phase a voltage E_R is induced proportional to the number of armature turns, the frequency of rotation and the component Ft of the field flux. In addition thereto the component Fc of phase 2 induces in the armature turns of phase 1 by rotation a voltage E_c proportional to the number of armature turns, the component F_c, and the frequency of rotation. As this flux in phase 2 differs 90 degrees in timephase from the current in phase 1, this voltage E_c lags 90 degrees behind the current when the motor is rotating opposite to the direction of rotation of the field excited by the quarter-phase supply and leads the current 90 degrees in case the motor is rotating in the same direction as the rotating field. The first case is covered by the diagram of Fig. 19, the second by Fig. 18. The value of the voltage E_c can be determined by the aid of Fig. 17 in which $\frac{CD}{OC} = \frac{Fc}{F}$

$$CD = CG - GD = OC\frac{c}{v} - OC\frac{\cos\alpha}{v}$$

$$F_c = \frac{c - \cos\alpha}{v}F$$

F induces by alternation with a frequency f in a winding having w_1 turns a voltage E; hence the voltage E_c induced in $c\ w_1$ turns with a frequency of rotation fr and a flux

$F_c = \frac{c - \cos\alpha}{v}F$ will be

$$Ec = E\frac{c(c-\cos\alpha)}{v}\frac{f_r}{f} = E\frac{c(c-\cos\alpha)}{v}(1-s)$$

In drawing the diagram of Fig. 18 we have proceeded as follows:

For a definite value of c and α we have found v by the aid of Fig. 13. Assuming a certain current I, we have taken from the saturation curve E, found as ordinate for the abcissae vI.

We make

$$OA = Ir,\ AB = e_b,\ BC = c_c,\ CD = Ix$$

$$DE = Ew = vE\ EF = E_R(for\ s-O) = E\frac{c\sin\alpha}{v}$$

$$FK = Ec\ \ (for\ s-O) = E\ \frac{c(c-\cos\alpha)}{v}$$

With the line voltage E_l as radius we draw from O as centre a circle which intersects KE in L; then the slip of the motor will be

$$s = \frac{KL}{KE}$$

$$\text{The power-factor} = \frac{LM}{OL}$$

The other values can be determined in the same way as explained for the single-phase motor. Instead of drawing the diagram the speed can be calculated. If we call the speed

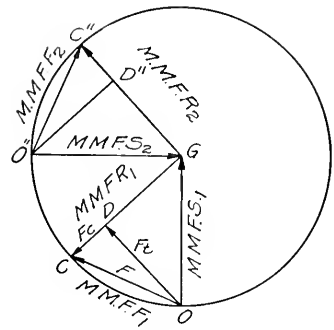


Fig. 17

S in percentage of synchronous speed, then it follows from Fig. 18 that

$$OL^2 = (OC + S \times EF)^2 + (CE - S \times KF)^2$$

or

$$S^2 + 2\frac{OC \times EF - CE \times KF}{EF^2 + KF^2}S - \frac{OL^2 - OC^2 - CE^2}{EF^2 + KF^2} = 0$$

from which S can be determined.

We have assumed that the leakage reactance of the rotor is independent of the speed. Actually the leakage reactance of the rotor consists of a constant part and a part which decreases proportionally to the speed. The ratio of the constant to the variable part depends on the number of phases and the voltage per bar and can be determined by test. If we call that part of the rotor reactance which varies x_v and make $KF = Ix_v + E_c$ instead of $KF = E_c$, then we will have taken this factor into account. CD equals as before Ix, the total reactance drop of both rotor and stator.

Fig. 18 shows how, with a given brush position and current (from which results a definite value of torque independent of the speed), the speed can be varied by changing the voltage. It further will be noted how the power-factor improves with increasing speed. In order to have a high power-factor in the neighborhood of synchronous speed, E_w should be small and E_c large. This can be obtained by giving the rotor a considerable number of turns more than the stator so that, as follows from Fig. 17, F_c which produces E_c becomes large. It is possible to make $KF = OH$ or $KF > OH$, in which case the motor will work with unity or leading power-factor.

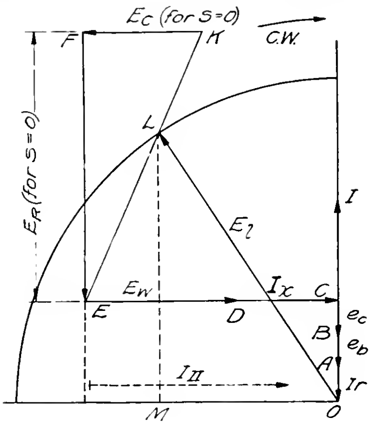


Fig. 18

Standard motors are designed with $KF < OH$ and have approximately 95 per cent power-factor at synchronous speed and full load. By going further with this power-factor compensation we would generally be obliged to build the motors of larger dimensions due to the increased number of rotor ampere turns. Moreover, as has been explained for Fig. 8, the torque relation is more favorable in case we have less turns in the rotor than the stator.

A comparison of Figs. 18 and 19 shows that at standstill the same characteristics will be obtained no matter whether or not the electrical field in the stator rotates in the same direction as the rotor. In the first case the torque will be somewhat higher than in the second case, since the circulating currents in the coils short-circuited by the brushes add to the torque, while in the second case they diminish the torque. When the motor is running the power-factor will be considerably lower in case the field in the motor rotates opposite to the direction of rotation of the rotor and the same torque can only be obtained by drawing considerably more current from the line.

If a polyphase induction motor is connected to a line of constant potential, then the rotating field flux will be practically constant. In the polyphase brush-shifting motor a rotating field also exists. This field varies, however, with the brush shift and the current, as follows from Fig. 17. The voltage induced by this flux in each turn of the stator is proportional to the frequency and the flux, and is independent of the speed. However, the voltage induced in each rotor turn will be proportional to the flux and the slip if the rotor is rotating in the same direction as the field. Hence this voltage will be zero at synchronism. This applies to each turn of the rotor and consequently also to the coils short-circuited by the brushes, from which it follows that at synchronism no voltage is induced in the coils short-circuited under the brushes.

If the rotor is rotating against the direction of the electrical field, then at synchronous speed the voltage per turn in the rotor will be double the voltage per turn in the stator, and large short-circuiting currents will flow through the brushes.

Thus it is clear that the quarter-phase commutator motor has better commutation conditions than the single-phase motor only when the rotor is rotating in the same direction as the electrical field.

We further have to take into consideration the voltage induced in the coils due to the change of the current while the coil is passing under the brush from one circuit to the other. For the single-phase motor this voltage can be determined in the same way as is the general practice in d-c. machines. In order to calculate this voltage for the quarter-phase machine we must remember that in passing from one circuit to the next the current is not reversed but changes only 90 deg. instead of 180 deg. in timephase. If we call this voltage e for the single-phase machine, then for the quarter-phase machine this voltage will be

$$e \sin \frac{90}{2} = 0.70\, e.$$

On modern d-c. machines this voltage is generally suppressed by the application of commutating poles. The use of commutating poles is not practical in brush-shifting motors. We have, however, other means of keeping this voltage down, i.e., by increasing the number of phases in the armature. By using an eight-phase instead of a quarter-phase armature the voltage will be $e \sin \frac{45}{2} = 0.38e$, or by using 12 phases $e \sin \frac{30}{2} = 0.258e$. As commercial circuits are usually arranged for three-phase or quarter-phase we have to make use of transformers for the multiplication of phases, in a way similar to that done for rotary converters. As a rule the stator is built three-phase or quarter-phase and the rotor is not connected in series directly with the stator but over a transformer, the secondary of which can have more phases than the primary. As an example we have shown in Fig. 20 a stator having three phases connected in series with an armature over a series transformer which changes over from three-phase to nine-phase. It is clear that to a motor of this kind the same equations apply as have been developed for the quarter-phase motor. The transformer at the same time steps the voltage down so that the armature can be designed for a lower voltage than the line voltage, it being impossible to design a-c. commutator machines with a high voltage on the commutator due to the commutating conditions mentioned above.

Standard motors are designed in such a way that they can be regulated with full torque between synchronous speed and half synchronous speed without injury to the commutator. When the motor is running at half speed the voltage per turn in the rotor equals half the voltage per turn in the stator, and in order to keep down the circulating currents under the brushes a brush with a high contact drop must be used. Brush renewals should be made with due consideration to this point.

In order to bring out the influence of the frequency on the dimensions of the commutator of these machines we will compare a 24-pole, 60-cycle motor with a 10-pole 25-cycle motor. The synchronous speed of both motors being the same, they can be equipped with commutators of the same diameter having the same number of bars, each being connected to a multiple armature. If we design the 25-cycle motor with 2.4 times the flux of the 60-cycle motor, then at half speed the voltage between two adjacent commutator bars will be the same, and the commutation conditions will be identical. On the 10-pole motor between two brush studs spanning a full pole pitch on the commutator will be 2.4 times as many commutator bars as on the 24-pole motor giving 2.4 times the secondary voltage of the 24-pole motor. If we design the secondary of the transformer of the 10-pole motor with 2.4 times the number of phases of the 24-pole motor, we will have the same number of brush studs. It is clear that the same commutator run at the the same speed will, when used on the 25-cycle motor, give 2.4 times the output that it will when used on a 60-cycle motor. 25-cycle

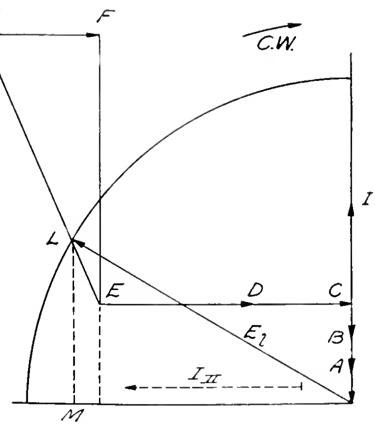


Fig. 19

circuits offer for this reason the best field for polyphase commutator motors. Depending on the output per pole the commutator for these machines can be designed for 110 to 180 volts, while on 60 cycles the voltage is limited to approximately 70 volts.

At standstill the diagram is very much simplified, as shown in Fig. 21. In order to simplify the calculation we have neglected the core loss. The space diagram of the windings of the two phases is represented in Fig. 22, which corresponds to clockwise rotation. In the resultant turns vw_1, a voltage E_w lagging 90 deg. behind the current will be induced, which can be resolved into two components, cE induced in the rotor and E induced in the stator. In order to determine the starting torque for a given line voltage E_l and assumed line current, we proceed as follows:

We first determine $OB = Ir$ plus e_b and $BD = Ix$. With E_l as radius and O as center, we draw a circle which intersects the line drawn through BD in E. In this way we find the field drop $E_w = ED$. By multiplying E_w by I, we find that it takes E_wI volt-amperes to produce the field flux which exists in the motor, with the given line voltage and current. By test or calculation we can determine the volt-amperes required for exciting different values of flux in the motor when the current is flowing through the stator winding having w_1 turns. In Fig. 23 curves have been plotted giving as ordinates

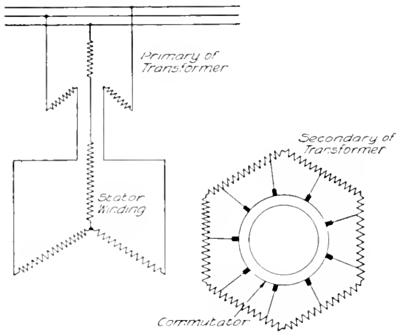


Fig. 20

the volt-amperes and applied voltage per phase, and as abscissa the current I flowing through w_1 turns. From this curve we find that in order to excite a flux requiring $E_w I$ volt-amperes, OX amperes would be required with a winding having w_1 turns. The brush shift must therefore have been such that $vI = OX$ or $v = \frac{OX}{I}$. After once knowing the value of v, we can find α with the aid of Fig. 13, the value of c being known. We know

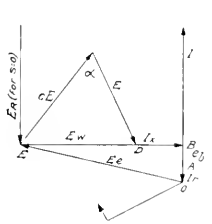


Fig. 21

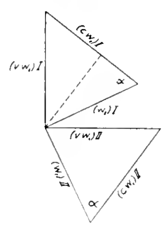


Fig. 22

that $E = \frac{E_w}{v}$. The torque per phase in synchronous volt-amperes equals $EI \frac{c \sin \alpha}{v}$, as explained for the single-phase motor. By multiplying this value by the number of phases, we find the total torque. In Fig. 24 we have plotted, with the angle of brush shift as abscissa and the torque, line current and voltage E as ordinates, the results of a calculation made in this way for a constant line voltage E_l. As E is directly proportional to the flux and the voltage induced in the coils short circuited under the brushes, we are in this way able to predetermine at the same time the commutation conditions.

As soon as stator and rotor have been connected in series over a transformer, which is designed in such a way that it saturates at about half speed, then at standstill this transformer will require a large magnetizing

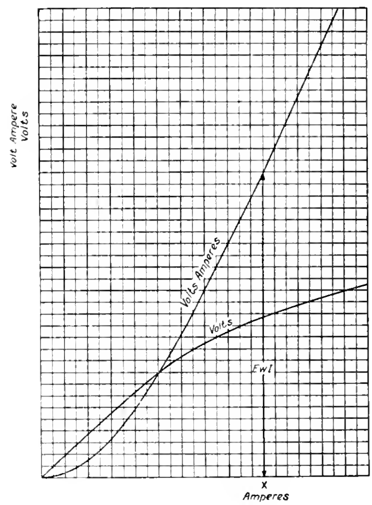


Fig. 23

current I_t, and the primary current I_1 and the secondary I_2 will differ in timephase. Besides this, the ratio of transformation of the transformer will be changed. We therefore divide the total resistance and reactance of the motor into r_1 and r_2, x_1 and x_2. In Fig. 25 we have drawn the diagram at standstill for an angle of brush shift α, in which the core loss has been neglected. In the preceding diagrams it was a simple matter to determine the field flux, as the flux was determined by the line current I flowing through the total number of resultant turns $w_r = vw_1$. In this case the total line current I_1 can be resolved into two components, I_2 flowing through both stator and rotor, hence yielding $I_2 vw_1$ ampere turns, and I_t flowing through the stator winding and the primary of the transformer only and yielding $I_t w_1$ ampere-turns. The axis of the stator winding w_1 lags in space over angle CBG behind the axis of the resultant turns w_r, and we can replace the current $OK = I_t$ by a current $ON = \frac{I_t}{v}$ shifted over an angle $HON = GBC$, and flowing through the resultant turns w_r, and retain the same resultant turns. We then can add $NM = I_2$ vectorially to ON and find as a resultant

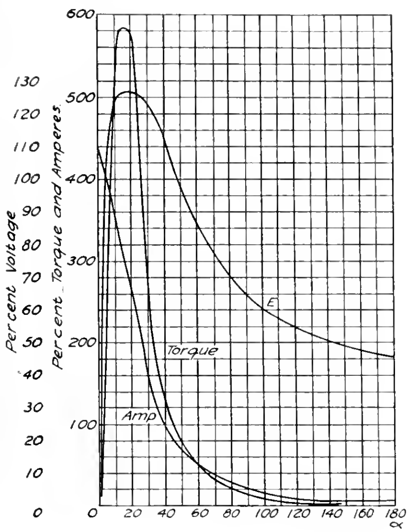


Fig. 24

current, $OM = I_m$. By means of the saturation curve we determine again the voltage E induced in w_1 turns with a current vI_m, and we can draw $CB = Ew = vE$ lagging 90 deg. behind OM. The triangle BGC can be completed by making $CG = cE$ and $BG = E$. $CD = e_b$ plus $I_2 r_2$ is opposite to I_2 and $FD = I_2 x_2$ lags 90 deg. behind I_2. FG is equal to the voltage across the secondary of the transformer reduced to the primary.

This diagram cannot be drawn directly like the previous ones, as there are too many variables depending on each other, but can only be obtained after a few trials, unless we neglect the resistance and reactance

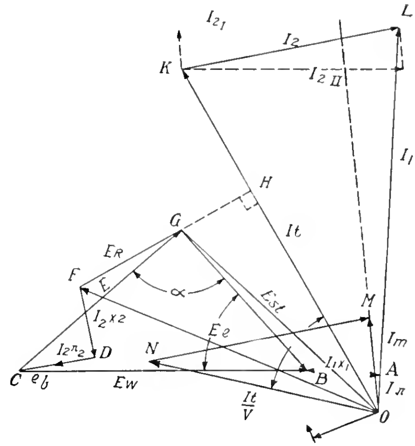


Fig. 25

drops, which is satisfactory for an approximation. For calculating the torque, we resolve I_2 into two components I_{2I}, in the same direction as I_m yielding the flux in the phase

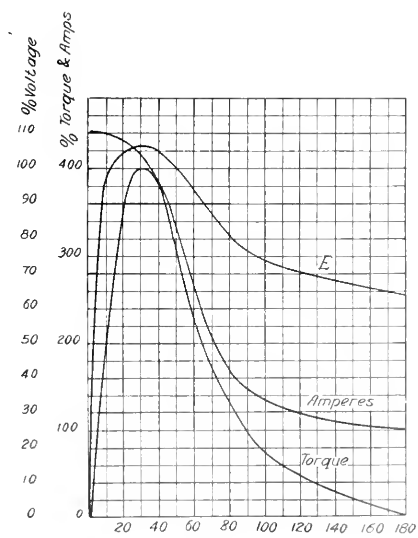


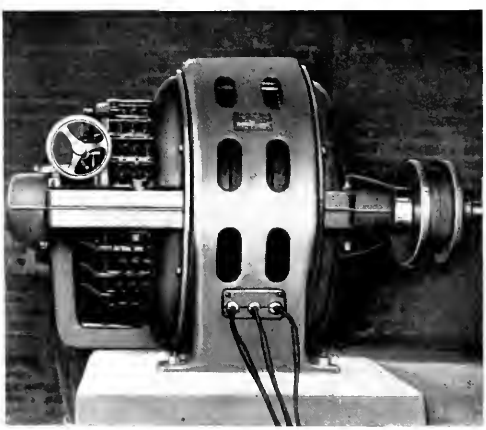
Fig. 26

we are considering, and I_{2II} at right angles to I_m. The torque in synchronous volt-amperes exerted by I_{2I} equals $I_{2I}\frac{CE}{v}\ sin\ \alpha$. I_{2II} has the same timephase as the current I_m in phase II. The flux yielded by this current is displaced in space over such an angle that only the fraction $\frac{c-cos\ \alpha}{v}$ is effective, which can be proved in the same way as was explained for the calculation of the voltage E_c of Fig. 18. Hence, the torque exerted by this current will be $I_{2II}\frac{E\ c\ (c-cos\ \alpha)}{v}$. The total torque per phase will be:

$$\frac{cE}{v}\sqrt{\left((I_{2I}\ sin\ \alpha\right)^2+I_{2II}^2\left(c-cos\ \alpha\right)^2}$$

and the torque of the motor can be found by multiplying the torque per phase by the number of phases.

In Fig. 26 we have plotted with the angle of brush shift as abscissa, the torque, line current and voltage E as ordinates for a motor at standstill having a transformer with a high magnetizing current. A comparison of Fig. 24 and Fig. 26 will show how in the latter case both the starting current and torque are increased with large brush shift and how with the same voltage E, which determines the sparking, a larger torque can be obtained. This is of great importance, since it enables us to design the commutator with a higher voltage per bar than otherwise would be permissible. In special cases, where only small regulation is required, we can raise the voltage per bar considerably and thereby obtain a more economical design. The torque per ampere, however, is much less, due to the volt-amperes consumed in exciting the flux of the transformer and such motors are therefore only suitable for light starting duty, as required for blowers.



THE STATUS OF CARGO HANDLING IN AMERICAN MARINE TERMINALS

By James A. Jackson and Robert H. Rogers

Power and Mining Engineering Department, General Electric Company

The writers describe the awakening of the great terminals to the possibilities of machinery and treat of the differences in the problems that arise in the handling of bulk and package freight. The handling of free-flowing material is much farther advanced both mechanically and electrically than is package freight handling. The first part of the article describes the machines, ships and terminals developed for the handling of bulk freight. Very special machines have been designed for handling package freight. Considerable space is given to terminal accessories and particular stress is laid upon the economic benefits to be derived from a more general use of high grade machinery and operators in this wide-spread industry.—Editor.

This article is a digest of two papers by the above writers read before the International Engineering Congress in San Francisco in September, 1915. The natures of the papers are such that the salient points are readily combined in this article to indicate the status and trend of the methods and apparatus used in the handling of bulk and package cargoes in our Marine Terminals.

The last few decades have seen practically every great industry stimulated and intensified by the wholesale adoption of modern organization and modern mechanism.

No better example of this tendency can be found than in the improvements in the transportation of commodities between communities, by land and sea. Freight movements, in the broad sense, are carried out with marvelous dispatch, low cost and commendable safety, all making for an efficiency that does not leave much margin for improvement. Only very lately has this time and money saving movement invaded the terminals, which, heretofore, have seemed immune to the infection of modern tendencies.

The methods and machinery associated with bulk freight will be treated of first.

Freight can be classified into three main divisions, viz., bulk freight, live freight, and miscellaneous or package freight.

Bulk freight consists of free-flowing material, such as coal, ore, grain, certain fertilizers, etc., which can be transported and handled in bulk. The classification of bulk freight can be carried only two steps, viz., kind of material and weight; and this simplicity has been a large factor in the development of the rapid means now used for handling such freight.

The history of the handling of bulk or free-flowing freight makes interesting reading, and there is probably no better place to follow it out than on our own Great Lakes, where the development of rapid, economical handling has been carried to a very high degree.

In the early days, any kind of boat willing to take a bulk cargo was used, and loading and unloading was accomplished, largely, by men with wheelbarrows. As business increased, keen competition arose and the hand methods became too slow and too expensive. This condition spurred on the designers of boats, piers and handling machinery, with the result that specially designed bulk-freight boats began to appear; grain elevators, coal and ore piers, etc., arranged to load the boats from spouts, were built; steam-operated cable-type bridges replaced the wheelbarrows for unloading, thereby causing a revolution in the handling of bulk freight. Development along these same lines, with perhaps some radical improvements in unloading machinery, have continued unabated, until Lake boats now carry cargoes of 12,000 to 13,000 tons, which, in some instances, have been loaded at a maximum rate of over 22,000 tons per hour, and unloaded at the rate of over 2000 tons per hour. The cost per ton has been reduced from somewhere around $3.00 to about $1.07 and the time saved is enormous.

Bulk freight, by virtue of its free-flowing nature, lends itself very readily to mechanical handling, and machinery for handling it has been developed to a high degree of efficiency. It is beyond the scope of this paper to go into a detailed description of this apparatus, so only a broad view of some of the general types of machinery will be given.

The boats designed for this service, particularly on our Great Lakes, deserve special mention. Machinery and living quarters are crowded fore and aft, leaving the center free for freight. This central space is so designed, structurally, that it is entirely free from stanchions, bulkheads or obstructions of any kind—in other words, it is one immense bin, offering the greatest amount of freedom for the huge unloading buckets to pick up their load. The deck contains a continuous line of hatches, close enough together so that the jaws of a clean-up bucket will span from one hatch to the next, thus doing away with the necessity for hand shovelling.

Ocean going bulk freighters have been given the same special consideration with regard to maximum carrying capacity and special adaptation to the use of loading and unloading machinery. While their design is somewhat different from the Lake boats, the same requirements are met. In each case, ease of loading and unloading and capacity are given careful consideration.

Bulk-freight loading and unloading equipment varies according to the kind of material handled and the conditions to be met. For loading vessels, where storage facilities are desired as well, a typical arrangement consists of the bin-type pier. This consists of a pier entirely covered with storage bins. Railroad cars are run to the top of the bins and dumped directly into them. Numerous hinged spouts lead from the bottom of the bins to the hatches of boats lying alongside, and the material flows by gravity from the bins to the boats. Where storage facilities are not required, car dumpers represent an efficient type of loading apparatus. With this apparatus, gondola type freight cars are hoisted to the required height and turned over bodily, thus dumping their contents into a chute leading to the vessel's hatch. In other cases, where conditions justify it, continuous bucket or belt conveyors are used, which deliver material from stock bins to the vessels.

In general, the unloading of bulk freight is taken care of today by bridges, stiff-leg unloaders, towers, conveyors and combinations of the above devices. The first three of these devices use self-digging, self-dumping buckets of various capacities.

Bridges are of two general designs—the man trolley type, where the operator rides with the trolley and bucket, and the rope-operated type, where the operator and the machinery are stationary and the bucket travels across the bridge by a cable. Both accomplish the same purpose, which is to unload the boat and deliver the material to either the stock pile, railway cars, transfer cars or weighing larries. Buckets, with capacities of from ten to fifteen tons, are in use, which will handle a bucket load in a minute to a minute and a half, depending on where the load is being dumped. One bridge is in operation at a port on the Great Lakes, which has a maximum unloading capacity of 880 tons of coal per hour when dumping about 150 feet back from the boat.

Perhaps the most radical departure in unloading machinery came with the introduction of the stiff-leg pantograph unloader, generally known as the Hulett Unloader, and it makes an excellent example of what inventive genius and boldness will do under stress of pressure. These unloaders are built in the shape of a huge pantograph mounted on a track. The lower end of one of the vertical arms carries the bucket and the operator's cab so that the operator travels with his bucket and can work to the best advantage. On picking up a bucket of ore in the hold of the vessel, the bucket is raised, after which the entire pantograph travels backwards on tracks until the bucket is over a hopper, into which it is dumped. From the hopper, the ore goes to a weighing larry, and thence to the stock pile or a railroad car. The largest of these unloaders has a 15-ton capacity bucket, and a complete cycle of operation takes about one minute. By actual weight, the 15-ton bucket has picked up 21 tons at one grab. The capacity of the machine, under favorable circumstances, is somewhere around 900 tons per hour. The design of the bucket is such that it is very efficient in cleaning up material in the bottom of boats, thus doing away with hand shovelling.

Tower-type unloaders are usually used where great rapidity is necessary; they simply hoist the material out of the boat and dump it into a hopper with the shortest possible trip. Conveyors are generally used to take the material from the hopper to the storage pile. On account of the high speed, which, on some towers, is 20 seconds per round trip, the buckets are of moderate capacity, ranging from one to two and a half tons.

Conveyors are most generally used in connection with some of the above unloaders, except in handling grain, and in some special cases where conveyors load and unload directly in the boat.

Package freight requires entirely different treatment as the following shows:

Miscellaneous or package freight presents the most serious problem, as it forms the greater part of all freight, both in weight and bulk. The varying size, shape, strength and weight of packages make its classification an endless task; a single cargo often containing 50 to 100 thousand packages, divided into hundreds of different sizes, shapes and weights, and consigned to several hundred different parties. The transportation companies have an elaborate system of classifying this package freight to determine the freight charges, but such a classification would be of little value so far as handling is concerned. A classification based on size, weight and shape would be the logical way of attacking the problem.

The greatest advance toward dispatch and economy is attained in terminals by the use of mechanical devices for handling freight in and out of ships, to and from storage piles and warehouses, and into and out of cars. Many of the larger and more progressive ports are investigating and testing various electrical machines, and there is, at present, quite a commendable quantity of such machinery in the package freight work; but the surface has hardly been disturbed as yet, either in the design of such devices or in their general adoption. A brief review of progress, to date, along these lines is too important to be omitted.

Winches

Electric winches, single, double, and with one or two motors are in quite general use to supplant or supplement the ship's cargo winches. Head frames are provided on pier buildings to accommodate one whip, while the other is trained through the block or the ship's boom. Such apparatus provides greater speed, with greater safety, than is the case with steam, due to the uniform speeds, ample power braking and quickness of control that electricity provides. The most recent innovation in this country in this line is the use of a double portable master-controller carried by the winch operator, which gives him perfect control of both drums from any convenient position on the ship or elsewhere. The advantage of always having the draft in sight adds greatly to the dispatch, and this end can be attained in no other way.

Conveyors

Sectionalized portable conveyors of ingenious design and great utility are rapidly becoming common on the piers, where they are used to discharge from the decks of ships, lighters or barges to the pier or storage pile, without rehandling. A single whip, or two working in multiple from the same hatch, supply the conveyor, which makes the horizontal transfer at great speed. A remarkable feature of this type of machine is its reservoir capacity, or fly-wheel effect, by virtue of the receiving area provided through its constantly presenting new empty surfaces to the loading device. Power consumption is very low, and the machines are not expensive to install or limited in their application.

Cranes

While much relied upon abroad, cranes are but little used along our coasts in the package cargo handling. Some of the most notable are: The banana conveyor cranes at New Orleans (ten in number), each with a capacity of forty-two bunches per minute; the battery of cargo cranes at Balboa, Panama Canal; and the variety of types seen about New York Harbor, which, however, are largely used for lighters and barges.

So much depends upon the proper storage of cargo in ships, that much improvement in dispatch in that direction cannot be looked for with package freight.

One of the most striking advances in dispatch is found in the use of portable electric cranes for loading and unloading gondola and flat cars.

Another system which speeds up internal movements of freight is the trailer and tractor plan, whereby simple platform four-wheel trucks are towed in groups by an electric tractor, which carries no load itself. Trailers are provided far in excess of the number towed at one time, so that the tractor never waits for loading or unloading but picks up the trailers that are ready each time.

The pressure of factory production is as nothing compared with the pressure that traffic puts on the terminals. Each day's burden must be disposed of to make place for tomorrow's load. Like a man in a leaky boat, who must keep bailing or be swamped, the terminals are ever faced by the grave emergency of congestion, where dispatch is no more, and the trouble spreads to unbelievable distances along the arteries of commerce. The ample provision of varied and well-adapted machinery is the simplest method of attaining dispatch and retaining it, and it is the line along which most terminal progress is being made at the present time.

Industrial Trucks

These little machines are readily operated by longshoremen, and when the surrounding conditions are right, they cut the costs of moving freight to a marked extent. They work to best advantage on packages that can be readily handled by one or two men, because each piece has to be lifted on or off by hand, or by some other means. The distances must be rather great to make a good showing over hand trucks, and the approaches to loading and unloading points must be good.

Car Pullers

These machines may be vertical or horizontal; the vertical type can be set into a wharf, so that the drum only is visible. These pullers are very handy in minor car movements that would not warrant the calling of a switch engine. While the savings effected by these devices are indirect, they are nevertheless important. By moving cars from twenty to fifty feet, the cost of unloading or loading them can sometimes be cut in two; whereas, without this convenience, hand bars would have to be resorted to or work done in an inconvenient manner.

Portable Cranes

The type using a storage battery for its source of power has a wide range of utility, with its most marked economies in the loading and unloading of gondola and flat cars. The machine, being a combined crane and electric truck, makes one handling of iron pipes, structural steel, timbers, logs, etc., between car and storage pile and gives the added advantage of economical tiering. Its greatest usefulness lies in short lifts of heavy weights, with moderate distance transfers. Another type is actuated by means of a motor having a cable leading to a receptacle or service station forming a part of the power distribution system. This machine is not self-propelling and is used principally to give unrugged barges, floats or lighters a rapid and economical cargo-handling equipment equal to or better than that of ships. These devices make the best showing on quantities of freight in units up to 1000-pounds weight and requiring a considerable vertical movement. They discharge onto industrial trucks, trailers or hand trucks, or receive from them when loading boats.

Air, steam and water have been used to actuate cargo machinery, but just as electricity has superseded all other forms of power in all large industries, so will it be universally adopted for cargo handling machinery. Ship's boilers or donkey boilers should not be depended on for cargo handling machinery, as they have not proved reliable. Central station electric power is available in all port cities and is sufficiently reliable to meet the requirements demanded of it by dock machinery.

Direct current seems ideal for this service, as control and wiring problems are much simpler and more satisfactory than with alternating current. However, alternating current can be used satisfactorily, if necessary. With either direct or alternating current the most desirable voltage is from 220 to 250, from the standpoint of safety and insulation.

Terminal accessories are of great importance and interest, and while not directly involved, they influence greatly the safety, despatch and economy of great commercial centers.

At large progressive seaports, particularly at those whose facilities are in part or wholly publicly owned, many provisions for the safety of rolling and floating property are to be found, and are becoming considered in a greater degree. Among these tendencies may be noted: The deepening, widening and straightening of approach channels, with improved buoying and lighting by Federal authorities, is doing much to make safe and easy the arrival and departure of shipping. Compulsory piloting, while deemed a hardship by some navigators, tends toward reducing losses by collision or grounding, especially in ports where tidal and current conditions are severe and changeable. The gradual increase in the size and power of harbor tugs and the wonderful skill of tugmen are factors agreeable to all who go down to the sea in ships.

Dry docks and marine railways in sufficient numbers and of ample size inspire the confidence of foreign ship-owning companies and allow of periodical cleaning, even if no repairs are needed. While dry docks of enormous size are under construction and planned, there are many ships touching at our ports that could not possibly be docked on our coasts.

In ports, such as New York, where there is much car float traffic, recent improvements in floats and float bridges are notable additions to harbor and property safety features. The newer, all-steel, water-tight compartment floats, carrying twenty and more cars, are practically non-sinkable, and much more care and judgment is being used in the design and equipment of float bridges, thereby minimizing the damage to and loss of freight cars in this peculiar branch of traffic.

In terminal yards, the extensive and successful introduction of electric yard locomotives is largely accounted for by the reduction in damage to property by their use, where the entire work is largely starting, stopping and short shifting—requiring a maximum of control in order to avoid rough work. Clever and extensive yard-signal and switch-interlocking devices all lend their aid to the conservation of property.

Taking up the precautions necessary for the protection of employees, we come to a condition that has been neglected as far as terminals are concerned, though well advanced in almost every other industry. Such an advance is very desirable in this work, as great numbers of men are here employed in the most strenuous labor, under high pressure night and day, amid rapidly moving and swinging loads and under changing conditions, so that accidents of every kind are very frequent. The ambulance is as familiar a sight along the "beach" as the lunch wagon, largely because even the most obvious precautions are entirely neglected. If one should look for the one thing that best proves the backwardness of terminal development, it could be found in the circumstance under which men do their work.

Under ordinary accidents may be enumerated: Falling into hold; being hit by falling freight from sling or pile; being struck by broken gear, such as wire ropes, hooks, staging, etc.; injuries to feet and ankles, by hand and power trucks; torn hands, by bands and wire on packages and by box and bale hooks. Other accidents are all too frequent, such as falling into harbor; being suffocated by fumigating operations; being overcome by fumes, dust or poisonous exhalation from cargoes; scalding, from broken valves or steam pipes to winches; injuries due to shifting or banging cars without warning, etc. Stages are erected, to meet temporary conditions, on which men work, handling material under conditions that would not be tolerated in any other line of work.

Good drinking water is frequently not available or is not located nearby. Sanitary precautions and conveniences are absent or are of a low order. Poor food, improperly prepared, is served along the front from carts, under no supervision or inspection. The laborers frequent water-front saloons of the lowest order—unclean, unventilated and mismanaged.

Absence from work, due to accident or sickness, is hardly noticed, as most of the employees are "casual laborers" or shenangoes.

Therefore, it is clear that there is great necessity for improvement in the conditions surrounding the nearly a million terminal employees, and at least the ordinary, obvious precautions should be adopted to reduce the great economic losses now prevailing due to sickness and accident.

The matter of fire prevention is rapidly forging ahead, as is proven by the general introduction of large and efficient steam and steam-electric fire tugs in all ports of importance. Warehouses, piers and sheds are being piped for sprinkler systems, and the water-front skyline is becoming punctuated by elevated tanks for fire service duty.

Yard locomotives are being fitted with fire fighting apparatus, and being on the spot, often prevent serious fires among freight cars, inflammable freight and terminal properties. Smoking is universally prohibited in piers, and only recently have automobiles and power trucks been allowed access to these places. Electricity has largely superseded the open gas jet as a lighting medium, thereby adding another step in the right direction.

In the design of cargo ships, many improvements are manifest, looking to speedier discharging and receiving. The new cargo boats have large steam winches in greater numbers than formerly prevailed, and well they may, for the standby charge on a moderate-sized ship runs from $300 to $500 per day, and money cannot be better invested than in facilities tending to shorten the stay in port. Modern coastwise ships are provided with more and larger side ports. It is a new and good practice to provide an elevated position for the cargo winches, leaving a clear deck for deck loads and placing the winch man in a more commanding position. Hatch covers have come in for their share of attention, and the old standard strongback construction, with hand boards, is giving way to hinged steel trap-doors of clever design that are quickly handled by the cargo winches and provided a certain closure when at sea.

The holds of the newer ships are free, or nearly so, from the stanchions that so profusely stud the working spaces of the older ships. The former tendency to specialize ships for certain cargoes has not been found expedient, as commerce does not usually provide similar cargoes both ways, consequently the normal cargo carrier is almost a universal ship. Donkey boilers are now of more liberal capacity, as in the older ships much delay is caused by lack of steam for all the winches without firing up the main boilers.

In review of the whole field the costs of handling freight through terminals is enormous as compared with the cost of hauling the same freight from place to place. The reason for this high cost is the universal use of manual labor, which has been retained largely because it is plentiful in the coast cities. The farmer has not adopted his wonderful machinery, to the almost entire exclusion of manual labor, from any love for machinery, but from dire necessity. His load factor is low, for his machinery is of special nature for seasonal work, a couple of weeks per year being an average condition. With the terminals, the load factor could be nearly 100 per cent, but not being forced into its use by the absence of good labor, the terminals have been satisfied to work along the old lines. The use of machinery well adapted for the work has in many cases cut the labor costs to one fourth the figure that formerly prevailed.

Broadly speaking, the future trend is toward more machinery for cargo handling. Three important steps must be covered in order to bring about the adoption of machinery:—First, the educating of steamboat companies, stevedores and labor unions to see its advantage; second, the design of vessels and piers to be especially adaptable to the use of machinery; third, a systematic scientific study of freight and freight movements.

THE SALINE METHOD OF WATER FLOW MEASUREMENT AS USED IN THE ACCEPTANCE TEST OF A PUMPING PLANT

By W. D. Peaslee

Consulting Engineer, Portland, Oregon; Department of Electrical Engineering, Oregon Agricultural College

The saline method of water flow measurement discussed by the author is accurate yet inexpensive, and may be applied to practically any turbine or pump installation. The apparatus required is relatively simple and the chemical operation can be performed without the aid of an expert chemist. The author has described the method very clearly and has given examples which assist the reader to readily comprehend it. Several large operating companies are using this process for measuring the water taken by their power turbines and mention of these has been made in the technical press. Among these companies are the Alabama Power Company and the Pennsylvania Water and Power Company. In the *Electrical World*, July 31, 1915, the equipment was described.—Editor.

The great number of pumps used in irrigation and the utilization of numerous small water powers in the West has caused a demand for a method of water flow measurement that while accurate and simple can, at the same time, be carried on at small expense. The Saline method as developed by the author to meet the conditions has been so successful that a description of the procedure and the results of a recent acceptance test on a pumping plant may be of interest.

The description of the method has been published (*Journal of Electricity, Power and Gas*, August 21 and 28, 1915) but the main features will be described herein for the benefit of those not familiar with it.

Theory

If we take a large volume of pure water and add to it a small amount of chemical solution, such as common salt ($NaCi$), of known saturation, since the amount of chemical in the two cases is the same, we can write:

$$V_0\,S_0=(V_2+V_0)\,S_2,\ \text{or}\ V_2=V_0\left[\frac{S_0}{S_2}\right]-V_0 \qquad (1)$$

V_0 = Volume of dosing solution.

V_2 = Volume to be measured.

S_0 = Salt per unit volume in dosing solution.

S_2 = Salt per unit volume in mixture.

The solution of this equation will then give the volume of pure water to which the chemical solution was added. If, however, this volume to be measured contains some of the chemical used in the dosing solution this content must be determined. Calling this S_3 we can then write:

$$(V_0\,S_0+V_2\,S_3)=(V_0+V_2)\,S_2,$$

or

$$V_2=\left[\frac{S_0-S_2}{S_2-S_3}\right]V_0 \qquad (2)$$

S_3 = Salt per unit volume in water to be measured.

These equations result simply from the fact that the total quantity of chemical is the same after mixture as before.

Now referring this condition to a stream of constant flow, if the solution be introduced at a definite constant rate q, and thorough mixture be secured, it is evident that the relation between the volume of water in the stream, passing any section in any given time, and the volume of dosing solution introduced in that time is indicated by the above equation. Expressing these quantities in terms of discharge the equation becomes:

$$Q=\left[\frac{S_0-S_2}{S_2-S_3}\right]q \qquad (3)$$

Q = Discharge of stream in any convenient units.

q = Dosing rate in the same units.

S_0 = Salt per unit volume in dosing solution.

S_2 = Salt per unit volume in stream after dosing.

S_3 = Salt per unit volume in stream before dosing.

Now if we wish to measure the flow of a stream such as the discharge of a pump, where the pump is used as the mixing agent, with the dosing station near the intake and the sampling station near the discharge, we find that the discharge of the pump includes the dosing flow, and the equation representing the discharge becomes:

$$Q+q=\left[\frac{S_0-S_3}{S_2-S_3}\right]q \qquad (4)$$

If the water be initially free from salt the analysis shows $S_3=0$ and the discharge is then shown by the equation:

$$Q+q=\left[\frac{S_0}{S_2}\right]q$$

at the sampling station, and

$$Q=\left[\frac{S_2}{S_0}\right]q-q$$

at the dosing station.

The validity of this relation depending in no way on the cross section area of the stream or on any determinations of water velocity, we have a method which for its accuracy depends on the degree of accuracy with which we can determine the following conditions:

1. Determine the amount of salt per unit volume in the samples taken.
2. Determine and maintain a constant dosing rate.
3. Secure a perfect mixture of the dosing solution and the water of the stream to be measured.

Method

Analysis.—Taking these requirements in the order given it is obvious that a quantitative gravimentric analysis of the samples will give the required information. This analysis, however, is a difficult one and requires the services of an expert chemist.

If the dosing solution be common salt, ($NaCi$), we can determine in a relative way the amount of salt per unit volume in each sample by precipitating the salt with silver nitrate ($AgNO_3$). The volumes of the silver nitrate solution required to precipitate the salt in the samples will be in the same ratio as the total salt in the samples. Therefore, if we treat equal volume samples, the volumes of silver nitrate required to precipitate the salt in the various samples will be in direct proportion to the salt per unit volume in the samples.

In the practical use of the precipitation method it is necessary to use a reagent as an indicator to show when the precipitation is complete by the change of color of the solution. Potassium bichromate is the reagent commonly used. In this case a certain excess of the silver nitrate solution is required to act on this indicator to change its color and, in very accurate work, account must be taken of this. This excess has been found to depend, for all practical purposes, on the volume of solution treated and the amount of indicator present. Treating then equal volumes of the samples, and using in them equal volumes of the indicator, we will find the excess the same in all cases; and, as will be shown, it will cancel out of the equation.

Thus when the samples treated are of the same volume and the amounts of indicator are the same in each, the following conditions are fulfilled.

1. The volumes of silver nitrate required to precipitate the salt in the different samples are in direct proportion to salt per unit volume in the samples.
2. The excess silver nitrate required to react on the indicator is the same in each case.

Bearing these points in mind, we can rewrite equation (4) as follows:

$$Q+q=\left[\frac{(V_0+X)-(V_3+X)}{(V_2+X)-(V_3+X)}\right]q=\left[\frac{V_0-V_3}{V_2-V_3}\right]q \qquad (5)$$

V_0 = silver nitrate to precipitate the salt in one litre of dosing solution.

V_2 = silver nitrate to precipitate the salt in one litre of sample after dosing.

V_3 = silver nitrate to precipitate the salt in one litre of sample before dosing.

X = Excess silver nitrate to react on indicator in each case.

$Q+q$ = Stream flow in litres per second at sampling station.

q = Dosing rate in litres per second.

Remembering that the volume of silver nitrate used to precipitate the salt in the solution and change the color of the indicator in each case represents (V_0+X), (V_2+X) and (V_3+X), respectively, we see that the above equation is still valid when for V_0, V_2, and V_3 we substitute the volumes of silver nitrate required to precipitate the salt and change the color of the indicator. Experiments have shown that this excess is so small that it is almost impossible to detect it; and this fact renders the practical use of the method simple as will be shown later, since titrations can be made of dilutions and concentrations of the samples and the results reduced to the original sample strength with negligible error. A further discussion of this analysis will be taken up later.

Dosing.—Turning now to the second requirement it is an easy matter to secure a constant flow of dosing solution by means of a standard orifice calibrated with the dosing solution and used under constant head. Calibration of the orifice with any pure water is accurate within an entirely negligible error. The device shown in Fig. 1 has been used with excellent results. It consists of a box with a long weir on one side and a pipe leading from the bottom. Caps are provided for the lower end of the pipe, each of which has a different sized hole, thus giving different discharges with the same equipment. The solution is allowed to flow into the weir box, part flowing out through the pipe as the dosing solution and the rest flowing over the weir to be returned to the supply tank. By keeping the head over the weir constant by means of a hook gage the head over the orifice in the pipe cap is kept constant and a uniform dosing rate is secured. The different orifices are calibrated, preferably with the dosing solution used, and have been found very accurate. The use of the weir has been deemed advisable as it acts as a guard against momentary inattention on the part of the operator attending to the maintenance of the water level. If, for any reason, the flow into the device from the storage tanks is increased the weir will prevent any great increase in head over the orifice; and, within commercial limits, will hold the dosing rate constant over a considerable range of inflow from the tanks.

With this device it has been found easy to maintain and know the dosing rate over wide ranges within an accuracy of better than 0.1 per cent. In the dosing of large streams, where the dosing solution might be pumped into a large perforated pipe, other means may be devised for measuring and maintaining the dosing rate.

Mixture.—A great many tests have been conducted to determine the requirements for securing a perfect mixture and it is fortunate indeed that this requirement is so easily secured.

It has been found that any pump, rotary or reciprocating, will effect a perfect mixture, as will of course any water wheel or turbine.

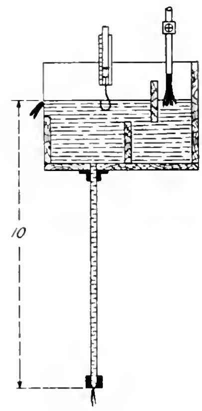


Fig. 1. Equipment for Securing Constant Dosing Rate

A pipe discharging into a basin or ditch also gives a perfect mixture and in a flume two baffles placed as in Fig. 2 have proved entirely efficient in this respect. A small stretch of rapids or a water fall has in small streams proved effective and should, with proper dosing methods, be found effective in large streams.

Thus it is seen that the three requirements mentioned can be easily and cheaply met in almost all cases.

Equipment.—The equipment required, besides that used in introducing the dosing solution, is simple and inexpensive. The manipulation is of such simplicity that untrained operators can, by following directions, secure reliable and consistent results.

The dosing rate, and so the amount of salt solution required to run a given test, depends on the rate of flow of the stream to be measured, the governing requirement being that enough salt is secured in the sample to give accurate results. That is, the volume of silver nitrate required to precipitate the salt in the sample must be great enough to be measurable to the degree of accuracy required of the test. With a magnifying glass a burrette can be read to 0.01 cc., so ten cc. can be measured to within 0.1 per cent. It has been found from practice that using practically saturated salt solution and the strength reagent hereinafter described, a dosing rate of about 15 gallons per minute for each 100 second feet of flow to be measured gives very good results. It should be remembered that the particular value of the dosing rate is not material as long as it is accurately known and maintained constant. Dosing need be continued only long enough to insure that the salt solution has reached the sampling station. When samples are taken dosing may be stopped, so the amount of salt required is not so great as would at first be supposed.

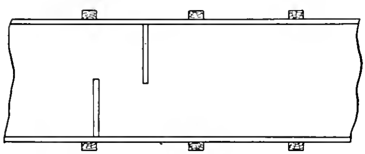


Fig. 2. Mixing Baffles in Flume to Insure Thorough Mixing

Thus to make a ten minute test on a flow of approximately 100 second feet requires about 150 gallons of salt solution.

In the case of a turbine where the dosing solution is introduced in the penstock and the sample taken in the tail-race it requires only a few moments for the salt to appear at the discharge and so this amount of salt solution will give several determinations. As it is seldom necessary to locate the dosing and sampling stations at any great distance apart, the salt dosed in will appear very quickly at the sampling station; so the individual determinations need not cover more than a few minutes in most cases.

If the rate of flow is not constant it must be remembered that the sample indicates the rate of flow at the instant the water from which it is taken was passing the dosing station.

Samples should be taken of the stream before dosing, the dosing solution, and the stream after dosing, being kept in clean jars or bottles with effective stoppers. After sealing, the jars should have their stoppers dipped in hot pitch or wax to insure thorough sealing and prevent evaporation of the sample before it can be tested. Of course if the analysis is to be performed at once this precaution is unnecessary.

For carrying out the test by the precipitation method the following equipment will be required:

3 Calibrated burrettes, 25 or 50 cc.
1 Burrette stand.
1 Calibrated one-litre flask.
1 Magnifying glass for reading burrettes.
2 Two-litre beakers.
6 200-cc. beakers.
1 White porcelain plate, 6 in. by 6 in.

Two or more evaporating lamps, bunsen burners or similar lamps.

About 200 cc. of normal potassium bichromate solution.

About one litre of normal silver nitrate solution.

Distilled water; about two gallons will be required for each test.

Procedure.—Be sure that all apparatus is clean. Place in one of the burrettes a solution of potassium bichromate made up of about ten parts of distilled water and one part of the normal solution.

Prepare in one of the two litre beakers a solution of silver nitrate, about one part normal silver nitrate solution and ten parts of distilled water. Be sure to prepare enough of this solution, as the same solution strength must be used throughout the test. About one litre of the dilute solution is enough for any ordinary set of samples. This solution is to be used in the second burrette for precipitation of the salt in the samples.

By means of the third burrette, measure accurately into the calibrated litre flask 10 cc. of the dosing solution and add distilled water to make up the litre; then measure out accurately 10 cc. of this solution into one of the small beakers. Add to this 1 cc. of the potassium bichromate solution from the first burrette; then add drop by drop the silver nitrate solution from the second burrette. Continue this, agitating the treated sample constantly, until the first persistent brownish color appears. A little practice will enable one to detect this change with great delicacy. The white porcelain plate should be used under the beaker to assist in detecting this color change. Since, due to the dilution of the sample, the solution in the beaker contained one ten-thousandth of the salt in a litre of the dosing solution, we multiply the volume of silver nitrate used by 10,000 and the result is V_0 which is proportional to the amount of salt in one litre of the dosing solution. The dilution of the dosing solution is simply to avoid using an excessive amount of the silver nitrate to precipitate the salt in this strong solution.

Evaporate one litre of the sample of the water before dosing to 10 cc., add 1 cc. of the potassium bichromate solution and titrate as described above. Since this sample contained all the salt in one litre of the water before dosing, the volume of silver nitrate used is proportional to the salt in one litre of the water before dosing, so is V_3.

Evaporate 50 cc. of the sample taken after dosing to 10 cc. and titrate as above described. Since the 50 cc. sample contained one-twentieth of the salt in a litre of the water after dosing, we multiply the volume of silver nitrate used by twenty and the result is V_2, which is proportional to the salt in one litre of the water after dosing.

Always use the same burrette for silver nitrate solution and when using equipment for different solutions be sure and clean thoroughly before proceeding from one to the other.

The discharge when Q and q are in litres per second is then obtained from equation (5).

It has been found that the use of ordinary commercial rock salt for making up the dosing solution is entirely satisfactory as the error introduced by its use is less than 0.1 per cent.

A large number of tests on discharges ranging from a few gallons per minute to 150 second feet, and under widely variant conditions of mixture, indicate that with proper care this method will give results within 0.1 per cent consistently; and, with a very little practice any ordinarily intelligent operator can become expert in the performance of the test.

Conductivity Method

At this point in the investigation it became evident that while the method as developed was extremely accurate and reasonably easy of manipulation, there was need of further simplification of the method of analysis. The attention of the writer and staff was then turned to the investigation of the relation, in electrolytic solutions, between the electric conductivity and the salt content of the solution.

Working on the fact well established by Kohlrausch that the conductivity of pure water containing any electrolytic substance in solution is due almost entirely to the dissolved substance and only in negligible degree to the water itself, it was found that with a dilute solution the conductivity is almost exactly proportional to the amount of the substance dissolved in the water. In other words the conductivity is proportional to the number of ions present as long as they are not so numerous as to prevent each ion moving in its own free path without collision with any other ion. Thus with proper precautions the electric conductivity is a measure of the amount of salt in the solution.

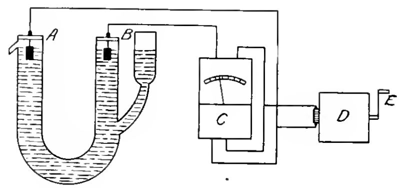


Fig. 3. Apparatus for Electrolytic Determinations

After considerable work in the field and laboratory the instrument shown in Fig. 3 was designed. A U-tube is arranged as shown with an overflow so that the height of liquid in it is always the same. A and B are bright platinum electrodes, C is a conductivity meter, and D is a continuous current hand driven dynamo, driven through gears by the crank E. The U-tube is arranged so that when in place the distance through the electrolyte between the electrodes is always the same.

Making the tube long enough so that the resistance of the sample is much greater than the resistance of the lead-in wires and the current path near the electrodes, the formation of a small amount of gas on the electrodes has an entirely negligible effect on the resistance of the total circuit and further the electrodes are of such design as to reduce this effect to a minimum. They are made long and consist of radially spaced leaves, giving great surface. Also as a result of this design any bubbles formed rise in the tube and escape, so that they cannot pass down into the sample and increase its resistance. Since it takes some time for gas to form on such electrodes in dilute solutions and the current need be applied for only three or four seconds to obtain a reading, it will be readily appreciated that the gas formed is entirely inappreciable in effect. It has been found that with ordinary laboratory methods of measurement the effect of the gas is not noticeable within the time required to secure a reading, using the electrodes described.

The counter electromotive force of polarization has been found, in the case of bright platinum electrodes and dilute salt solution, to be close to two volts. This would of course increase the apparent resistance of the sample

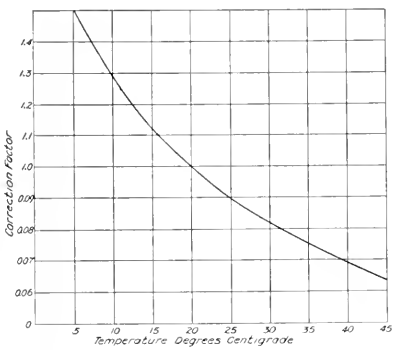


Fig. 4. Curve of Temperature Correction Factor for Conductivity of Dilute Aqueous Salt Solutions

and so decrease the apparent conductivity and is therefore taken into account in calibrating the instrument.

The dynamo may be of the slipping clutch type which will give a constant voltage when the crank is turned above a certain speed or the conductivity meter may be arranged, as is the case with some meggers on the market to indicate conductivity regardless of the voltage applied.

In using the meter care must be taken to wash the tube thoroughly after each test with distilled water and to dry it to preserve the integrity of the next sample.

The effect of temperature on the conductivity of such solutions is well known; the curve of correction factors for temperature of the samples is shown in Fig. 4. In using the equipment a thermometer is placed in the filling tube to indicate the temperature of the sample. The reading of the conductivity meter is then multiplied by the correction factor corresponding to the temperature of the sample which gives the conductivity at 20 deg. C. and all readings are reduced to conductivity at this temperature.

This entire equipment can be put up in a reasonable size case, making a compact and portable set.

The instrument is calibrated as follows: several standard salt solutions are made up from 0.01 to about 1.0 gram equivalents per litre of salt content and brought to 20 deg. C. At this point the relation between conductivity and salt content is known. The conductivity of these samples is then measured and the results plotted as shown, Fig. 5. This gives a calibration curve between readings of this particular instrument and the salt content of any sample tested within its range. This curve takes into account the cross section variation of the U-tube, the polarization and gas effects, and any individual characteristics of the meter and dynamo.

Fig. 5 is the actual calibration curve used in some of the experimental work, employing a potentiometer to measure the resistance of the sample and computing the conductivity from the resistance readings.

The plant tested was one installed to drain a 1000 acre "beaverdam" lake at Gaston, Oregon*. The pump is a 30-in. vertical centrifugal pump, rated at 32,000 gallons per minute at eight feet normal head. It is driven through a friction clutch and bevel gears by a synchronous motor with the following rating: ATI 14-pole, 180 kv-a., 514 r.p.m., 2200 volt. The equipment is standard in every respect and is equipped with overload and low voltage protection and arranged to be operated by unskilled operators. All the electrical equipment was furnished by the General Electric Company.

In making the test the input was measured by means of a calibrated recording three-phase wattmeter and the discharge was measured by the method described above, using the dosing equipment shown in Fig. 1.

Four five-minute runs were made and the dosing solution introduced in each run at the rate of 0.775 litres per second (12.3 gallons per minute) in each case. Samples were taken at the pump discharge as de-

* This plant was described in detail in the *Journal of Electricity, Power and Gas*, September 12, 1914.

scribed previously and using the titration the following values were secured:

Input to motor (Fig. 6), 80.9 kw.

Total head pumped against, 8.04 feet.

Efficiency of motor at above input, 94.1 per cent.

The volumes of silver nitrate required to titrate the dosing solution sample as described above, determined independently by four different observers:

92.1
92.08
92.04
91.94

Average 92.0425

V_0 then is $92.0425 \times 10{,}000 = 920{,}425$.

V_3 determined as described was 16.1.

In the titration of the discharge samples, two determinations were made for each run as follows:

Run 1 18.813 — 18.806 ave. 18.8095
Run 2 18.804 — 18.811 ave. 18.8075
Run 3 18.796 — 18.805 ave. 18.80
Run 4 18.811 — 18.808 ave. 18.8095
Average of all determinations 18.8066

V_2 then is $18.8066 \times 20 = 376.132$.

Then from equation (5)

$$Q+q=\left[\frac{920{,}425-16.1}{376.132-16.1}\right]\times 0.775=$$

1981.42 litres per second = 69.963 second feet.

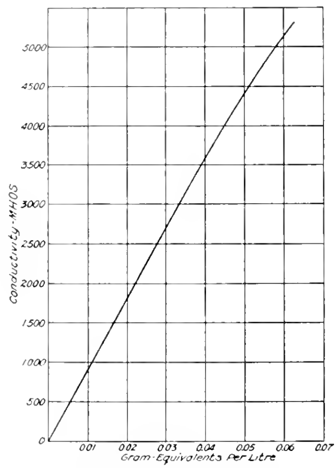


Fig. 5. Calibration Curve Tube No. 4, Electrodes No. 2 Used with Potentiometer

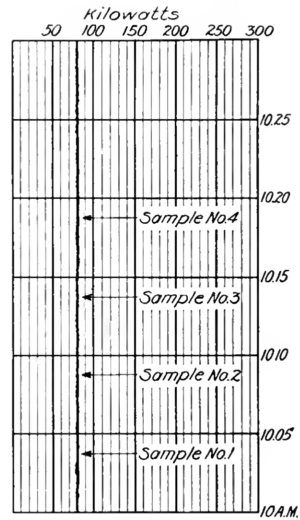


Fig. 6. Input to Motor Indicating Time of Taking Samples

The pump output then is

$$\frac{69.963\times 62.43\times 8.04\times 0.746}{550}=47.65 \text{ kw.}$$

The pump input is $80.9\times 0.941 = 76.1$ kw.

The pump efficiency $47.65/76.1\times 100 = 62.6$ per cent.

The remarkable degree to which the different determinations check shows the accuracy of this method.

250 gallons of salt solution were used in this test and the total expense was $48.60 for labor and materials.

So far as the writer is aware, there is no other method by which such a test could be made to the degree of accuracy required of an acceptance test at this low cost.

THE ATTITUDE OF THE PUBLIC TOWARD ELECTRIC RAILWAYS

By C. E. Eveleth

Commercial Engineer Railway Equipment, General Electric Company

That good relationships should exist between the public and those conducting the affairs of our public utilities is essential—if the best and most economical results are to be obtained. To help bring about good relationships the American Electric Railway Association has adopted a "Code of Principles," which we publish in this article. This code has special value as representing the carefully considered work of those representing the public utilities.—Editor.

It is of vital importance to all of us who have at heart the best interests of the communities in which we live that every industry tending to promote public welfare, make living conditions better, and improve values of property and business, should receive intelligent support. The electric railways of this country, with all they have done in these directions, certainly deserve commendation and any assistance that can be rendered.

How prone we are to sit back when our local railway is being knocked by some unthinking individual, who perhaps does not appreciate the existing conditions with which the railway management is confronted. This is not right. A few remarks outlining what the electric railways have accomplished, the difficulties — financial and physical — under which they work, and the ever present frailty of the human element, a word of commendation regarding the way the service was restored after some recent storm would help to set things right and give the thoughtless critic something to consider.

Once in a while it does no harm to shake ourselves together and take a fresh start, especially in any matter which involves public duty or personal inconvenience. We need to do this to get out of the practice of the little girl's father in the trite old story. She was asked if her father was a Christian. "Yes," she said, rather dubiously, "he is, but he isn't doing much at it."

The American Electric Railway Association has adopted a Code of Principles to which we can all subscribe. The code follows and is published anew that we may all do something "at it," say something to make the critics think, labor with our friends in the Common Council, explain the conditions, limitations and needs on every occasion that presents itself, most particularly at every contact with legislators and public officials. A clear understanding by everyone is all that is required to bring about satisfactory conditions to both the public and the companies.

CODE OF PRINCIPLES

(1) The first obligation of public utilities engaged in transportation is service to the public.

The first essential of service is safety.

Quality of service must primarily depend upon the money received in fares. For this reason it is necessary that the rate of fare should be sufficient to permit the companies to meet the reasonable demands of patrons and to yield a fair return on a fair capitalization.

(2) Regulated private ownership and operation of electric railways is more conducive to good service and the public welfare than government ownership and operation because the latter are incompatible with administrative initiative, economy and efficiency, and with the proper development of cities through the extension of transportation lines. The interests of the public are fully protected by the authority given to regulatory bodies.

(3) In the interest of the public and good service local transportation should be a monopoly and should be subject to regulation and protection by the state rather than by local authorities.

(4) Short-term franchises are detrimental to civic welfare and growth because they ultimately check the extension of facilities and discourage good service.

(5) In order to render good service, electric railways must be allowed to earn a fair return on a fair capitalization, and the foundation for this result will be obtained, if the issuance and sale of securities representing such fair capitalization shall be legally authorized on such terms as will produce the requisite funds.

(6) Securities which have been issued in accordance with the law as it has been interpreted in the past should be valid obligations on which an electric railway is entitled to a fair return.

(7) The relation of adequate wages to efficient operation should always be recog-

nized, but electric railways, being public servants regulated by public authorities, should be protected against excessive demands of labor and strikes.

(8) The principle of ownership of securities of local companies by centralized holding companies is economically sound for the reason that the securities of the latter have protection against the varying business conditions of a single locality or company and because money for construction and improvements can thus be more readily obtained.

(9) In the appraisal of an electric railway for the purpose of determining reasonable rates, all methods of valuation should have due consideration.

(10) Full and frank publicity should be the policy of all transportation companies to the end that proper information may be available to the investor and the public.

The following recommendations concerning the establishment of a Bureau of Public Relations are worthy of note:

PUBLICITY AND EDUCATIONAL PLANS

We recommend the establishment under the auspices of the American Electric Railway Association of a BUREAU OF PUBLIC RELATIONS.

This Bureau to have a competent Director with the necessary assisting employes. The work of the Bureau to be under the general supervision and direction of the Committee on Public Relations of the American Electric Railway Association, with the power in that committee to appoint, either from its own membership or outside, Sub-advisory Committees, who will co-operate in the work of the Bureau.

The Committee on Public Relations to appoint the Director of the Bureau and his employes and to fix their compensation; also, so far as practicable, to make up in advance the budget of the Bureau's expenditures.

The work of the Bureau to be along the lines suggested from time to time by the Committee on Public Relations and to cover particularly the following:

I

The dissemination of information and literature on subjects of general importance to Public Service Corporations, including particularly:

(a) Relations with employes.
(b) Public relations.
(c) Regulatory laws and commissions.
(d) Publicity concerning facilities, service and accounts.
(e) Rate making.
(f) Depreciation and reserve accounts.
(g) Taxation.
(h) Franchises.

The above contemplates close association between the Bureau and Member Companies of the Association as to the furnishing and distribution of reports, information and statistics, and it is suggested that each Member Company be requested to designate a representative through whom correspondence with the Bureau may be conducted.

II

Co-operation with similar committees of other Public Service Associations.

III

Influencing the sources of Public Education, particularly by:

(a) Lectures on the Chautauqua circuits.
(b) Formation of a committee of prominent technical educators to promote the formulation and teaching of correct principles and public service questions in technical and economic departments of American colleges through courses of lectures and otherwise.
(c) Formation of a similar committee in each of the great technical societies, such as the electrical engineers, mechanical engineers, civil engineers, chemists, hydraulic engineers, telephone engineers.
(d) Formation of a similar committee to work in connection with the various civic and economic societies.
(e) Discussions at institutions of learning and Y. M. C. A.'s on subjects pertinent to the relations between the public and service corporations.

IV

The publication in magazines and periodicals of signed popular articles on public service questions by prominent workers in the electric railway industry.

V

Newspaper advertising when desirable and financially possible.

In order to provide the necessary funds for carrying on this work it will be necessary to raise a sum of money, to be subscribed and paid in installments as called for by the committee. All monies to be expended under the direction and upon the authority of the committee.

Obviously the ability to carry out the extensive program here outlined will depend upon the raising of sufficient money and the wise expenditure thereof. Your committee believes that much of the work outlined can be accomplished through the assistance of Advisory Committees and at comparatively little expense. Even if the funds available should not permit the carrying out of the full program, much good may be accomplished if only certain phases of the work are undertaken. Your committee has enumerated advertising as one field of work and believes in the effectiveness of this method of reaching the public but it is convinced after careful consideration that to carry on any comprehensive program of advertising would involve the employment of more money than can probably be raised and it, therefore, recommends the use of advertising only for specific purposes and on special occasions where conditions would seem to justify the expenditure.

THEORY OF ELECTRIC WAVES IN TRANSMISSION LINES

Part II

By J. M. Weed

Transformer Engineering Department, General Electric Company

In the first article of this series, appearing in the last issue of the Review, fundamental equations were developed for the propagation of waves in a transmission line, and detailed consideration was given to the reflections and resulting oscillation produced when an open ended line is switched onto a generator of zero impedance. The present installment discusses the case where the line switched on is closed or short circuited at the end, and then considers the effect of opening the switch under various conditions, 1st, when the line is open, 2nd, when it is short circuited, and 3rd, when supplying current to inductive receiving apparatus.—Editor.

If we consider now the case of switching on a line which is closed at the end, we find that the charging wave enters the line just as in Fig. 2. When this wave reaches the further end of the line, the counter e.m.f. due to the current I entering new inductance vanishes, since this current occupies the entire inductance of the line, flowing from the end of the line into the ground. The voltage E produces an additional current into the ground, resulting in a wave of discharge entering the line from the grounded or closed end. This wave of voltage $E' = -E$ and current I', such that

$$I'L\,(-dx) = -E\,dt \qquad (41)$$

which may be called the reflected wave, is superposed upon the condition of voltage E and current I. The resultant condition is zero voltage and current $2I$. (See Fig. 10.)

When this reflected wave has returned to the generator, we find the entire line at zero voltage, with current $2I$ flowing. Another charging wave will now enter the line, which, superposed upon this condition, gives a condition in the line of voltage E and current $3I$. The reflection of this wave at the end of the line gives zero voltage and current $4I$. The current thus goes on building up in wave steps of I, while the voltage alternates between E and zero.

It is instructive to note the wave steps of energy in this case also. In the first entering wave, the energy per unit length is

$$W = \frac{L\,I^2}{2} + \frac{C\,E^2}{2} = L\,I^2 \qquad (42)$$

After reflection has taken place, the energy per unit length, which is the sum of the energies of incoming and reflected waves, is

$$W + W' = \frac{L\,(2I)^2}{2} = 2L\,I^2 \qquad (43)$$

Until the time that the reflected wave reaches the generator, the power taken from the generator is uniform, with the value (see equation 13)

$$P = I^2\sqrt{\frac{L}{C}} = I^2 Z \qquad (44)$$

With the entrance of the second charging wave the energy per unit length of the line becomes

$$\frac{L(3I)^2}{2} + \frac{CE^2}{2} = 5L\,I^2 \qquad (45)$$

And since the energy already in the line before this wave enters is $2L\,I^2$, the energy entering with this wave is

$$5\,L\,I^2 - 2\,L\,I^2 = 3L\,I^2 \qquad (46)$$

The power absorbed from the generator by this wave is

$$3\,L\,I^2\frac{1}{\sqrt{L\,C}}=3\,I^2\sqrt{\frac{L}{C}}=3\,I^2Z \qquad (47)$$

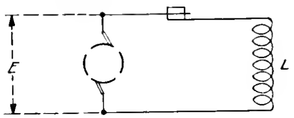


Fig. 1

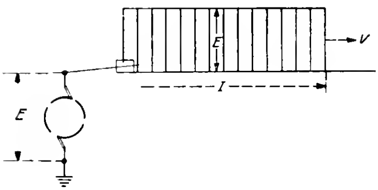


Fig. 2

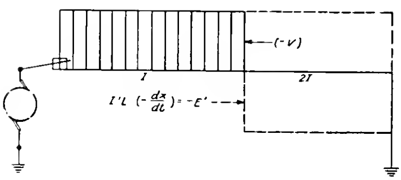


Fig. 10

After reflection of the second charging wave, the energy in the line per unit length is

$$\frac{L\,(4I)^2}{2}=8\,L\,I^2 \qquad (48)$$

When the third charging wave enters the line, the energy per unit length becomes

$$\frac{L\,(5I)^2}{2}+\frac{C\,E^2}{2}=13\,L\,I^2 \qquad (49)$$

The energy entering with this wave is

$$13\,L\,I^2-8\,L\,I^2=5\,L\,I^2 \qquad (50)$$

and the power absorbed from the generator by this wave is

$$5\,L\,I^2\frac{1}{\sqrt{L\,C}}=5\,I^2\sqrt{\frac{L}{C}}=5\,I^2Z \qquad (51)$$

etc.

It will be interesting now to make a comparison of the behavior of this transmission line with that of the inductance of Fig. 1. Counting time from the instant when the switch is closed, we note that the power delivered to the line from time $t=O$ till time $t=2T$ is IE, that delivered from time $t=2T$ till time $t=4T$ is 3 IE, that delivered from time $t=4T$ till time $t=6T$ is $5IE$, etc., so that, counting to the end of any period $2T$ during which the power is constant, the total energy delivered is the same as though the power were increasing uniformly, the rate being

$$P=t\frac{IE}{T} \qquad (52)$$

Substituting the values

$$I=E\sqrt{\frac{C}{L}} \text{ and } T=X\sqrt{LC},$$

from equations 8 and 16 we have

$$P=t\frac{E^2}{XL} \qquad (53)$$

where XL is the total inductance of the line.

For the concentrated inductance of Fig. 1, we will integrate equation (1), whence

$$Li=Et \qquad (54)$$

$$i=t\frac{E}{L} \qquad (55)$$

and

$$P=iE=t\frac{E^2}{L} \qquad (56)$$

This power is all stored in the inductance, so that the total energy in the inductance at time t is

$$W=\frac{E^2}{L}\int_0^t t\,dt=\tfrac{1}{2}\,t^2\frac{E^2}{L} \qquad (57)$$

Equation (57) may also be obtained directly by substituting the value of i from equation (55) in the equation

$$W=\frac{L\,i^2}{2} \qquad (58)$$

Equation (56) for the concentrated inductance corresponds with equation (53) for the transmission line. Equation (57) may be checked for the transmission line, at the end of any period $2T$ as follows. For $t=4T$, the total energy in the transmission line from equation (48) is

$$W=8X\,LI^2 \qquad (59)$$

whence

$$W=8X\,CE^2 \qquad (60)$$

and since

$$\frac{1}{2}t^2 = 8\ T^2 = 8X^2\ LC \qquad (61)$$

we have

$$W = \frac{1}{2}t^2 \frac{E^2}{XL} \qquad (62)$$

We have seen that, when suddenly switched onto a generator, a transmission line of indefinite length acts as a pure resistance, taking constant power from the generator; and that an open ended line acts like an inductance and a capacity in series, first taking power and then returning power, except that the giving and receiving of power are at uniform rates, instead of sinusoidal; while a line with its further end grounded, or closed, acts like a pure inductance, except that the power instead of increasing uniformly increases by a series of equal steps. In all cases, the entire energy which has been received by the line and not returned is stored up in the magnetic and the electric fields. This applies, of course, only to the theoretical line with zero losses.

We will now note the effect of opening the switch, thus disconnecting the line from the generator. In general, if the switch be opened at an instant when the line is at voltage E_o, with zero current flowing, there is no disturbance whatever. The line merely remains at voltage E_o. If the switch is opened with current I_o flowing, the interruption of the current being instantaneous, if the current in the line is flowing toward the switch, the positive voltage $I_o Z$ will be set up in the line. The action here is exactly the same as that which produced the reflected voltage E' at the open end of the line. (See equation 28.) If the current is flowing away from the switch, the voltage produced is the same, but negative. This voltage is superposed upon the voltage E_o, if any, which existed in the line before the switch was opened.

If, with the open ended line, the switch be opened during the transient state produced by closing, the maximum current which will be found is I of the charging or discharging wave, with the line voltage E. If the current is discharging (flowing toward the switch) the voltage produced at the switch is $2E$. If the current is charging, the resulting voltage is zero.

In this case, however, after that portion of the charging wave which passed the switch before interruption has been reflected with double voltage at the end of the line, it returns to the open switch, and is again reflected with double voltage in the same manner as at the end of the line. The details of the reflection of a limited wave, such as is here produced are worthy of further notice, and are illustrated in Fig. 11, which is self-explanatory.

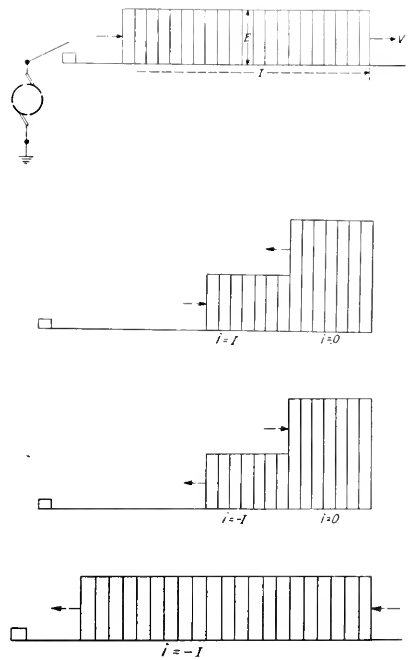


Fig. 11

With the closed line, the current which must be interrupted by the opening of the switch, for the ideal circuit with zero losses which we have been considering, and continuous voltage applied, will depend upon the length of time the switch has been closed, and may be indefinitely large. With practical lines, if this time is sufficient, it will be the short circuit current. It is likely to be much larger than the current of the initial charging wave, and the e.m.f. produced by the interruption will be correspondingly greater than the voltage, E, impressed upon the line. The voltage due to this interruption will be the same whether the interruption is instantaneous or gradual, unless it is sufficiently gradual that the reflection of the first part of the interruption returns to the switch before the last part is completed.

Each partial interruption of current is the equivalent of a wave of negative current and negative voltage impressed upon the line, this wave being superposed upon the condition which existed before it. The superposition of several such waves gives a correspondingly large negative voltage, but the voltage of each wave is eliminated by its own reflection, which appears at the switch at the end of a period $2T$ from the time when it started. This reasoning applies equally well if the interruption of current is gradual, i.e., in a continuous series of infinitesimal steps. If it is desired to limit the voltage due to the interruption of the current to a given value E_{max} it is necessary therefore to restrict the amount of current interrupted during any period of time $2T$ to a value not greater than

$$\int_t^{t+2T} \frac{di}{dt} dt = \frac{E_{max}}{Z} \qquad (63)$$

That is, if the rate of current interruption is uniform,

$$\frac{di}{dt} = \frac{1}{2T} \cdot \frac{E_{max}}{Z} \qquad (64)$$

whence, substituting the values of T and Z

$$\frac{di}{dt} = \frac{E_{max}}{2\,XL} \qquad (65)$$

This is the maximum permissible rate of current interruption when it is continued over a period of time $2T$.

If inductive receiving apparatus is connected to the end of the line, with current I_o flowing, the sudden interruption of the current produces a wave of voltage $\mp I_o Z$. When this wave reaches the end of the line, since current cannot cease suddenly in the inductive apparatus, the wave is reflected with double voltage, the same as with an open ended line. If the voltage E_o exists on the line at the moment of interruption, the resulting voltage is

$$E_o \pm I_o Z \qquad (66)$$

When this wave of interruption reaches the end of the line, the reflection produces the voltage

$$E_o \pm 2\,I_o Z \qquad (67)$$

and when the reflected wave returns to the switch, it is again reflected, giving the voltage

$$E_o \pm 3\,I_o Z \qquad (68)$$

These reflections will continue, with increase of voltage, until current ceases flowing in the inductive receiving apparatus. The maximum voltage produced in the line in this manner, if the inductance of the receiving apparatus is large, may be calculated from

$$E_{max} = I_o \sqrt{\frac{L_a}{XC}} \qquad (69)$$

where L_a is the inductance of the receiving apparatus, and XC the total capacity of the line. Even with a small value of inductance in the receiver the voltage

$$E_o \pm 3\,I_o Z \qquad (70)$$

is produced.

No effort is here made to apply the above deductions to the subject of switching in practice. This would be best not attempted at this point, nor until the whole subject of this series of articles has been covered in a theoretical manner. It should not be attempted in any case without full knowledge of the action of the switch.

(To be Continued)

ERRATA

POSITION LIGHT SIGNALS FOR RAILWAYS

By L. C. Porter

On page 6S in our January issue the titles of the two photographs were transposed.

NOTES RELATING TO THE ELECTRICAL MACHINERY SECTIONS OF THE STANDARDIZATION RULES OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

By H. M. Hobart, M. Inst. C. E.

Consulting Engineer, General Electric Company

(These notes are based upon the July, 1915, edition of the American Rules)

The American Institute of Electrical Engineers created a Standards Committee in 1898. During the seventeen years of existence of this Committee, several editions of its Standardization Rules for Electrical Machinery have been issued. In the preparation of the present edition (which was approved by the Board of Directors in July, 1915, the Committee enjoyed the valuable collaboration of the National Electric Light Association, the Association of the Edison Illuminating Companies, the Electric Power Club, the Verband Deutscher Elektrotechniker, and the Engineering Standards Committee of Great Britain. The last-mentioned Committee has recently issued (October, 1915) the British Standardization Rules for Electrical Machinery, and in the preface to these British Rules occasion is taken to allude to the "considerable advantage" which has "accrued through the co-operation of the American Standards Committee," and to state that the conferences between the two bodies have "gone far towards bringing about agreement on all essential details." Mention should also be made of the fact that the latest editions of the British, the German, and the American Standardization Rules have been based on the Limiting Temperatures for insulating materials agreed to at the last Plenary Meeting of the International Electrotechnical Commission, held in Berlin in 1913.—Editor.

PREFATORY EXPLANATIONS OF UNDERLYING PRINCIPLES

The A.I.E.E. Standardization Rules for Electrical Machinery have two objects.

First object of the Standardization Rules: To establish a standard code for acceptance tests of machinery.

In order that such a code shall be widely employed the stipulated tests should be simple and inexpensive.

Nevertheless, the requirements should be such as to place a premium on sound design and construction.

In the accomplishment of these purposes resort has been freely made to the plan of adopting reasonable assumptions in the place of values which could only be obtained by means of elaborate and expensive tests.

Furthermore, and for the same reason, simple although admittedly-inexact tests have sometimes been specified as the criteria for quantities whose values could have been more precisely ascertained only by elaborate and time-consuming tests.

Second object of the Standardization Rules: To provide statements of approved practice for the operation of electrical machinery in actual service. This second object is closely associated with the first, to the extent that the specified temperature limits for acceptance tests are the same as those approved for actual service.

This second object *differs* from the first in that a statement of limits for approved practice for service conditions obviously can only be put forward AS RECOMMENDATIONS to those who have acquired the machinery, whereas for the first object, the conditions for acceptance tests ARE MANDATORY for machines professing to conform with the A.I.E.E. Standardization Rules.

The American Rules have been so framed as to accomplish the above two objects. Great advances have been made in the design and construction of electrical machinery during recent years. These advances have been accompanied with corresponding progress in methods of testing. It has been clearly established that some internal parts of electrical machinery are subjected to temperatures decidedly in excess of those observable in any ordinary way with thermometers, and the existence of these higher temperatures has been recognized in establishing the permissible limits set forth in the American Rules.

THE "HOTTEST-SPOT" TEMPERATURE AND THE "OBSERVABLE" TEMPERATURE

The highest temperature occurring anywhere in the machine is termed the "Hottest-Spot" temperature. It is rare that the temperature of the hottest spot can be actually ascertained by direct measurement. The highest temperatures which can thus actually be ascertained are termed "Observable" temperatures. Suitable allowances are assigned in the American Rules for the amounts by which the "Hottest-Spot" temperatures are liable to exceed the "Observable" temperatures, as ascertained by the recognized methods of measurement.

While it is admitted that insulating materials may be subjected for brief periods of time to much higher temperatures than would be safe for longer periods, it is utterly impracticable to take this into account in Standardization Rules. In all countries which have made satisfactory progress with the standardization of electrical machinery, limiting temperatures have been assigned to various kinds of insulating materials, on the basis that such temperatures represent approved practice for CONTINUOUS OPERATION, but shall never be exceeded in actual service EVEN FOR SHORT INTERVALS. This rigorous principle has been adopted by the Standards Committees of Great Britain, Germany and America and underlies the Standardization Rules of the International Electrotechnical Commission which embraces not only the above three countries, but many others. The acceptance of this principle by the A.I.E.E. has involved the adoption of temperature limits considerably lower than those which could be sustained occasionally for short intervals, without injury, but the margins are to be regarded as constituting factors of safety and *any encroachment whatsoever* upon them is contrary to the Recommendations set forth by the American Institute of Electrical Engineers as constituting approved practice.

THE AMBIENT TEMPERATURE

With this understanding of the significance of the UPPER limits of permissible temperature, attention should now be directed to the temperature of the cooling medium, or, as it is termed in the American Rules, the "Ambient Temperature."*

While the ambient temperature will differ greatly for different cases, the maximum temperature *reasonably* liable to occur in any part of the temperate zone AT ANY TIME OF THE YEAR is adopted in the American Rules as the AMBIENT TEMPERATURE OF REFERENCE. This is taken at 40 deg. C. for air and at 25 deg. C. for water.

Meteorological records from all over the temperate zone indicate that in most parts of this region a shade temperature of 35 deg. C. is exceeded on certain days in summer. The shade temperatures are taken at points of observation where there is no artificial source of generation of heat and where the air circulates freely. But electrical machinery, when in operation, itself constitutes a source of heat and hence usually increases the temperature of the cooling air in its neighborhood, above the "Shade temperature" recorded at the Meteorological Station. Furthermore, electrical apparatus is often located in places where the circulation of air is very much restricted. As a consequence of these considerations, the cooling air temperatures for electrical machinery will range materially higher than the shade temperatures recorded by the Meteorological Stations. Viewed in this rational way, it becomes a matter for serious consideration whether even 40 deg. C. is high enough for the reference temperature, on the basis that it is to be a value which shall NEVER even be SLIGHTLY exceeded. Probably, even with 40 deg. C. as a reference ambient temperature for regions in the temperate zone, we shall have to admit that in some places where electrical machinery is located, there will be the probability that the ambient temperature will occasionally rise a degree or two above 40 deg. C. But by the adoption of 40 deg. C. as the AMBIENT TEMPERATURE OF REFERENCE we shall probably, in MOST instances, have a margin of a couple of degrees. For such an indefinite state of affairs, it is only reasonable to adopt a value which affords some prospect that there will usually be a margin of one or two degrees, which corresponds to maximum ambient temperatures of 38 deg. or 39 deg. It is practically impossible to ever predict within several degrees, what the maximum ambient temperature will be in the neighborhood of an electrical machine, *even when the machine is not running* and it is still more certainly impossible to estimate the value which it will attain WHEN THE ELECTRICAL MACHINE IS IN OPERATION. In view of this indefiniteness and of the importance of taking a conservative value, it follows that if the reference value of 40 deg. for the ambient temperature, in regions in temperate climates, can reasonably be criticised, the criticism would be that it is TOO LOW and certainly not that it is too high.

THE RATING OF A MACHINE

So far as relates to thermal limitations, the American Rules define the RATING of a machine as the continuous output which, were the machine to be operated in the

* With the variety of methods at present employed in cooling electrical machinery the term "Room" temperature no longer suffices. Some machines are cooled by the circulation through them of air led to the machines from ducts from outside of the building. Other machines are cooled by circulating water through suitably-disposed pipes. In other cases reliance is placed upon the surrounding air for effecting the cooling. The temperature of whichever medium is employed is termed the "Ambient" temperature.

ambient temperature of reference (40 deg. C. for air and 25 deg. C. for water), would occasion temperatures not greater than those stated to be permissible for the kinds of insulation employed.

It should not be necessary to lay further stress on the proposition that it is very important and entirely justifiable to provide a reasonable factor of safety at the LOWER end of the temperature range. Consequently, it is necessary that the ambient temperature of reference be fixed at such a value that in all cases of standard machinery for use in temperate climates, such machinery will never be subjected to ambient temperatures higher than the ambient temperatures of reference set forth in the American Rules.

Furthermore, when machines are OPERATED IN TEMPERATURES LOWER THAN THE AMBIENT TEMPERATURE OF REFERENCE, it is not permitted by the rules that such machines shall be used for loads exceeding their RATINGS as above defined.

The recommendations of the American Institute of Electrical Engineers thus provide that all the circumstances associated with the operation of electrical machines shall be such as to ABSOLUTELY PRECLUDE the subjection of the insulation to temperatures in excess of those set forth in the rules as approved practice, EVEN FOR THE BRIEFEST PERIODS OF TIME. It is obviously desirable to conform to these conservative recommendations in the operation of electrical machinery under service conditions.

The Engineering Standards Committee of Great Britain and the American Institute of Electrical Engineers have both based their Standardization Rules upon the same fundamental principle, which is, so far as it relates to thermal characteristics, set forth in the following section of the American Rules:

> *Section 263*. The principle upon which machine ratings are based, so far as relates to thermal characteristics, is that the rated load, applied continuously or for a stated period, shall produce a temperature rise which, superimposed upon a standard ambient temperature, will not exceed the maximum safe operating temperature of the insulation.

THE PERMISSIBLE TEMPERATURE RISE SHALL NOT BE EXCEEDED

The permissible temperature rise referred to above must not be increased EVEN WHEN THE AMBIENT TEMPERATURE IS LOWER THAN THE STANDARD AMBIENT TEMPERATURE OF REFERENCE. This is a matter of such importance as to justify reproducing from the American Rules, the text of the following four sections:

> *Section 265. Standard temperature and barometric pressure for Institute Rating.* The Institute Rating of a machine shall be its capacity when operating with a cooling medium of the ambient temperature of reference (40 deg. C. for air or 25 deg. C. for water) and with barometric conditions within the range stated in section 308.

> *Section 266. The temperature rises specified in these rules apply to all ambient temperatures* up to and including 40 deg. C. for air and 25 deg. C. for water.

> *Section 267. Any machinery destined for use with higher ambient temperatures or* cooling mediums and also any machinery for operation at altitudes of more than 1000 meters above sea level, should be the subject of special guarantee by the manufacturer. The methods of test and performance set forth in these rules will, however, afford guidance in such cases.

> *Section 342*. Whatever may be the ambient temperature when the machine is in service, the limits of the maximum observable temperature *and of temperature rise* specified in the Rules should not be exceeded in service; for, if the maximum temperature be exceeded, the insulation may be endangered, and if the *rise* be exceeded the excess load may lead to injury, by exceeding limits other than those of temperature; such as commutation, stalling load and mechanical strength.

On these premises there is built up in the American Rules a plan of rating which is much more definite than the old plan involving overloads.

Moreover, it should be especially noted that this plan of rating permits of building electrical machinery of the kinds of which large stocks are accumulated (as, for instance, distributing transformers and small motors), without any concern as to their ultimate destination, since the Rating corresponding to the American Rules is reasonably conservative in all locations where the ambient temperature never exceeds 40 deg. C., the Ambient Temperature of Reference. It is just so much to the good (since it simply means a slightly greater factor of safety), if such machines come to be installed in locations where the ambient temperature is never as high as 40 deg. C.

"KINDS" OF RATING

The American Rules provide for two "Kinds" of rating, "Continuous" and "Short time."

The CONTINUOUS RATING of a machine is that at which it can operate continuously without exceeding any of the limitations set forth in the Rules.

A SHORT-TIME RATING of a machine is a rating which (starting Cold), it can carry for a stated short time without exceeding the permitted temperatures and temperature rises or any other limits set forth in the Rules. Thus when it is stated that a machine has a 10-minute rating of 100 kw., it is meant that if, starting cold, the machine is loaded with 100 kw, the temperature rise at the end of 10 minutes will not exceed values set forth in the Rules as approved.

For the many complicated cases of intermittent service occurring in practice, the "equivalent," CONTINUOUS or SHORT-TIME load (whichever is the most convenient), will be employed as its "rating."

THE SPIRIT UNDERLYING THE AMERICAN RULES

The American Rules are framed on the assumption that reliance can be placed on a desire on the part of both parties to a transaction to live up to the *spirit* of the Rules. As an interesting instance of this assumption the following rule is quoted:

> *Section 322. Duration of Temperature Test of Machine for Continuous Rating.* The temperature test shall be continued until sufficient evidence is available to show that the maximum temperature and temperature rise would not exceed the requirements of the Rules, if the test were prolonged until a steady final temperature were reached.

The Rules contain many other clauses evincing a similar commendable spirit.

AMBIENT TEMPERATURE AT THE TIME OF ACCEPTANCE TESTS

The American Rules do not set up any mandatory requirement as to the ambient temperature at the place at which the acceptance tests of machinery shall be made. The nearest approach to any suggestion on this score is contained in the last sentence in Section 320, which reads as follows:

> "It is, however, DESIRABLE that tests should be conducted at ambient temperatures not lower than 20 deg. C."

Furthermore, the new Rules differ from the former Rules in that (with the exception of air blast transformers) it is assumed that the temperature rise for a given load will not vary with variations in the ambient temperature. Thus, if a machine is tested in a room whose temperature is 20 deg. and it is found to have, at its rated load, a temperature rise of, say, 46 deg. it is assumed that at *any* ambient temperature, say 30 deg., or 40 deg. or 50 deg. the temperature rise for this same load would always be 46 deg. Thus no restrictions are placed upon the temperature of the room or of the cooling medium (i.e., on the *ambient* temperature), at the time of the acceptance tests, the approved limits of *temperature rise* constituting the criterion.

For air blast transformers the Rules stipulate that a correction shall be applied to the observed temperature rise of the windings. This is set forth in section 321 in which is also given an example of the way in which the prescribed corrections shall be applied. It is to be noted that air blast transformers constitute *the only instance* where it is required that a correction shall be applied to take into account the precise ambient temperature at the time of the test.

If Section 321 is carefully studied, there cannot be any misunderstanding as to the intentions of the American Rules in this matter. It reads as follows:

> *Section 321.* EXCEPTION—A Correction shall be applied to the observed temperature rise of the windings of Air-Blast transformers, due to difference in resistance, when the temperature of the ingoing cooling air differs from that of the standard of reference. This correction shall be the ratio of the inferred absolute ambient temperature of reference to the inferred absolute temperature of the ingoing cooling air, i.e., the ratio 274.5/234.5+t); where t is the ingoing cooling-air temperature.
>
> Thus a cooling-air room temperature of 30 deg. C. would correspond to an inferred absolute temperature of 264.5 deg. on the scale of copper resistivity, and the correction to 40 deg. C. (274.5 deg. inferred absolute temperature) would be $274.5 / 264.5 = 1.04$, making the correction factor 1.04; so that an observed temperature rise of, say, 50 deg. C., at the testing ambient temperature of 30 deg. C. would be corrected to $50 \times 1.04 = 52$ deg. C., this being the temperature rise which *would have* occurred had the test been made with the

standard ingoing cooling-air temperature of 40 deg. C.

THE AMERICAN STANDARDIZATION RULES FOR ELECTRICAL MACHINERY

In the light of the preceding Prefatory Discussion let us now take up the three main divisions of those portions of the American Rules which deal with Electrical Machinery. These three main divisions respectively relate to: Temperature, Efficiency and Insulation.

TEMPERATURE

It is recommended in the American Rules that electrical machinery shall not be operated under such conditions as shall occasion in the insulating materials employed in their construction temperatures in excess of the values given in the following table:

Class of Insulation	Description of Insulating Material	Maximum Temperature to which the material may be subjected.
A	Cotton, silk, paper and similar materials when so treated or impregnated as to increase the thermal limit, or material permanently immersed in oil; also enamelled wire*	105 deg. C.
B	Mica, asbestos and other materials capable of resisting high temperatures, in which any Class A material or binder is used for structural purposes only, and may be destroyed without impairing the insulating or mechanical qualities of the insulation	125 deg. C.
C	Fireproof and refractory materials, such as pure mica, porcelain, quartz, etc.	No limit specified.

* For cotton, silk, paper and similar materials, when neither impregnated nor immersed in oil, the highest temperatures shall be 10 deg. lower than the limits given above for Class A.

When delivering a given output, an electrical machine will be hotter the higher the ambient temperature. Most kinds of electrical machinery will also run warmer the higher the altitude of the location.* Consequently in order to provide a definite basis, the rating of a machine must be referred to some reference values of ambient temperature and altitude.

* The latter variation is of small amount at reasonably low altitudes.

Ambient Temperature of Reference. The cooling air surrounding or circulated through a machine is, in most places, liable at times to approach 40 deg. C. (i.e., 104 deg. Fahrenheit). (Indeed in tropical countries, and in the southwest of the United States, and in Texas, ambient temperatures of 45 deg. C. are sometimes encountered. Such machinery, however, must be regarded as special and no provision is made for it in the American Rules).

In the case of water-cooled machinery, the circulating water will rarely have a temperature in excess of 25 deg. C.

For altitudes of not over 1000 meters above sea level, the variations, due to location, will not be of sufficient amount to require to be taken into account.

The object to be attained is that the rating assigned to a machine shall be such as to ensure that, so long as the machine is not operated under conditions where the ambient temperature will ever exceed the reference value (40 deg. C. for air and 25 deg. C. for water) or in altitudes of more than 1000 meters above sea level, their insulations will not be subjected to temperatures greater than those set forth in the preceding table.

By deducting the ambient temperatures of 40 deg. C. for air and 25 deg. C. for water from the maximum temperatures set forth in the preceding table as permissible for the insulation, we obtained the permissible temperature *rises*. These are given in the following table:

Class of Insulation	MAXIMUM PERMISSIBLE TEMPERATURE RISE TO WHICH THE INSULATION MAY BE SUBJECTED	
	For air-cooled machinery (Ambient Temperature of reference = 40 deg. C.)	For water-cooled machinery (Ambient temperature of reference = 25 deg. C.)
A†	65 deg. C.	80 deg. C.
B	85 deg. C.	100 deg. C.
C	No limit specified	

† For cotton, silk, paper and similar materials, when neither impregnated nor immersed in oil, the highest temperatures shall be 10 deg. lower than the limits given above for Class A.

Even when the ambient temperature never reaches 40 deg. C. for air (or 25 deg. C. for water), the American Rules do not sanction such loads as shall occasion in the insulation temperature rises in excess of those set forth in the above table. This, as already emphasized in the Prefatory Explanations to these notes, is a matter of fundamental importance, and is the subject of four Sections, numbered 265, 266, 267 and 342, the text of all four of which has already been given in the Prefatory Explanations (see page 147).

"Hottest-Spot" Temperatures

The temperatures set forth in the last column of the table on p. 149, left-hand column, are the "hottest-spot" temperatures and are practically always higher than those which can be **"observed"** by commercial methods of measurement. Similarly, the temperature rises in the table in the right-hand column of page 149 correspond to the temperature rises of these **"hottest spots"** and are *greater* than the **"observable"** temperature rises.

In the American Rules are set forth approved values for the allowances to be made for the differences between the "Observable" temperatures and the "Hottest-Spot" temperatures. These allowances vary with the method of measurement, and, in some cases, with the pressures for which the machines are wound.

Methods of Measuring Temperature

The American Rules provide three methods of measuring the temperature of electrical machinery. The appropriate method to be used in any particular case is indicated in the Rules.

The three methods are designated respectively:

Method	Description
I	Thermometer
II	Resistance
III	Embedded Temperature Detector

Method I, Thermometer Method

When Method I is used, the "hottest-spot" temperature FOR WINDINGS shall be estimated by adding 15 deg. to the highest temperature observed by any of the thermometers.

Exceptions: When thermometers are applied directly to the surfaces of BARE windings, such as an edgewise strip conductor, or a cast copper winding, only 5 deg. C. is to be added to the highest thermometer reading in deducing the "hottest-spot" temperature.

For commutators, collector rings, BARE METALLIC SURFACES NOT FORMING PART OF A WINDING, or for oil in which apparatus is immersed, NO correction is to be applied; i.e., the highest reading obtained by any thermometer applied to these parts is to be taken as the "hottest-spot" temperature of these parts.

(It should be noted that by the word "thermometer" the Rules include, not only the customary mercury, or alcohol, thermometers, but also Resistance Thermometers or Thermocouples, when any of these devices are applied to the hottest accessible parts of the COMPLETED machine, as distinguished from thermocouples, or resistance coils *embedded in the machine*, as described for Method III.)

Method II, Resistance Method

Although termed briefly the Resistance Method, the American Rules require that it be supplemented by careful thermometer measurements whenever it is practicable to make such thermometer measurements WITHOUT DISASSEMBLING THE MACHINE. The highest reading obtained, whether this be by the resistance measurement, or by the additional thermometer measurements, must be taken as the highest "observable" temperature. To this highest "observable" temperature, a correction of 10 deg. C. is to be added in deducing the "hottest-spot" temperature. In Section 349 is given a table of Temperature Coefficients of Copper Resistivity, which will be of assistance in deducing the "observable" temperature rise from the resistance methods.

Method III, Embedded Temperature-detector Method

The use of this method is mandatory for stators of machines with cores having a width of 50 cm. (20 inches) and over. It must also be used for all machines of 5000 volts and over (if of over 500 kv-a.), regardless of core width.

(It is provided in the Rules that when it shall be required, Method III shall be checked by Method II and the "hottest-spot" shall then be taken to be the highest value deduced by either method, the required correction factors being applied in each case.)

It is necessary in Method III that there shall be built into the machine a liberal number of temperature-detectors, all reasonable efforts consistent with safety being made to locate these detectors at the various places where the highest temperatures are liable to occur. As a minimum requirement, it is expressly stated in the Rules that the temperature-detectors shall be placed in at least two sets of locations in double-layer windings. One of these is the location indicated at *A* in Fig. 1. The other is the location indicated at *B* in Fig. 1. For single-layer windings, which may be diagrammatically represented as shown in Fig. 2, the Rules also provide for two sets of locations. In this case, however, one of these is that indicated at *B* in Fig. 2 and the other is that indicated at *C* in Fig. 2.

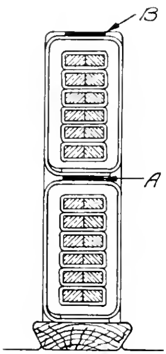


Fig. 1

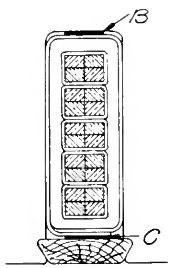


Fig. 2

The corrections to be added to the "observable" temperature when Method III is used, are as follows:

For double-layer windings	5 deg. C.
For single-layer windings for 5000 volts or less	10 deg. C.
For single-layer windings for more than 5000 volts	10 deg. C. plus 1 deg. for every kv. by which the voltage between the terminals of the machine exceeds 5 kv.

Thus, for a three-phase machine with an 11,000-volt single-layer winding, the correction to be added to the maximum "observable" temperature in estimating the "hottest-spot" temperature, is 16 deg. C.

Selection of Method to be Employed in Temperature Determinations

As will be seen from a preceding paragraph, the field for the use of Method III is definitely prescribed in the Rules.

The Rules prescribe that Method II is always to be employed in determining the temperatures of the WINDINGS OF TRANSFORMERS, and also in determining the temperatures of the WINDINGS OF INDUCTION REGULATORS. In this connection attention should be called to the sentence in Section 351, which points out that

> "In the case of air-blast transformers, it is especially important to place thermometers on the coils near the air outlet."

It is expressly required in the Rules that Method I shall be used in the case of COILS OF LOW RESISTANCE, where the joints and connections form a considerable part of the total resistance. Obviously, Method II would give misleading results if employed for such cases.

Aside from these express provisions, it remains, at present, optional for other cases, whether Method I or Method II be employed. This will, in practice, mean that usually Method I will be preferred, notwithstanding the requirement to add 15 deg. C. to the "observable" temperature in obtaining the "hottest-spot" temperature, as against the 10 deg. C. to be added when Method II is employed.

NOTE.—Although the Rules contain no explicit statement to that effect, it may doubtless be understood that it is not intended that the prescribed method need necessarily be made upon every individual machine comprised in a transaction. The simplest method, as above explained, is usually Method I, and in the interest of avoiding needless expense, it should often be practicable to arrange for a judicious employment of Method I for most of the machines of a given size, employing Method II or III, as the case may be, on a few of the machines, and thereby arriving at a factor by which the results obtained by Method I require to be multiplied in order to arrive at the results which *would have been obtained* on those particular machines had Methods II and III been employed. In other words, it should not be concluded that the less-simple measurements will necessarily be made on every machine, but rather that conclusive evidence shall be provided to insure that HAD THE MEASUREMENTS BEEN MADE, the temperature would have been within the required limits.

SPECIAL CASES OF TEMPERATURE LIMITS

Temperature of Oil. The oil in which apparatus is permanently immersed shall in no part have a temperature, observable by thermometer, in excess of 90 deg. C.*

Water-Cooled Transformers. In these the "hottest-spot" temperature shall not exceed 90 deg. C.†

As to SQUIRREL-CAGE AND AMORTISSEUR WINDINGS, COLLECTOR RINGS, COMMUTATORS AND CORES, no temperature limits are prescribed further than to require that they shall not exceed values which shall occasion in any insulating parts, temperatures greater than those set forth in the table on page 149 as the maximum to which those insulating materials should be subjected.

EFFICIENCY

The American Rules deal with *efficiency* on the basis of the recognition of two efficiencies:

Conventional Efficiency and Directly-Measured Efficiency.

"Unless otherwise specified, the Conventional Efficiency is to be employed."

The Conventional Efficiency is defined (in Section 423) as follows:

> "Conventional Efficiency of machinery is the ratio of the output to the sum of the output and the losses; or of the input minus the losses to the input; when, in either case, conventional values are assigned to one or more of these losses. The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practically indeterminable, and must, in many cases, either be approximated by an approved method of test or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "Conventional Efficiency."

In Sections 440 to 445 are given lists of the losses to be taken into account in arriving at the conventional efficiency in various types of machines. In the table on page 153 the data in Sections 440 to 445 have been arranged in a form for ready consultation.

As a temperature of reference for efficiency determinations, 75 deg. C. has been standardized. Thus the efficiency of a machine with an A.I.E.E. rating is the efficiency which would have been obtained if the tests had been made (or the calculations transposed to) 75 deg. C.‡

The rules relating to the conventional efficiency of railway motors are set forth in paragraphs 815 to 820.

INSULATION

Insulation requirements are, unless otherwise specified, only to relate to tests on the completely-assembled machinery and not to tests on individual parts. The machinery shall be in good condition and the high-voltage tests shall be applied before the machine is put into commercial service, and shall not be applied when the insulation resistance is low, owing to dirt or moisture. High-voltage tests shall be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial testing. In lieu of any express provision to the contrary, high-voltage tests of a machine shall be understood as being made at the factory and only on new machines. The duration of the application of the voltage shall be one minute. The test voltage shall be successively applied between each electric circuit and all other electric circuits and metal parts grounded. Interconnected polyphase windings are considered as one circuit. All windings of a machine except that under test shall be connected to ground.

Apparatus such as transformers, which may be used in star connection on three-phase circuits, shall have the delta voltage of the circuits on which they may be used indicated on the rating plate and the test shall be based on such delta voltage.

The fundamental A.I.E.E. Rule for high-voltage tests is as follows:

> **"The standard test for all classes of apparatus, except as otherwise specified, shall be twice the normal voltage of the circuit to which the apparatus is connected, plus 1000 volts."**

* Oil maintained at higher temperature is liable to deterioration by "sludging."

† It is considered desirable to employ this lower limit for water-cooled transformers to lessen the liability to serious consequences through an interruption in the water-supply or a decreased supply.

‡ The average operating temperature taken over the entire life of a machine at all loads varies greatly with the type of the machine and the service. After a careful study, by the Standards Committee, 75 deg. C. was taken as the mean for electrical machinery in general. While the average temperature of some kinds of electrical machinery will be 20 or 30 degrees greater, the average temperature of other kinds (such as distributing transformers), may be 10 or 20 degrees lower. But simplicity is essential and as long as engineers associated with all interests, deal with the efficiency on the basis of the reference temperature of 75 deg. C. when no explicit statement is made to the contrary, the consequent simplification in tenders and in comparisons in general, will be of great importance.

Section Numbers	Kind of Machine	Friction (other than Brush Friction) and Windage	Brush Friction	No-load Core Losses	I^2R Losses in Windings	Brush Contact I^2R Loss	Rheostat Losses	Stray Load Losses	Notes
440	Direct-current commutating motors (except railway motors) and generators	Approximately measurable or determinable See par. 450	Approximately measurable or determinable See par. 451	Accurately measurable or determinable See pars. 452 and 453	Accurately measurable or determinable	Unless otherwise specified use Inst. standards See par. 454	Accurately measurable or determinable See par. 455	To be taken at zero per cent in estimating conventional efficiency See par. 440	
441	Synchronous motors and generators		Assume to be negligible See par. 441		Accurately measurable or determinable. Base on rated kw. and power factor[1]	Assume to be negligible See par. 441	Accurately measurable or determinable. See pars. 455 and 457	Indeterminable; approximate in accordance with par. 458	[1]See also par. 430
442	[2]Induction machines		When collector rings are present, approximately measurable or determinable See par. 451			Unless otherwise specified, use Institute standards See par. 454		Indeterminable; approximate in accordance with par. 459	[2]See also pars. 430 and 460
443	Commutating a-c. machines		Approximately measurable or determinable See par. 451		Accurately measurable or determinable			Institute not yet prepared to make recommendations	
444	Synchronous converters				[3]Approximately, measurable or determinable		Accurately measurable or determinable. See par. 455		[3]The I^2R losses in the arm. winding shall be derived from those corresponding to its use as a d-c generator by using recognized factors
445	Transformers	None	None	Accurately, measurable or determinable See par. 470	Accurately measurable or determinable	None	None	Approximately, measurable or determinable See par. 471	
815 to 820 also 1100 and 1101	Railway motors	See pars. 817, 818, 820 and 1100	See pars. 817 and 1100	See pars. 817, 818 and 1101	See par. 816	See par. 819		See par. 818	

To this rule there are the following exceptions:

Exception: **Alternating-current apparatus connected to permanently grounded single-phase systems, for use on permanently grounded circuits of more than 300 volts,** shall be tested with 2.73 times the voltage of the circuit to ground plus 1000 volts. This does not refer to three-phase apparatus with grounded star neutral.

Exception: **Distributing transformers,** Transformers for primary pressures from 550 to 5000 volts, the secondaries of which are directly connected to consumers' circuits and commonly known as distributing transformers, shall be tested with 10,000 volts from primary to core and secondary combined. The secondary windings shall be tested with twice normal voltage plus 1000 volts.

Exception: **Auto-transformers** used for starting purposes shall be tested with the same voltage as the test voltage of the apparatus to which they are connected.

Exception: **Household devices.** Apparatus taking not over 600 watts* and intended solely for operation on supply circuits not exceeding 250 volts, shall be tested with 900 volts, except in the case of heating devices which shall be tested with 500 volts at operating temperature.

Exception: **Apparatus for use on circuits of 25 volts or lower,** such as bell-ringing apparatus,† electrical apparatus used in automobiles, apparatus used on low-voltage battery circuits, etc., shall be tested with 500 volts.

Exception: **Field windings of alternating-current generators** shall be tested with 10 times the exciter voltage, but in no cases with less than 1500 volts nor more than 3500 volts.

Exception: **Field windings‡ of synchronous machines, including motors and converters which are to be started from alternating-current circuits,** shall be tested as follows:

a. When machines are started with fields short-circuited they shall be tested as specified in the penultimate paragraph.

b. When machines are started with fields open-circuited and sectionalized while starting, they shall be tested with 5000 volts.

c. When machines are started with fields open-circuited and connected all in series while starting, they shall be tested with 5000 volts for less than 250-volt excitation and 8000 volts for excitation of 250 volts to 750 volts.

Exception: **Phase-wound rotors of induction motors.** The secondary windings of wound rotors of induction motors shall be tested with twice their normal induced voltage, plus 1000 volts.

When induction motors with phase-wound rotors are reversed, while running at approximately normal speed, by reversing the primary connections, the test shall be four times the normal induced voltage, plus 1000 volts.

Exception: **Switches and circuit control apparently above 600 volts,** shall be tested with $2\frac{1}{4}$ times rated voltage, plus 2000 volts.

Exception: **Assembled apparatus.** Where a number of pieces of apparatus are assembled together and tested as an electrical unit, they shall be tested with 15 per cent lower voltage than the lowest required on any of the individual pieces of apparatus.

Testing transformers by induced voltage. Under certain conditions it is permissible to test transformers by inducing the required voltage in their windings, in place of using a separate testing transformer. By "required voltage," is meant a voltage such that the the line end of the windings shall receive a test to ground equal to that required by the general rules.

Transformers with graded insulation** shall be so marked. They shall be tested by inducing the required test-voltage in the transformer and connecting the successive line leads to ground.

Transformer windings permanently grounded within the transformer shall be tested by inducing the required test voltage in such windings.

For specifications relating to methods of measuring the voltage in dielectric tests of machinery, sections 530 to 541 inclusive

* The present National Electric Code power limit for a single outlet.

† This rule does not include bell-ringing transformers of ratio 125 to 6 volts. See National Electric code.

‡ Series field coils should be regarded as part of the armature circuit and tested as such.

**The term "graded" is here used to indicate the employment of less insulation at the ends of the windings where the insulation stresses are low and more insulation at the high potential ends.

must be consulted, since the text of those sections of the Rules is not of a nature permitting of preparing a useful abstract.

CONCLUDING OESERVATIONS

It is believed that the above abstract covers the more important clauses in the American Standardization Rules for Electrical Machinery. But it must be understood that the electrical machinery sections of the Rules comprise about 40 pages of rather small type and that no abstract can possibly provide a thoroughly reliable substitute as a source of reference.

In view of the importance of continuing, in this matter of Standardization of Electrical Machinery, the valuable policy of co-operation with Committees of Societies representing the various activities (both engineering and commercial), in the Electrical Industry in this and other countries, it is necessary to accept the fact that, henceforth, changes of any consequence can only be adopted in the American Rules after careful and exhaustive consultation. With the development of the Art, it can reasonably be expected that the *quantitative* values of the limitations will gradually be modified. It is, however, highly unlikely that any alterations in the *fundamental principles* will be undertaken for a long time to come.

Consequently, it is the more fortunate that such care and circumspection should have been exercised in their formulation. In the Technical Report of the Thirty-Eighth Convention of the National Electric Light Association, held at San Francisco June 7-11, 1915, the Committee on Electrical Apparatus, whose chairman is Mr. L. L. Elden of the Edison Electrical Illuminating Company of Boston, submitted a report (see page 128), containing the following paragraph:

"The importance of standardizing practice in the purchase of electrical apparatus to conform with the A.I.E.E. Standardization Rules is again brought to the attention of the Member Companies, and it is strongly recommended that the benefits to be derived by adhering to the new rules be recognized in commercial transactions."

At page 171 of the same volume the subject received further attention as follows:

"The Rules were prepared with the cooperation of all the interests which could possibly be concerned in the use of, or affected by, them. Your Apparatus Committee was very active in its efforts to have incorporated in the Rules every clause which could be thought of as helping Operating Companies to secure better apparatus and prevent misunderstandings between customer and manufacturer, as well as to eliminate matters detrimental to the interests of our companies. The members of the Standards Committee of the Institute were very appreciative of the Association's efforts, and your Committee believes that the results as put forth in the Rules AMPLY JUSTIFY THEIR UNIVERSAL USE."

Again on the following page:

"Our membership is, therefore, urged to obtain copies of the revised Rules, COMPLY WITH THEIR REQUIREMENTS WHEN SPECIFYING APPARATUS and wherever else applicable."

In the course of the discussion of the Report of the National Electric Light Association Committee, Mr. Philip Torchio, who represented the Association of Edison Illuminating Companies on the Sub-committee which framed the Sections of the A.I.E.E. Rules dealing with electrical machinery, stated that members were:

"perfectly right in recommending to users the adoption of these Rules, as they are good Rules."

Mr. Torchio continued his remarks as follows:

"I want to emphasize the fact that Manufacturers should make their bids also on the new Rules. In the last two months I have had to ask Manufacturers to revise their quotations according to the new Rules, as they continue to quote on the old basis of 35 or 40 deg. continuous and 55 or 65 deg. overload."

It would be remarkable if Customers were to be in advance of Manufacturers in giving practical evidence of their support of the Standardization of Electrical Machinery, and it is to be hoped that any indication that such is the case is due merely to the initial magnitude of the undertaking from the Manufacturers' standpoint. If this is the case, the efforts of the Manufacturing Companies in this direction will doubtless soon be very much in evidence. There can be no question but that it is to the interests of manufacturers to take advantage of such a formulation of approved practice as that set forth in the American Rules. It has been interesting to notice in the pages of a British publication the advertisement of a firm manufacturing electrical machinery. Besides stating the features of their machinery and pointing out that they are:

"As supplied to War Departments, Admiralties, Leading Railways and Shipbuilders,"

the advertisement states that they are:

"Constructed in accordance with the specifications of the British Standards Committee."

Indeed, as an indication of the alertness with which manufacturers in most countries are regarding the possibilities of World Markets, and as an indication of the world-wide regard for any Standards put forward by the Engineering Standards Committee of Great Britain, this part of the advertisement is reiterated as follows:

"Construction conforme aux conditions imposées par la Commission Britannique des Modèles normaux."

The attitude of this firm is typical of that which naturally will be eagerly adopted by all manufacturers in countries privileged to possess practical Standardization Rules framed on International agreements as regards Standardization of approved practice. Failing such Rules, there is no common basis to which manufacturers can refer and each must vie with his competitors in guaranteeing low temperatures, high overloads, high efficiencies and severe insulation tests. Since specifications calling for unreasonable limitations do not result in the provision of machinery of any greater value to its possessor than machinery conforming with *reasonable* standards of approved practice, exemption from all such uncontrolled and unreasoning competition must necessarily be in the best interests of the Electrical Industry.

SEWERAGE SYSTEM AT THE GENERAL ELECTRIC COMPANY'S WORKS, SCHENECTADY, N. Y.

By Paul G. Koch

Improvements in a sewerage system usually come slowly, for it seems to be the common practice that cities will not supersede or render adequate their sewage disposal facilities until absolutely compelled to do so. Consequently, the initial interesting feature of this article is the reference to the willingness of one large manufacturing company to promptly co-operate with the city when the sewerage system was under revision. The greater part of the article is devoted to a description of the pumping station which is electrically driven, and to the simple and inexpensive method of disposing of the screenings.—Editor.

In 1906 the Department of Health of New York State approved plans for local sewers in the city of Schenectady, with the understanding that within five years the city would cease polluting the waters of the Mohawk River with sewage. As is often the case with cities, Schenectady paid no attention to carrying out its part of the agreement after the construction of the sewers. It was not until 1912 that steps were taken to meet the obligation. Designs of an interceptor, sewage pumping station, and sewage treatment works were prepared by the firm of George W. Fuller, and the work which has recently been completed was under the supervision of James C. Harding of New York City, Consulting Engineer to the City of Schenectady.

The General Electric Company with its 20,000 employees, an important factor in the river pollution, willingly agreed to make at its own expense those changes that would conform its sewerage system to the general program of the city. Careful investigations and a design for a separate system to take the place of the combined system, then in existence, were made by the city's Consulting Engineer. The system included some seven miles of sanitary sewers and a sewage pumping station. The entire cost including engineering was about $100,000, the cost of the pumping station being about $20,000. The average quantity of sewage from the works is about 1¼ million gallons per day, with maximum rates much greater than this. Previous to designing the system, measurements were taken in the old system with Bristol recording gauges to determine as nearly as possible the flow of the sanitary sewage and trade wastes.

The work proved to be exceptionally difficult of construction as the excavated material was mostly sand in which water was met at from six to eight feet below the surface, as pipes of all kinds were encountered (water, gas, oils, air, steam, etc.), as the location of many of the sewer lines lay beneath storage yards filled with tons of castings and lumber, and as serious difficulties such as avoiding interference with the network of industrial tracks about the plant had to be surmounted, for a condition in prosecuting the work demanded that the business of the plant should not be interfered with in any way. All sewers below ground water level were laid with water-tight joints, the packing usually being "Jointite;" and tests made after completion of the construction showed that the allowable infiltration of one gallon per twenty-four hours per foot of sewer was more than lived up to. There are no especially noteworthy features in the piping system itself, except in providing for non-interference with other structures as described.

The pumping station excavation was made mostly in fine sand containing a large quantity of water and was lined with a sheathing of three-inch splined piling, braced with 12-in. by 12-in. timbers across the opening. The extreme bottom of the excavation was carried to about 25 feet below the surface of the ground or about 17 feet below the surrounding ground water level. The building is about 22 feet by 28 feet on inside lines, is entirely of concrete, and its windows and doors are steel covered. It contains three centrifugal motor-driven pumps, the control of which is entirely automatic.

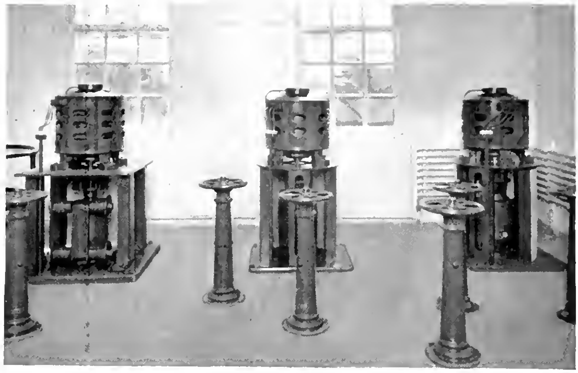


Fig. 1. A View of the Pump Room showing the Pump Motors

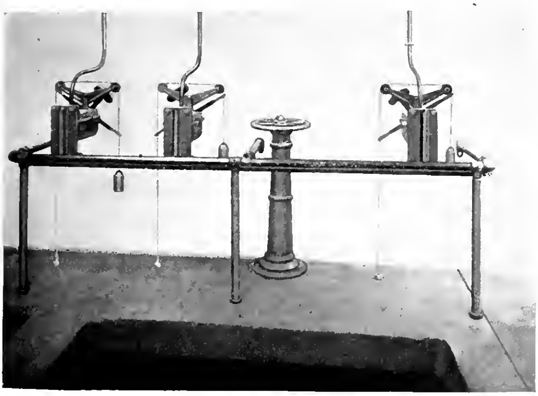


Fig. 2. The starting switches that control the motors shown in Fig. 1

All of the motors are of the vertical, squirrel-cage, induction type and are wound for 550 volts, 40 cycles, and quarter-phase. Each motor is controlled by an automatic self-starter of the contactor type provided for current-limit acceleration and equipped with a low-voltage release. The motors on pumps Nos. 1 and 2 are of 10 horse power and the motor on pump No. 3 is of 15 horse power.

The self-starters are controlled by a pilot circuit which is opened and closed by a totally enclosed single-pole float switch, which is actuated by means of chain, float, etc.

The arrangement of the motors is shown in Fig. 1, in which it will be noticed that the motor on the left-hand side is supported on a base somewhat different from the other two. The thrust bearing of this unit has been located beneath the floor and a pulley installed in its place so that a belt-drive electric motor can operate the pump in case of an emergency. The starting switches shown in Fig. 2 are so arranged that the pumps will start at different elevations of the sewage, to provide for varying rates of flow and for emergency conditions should anything happen to render one or more of the pumps inoperative. Fig. 3 shows the motor control, which is located in the same room as the motors.

The most unique feature of the design is the installation of an ejector for removing the screenings. In small pumping stations trouble is usually experienced in taking care of the suspended materials that are removed from the sewage by screens to prevent clogging the pumps.

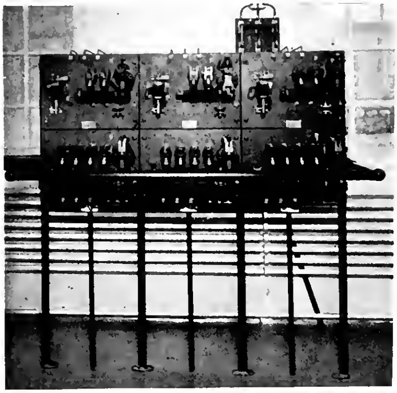


Fig. 3. The Motor Control Panels

In an industrial plant such as this the removal is particularly troublesome, for the sewage reaches the station in a very fresh state, the solids not being appreciably broken up, and the quantity of screenings is large. The burial of this matter is not practicable and incineration is costly and otherwise objectionable. Fig. 4 shows clearly the scheme which has been installed and which has successfully accomplished the desired result. The ejector is located in the pump room and 12-in. connections go to a depression in the floor in front of each of the screens. When the screens become clogged, the operator pumps the sewage down to a low level in the pump well, pushes the matter collected on the screens into the depression in the floor with a rake, and then opens the hydraulic valves to the ejector, thereby forcing the screenings into the ejector pot. The valves on the inlet pipes are then closed, the discharge opened, and the screenings forced by compressed air into the force main. Generally this operation is repeated until the screens and floor are perfectly clean. The entire operation takes but a few minutes and is much less objectionable than the usual method of collecting these matters in cans and disposing by burning or burial.

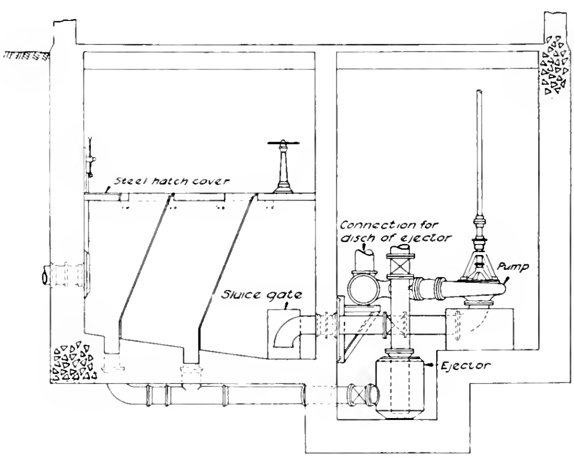


Fig. 4. Sectional drawing showing the screens, a pump, ejector, etc.

PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

PART XVI (NOS. 69 AND 70)

BY E. C. PARHAM

CONSTRUCTION DEPARTMENT, GENERAL ELECTRIC COMPANY

(69) AN ERRATIC REGULATOR

The closeness with which the generator automatic voltage regulator will hold the voltage of a separately excited alternator to normal value is little short of marvelous. It is difficult to conceive how voltage regulation could ever have approached satisfaction before the advent of this device which is now installed as a matter of course wherever voltage is to be maintained constant at a given value.

An experienced operator complained that his regulator, after giving perfect satisfaction for several years, had developed peculiarities the reason for which he could not fathom. To use his expression, "The a-c. and d-c. control magnets were chasing each other at certain times of the day." He had checked all adjustments, alignments, and connections, and could find nothing irregular, so he sent for a regulator expert. When this man reached the station he found the regulator performing in a perfectly satisfactory manner, but he was told that the "regular performance" would not begin until around 3:30 or 4 o'clock in the afternoon; sure enough, at 3:40 the erratic action began. He immediately cut out the regulator and noticed that the voltage maintained fairly well although there evidently was but little regulation. On making inquiries he ascertained that as the station load increased in the afternoon the inductive drop of the line became excessive; the regulator was able to maintain the station voltage fairly well but out on the line the voltage available became so low as to interfere with the service to consumers. Accordingly, a synchronous condenser was being used for the purpose of improving the power-factor. During the winter, the time of the complaint, it was customary to put the condenser into service every afternoon between the hours of 3 and 4. As soon as the condenser neutralized the inductance of the system, the voltage at the station where the regulator was installed began "banking up." With the station voltage above normal as a result of the condenser action, the regulator would do all that it could to reduce the voltage, but of course the regulator was unable to control the independent source of erratic regulation.

To relieve the situation, the regulator man installed a switch by means of which the resistance of the alternator field circuit could be increased at such times as the condenser was in use. This resistance tended to decrease the alternator voltage, and thereby gave the regulator a working range for regulation.

(70) VOLTMETER WOULD NOT WORK

In ordinary induction motors the energy, by virtue of which the rotation of the rotor is produced, is transmitted across the motor air-gap—the rotating magnetism being the medium of energy transmission. Induction types of meters act on the same principle. In neither case is there any electrical connection between the stator, to which the e.m.f. is applied, and the rotor, on which the resulting rotating magnetic field acts. Therefore in both cases the energy that is imparted to the primary must be pulsating in character, otherwise its amount can not be indicated by any movement of the rotor because there will be no movement. This means that induction types of meters can not be used for indicating continuous (or direct) currents.

An operator whose equipment included a 125-volt exciter had no voltmeter for it—a condition that too often is found. He, therefore, seized an opportunity to secure cheap an alternating-current voltmeter with the intention of using it as a continuous-current voltmeter for his exciter; because, to the extent of his experience, any alternating-current meter would indicate equally well on alternating or on continuous currents. The purchased voltmeter, however, was shortly to extend the limits of his experience for the instrument was not "universal;" it was an induction voltmeter.

On trying out the meter on alternating voltage, the meter acted normally. Ringing out showed a clear circuit from terminal to terminal, but the continuous current was not qualified to produce the rotating field necessary to the operation of a meter of this kind.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

WHY AN ARC PRODUCES OSCILLATIONS

The reason why an arc produces oscillations is the shape of the voltampere characteristic of the arc. In the arc, the voltage decreases with an increase of current, following roughly the equation:

$$e = a + \frac{b\,l}{\sqrt{I}}$$

where l = arc length, and a and b are constants.

Such a voltampere characteristic produces instability under certain conditions. For instance, if an arc is operated on a constant potential supply (without "steadying" resistance or reactance). Naturally, absolute constancy can never exist, and certainly not in a conductor, as the arc, which is a moving vapor stream, and as such is affected by every air draft, etc. If then the current in the arc decreases momentarily, ever so little: this causes an increase of the required arc voltage, and if the supply voltage is constant, it becomes too low for that required by the arc, and the arc current decreases; this decrease causes a further increase of the required voltage, and a further decrease of current, and so with increasing velocity the current decreases and the arc goes out. Inversely, if the current increases momentarily, the arc voltage decreases, there is thus, at constant supply voltage, an excess of voltage available, which increases the current and still further decreases the required arc voltage and again increases the current, etc., and the arc short circuits. Thus on constant voltage supply, an arc either goes out or short circuits, and becomes stable only, if sufficient resistance (or reactance) is inserted in series, so that the increase of voltage consumed by the resistance, at an increase of current, is more than the decrease of voltage consumed by the arc, and thus checks the increase of current, and inversely at a decrease of current.

If now an arc is operated on a constant current circuit, or with sufficient resistance in series, to be steady, and a *resistance* is connected in shunt to the arc, let us see what happens:

If the current in the arc momentarily decreases, the arc voltage increases, and therefore more current passes through the resistance. If now the resistance is so low that the increase of current through the resistance, which results from the arc voltage increase caused by a decrease of the arc current, is more than the decrease of the arc current, the resistance robs the arc of current, the arc current decreases, its voltage increases, sends still more current over the resistance, further decreasing the arc current, and so on, and the arc gets unstable and goes out. Shunting an arc by a resistance, therefore, decreases its stability, and at a certain resistance makes the arc unstable—causes it to go out.

Suppose now we shunt the arc by a condenser—a capacity. The current taken by the condenser is proportional to the *rate of increase* of the voltage. With a sudden decrease of arc current, and corresponding sudden increase of arc voltage (in the arc as a vapor stream moving at a rate of thousands of feet per second, the changes naturally are very sudden) the condenser, even if small, takes a large current, due to the high *rate* of voltage increase, even though the increase itself is small. Thus a condenser in shunt to the arc, puts the arc out—makes it unstable.

Suppose now we shunt the arc by a capacity with an inductance in series. A momentary decrease of arc current and corresponding increase of arc voltage, send a current through the capacity-inductance, which still further decreases the arc current, and so on, that is, puts out the arc, if the condenser is large enough, though the extinction of the arc is slower, as the inductance retards the current flow. However, if the condenser is not very large, the current which the condenser takes away from the arc, charges the condenser and raises its voltage, until it becomes equal to the arc voltage, and thereby tends to stop the current into the condenser. However, the inductance in series with the condenser, maintains the current into it for some time, and so charges the condenser up to beyond the arc voltage. The condenser then discharges back through the arc, thereby, by the increase of arc current, lowers the arc voltage and thus continues to discharge, that is, over discharges, hence begins to charge again, etc., and thus, with a condenser-inductance in shunt to the arc, the condenser alternately charges and discharges at a rate depending on the values of capacity and inductance, that is, with a frequency which is approximately $\frac{1}{2\pi\sqrt{LC}}$. Hence, a capacity-inductance in shunt to the arc, causes a high frequency alternating current to pass through the condenser-inductance, and therefore through the arc, that is, makes the arc oscillating. This oscillation, however, is nothing but the instability of the arc, resulting from its voltampere characteristic. It thus is similar to the effect of the organ pipe put over the air outlet, which makes the irregular noise of the escaping air, a harmonic vibration by giving a resonant body of air.

Thus, wherever an arc occurs in a circuit capable of oscillation, that is, having inductance and capacity, as a transmission line, oscillations are set up; but the arc itself has no frequency, but oscillates with the frequency set by the oscillating circuit, and it depends on the circuit condition, whether we get a steady continuous oscillation, as in the singing arc, or a series of disconnected wave trains, as with an arcing ground, on a transmission line, or, with low inductance and very large capacity, the arc is merely made unstable and put out.

C. P. S.

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.

LIGHTNING ARRESTER: FOUR *vs.* THREE TANK FOR GROUNDED NEUTRAL THREE-PHASE

(160) Aluminum arresters for three-phase grounded neutral circuits originally consisted of three sets of trays connected in Y from the line conductors to ground. The more recent type for such circuits has four sets of cones, three sets connected in Y from the line conductors to a common point between which point and ground the fourth is inserted.

Please explain why this change was found to be advisable, and show how the latter arrangement protects against high voltages to ground (the normal operating voltage to ground is $\frac{1}{\sqrt{3}}$ of the line voltage and any two arresters in series are charged for full line voltage).

First of all it should be understood that there is a legitimate field for the three-tank arrester; but at the same time it must be realized that only such systems are eligible to this field as have the neutral thoroughly and permanently connected to ground by a constant low resistance at all stations and also have relays set for instantaneous operation on the circuit-breakers and oil switches. Such conditions are rather ideal, however, and are rarely found in practice.

When a three-tank arrester is operated on a three-phase grounded neutral circuit, each stack of cones normally receives the neutral voltage when the arrester discharges; but, if a line becomes accidentally grounded, approximately full line voltage is thrown across each of the other stacks of cones until the circuit-breaker opens the circuit. Line voltage is 173 per cent of the neutral or normal operating voltage of the cells, therefore it is about 150 per cent of the permanent critical voltage of each cell. This means that when a ground occurs on a line this 50 per cent excess dynamic potential is short-circuited through the cells, until the circuit-breaker opens. The amount of energy that will be dissipated in the arrester depends upon the kilowatt capacity of the generator, the internal resistance of the cells, and the time required to operate the circuit-breakers. It is evident that the greater the resistance in the neutral, the longer will be the time required for the circuit-breakers to operate.

In those cases where the earthing resistance in the neutral is great enough to prevent the automatic circuit-breakers from opening practically instantaneously, it is difficult to accurately determine these factors of ground resistance and time lag of switches. This is the leading reason for abandoning the three-tank arrester.

Another reason is that often the neutral is grounded through only one bank of transformers and the neutral connections are made through switches which may be accidentally left open, which condition will remove the ground from the system and render a three-tank arrester subject to strains for which it was not designed. Furthermore, some lines are operated with the neutral grounded at only one station and. in case of trouble, this may be removed without consideration being given to the arrester. The unreliability of grounds constitutes another source of trouble for the three-tank arrester.

A full consideration of the following will make it evident that a far greater degree of reliability of protection is offered by the four-tank arrester on a so-called grounded neutral circuit.

While it is of course obvious that the three-tank arrester places a lower resistance in the discharge circuit to ground than does the four-tank arrester, a closer investigation will show that this fact is not as important as it would appear to be at first thought.

The horn-gap setting on both three- and four-tank arresters is made with reference to the delta or line-to-line voltage in all cases. It averages about 20 to 35 per cent above the delta voltage and varies from practically the delta voltage on high-voltage arresters to approximately 175 per cent of delta voltage on arresters for 2300-volt circuits. There is but one gap in the ground discharge path in either type of arresters, therefore the breakdown voltage to ground in each is the same. Consequently, the whole electrical difference between the arrangements is found in the additional resistance in the ground stack of the four-stack arrester. Theoretically, this will not allow the four-tank type of arrester to discharge as much current to ground as the three-tank type; but because of the enormous discharge rate of an aluminum arrester under excess potential, the current passed even with the double ohmic resistance is more than sufficient to relieve the circuit from the surge or disturbance.

While it is true that the normal dynamic potential to ground on a grounded neutral circuit is the delta or line voltage divided by the square root of three, yet all apparatus for such service is designed with a sufficient factor of safety to operate on non-grounded circuits; thus, from the standpoint of the apparatus and line insulation, the degree of protection offered by either type of arrester is the same.

E.K.S.

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General Electric Review

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Victor Ernst

LOBBY OF HOTEL STATLER, DETROIT. PHOTOGRAPHED AT NIGHT BY LIGHT FROM MAZDA LAMPS. EXPOSURE 20 MINUTES AT F-32. (See page 186.)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

We publish in this issue Senator Oscar W. Underwood's address delivered at the American Electric Association's dinner in Chicago, February 4th. Such addresses are timely. But it is essential that the public at large should realize the serious position of the steam railroads as well as those directly and indirectly financially interested. The welfare of our railroad systems is inseparably tied up with the prosperity of the whole community, and if this vital truth were once widely recognized common sense would dictate that prosecutions and persecutions for past sins, some real and some imaginary, should cease; and that the railway problem should be dealt with in the light of reason.

It must be generally recognized that the public interest cannot be adequately served until such time that the railroads can earn sufficient money to meet increased operating expenses, to defray the cost of new equipment and the proper maintenance of old, the maintenance of ways and structures, to make necessary improvements and to earn a fair rate of interest on the capital expenditure involved. It is to be sincerely hoped that the President's recommendation, in his recent message to Congress, that a committee be appointed to investigate the problems that confront us in the field of transportation will lead to these happy results.

The public interest in our transportation systems is much larger than the public themselves recognize, as an example, we quote from Senator Underwood's address:

"The capital invested in transportation is about one-sixth of all the wealth of the country and about one-twelfth of all our people depend for their livelihood on the wages paid by transportation corporations."

When we add to these vested public interests the dependance of our industrial life, both directly and indirectly, upon transportation, it must be apparent that the efficient operation of our steam railroad systems is a vital factor in the structure of our whole economic life.

Our modern mode of living which has been so changed in recent years by engineering developments is a highly complexed affair, in which every vital factor is tied together by, and is dependent, to a greater or lesser degree, on transportation. This being the case, it is for the public welfare that our railroads are operated upon as highly an efficient and as economical a basis as is possible, and this can only be accomplished when faith is restored in railroad securities as sound investments.

It often requires the expenditure of a very considerable amount of capital to secure the economies made possible by modern scientific and engineering developments—The results already accomplished in the fields of steam railroad electrification, for the heaviest and most severe nature of traffic, warrants the belief that many roads will avail themselves of this great opportunity to effect economies in operation as soon as the necessary capital is procurable at satisfactory rates.

That very marked economies can be secured by electrification is today beyond question. The results accomplished in the case of the Butte, Anaconda & Pacific Railway have been published in detail, and the rapid progress being made on the very extensive electrification in progress on the Chicago, Milwaukee & St. Paul Railway is holding the attention of the entire railroad world focussed on the developments in, and the possibilities of, high-potential direct current railway apparatus, as a most important factor in introducing economies into our transportation systems.

LIGHTNING: ITS RISKS AND HOW TO AVOID THEM

By Prof. Elihu Thomson

In collaboration with Prof. C. A. Adams, Dr. Louis Bell, Prof. D. C. Jackson and Prof. A. E. Kennelly

The authors have compiled this story in simple popular language, to give the layman a general knowledge of the dangers of lightning and how to avoid them. An authentic statement on the different kinds of lightning is welcome and it is most useful to have recorded the common sense methods of avoiding danger during thunderstorms, which should be more generally known than they are at present.—Editor.

This pamphlet is not intended as a technical document, but is meant to convey, in popular form, such reliable information as may be helpful for the preservation of life and property from the lightning hazard. Hence it is necessarily brief, only dealing with those parts of the subject which concern the public to whom it is addressed.

Fig. 1. Direct Stroke or Forked Stroke of Lightning (McAdie)

In the following pages, it is not desired to exaggerate the danger to human life from lightning; for in fact this danger is small. It is, however, hoped to decrease such small danger as exists, by pointing out what precautions may be taken to minimize it.

Lightning is a visible electrical discharge in the atmosphere. Thunder is the sound accompanying a lightning discharge, and is due to the sudden and violent expansion, caused by heating of the air in the path of the discharge. An observer, close to the lightning stroke, would observe the flash and thunder at the same instant. The farther he is away, the greater the interval of time between the light of the flash and the sound of the thunder, since light travels at the rate of 186,000 miles (300,000 kilometers) per second; while sound only travels about 1100 feet (333 meters) per second. Consequently, an observer can tell how far he is from a lightning flash, by counting the seconds which elapse from the moment he sees the flash to the moment when he hears the thunder, allowing about 5 seconds to the mile* (3 seconds to the kilometer).

Different Kinds of Lightning

Lightning may be divided into the following classes:

(1) *The "Direct Stroke,"* as considered above, and including the "forked stroke," is a huge electric spark, occurring either between cloud masses, or between a cloud and the earth. See Fig. 1. It usually takes a zigzag course, and may be either forked or multiple.

(2) *Band Lightning.* (Fig. 2.) This stroke is often so broad as to resemble a ribbon or band, and is caused by a rapid succession of discharges along the path, which has meanwhile been slightly displaced by the wind. Occasionally, there seems to be no displacement of the discharge path; but a succession of violent discharges occur in it. This constitutes the multiple or repetitive stroke. Both of these are manifestly dangerous forms.

(3) *Sheet Lightning,* due to flashes in or between clouds, or between a cloud and earth, where the direct stroke is itself invisible,

* In counting these seconds, the time should be taken to the arrival of the heavy explosion, and not to the first rumble, which sometimes precedes it, owing to tributary electric discharges in the clouds more nearly overhead.

but lights up the clouds.* Such lightning is so remote that no appreciable danger is associated with it.

(4) *Heat Lightning*, a form of sheet lightning, in which the storm is so distant that neither the direct stroke nor the accompanying thunder are observable. Heat lightning is so called because of its prevalence on summer evenings. Being so remote, it is harmless at the place where it is seen.

(5) *Ball or Globular Lightning.* There are numerous records to the effect that a very rare and perhaps dangerous form exists, described by some observers as a luminous but not very brilliant ball or patch, which may persist for some little time, and may move from place to place. It is described as terminating, in many cases, in a loud explosion. No doubt many cases of reported ball lightning are either fictitious or illusory. Owing to the great rarity of ball lightning, practically nothing is known of its nature or of the dangers, if any, accompanying it.

(6) *Bead Lightning* is another very rare form of discharge described as resembling a chain of luminous beads, gradually fading away. Nothing seems to be known as to the danger, if any, connected with it.

(7) *Induced Discharges.* Any powerful electric discharge, such as a lightning stroke, produces local electric disturbances in its vicinity, which may manifest themselves as sparks between adjacent metallic bodies; e.g., pipes or wires. These local spark discharges are usually harmless, so far as life and person are concerned; but they may start fires in the presence of highly inflammable material. Lightning discharges may also be conducted to a distance by wires, or other metallic conductors, and produce local discharges remote from the locality of the stroke.

Causes of Lightning

While much discussion has occurred as to the causes of lightning, it may suffice, for present purposes, to say that the electric charge of a cloud, of which lightning is the discharge, accompanies the condensation and upward motion of water droplets formed from aqueous vapor carried by the air, which rises by being heated in sunshine on the earth's surface. This forms the well known cumulus cloud, or typical thunder cloud. The rarity of thunderstorms in winter is probably due to the fact that ice or snow particles, unlike water particles, are electrically non-conducting, and do not undergo the same actions in the cloud.

* A sub-type of sheet lightning probably exists, in which a silent glowing discharge occurs within a mass of cloud, or, in rare cases, between a cloud and earth, no thunder being heard.

Brief Historical Outline

Although man has been familiar with lightning for an indefinitely great period of time, it was not known until Franklin's celebrated kite demonstration, at Philadelphia in 1752, that lightning is, in reality, an electrical discharge, although suggestions to that effect had previously been made. As a direct consequence of his discovery, Franklin invented the lightning rod and proposed its introduction for the protection of buildings, ships, and other structures likely to be injured by lightning. Many high structures of wood or stone which had been previously damaged by lightning, escaped subsequent injury, after being provided with the Franklin rod, although sometimes struck. All such buildings which, by their construction, do not permit free passage of a lightning discharge to earth, may nowadays be protected by an intelligent application of the lightning rod.

Fig. 2. Band or Ribbon Lightning (Justus)

Dangers from Lightning

The dangers from lightning are of two kinds, which may be simultaneously associated; namely

(1) Dangers to person.
(2) Dangers to property.

Danger to person is practically confined to shock, which may produce either injury or death. Danger of injury may arise from the mechanical concussive shock of a discharge in the immediate neighborhood, acting like an explosion; but it arises more frequently from the passage of the electric discharge through the body in sufficient quantity to injure or destroy the vital functions. Occasionally, a very mild electric shock may be the indirect cause of injury by a fall or other accident. Danger to property may consist either of injury or death to livestock; or of destruction, partial or complete, of objects, including trees, buildings, etc., which may be either shattered or set on fire.

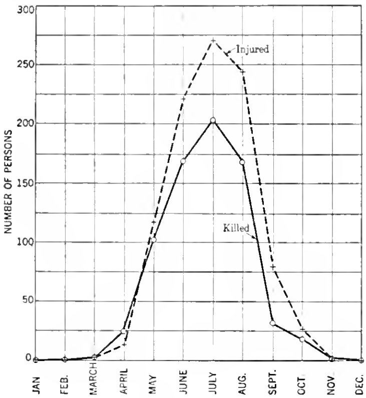


Fig. 3. Curves Showing Number of Persons Killed and Number of Persons Injured by Lightning in the United States During the Different Months of 1900

Brief Account of Lightning Damage

The United States Weather Bureau published in 1901* some extensive statistics of deaths, injuries and damage from lightning in the United States during the year 1900. It appears from these reports that the total number of persons killed in that year was 713, and of injured 973, making a total of 1686 casualties in the United States for that year. The curves in Fig. 3 have been drawn from the data contained in the report, and show the number of deaths and injuries in each month of the year. It will be seen that during the winter months December, January and February, there were no casualties, in March and November very few, in April and September a relatively small number; while the casualties are numerous in May, June, July and August, with a maximum in July. Of the 562 deaths under reported conditions, 52 per cent are stated to have occurred in the open, 38 per cent in houses or barns, and 10 per cent under trees. The observance of simple precautions would doubtless have saved a considerable proportion of these lives.

The casualties from lightning during the year 1900 appear to have been nearly all east of the 105th meridian. The immunity of the western States is to be attributed both to the infrequency of severe thunderstorms in them, and to relatively low population density.

The number of buildings in the United States struck during the year 1899, is stated to have been 6256, with a loss of over three millions of dollars, and the number of live stock killed in the fields 4251, with a total estimated loss of nearly $130,000

Useful Precautions to be Observed in the Open, as in Fields or on the Water

Many of the persons who have been harmed by lightning were struck in the open fields, especially on hills or slopes, towards which a thunderstorm was approaching. Even when the ground is level, as in a flat country without trees in the vicinity, a relatively small object, such as a man walking or plowing, may cause the lightning to find its discharge through his body, as the shortest conducting path to ground. In the same way, live stock wandering in the open may be killed by direct stroke. Again, groups of men or of livestock in the open are yet more likely to receive a stroke. The safest procedure under such conditions is to seek a dry depression in the ground, and to crouch down in it. Groups should scatter, and, if possible, follow a like procedure.

The precautions to be observed in open boats are of the same character as those to be taken in the open fields; i.e., the boat itself, even though it may be a small object, may determine the location of the lightning stroke over an area of water surface. More especially is this the case if the masts are tall. In an open boat, it is safest to crouch down during the height of the storm. Wooden masts should be protected by lightning rods. Steel masts and smoke stacks need no protection when in a steel hulled

* United States Weather Bureau Bulletins No. 26 and No. 30, 1901.

boat, but in a wooden boat should be connected to the sea by chains. The hold of a metallic boat is a safe place, and a person is perfectly safe under the steel deck of a steamer's steel hull.

It is unsafe to take refuge in a thunderstorm under a tree, particularly a tall tree; because trees, in general, are apt to be struck, the taller ones the more readily. A person standing under a tree runs three risks. His body may cause to be diverted from the trunk of the tree a portion of the discharge, which may injure or kill him; or a limb of the tree may be shattered and fall upon him; or, further, the tree trunk may be disrupted explosively, with numerous and heavy splinters projected violently outwards.

While it is unsafe to take shelter underneath a tree during a thunderstorm; yet, if no safe situation can be found in the open fields surrounding trees, it is better to take up a position near a tree, avoiding the tallest, but not under its foliage. This exposes the person to rain; but removes some of the danger. In the first place, because a tree is tall, it may act somewhat like a lightning rod to the space in its immediate vicinity. In the next place, a man, with his clothes thoroughly wet, is less likely to be injured if he receives a partial discharge. In general, a person should take refuge in a house before the storm has commenced, and should avoid taking chances, during the height of a storm, in traversing an open field.

Forest lands are always safer than open fields during a heavy thunderstorm; because the presence of a man in a forest cannot determine the locality of a stroke, on account of the greater height of the trees. Nevertheless, there is still the risk of being near to a tree which is struck. If there are small open spaces between the trees, it is safer to select such a position, so as to avoid being immediately under a tree.

Just as a man standing up in the open is in a more dangerous position under a discharging thundercloud than when crouching down, so a man on horseback is more exposed to danger than when standing on the ground. There is also risk in a carriage or automobile, in the open, during the height of a storm. The risk is increased by riding or driving over an exposed peak, or treeless hill, when a storm is either approaching, or is central overhead.

Shelters

It is dangerous to take shelter from a storm under a metallic roof which has no metallic connection with the ground. Some of the worst recorded accidents have occurred to a number of persons crowded under a low metallic roof on wooden pillars.

A dwelling house of any kind is usually safer than an open shed, and the more so if it contains in its construction metal of any kind such as water-pipes, gas-pipes, drains, or ventilators, running continuously from the ground level to the roof. Many buildings of wood, brick or stone frequently afford ample protection to persons within them, by reason of such internal metallic conductors, though no lightning rod has been applied to them. Buildings having metal frames, such as reinforced concrete structures, steel office-buildings, etc., afford perfect protection, and need no lightning-rods, so far as danger to life is concerned. The metallic cage formed by a steel frame building affords ideal protection. There is no case recorded of a personhaving been either killed or injured by lightning within a steel-frame office building, where unprotected wires have not entered the building to produce local discharges. Such buildings, if tall, are often struck; but the discharge is harmlessly carried to ground by the metallic frame.

On the other hand, a building in the open country, which does not include well-grounded metal within its structure extending to the roof, involves an element of danger in the presence of a severe thunderstorm. The danger is considerably increased if the house is on the top of a hill; or if it occupies an exposed position on a slope. Tall trees in the neighborhood, if not immediately over the house, tend to lessen the danger, by diverting strokes to themselves. Similar remarks apply to barns. The safest places, in such a house, during the onset of an electric storm, are away from fireplaces, chimneys, or chimney foundations, and not too near the walls. The element of danger from a chimney is its vertical layer of conducting soot from the room to the chimney top, above the roof. If a fire be alight in the grate, there is the additional element of danger in the column of smoke and hot gases, rising to a considerable height through the air above the house, and tending to invite a discharge. For the same reason, it is advisable for a party camping in the open country to extinguish a campfire, or at least to avoid its immediate neighborhood, on the approach of a heavy thunderstorm.

Property Damage

This consists of destruction either by disruption or fire. A large aggregate amount of such damage is done by lightning in American forests, principally through fires. Although heavy rains accompany thunderstorms; yet a lightning stroke may set fire to a dry tree trunk, or to woody humus material at its base. This fire may smoulder for days,

Fig. 4. Lightning Stroke at Top of the Eiffel Tower, Paris, May 31st, 1897 (Lappe)

and spread to more inflammable material in later dry weather. According to United States Government reports, during the years 1906–1911, the number of fires in the National forests alone, due to lightning, averaged nearly 500 annually.

In cities, owing to the close association of many large structures containing piping, grounded metallic roofing, or steel frames, there is little danger of injury either to life or property; although lightning strokes are probably just as frequent there as in equal areas elsewhere. The principal damage occurs in isolated and exposed structures in the open country, where the protection just referred to does not exist. A low frame house, in a hollow or valley, with tall trees in the neighborhood, and not near a body of water, is not likely to be struck at any time; but the same house on the top of an exposed hill without trees is much more likely to be struck. Without adequate metallic protection, a lightning stroke may do damage to a building either by disrupting its structure or by setting fire to it, particularly if it contains inflammable material.

A building in the open country, containing in its structure a continuous conducting metallic path from moist ground up to the roof and its projections, is not likely to be appreciably damaged, even if struck by lightning. Standing by itself in an exposed position, it is more likely to be struck, than if grouped with a number of other buildings, any of which might share the chance of discharge. The mere fact, however, that a building containing metallic protection is more frequently struck, is of little consequence, so far as damage is concerned. For example, the Eiffel tower in Paris, the tallest structure in the world, and composed of steel, is frequently struck, see Fig. 4; but no damage has yet been reported, as occurring either to the tower itself, or to persons within it. Protection from lightning therefore depends not on preventing a building from being struck; but on providing an easy path of discharge, through conducting metal, from the highest projecting roof point to the ground.

Ground

By ground, is meant the best electrically conducting ground connection to be found on the premises, or in the immediate vicinity. Merely leading a lightning-rod into comparatively dry ground may be altogether inadequate. It does not necessarily follow, either, that a lightning-rod terminated below in moist soil is adequately grounded, if there is better ground close by, for the reason that a lightning discharge will tend to reach the best ground, by a partial diversion through some part of the building, with corresponding hazard of disruption or fire. Perhaps the best possible ground is an extensive continuous metallic pipe-system, which is buried in the earth, such as a water-pipe system. In the absence of a pipe system, one may use a pit carried down to permanently moist soil, say 2 or 3 ft. in diameter (half a meter to a meter) and containing, at the bottom, a layer say 2 ft. deep (60 cm.) of coke, into which the terminal plate of the lightning conductor is embedded. Instead of a pit, a narrow trench, the longer the better, leading away from the building, may be dug to the depth of moist soil, to contain the coke layer. If coke is not available, scrap iron, charcoal, or anthracite coal, preferably partly burned (not ashes), may be used as substitutes. Soil that is saturated with stable drainage makes excellent ground, and, if connection can be made to it, so much the better. If more than one rod is applied to a building, each rod should be provided with equally good ground.

Rods

Rods should be constructed either of galvanized iron or of copper. Iron is the cheaper metal, but is more subject to corrosion. It therefore has to be used in larger sizes, and kept painted if possible, especially at the ground line. Wire, either solid or stranded, piping, or strips may be used. A galvanized iron wire cable ⅜ in. (1 cm.) in diameter over all, is adequate; or, small iron standard gas piping of ⅜ in. (1 cm.) size (internal diameter) will serve, with the ordinary screw couplings well tightened, and the whole painted. Strap iron of equivalent section, using double-riveted joints, and well painted, may also be employed. Insulators to support the rod away from the building are probably unnecessary, and the rod may be conveniently carried down the walls. On the other hand, it is inadvisable to use long spikes for fastening the rod into wooden walls. Screws, being shorter, are preferable.

Metallic roofs, gutters or water conductors should always be connected to the lightning-rod, either by direct clamping or by strips. Unless the building to be protected covers much ground, a single rod is sufficient. A long building would advantageously be provided with a rod at each end. Long L's or wings of the same height should have similar protection. The upper extremity of a rod should project about a yard (1 meter) above the highest portion of the building, such as a chimney, and, for this purpose, should consist of a stiff rod, well secured. It may be roughly pointed, but special points of precious metal are altogether unnecessary.

If copper is used, instead of iron, on account of its lesser liability to corrosion, and consequent durability, wire or strap copper may be employed, preferably hard rolled. The hard drawn copper wire used for overhead trolley conductor and known as size No. 1, American wire gauge, diameter 0.289 in. (0.735 cm.), (cross-section 0.0657 sq. in. or 0.424 sq. cm.), is excellent. Copper strap of equivalent cross-section may also be conveniently used. Connections between lengths of copper wire or strap should preferably be made permanent by either twisting and soldering, or riveting and soldering, and the supports may be the same as for iron conductors. If a house is provided with one or more iron ventilating pipes, having metallic joints, from sewer to roof, no separate lightning rod is ordinarily needed, but a rod connection is then especially desirable from the top of the ventilating pipe to the nearest tall chimney, so as to project 2 or 3 ft. above it.

Popular Fallacies

The current notion that lightning never strikes twice in the same place, is a wide spread fallacy, not in accordance with the facts; since numerous cases are reported of strokes having occurred to the same buildings or to the same trees, and even in the same year. If adequate protection is provided, no particular harm arises from repeated lightning strokes. Another common fallacy is that there is great danger in holding a small metallic body, such as a needle or penknife, during a thunderstorm. There seems to be no rational basis for this belief. It is also an unwarranted assumption that lightning follows draughts of air; or that it is particularly unsafe to stand by an open window; although there may, however, be some risk in leaning out of a window during a storm. Many persons appear to be more terrified by the noise of thunder, than by the flash. The thunder, in itself, is harmless, and a thunder clap can only be heard after the personal danger from the flash which produced it has passed by. In fact, a person who sees a flash is already out of danger from that particular discharge. Finally, it is a common fallacy that, for adequate protection, a lightning rod should have either a large cross-section, or very large surface; or that some particular material or arrangement of material should be used in its construction, it being supposed that lightning travels or oscillates in some peculiar way, so as to call for such precautionary dispositions. There is no evidence in support of such a contention. The cross-section of a lightning conductor should be so chosen as to give assured mechanical stability, and adequate durability against corrosion. Lightning rods large enough for this are ample for conducting lightning discharges to ground.

Procedure in Case of Lightning Stroke

Since a person struck by lightning is not necessarily thereby killed outright, but may only be rendered temporarily unconscious and deprived of breathing, steps should be taken at the earliest moment to send for medical aid, and meanwhile, to resuscitate such a subject by artificial respiration. The infrequency of such lightning strokes rendering persons unconscious is such that it would be unnecessary to describe the procedure on this account alone. Since however the same method of artificial respiration is proper in cases of suspended animation or shock caused by electric wires, drowning, or suffocation by gas, the method recommended by the National Electric Light Association is given in the Appendix.

Fig. 5. Position of Patient for Resuscitation from Electric Shock by Artificial Respiration

In conclusion, it may be again pointed out that whereas the actual danger of being struck by lightning is in reality very small; yet, in order to minimize such danger as exists, it has been necessary to enlarge upon the conditions as though they were of common occurrence.

APPENDIX

Extracts from the "Rules for Resuscitation from Electric Shock" recommended by the National Electric Light Association, New York.

Instructions for Resuscitation of those Rendered Unconscious by an Electric Shock

I. Send for the nearest doctor.

II. Attend instantly to the victim's breathing.

(1) As soon as the victim is clear of the live conductor,* quickly feel with your finger in his mouth and throat and remove any foreign body (tobacco, false teeth, etc.). Then begin artificial respiration at once. Do not stop to loosen the patient's clothing; *every moment of delay is serious.*

(2) Lay the subject on his belly, with arms extended as straight forward as possible, and with face to one side, so that the nose and mouth are free for breathing (see Fig. 5). Let an assistant draw forward the subject's tongue.

If possible, avoid so laying the subject that any burned places are pressed upon.

Do not permit bystanders to crowd about and shut off fresh air.

(3) Kneel straddling the subject's thighs and facing his head; put the palms of your hands on the loins (on the muscles of the small of the back), with thumbs nearly touching each other, and with fingers spread over the lowest ribs (see Fig. 5).

(4) With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the subject This operation, which should take from two to three seconds, *must not be violent*—internal organs may be injured. The lower part of the chest and also the abdomen are thus compressed, and air is forced out of the lungs.

(5) Now *immediately* swing backwards so as to remove the pressure, but leave your hands in place, thus returning to the position shown in Fig. 5. Through their elasticity, the chest walls expand and the lungs are thus supplied with fresh air.

(6) After two seconds swing forward again. Thus repeat deliberately twelve to fifteen times a minute the double movement of compression and release—a complete respiration in four or five seconds. If a watch or a clock is not visible, follow the natural rate of your own deep breathing—swinging forward with each expiration, and backward with each inspiration.

While this is being done, an assistant should loosen any tight clothing about the subject's neck, chest, or waist.

(7) Continue artificial respiration (if necessary, two hours or longer), *without interruption*, until natural breathing is restored, or until a physician arrives. Even after natural breathing begins, carefully watch that it continues. If it stops, start artificial respiration again.

During the period of operation, keep the subject warm by applying a proper covering and by laying beside his body bottles or rubber bags filled with *warm* (not hot) water. The attention to keeping the subject warm should be given by an assistant or assistants.

(8) *Do not give any liquids whatever by mouth until the subject is fully conscious.*

* Manifestly, in the case of persons rendered unconscious by lightning, as also in the case of those being rescued from drowning, the reference to a live conductor, rendered necessary for cases of accident by contact with a high-voltage live wire, is superfluous.

THE PRODUCTION OF CONSTANT HIGH POTENTIAL WITH MODERATE POWER CAPACITY

By A. W. Hull

Research Laboratory, General Electric Company

Serious obstacles and unsatisfactory results have always attended any attempt to produce a high-voltage direct current of more than very small power capacity. Recently, however, a method employing the newly developed kenotron has been utilized for producing high-voltage direct current having a moderate power capacity. The article describes in detail the method, the calculations, and the necessary apparatus, and is supplemented by oscillographic records.—Editor.

Introduction

Up to the present time only two methods have been available for the production of constant high potential, viz., the electrostatic induction machine, and the combination of a large number of low-voltage d-c. generators in series.

The electrostatic induction machine was invented simultaneously by Holtz and Toepler in 1865, and consists essentially of two or more conductors, one of which is permanently charged and may be considered as stationary, while the others move past it at high speed. If one of the moving conductors is momentarily earthed at the instant when it is opposite the stationary conductor, it will receive, by induction, a charge equal to the product of potential of the stationary conductor and the capacity of the condenser formed by the two conductors at that instant. The movable conductor retains this charge as it moves on, and, since its capacity gets smaller and smaller as it moves away, its potential gets higher and higher. When it is completely out of the field of the stationary conductor, and its potential is therefore a maximum, it is momentarily connected to the utilization circuit, to which it delivers its charge at high potential. By making the number of movable plates sufficiently large and their speed high, the rate at which these small installments of high potential current are delivered to the circuit can be made nearly continuous, and the total current delivered is limited only by the number, capacity, and speed of the plates. The plates are generally made in the form of sectors of a circle, and mounted on large disks of glass or other insulating material, each disk carrying a large number of plates. Machines have been built, having 20 movable and 20 stationary disks, which can generate as much as 80 milliamperes. But a large part of this is lost at high voltages by surface leakage, which becomes so great at about 50,000 volts that it is usually impossible to get anything above this voltage unless the plates are extremely dry and clean. Some of the most recent machines have plates made of a composition that is less hygroscopic, and one of the best of these, with 8 moving and 4 stationary plates, gives 4 milliamperes at voltages of nearly 100,000, and can deliver a little current even at 150,000 volts.

The chief limitation of machines of the electrostatic type, besides their small power, is that the voltage is not constant, but builds up indefinitely until limited by spark-over or brush discharge.

The combination of d-c. generators in series is used in a few power installations where long distance or underground transmission is necessary,* and occasionally for other purposes, where only a few thousand volts is desired. Its chief disadvantage is that the generators must be mounted on insulated beds and driven with insulating belts or shafts. For smaller power work the cost would be prohibitive for high voltages.

Recent developments in the field of electric conduction through vacuum, and especially the development† and extensive use of high power X-ray tubes, have created a considerable demand for a source of power that will furnish from 1 to 50 kw. at voltages between 10,000 and 200,000. The apparatus to be described was not designed to meet this general demand, but as an accessory to a definite investigation on X-ray spectra. It has, however, proved so satisfactory as to recommend itself for quite general use where constant high voltage of a few kilowatts capacity is needed.

Outline of Method

The method used was that which has been under investigation in this laboratory,‡ namely,

* For an excellent review of the history of d-c. transmission, with its advantages and disadvantages, see Baum, "The Thury System of Direct Current Transmission," G.E. Review, XVIII, p. 1026, November, 1915.

† See Coolidge, *Phys. Rev.* 2, 409-30, (1913).

‡ See Langmuir, G.E. Review, May, 1915, and Dushman, G.E. Review, March, 1915.

the rectification by kenotrons of high tension alternating current, and using this rectified current to feed a high-voltage condenser of such capacity that it can supply the desired current during the part of each cycle when it is receiving nothing without having

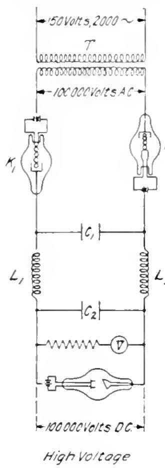


Fig. 1

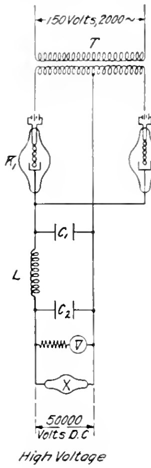


Fig. 2

Diagrams of Connections for the Production of High-voltage Direct Current

its voltage drop more than a small specified amount. In the present case the capacity used was much smaller than that necessary to keep the voltage fluctuations within the desired range, and these fluctuations, which were about 25 per cent for full load, were damped out by the use of another small condenser of the same size and a small choking coil. The arrangement is shown in Fig. 1. Single-phase alternating current of 2000 cycles at 150 volts is stepped up to the desired voltage by a transformer T, rectified by kenotrons K_1 and K_2, and smoothed out by the condensers C_1 and C_2 (0.001 microfarad capacity each) and inductance L_1 and L_2 (about 200 henrys each). The manner of operation of the inductance and capacity is discussed below. The voltage is measured by an ordinary voltmeter V in series with a 10-megohm resistance R.

By this means it was possible to supply 5 kw. at any voltage between 10,000 and 100,000 volts with a voltage fluctuation of less than 1 per cent. This output could, if desired, be more than quadrupled by the use of 4 kenotrons instead of 2, and still further increased by the use of three-phase alternating current as described below.

The 2000-cycle Generator

The generator is of the dynamotor type, that is, one in which the same magnetic field is used for motor and generator, and has already been briefly described in the REVIEW.* It is designed for a 10 kw. single-phase 2000-cycle output, and operates on a 440-volt, three-phase, 60-cycle line. It can be built equally well to operate on any voltage, a-c. or d-c. Fig. 3, which is reproduced from Mr. Alexanderson's article, shows a photograph of a similar 2000-cycle generator built for 2 kw. with d-c. drive.

The Transformer

The transformer is built for 75 kv. r.m.s. It has an air gap in the magnetic circuit, and when untuned takes 75 amperes magnetizing current. By the use of 50 microfarads capacity across the primary this is reduced to about 3 amperes.

This use of an open circuit transformer makes it possible to use only one-half of each wave, as in the arrangement shown in Fig. 1, without appreciably distorting the voltage

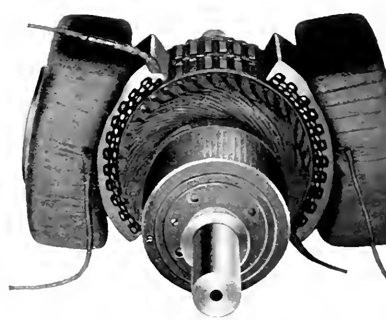


Fig. 3. Photograph of a 2000-cycle 2-kw. Dynamotor

wave (see Figs. 9 to 15), and it gives a very convenient means of voltage control, viz., by varying the capacity it is possible to vary the voltage over the entire range from 40,000 to 100,000 volts. This is the method of control used.

* Alexanderson, G.E. REVIEW, Jan., 1913.

The Kenotron

The kenotron has already been described in the REVIEW.* It consists of a hot filament cathode and a metal anode, generally tungsten or molybdenum, which is so thoroughly freed from gas by intense heating during evacuation that no gas phenomena ever appear, even at 100,000 volts. Under these conditions the conductivity of the tube is entirely unidirectional, the current being carried only by the electrons emitted by the hot filament.†

Figs. 4 and 5, which Dr. Dushman has kindly furnished, show the types of kenotron, and Fig. 6 shows the completeness of the rectification. On the positive half of the cycle the current and voltage follow the a-c. wave, the voltage drop in the kenotron being only 200 or 300 volts. On the negative half the current is zero, and the voltage drop in the kenotron is the full voltage of the a-c. wave.

It is evident from the manner of operation of the kenotron that it has two advantages over other types of high voltage rectifier, which make it especially adapted to the production of constant potential.

(1) It allows current to flow in only one direction, whatever the voltage may be. Hence, if used to charge a condenser it will feed current into the condenser whenever the a-c. voltage is higher than that of the condenser, but will never take back anything it has given. A mechanical rectifier, on the other hand, is just as likely to discharge the condenser as to charge it, unless the timing is exactly right.

(2) Being free from all lag, such as is inherent in a gas rectifier, and having no moving parts, it operates equally well at all frequencies. This is very important, as it allows the use of a high frequency generator which greatly reduces the amount of capacity that has to be used. For example, in order to obtain from 60 cycles the same power with the same constancy as that given by the 2000-cycle outfit, viz., 5 kw. with ½ per cent fluctuation, it would be necessary to use a capacity of 0.35 microfarads, nearly 200 times the amount necessary for 2000 cycles, and this would cost, at present prices, $35,000.

* Langmuir and Dushman, G. E. REVIEW, March & May, 1915.
† If the anode is heated to a temperature comparable with that of the filament it, of course, begins to emit electrons, and the conduction is no longer unidirectional. In normal operation this never happens. The anode runs quite cold.

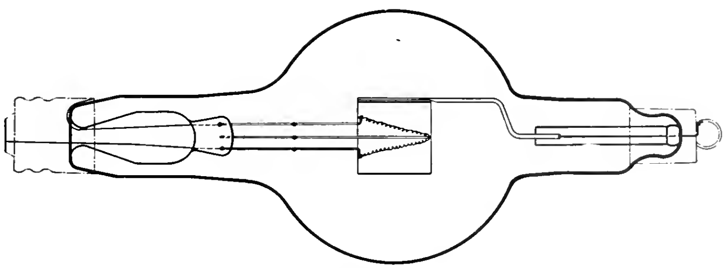


Fig. 4. Standard Kenotron for Rectifying 20,000-volt Alternating Current

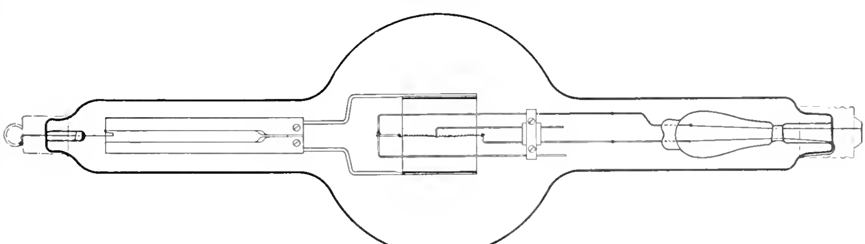


Fig. 5. Standard Kenotron for Rectifying 100,000-volt Alternating Current

The Condensers

Since no satisfactory high voltage condensers are on the market, it was necessary to use a number of low-voltage condensers in series. This introduced a new problem. When series condensers are used on a-c. the leakage in one direction is just as great as in the other, so that there is no tendency for the voltage to become unequally divided between them. With d-c., on the other hand, unless the leakage over each condenser is exactly the same, the tendency would be for the voltage to become more and more unequally divided between the condensers, until finally one would break down. The process would then be repeated with the condensers that were left, until all had broken down.

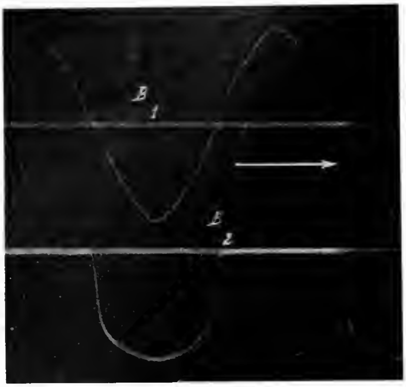


Fig. 6. Upper Curve; A-c. Voltage (Base Line B_1) Lower Curve; Rectified Current (Base Line B_2)

In order to avoid this possibility, each condenser was provided with a corona gap, of such length that the leakage over it at the voltage at which the capacity was rated would be large compared with all other leakage. Since the corona current increases very rapidly with the voltage, if the gaps are all equal it is impossible for the voltage across the different units to vary by more than 10 per cent. The arrangement is shown in Fig. 7. The condensers are of paraffin paper, rated at 10,000 volts each, ten in series. The gaps are standard sewing needles, spaced ¾-in. between points, and in order to prevent injury to the gaps from too heavy current in case of spark over, each gap is provided with a small resistance R in series with it. The best evidence of the effectiveness of this arrangement is that it has been in operation eight hours a day for eight months, often at 10 per cent above rated voltage, without an accident. At 110,000 volts, i.e., 11,000 across each condenser, spark over across the gaps occurs quite frequently, but is mild and harmless. At 100,000 volts, for which the gaps are set, it does not occur.

The Inductance

The high tension winding of a 6600/110-volt, 200-watt instrument transformer has proved quite satisfactory as a high impedance. It is difficult to calculate or to measure the effective impedance for a given frequency under operating conditions, because the actual current is an a-c., or rather a series of a-c. components, superimposed upon a d-c., and the effective permeability of the iron depends very much upon the degree of its saturation by the d-c. component. The best measurements obtainable indicated that the inductance varies from 1000 to 200 henrys. For different loads the values of voltage fluctuation calculated on this basis agree very well with the oscillograms shown in this article.

The Voltmeter Resistance

The 10-megohm resistance consists of 1000 voltmeter spools, 10,000 ohms each, in series. They are mounted 1 in. apart on lattices of ½ in. by ½ in. hard wood, 100 to each lattice, and the lattices are spaced 3 in. apart vertically above each other. The lattice allows free circulation of air, and the coils, which at maximum voltage carry only the same current as in the standard voltmeter, are in no danger of overload. In order to avoid any possible errors due to corona, the whole unit is immersed in oil, but this would not be necessary where more space is available.

Function of Kenotron and First Condenser

The kenotron may be characterized as a device which has a very low resistance, of the order of 1000 ohms, for current in one direction, and an infinite resistance for current in the other direction, and which is entirely free from the lag and "breakdown" that are necessary to the starting of gas rectifiers.

The condenser C_1 is a simple electric reservoir which absorbs energy from the transformer, through the kenotrons, during a small part of each cycle and delivers it to the circuit at a nearly constant rate during the remainder. Its operation can best be understood from Fig. 8, where the full curve represents the voltage at the transformer terminals, and the dotted curve that at the terminals of C_1. At the point A, on the peak of the a-c. wave, the condenser is charged to the full potential of the transformer. From this time on, for nearly a whole cycle, it receives nothing from the transformer, and its potential therefore falls at a rate given by the equation

$$-C_1 \frac{d\,V}{d\,t} = i \qquad (1)$$

where V is the voltage across C_1 and i the current that flows from it through the circuit. At the point B the transformer voltage becomes higher than that of C_1, and current again begins to flow through the kenotrons into C_1, charging it to the potential of the transformer at the point C, where the process of discharge begins anew.

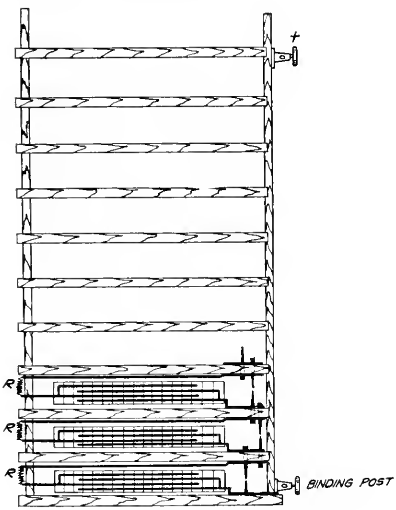


Fig. 7. Diagram Showing Arrangement of Condensers

In practical cases the current i is nearly constant, so that (1) integrates into

$$-\triangle V = V_A - V_B = \frac{i\,t}{C_1} \qquad (2)$$

where t is the time represented by the distance AB, practically one cycle. This allows the voltage fluctuation $\triangle V$, for any given values of i, C_1, and frequency n, to be very simply calculated. For example, with the values $i = 0.050$, $C_1 = 10^{-9}$ and $t = \frac{1}{n} = \frac{1}{2000}$, given above, $\triangle V = 25{,}000$ volts. Conversely, the capacity that would be necessary to reduce

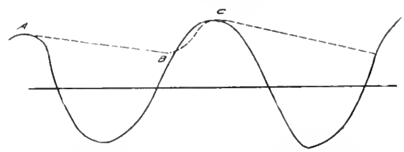


Fig. 8. Full Line; 2000-cycle A-c. Voltage. Dotted Line; Rectified Voltage at Terminals of Condenser C_1 (Fig. 1)

the fluctuation to any given value, say 1 per cent, can be calculated. In the above case, if the total voltage is 100,000, in order to reduce the fluctuation to 1 per cent or 1000 volts, one would have to use 0.025 microfarads, and this is the amount that would actually be necessary in the outfit described above if the inductances L_1 and L_2 (Fig. 1) were omitted. The actual value C_1+C_2 that is needed *with* the inductance is only 0.002 microfarads, which means a very great saving of expense, and demonstrates the value of using inductance.

Function of Inductance and Second Condenser

The inductances L_1 and L_2 and the capacity C_2 co-operate as follows: The voltage fluctuation at the terminals of C_1 is an irregular shaped wave (see Fig. 8) which when analyzed into a Fourrier's series gives a fundamental sine wave of frequency 2000 plus a series of higher harmonics. To each of these component a-c. frequencies, the inductance L_1+L_2 and the condenser C_2 offer definite impedances respectively. The ratio of the amplitude which any given component will have at the terminals of C_2, to its amplitude at the terminals of C_1 is the ratio of the impedance of C_2 to that of C_2 and L_1+L_2 in series, that is, the amplitude of the given component will be reduced to this fraction of its value by the action of $L_1+ L_2$ and C_2. In the case given above, where $C_2 = 0.001$ microfarad and $L_1 = L_2 = 200$, we have for the 2000 cycle component

$$\frac{\delta V_{C_2}}{\delta V_{C_1}} = \frac{\text{impedance of } C_2}{\text{impedance of } C_2 \text{ and } L_1+L_2} = \frac{1/C_2\omega}{1/C_2\omega + L\omega} = \frac{1}{64}$$

We have seen above that the maximum amplitude of the voltage fluctuation across C_1 is 25 per cent at 100,000 volts and 50 milliamperes, and if we take this as the amplitude of the 2000-cycle component, then the amplitude of this component at the terminals of C_2 would be $\frac{1}{64}$ of 25 per cent, or less than ½ per cent.

In like manner, the ratio of the amplitude of the second harmonic, the 4000-cycle component, at the terminals of C_1 and C_2 respectively, comes out to be $\frac{1}{256}$, of the third harmonic $\frac{1}{576}$, of the fourth $\frac{1}{1024}$, etc. It is evident that the higher harmonics are so much reduced that they need not be considered at all, even though their amplitude at the terminals of C_1 were many hundred thousand volts. This applies to the high frequency "surges" produced on closing the primary circuit, whose fundamental must always be higher than 2000.

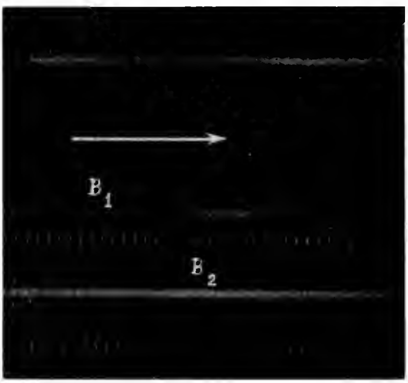


Fig. 9. Upper Curve: Constant Potential 50,000 Volts at Terminals of C_2 (Base Line B_1)
Lower Curve: 2000-cycle Primary Voltage (Base Line B_2)

A word should be said about the effect of inductance without capacity in the position C_2. It is often carelessly assumed that inductance in a line will of itself absorb current fluctuations. It is evident from the above reasoning that this is true only when the load itself has a low impedance. For small loads this is by no means the case, and for an X-ray tube of the Coolidge type, in which the current is constant and independent of voltage, the impedance is infinite for all loads and all frequencies. Hence, in this case, the use of inductances L_1 and L_2 without capacity, or some other low impedance, in the position C_2, would be entirely ineffectual. Fig. 15 partially demonstrates this fact, but the effect is rendered less striking by the comparatively low impedance of the resistance in series with the oscillograph, across the line, which had to be low enough to allow 0.040 amperes through the oscillograph.

Proportionment of Capacity Between First and Second Condensers

The most efficient proportionment of capacity between C_1 and C_2 can be calculated as follows; if we assume, as seems justified by the oscillograms (see Figs. 13 and 14), that the 2000-cycle component is the principal one and that its amplitude is approximately

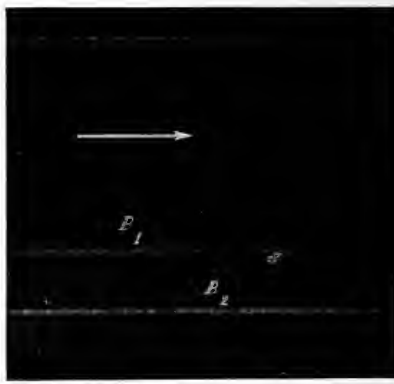


Fig. 10. Upper Curve: Constant Potential 92,000 Volts at Terminals of C_2 (Base Line B_1)
Lower Curve: 2000-cycle Primary Voltage (Base Line B_2)

equal to the maximum voltage fluctuation at the terminals of C_1:

Let $\triangle V$ = amplitude of 2000-cycle component at terminals of C_1.

Let δV = amplitude of 2000-cycle component at terminals of C_2.

By Equation (2),

$$\triangle V = \frac{i\,t}{C_1} = \frac{2\,\pi\,i}{\omega C_1} \text{ approx.}$$

and from Equation (3),

$$\frac{\delta V}{\triangle V} = \frac{1/C_2\,\omega}{1/C_2\,\omega + L\,\omega} = \frac{1}{1 + L\,C_2\,\omega^2}$$

Hence

$$\delta V = \frac{2\,\pi\,i}{C_1\,\omega(1 + L\,C_2\,\omega^2)} \qquad (4)$$

$$= \frac{2\,\pi\,i}{C_1\,\omega(1 + L\,\omega^2[C - C_1])}$$

where $C = C_1 + C_2$ is the total capacity, to be regarded as fixed in amount.

The optimum division is that which gives a minimum value of δV for a given total capacity C, and can be found by differentiating δV with respect to C_1 and placing the derivative equal to zero. This gives

$$\omega(1 + L\omega^2[C - C_1]) - L\omega^3 C_1 = 0$$

Whence

$$\begin{cases} C_1 = \frac{1}{2}\left(C + \frac{1}{L\omega^2}\right) \\ C_2 = \frac{1}{2}\left(C - \frac{1}{L\omega^2}\right) \end{cases} \qquad (5)$$

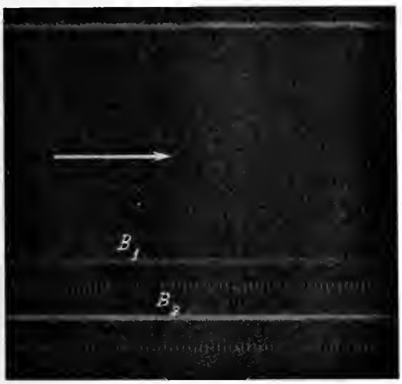


Fig. 11. Upper Curve; Constant Potential 50,000 Volts with Large Load (Base Line B_1)
Lower Curve; 2000-cycle Primary Voltage (Base Line B_2)

and

$$\frac{C_2}{C_1} = 1 - \frac{2}{1 + C L\omega^2}$$

Substituting in Equation (4) gives

$$\delta V = \frac{2\pi i}{\frac{1}{2}\left(C + \frac{1}{L\omega^2}\right)\omega\left(1 + \frac{L\omega^2}{2}\left[C - \frac{1}{L\omega^2}\right]\right)}$$

$$= \frac{8\pi i}{L\omega^3\left(C + \frac{1}{L\omega^2}\right)^2} \qquad (6)$$

In the above example, taking $\delta V = 1$ per cent of 100,000, or 1000 volts, $L = 400$, $\omega = 2\pi \times 2000$, C comes out to be 0.0013 microfarads, and $C_1 = C_2 = 0.00065$. The actual capacity used was $C_1 = C_2 = 0.001$, nearly twice the amount necessary to reduce the fluctuations to 1 per cent, and the oscillograms show that the fluctuations were actually about ½ per cent.

If 60-cycle current were used instead of 2000-cycle, the capacity necessary to keep the fluctuations to ½ per cent would be, from Equation (6),

$$C = 0.35 \text{ microfarads}$$
$$C_1 = 0.19 \text{ microfarads}$$
$$C_2 = 0.16 \text{ microfarads}$$

Results

The constancy of the voltage obtained under different conditions is shown by the oscillograms, Figs. 9 to 15. They were taken with a water resistance load in series with the

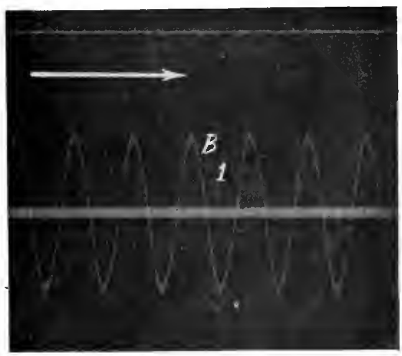


Fig. 12. Upper Curve; Constant Potential 50,000 Volts (Base Line B_1)
Lower Curve; 2000-cycle Primary Voltage (Base Line B_1)

oscillograph coil across the line, the end of the line adjacent to the oscillograph being earthed. For voltages above 50,000, where the end of the line could not be earthed, two water tubes of nearly equal resistance were used and the middle point between them grounded. Oscillograms were then taken on both sides of the ground, in order to detect any asymmetry in the form of a current to earth.

Fig. 9 shows the voltage obtained with the apparatus arranged as in Fig. 1, with a load of 50 milliamperes at 50,000 volts, and Fig. 10 shows the same for 92 kv. and 55 milliamperes. The fluctuations scarcely show in the reproduction, but on the negative they measure about ½ per cent. Fig. 11 shows the effect of a large load at lower voltage, 100 milliamperes at 50,000 volts. Here the fluctuations are clearly visible. Fig. 12 shows the results of using the two kenotrons in parallel, as in Fig. 2, thus rectifying both half waves of each cycle. The base line for the d-c. potential was made coincident with

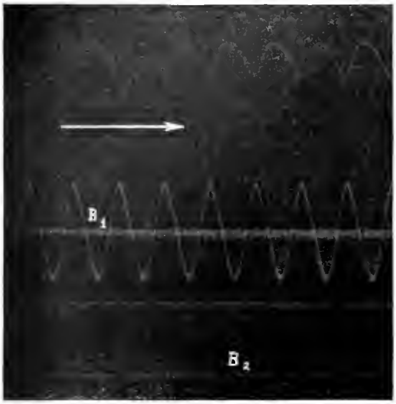


Fig. 13. Upper Curve; Voltage at Terminals of C_1, Fig. 1 (Base Line B_1). Middle Curve; 2000-cycle Primary Voltage (Base Line B_1). Lower Curve; Voltage at Terminals of C_2 (Base Line B_2)

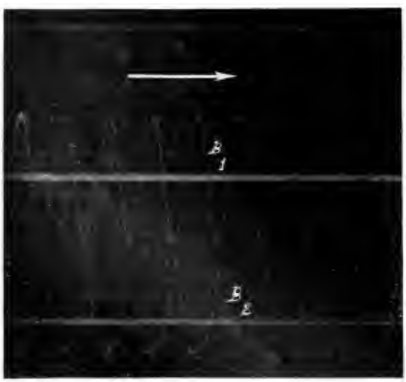


Fig. 14. Upper Curve; Constant Voltage at Terminals of C_2 (Besa Line B_1). Middle Curve; 2000-cycle Primary Voltage (Base Line B_1). Lower Curve, Current through Condenser C_1 (Base Line B_2)

that of the primary wave. The film was run at high speed so as to resolve the 4000-cycle or higher frequency fluctuations if any were present, but no fluctuations whatever can be seen, even on the original negative. This increased smoothness produced by rectifying both halves of the cycle, which means doubling the frequency of the lowest a-c. component, was to be anticipated from Equation (6), which shows that the amplitude of flucuation varies inversely as the cube of the trequency.

Fig. 13 shows the effectiveness of the inductance and capacity C_2 in reducing the amplitude of the a-c. components, and also gives an idea of the relative amplitude of the harmonics present in the voltage across C_1. The upper curve, whose base line has, to avoid confusion, been made coincident with that of the primary a-c. wave, is the voltage at the terminals of C_1, the lower curve that across C_2. It is seen that the a-c. part of the voltage across C_1 is not a sine wave, but the harmonics are comparatively weak. The curve does not correspond exactly to operating conditions, however, since a current of 30 milliamperes through a shunt circuit across C_1 was required to operate the oscillograph.

More exact evidence on this point is given by Fig. 14, where the upper curve shows the voltage across C_2 and the lower curve the current through C_1. The maximum value of this current is 60 milliamperes, which would mean at 2000 cycles a voltage fluctuation of 5000 volts or 10 per cent. A harmonic analysis of this curve should give cor-

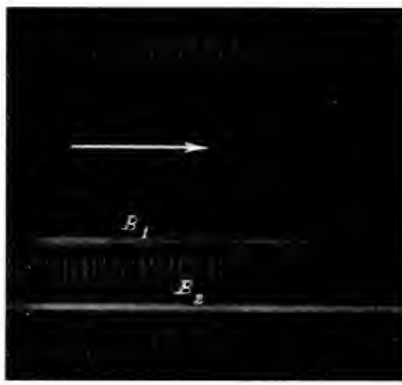


Fig. 15. Upper Curve; Voltage at Terminals C_2 (Base Line B_1) Lower Curve; 2000-cycle Primary Voltage (Base Line B_2)

rectly both the relative and absolute amplitude of the a-c. components of the voltage, but it has not been thought necessary to make this.

Fig. 15 shows the effect of putting the inductance on the farther side of C_2 (Fig. 1) between C_2 and the load. According to theory, the inductance should have no effect in this position, provided the load is one that has high impedance, as an X-ray tube. Unfortunately, it is necessary to use an ohmic resistance load as low as 500,000 ohms, in order to furnish the 0.040 amperes required to operate the oscillograph, and this somewhat reduces the amplitude of the oscillations. They are still quite striking, however, compared with those of Figs. 9 to 11.

Attention should be called to the fact, already mentioned, that in these oscillograms the primary a-c. wave shows no trace of distortion, even at maximum load, which is a strong advantage of the open magnetic circuit type of transformer.

The apparatus described is capable of great improvement. The fact that in its present crude form it operates so well is a strong recommendation of this method of obtaining constant high potential. By the use of three-phase 2000-cycle current and six kenotrons, it would be possible with present apparatus to furnish 100 kw. at 100 kv., with the same constancy as that of the 5-kw. installation described above, and there is every reason to believe that this can be increased to 1000 kw. in the near future.

THE EUROPEAN WAR AND INDUSTRIAL DEMOCRACY

By Joseph E. Davies

Chairman, Federal Trade Commission

We here print, by permission, the address made by the author before the American Manufacturers Export Association, in New York, on December 21, 1915. We feel that this general review of the industrial situation, not only of the United States but also of other countries, will be read with much profit and interest by many of our readers.—Editor.

The economic map of the world is being remade. The nations are today studying it keenly. This is so, whether it be in Australia, South Africa, Central America, the Orient, or in the warring countries themselves. The best thought of the world is seeking to forecast conditions and to so readjust affairs as to procure the greatest possible national advantage in future development. The industrial, commercial, and financial intercourse of the world is in the process of being recast. The next few years contain possibilities of as far-reaching and enduring consequence to our industry, commerce and finance as perhaps any years in the history of our country.

Possibilities of Industrial America

What are we doing under these circumstances? To be sure, in the immediate shock of change, our business community met conditions with splendid adaptability. Yankee ingenuity and American enterprise display themselves to no greater advantage than in remaking our industry to conform to the changing conditions of the last 14 months.

But that is not enough. How are we building? What are we going to do with this vast volume of gold coin, constituting one-fourth of the total of the world's supply, which is pouring into this country and bringing with it unprecedented expansion and prosperity? Shall it be dissipated by an era of wild speculation that will bring inevitable reaction, or shall it be utilized for the broad and extensive building of a firm structure which the constructive vision, sagacity, and daring of American industry can translate into enduring benefit for the American people?

What of foreign trade? Are we to be content with immediate and large profits? Or shall we recognize a great opportunity through which we may establish the character, quality, and value of American goods, and thereby establish a firm grip upon international markets, in anticipation of the keen competition that is to come, so that thereby a body of substantial foreign trade may be developed which shall serve as a back log and as a stabilizer of American industrial conditions for the long and great future?

American Statecraft Required

The character of your membership, and the fact that there exist organizations of this kind; the extension of banking facilities in South America, with splendid vision, and without regard to immediate profit; the projection of an American investment corporation to engage in the financing of projects in neutral countries that have been crippled by war conditions; these and other facts which might be named are indications that in the present situation there is a commercial and financial statecraft in this country today that is the equal of our best traditions, and that gives promise of enduring advantage for our people.

The Government and its Functions

But men engaging in business enterprise may well reverse the shield, and ask, "What has Government done, and what is it doing in this situation, to perform its functions of serving the people of the United States?" The manner in which the forces of the Federal Government were marshalled to avert the economic and financial catastrophe in the first fateful weeks of the war is now history. The millions in gold from the Federal Treasury which came to the support of the tottering financial structure not only of this nation but of the world were dispatched to the financial centers with a speed and a promptitude that was regarded as physically impossible. Executive order, legislative authorization, and executive action were projected into the situation with promptness and wisdom that will stand out as worthy of the finest achievements of American capacity to meet emergency.

Since that time, and through the long period of 14 months of delicate and hazardous international relations, the big, substantial fact remains that this country has been kept out of war and has been held upon the paths of peace. That is the signal service that your President of the United States has rendered in this situation, not only to the nation but also to humanity.

In lesser degree every agency of the Federal Government has been bending its efforts to the aiding and sustaining of American interests in this war crisis. Of these various activities I cannot speak with definiteness, except as to those of the Federal Trade Commission affecting our foreign and our domestic industry under those conditions.

With foreign trade we have come into contact through the provisions of the organic act creating the Commission.

Being charged by Congress with the obligation of ascertaining and reporting from time to time as to competitive conditions that exist in foreign countries of the world which affect adversely the interests of American industry, the Federal Trade Commission concluded that the present was a time than which there could be none more opportune or valuable for the exercise of that power. Information has been gathered from all published sources as to the existence of foreign combinations of an international character that existed prior to this war, and which were operating in the markets of the world; investigators have procured first-hand information as to conditions in foreign markets; hearings have been held in the principal centers of foreign trade in this country to obtain first-hand information from the business men engaged in foreign commercial enterprises; 30,000 letters have been sent out to business men, containing searching questionaries upon the facts connected with foreign trade, upon this subject. One of the most significant facts in this connection lies in this: that within the last six weeks we have received 20,000 replies out of those 30,000 requests to the business men of this country. From them we have received with promptness and generosity a vast volume of fact and detailed information, to be addressed to the solution of this problem of what steps, if any, are necessary that American manufacturers and merchants shall stand on an equality with their rivals in international competition. Time we have regarded as the essence in this situation. Within the next few weeks we hope to have assembled and digested a record of facts and opinions gathered from business sources, from publicists, from economists, and from first-hand knowledge of conditions in foreign countries, which will afford a substantial basis of accurate information for such legislative action as Congress may deem necessary and wise.

Customs Regulations in Pan-America

A somewhat similar investigation arose out of conditions which exist as between the United States and Pan-American countries, which operate to artificially and unreasonably restrict the commercial relations between the countries of this Continent. It is generally known to those conversant with conditions that customs tariff regulations, and tariffs of these countries operate as hardships upon America, where no reason obtains for their existence, as the conditions which they were designed to meet have long since passed away, and which indeed now serve to defeat the purposes for which they were imposed. Invoices and harbor regulations that are vexatious and useless, and other conditions have been permitted to obtain largely through inertia. Only an intelligent appreciation of their significance is required to bring about advantageous change. The time is peculiarly opportune for their consideration. The countries of South and Central America are studying conditions, and on the verge of simultaneously making changes in their legislation and their regulations, and not again in a decade will come so favorable an opportunity to bring about desired change.

Upon the request of the President of the United States and the Secretary of the Treasury the Federal Trade Commission is making an intensive, scientific study of these conditions. Investigators are now in South America gathering information of this kind, not only for the benefit of the United States, but for the benefit and advantage of all the countries involved. A report upon these conditions we hope will be ready and available for the meeting of the International Joint High Commission which will be held in Buenos Aires in April. next, and which will address itself to these matters. It is designed to be an impartial, reasonably complete and accurate statement of conditions which ought to be changed and remedied for the mutal advantage of all the countries and peoples concerned.

Dumping

The possibilities of dumping, by foreign manufacturers, of their product subsequent to the war, to the detriment and disadvantage of American industry, has also been an object of investigation and study in conjunction with the Secretary of Commerce. The Federal Trade Commission, with the Secretary of Commerce, will be prepared to make recommendations to Congress as to the methods by which any such anticipated situation may be best prevented.

These, in a general way, are the functions which the Federal Trade Commission has been seeking to perform in the interest of American industry in the foreign field.

What have been the activities and the benefit of the Commission as to domestic industry, you may well inquire.

Survey of Industries

The Federal Trade Commission has been in existence nine months. During that time the energies of the Commission have been largely devoted to a survey of the industries of the country. The sound basis for action comes only from an accurate and thorough appreciation of conditions. The processes of industry, the constituent parts thereof, and the interrelations that exist between different kinds and classes of industrial activities are matters of intricate and extensive importance. Information of this kind has been compiled, and is now available.

During that time the Commission has come into personal contact with practically two-thirds of the industries of the country measured in value of investment not only to know the men engaged in the businesses, respectively, but to see first-hand some of the problems that confront them. There is at hand and will be immediately available for the Commission on Preparedness, which it is reported the President of the United States is to appoint for the consideration of the mobilization of the industrial resources of this country, a record not only of the industries available, but their respective capacities, actual and potential, the degree of their integration, physical and financial. This is the first survey of these factors, assembled through governmental agency.

The investigations of specific subjects, formerly conducted by the Bureau of Corporations, have been continued. Under the directorship of Vice Chairman Hurley, the facilities of the accounting branch of the organization have been extended to such businesses as desire assistance in matters of cost accounting and efficiency methods in manufacture or commerce. This cost accounting service has not been imposed upon anyone, but exists for those who might wish to avail themselves of it. It has been received with great favor by all classes of business.

Unfair Methods of Competition

The principal function for which the Federal Trade Commission was created was undoubtedly to prevent practices of unfair competition in industry. The object was to destroy monopoly in the seed, and to protect the great majority of business units in industry, whose chief menace comes from practices of unfair competition which might be employed by not a more efficient but by a more powerful rival. Complaints covering many varieties of unfair methods have been filed with the Commission, such as false advertising, bogus independents, price discrimination, bribery of employees, boycotts, misbranding of goods, rebates, and the like. These complaints have come from all classes of industry, covering the fields of mining, agriculture, manufacture, and distribution. Of these complaints, and their disposition, the public has not heard much. This is so because of two conditions which the Federal Trade Commission has imposed upon its procedure, for the public interest. No information is given out, or is obtainable upon any application for a complaint which is made to the Federal Trade Commission until the case has been investigated and until it has been determined that a formal complaint is to be served by the Commission against the parties complained of. The reasons for this are, first, to protect those who in good faith make the complaint, from reprisals by those against whom the charges are made; and, second, to protect legitimate business from the injury which the publication of malicious or improper applications or complaints might subject them to. The other policy which has been adopted is that of advising the party complained against, of the nature and character of the charges made, before formal complaint is made and filed by the Commission, to the end that either the party complained of may establish the lack of public interest, or be given an opportunity, if the situation is clear, to agree that neither as to the complainant nor as to the general public will there be a continuance of such illegal practice. These policies tend to obscure the amount of work done by the Commission, so far as the publicity of its work is concerned; but it has been felt that a larger service was being performed by the proper protection of legitimate interests of business and by the speedy accomplishment of the relief to the general public and to the parties complained of.

The Federal Trade Commission was created out of a desire to bring into the relations between Government and business and society, a constructive agency. It was designed by those who created it not as a punitive, but as a corrective force. It was hoped that it would serve to bring about a more simple, direct and informal agency for adjustment of matters than would be afforded through a strictly judicial or a strictly administrative agency. The fact that there may be comparatively few complaints brought by this body is therefore not an indication that relief is not being accorded; but may be in fact an indication that the effectiveness of this agency is being demonstrated along the lines contemplated by those who sought its enactment. A few illustrations of the manner in which this operates will illustrate the situation.

A corporation engaged in the business of selling typewriters circulated among dealers in many cities a letter falsely stating that a competitor had moved its factory from Chicago, and that the customers of such factory would be compelled to make new arrangements for obtaining typewriters, which need the advertising corporation was prepared to fill. A letter directed to the corporation complained of resulted in a retraction, and in the circulation of such retraction extensively, and the applicant for a complaint thereupon requested the dismissal of the matter.

In still another case, a corporation engaged in the manufacture of an article, published advertisements in which were statements disparaging the goods of a competitor in an improper way. The practice was called to the attention of the Commission, with the result that it was immediately discontinued.

Recently complaint was made by one of the large so-called independents against an allowed price-discrimination practice indulged in by a larger competitive rival. Upon complaint being made by the Commission with the larger competitor, the assurance was voluntarily given that the practice would be discontinued, not only as to the party complaining but also as a general practice, and as to all persons in the trade. Thus it happens that the relief which the Commission could give, to wit, the procurement of the stopping of the practice, is secured with immediate relief to those injured, instead of going through a long process of litigation and procedure that might involve months, or possibly years, for its final determination.

It is contemplated that by the publication of a ruling upon each case, as it is disposed of, that ultimately a body of cases will be built up which will operate as a code of what establishes fairness and unfairness in trade, to the benefit of industry in this situation where formal complaints do not come to trial.

The powers of the Federal Trade Commission are limited by the law of its creation. They are not as extensive as many proponents might have desired; but its responsibilities are greater than its power. To the extent that lay in its power, it is bent and animated by a desire and purpose to aid in every possible manner that is consistent with democratic institutions, in the development of the power and greatness of this nation as an industrial, commercial and financial nation in the world.

It is one of the agencies of Government that must seek, in small part, to aid in the solution of the great problem of the future.

Efficiency in Industrial Competition

While the significance of Germany's efficiency may perhaps have been exaggerated, nevertheless it is true that an industrial as well as a military organization has been quietly developed in Europe that has eclipsed anything of the kind that we have seen. Economies have been induced in production; scientific methods effected in marketing and distribution; exploitation through combinations of an international character have been developed and are the complement of a military machine that has commanded the admiration of the world. Within the months last past these facts have not been apparent to us alone. England, France and Italy have, under the pressure of overpowering necessity, endeavored to specialize industry for greater economy and effectiveness, and to a degree that it is difficult for us to understand. These influences will obtain after peace has come. To speculate as to the future conditions following the war is idle. But it is still greater folly to assume that in the long future these lessons derived from these conditions will not be translated with military effectiveness and discipline into efficiencies and economies of production and distribution, when the energies pent up in the struggle shall be released for industrial endeavor. The reorganization of industry, when finally established in Europe, will in all probability be invested with a degree of efficiency that will command the respect of all rivals in international competition in the markets of the world. The stimulus of necessity will speed these processes, with the resumption of peace; for international bills will have to be paid through reversing balances of trade, if that be possible; people will have to be employed, and every effort will be made by governments involved to sustain themselves from destruction.

When these conditions will obtain in international industry it will require all of our vision and discipline, enterprise and conservatism, sagacity and daring, to meet them. It will require that our industries shall be integrated and stablized so that not only will the economies of sustained production be available, but it will require that the social well-being of the workers shall also be sustained upon a proper level, to the same end. It will require a large-minded intelligence and vision in the division of the fruits of industry between capital and labor. Socialized autocracy did this before this epochal war, in a manner that challenged the admiration of the world. It is our task to demonstrate that representative democracy can be equally efficient and serviceable. For a monarchy this task is relatively simple; the task for democracy is far more difficult. For in democracy we cleave to certain essential, fundamental principles as the covenant of our faith, whereas in autocracy there are no such principles that impede translation of theory into effect. We believe in democracy in America. We believe that it is our first mission in civilization to preserve and sustain it, and demonstrate it as the enduring form of government for the benefit of mankind. It is the very essence of our aspiration, and the spirit of democracy that there shall be fair opportunity for all, not only in political rights but in the exercise of industrial and commercial vocations. Autocracy and monopoly are not abhorrent; they are the same thing—one in political life, the other in industry. Democracy and monoply are incompatible, because monopoly consists of a denial of the principle of liberty in a sphere of action that touches most intimately and vitally the life of the people. But this does not mean that we should set our face against the advance of progress in industry. The economies of large-scale production to the extent that they exist, the advantages of integration of industry, the sustaining force of stabilization in industry, the prevention of feast and famine, the prevention of cutthroat competition, can all be encompassed in a democratic state without yielding to monopoly in principle or in effect. The problem of democracy is to conserve the efficiencies of industry to the highest degree that is compatible with the fundamental conception of liberty and freedom in industry. The problem of government is not only not to thwart efficiencies, but to stimulate them, to aid them, to develop them to the highest degree that is compatible with the general welfare. That is the problem for democracy. That is the great challenge that comes in the history of civilization to this great Republic, with renewed insistence, out of this epochal war.

It requires that we shall coordinate and marshal all of the best forces that are in our industrial, business, and political life, for its solution. The critical function is easy, the constructive function is hard.

We seek to build up, and not to destroy. We desire to aid, and not to harass.

To preserve for the benefit of posterity the real essence of liberty and freedom in opportunity which America has always prided herself in, is the fundamental source of our effort in Democracy.

THE MAZDA LAMP IN PHOTOGRAPHY

By W. E. Brewster

Engineering Department, National Lamp Works of General Electric Company

This article is written to show the uses of the Mazda C (incandescent gas-filled) lamps. The author first describes the photographic process in relation to light, and then tells of the characteristics of these lamps which render them particularly adaptable to a wide range of photographic work. The reason for burning these lamps at over voltage is given and the properties of the photographic-blue-bulb are described. Attention is drawn to the arrangement of lights for studios and useful hints are given on wiring. The copying of prints and drawings, photographic printing, enlarging, the making of photomicrographs and motion pictures, are dealt with by the author in more or less detail.—Editor.

With the introduction of gas-filled construction in its manufacture, the Mazda lamp became well adapted to the needs of photography, and although it has been available for only two years, the Mazda C lamp ("C" designating gas-filled construction) is now in extensive use in this field. The considerations involved in its application to the various branches of photography may be most readily explained by a brief preliminary analysis of the photographic process and its relation to light.

Photographic processes, with a few exceptions, depend for their operation upon the chemical alteration by light of a sensitive coating, upon some base such as glass or celluloid, of a salt of silver suspended in a medium, usually gelatin. The coating is generally known as an emulsion. The photographic image which is thus produced is made visible by the application of some developing agent which reduces the altered compound to metallic silver. The density of the image, that is, the amount of silver reduced, is a measure of the photo-chemical energy, or actinic intensity, of the light with respect to some particular emulsion. Emulsions such as are used on ordinary photographic plates are most sensitive to ultraviolet, violet and blue light. These same emulsions, if modified by means of organic dyes which absorb rays such as green and red, may be rendered photographically sensitive to green and red light also. Thus emulsions may be made which will register the brightness values of all colors more nearly as the eye sees them. The curves of Fig. 1 show the relative sensitiveness of the eye, an ordinary emulsion, and a color-sensitive emulsion, to the rays of the spectrum. It is evident from these curves that if a light is to be used for producing approximately correct photographs of objects as they are seen, its spectrum should include all the rays from violet to red. Also, it is obvious that the candle-power of a light source is not necessarily a measure of its ability to affect a sensitive emulsion; a yellow light of a given candle-power may be more active in altering the silver of a yellow dyed emulsion than a green light of higher intensity. The emulsions in common use are sensitive to color in widely varying degrees and it is evident therefore that, in stating the actinicity of a given light, reference should always be made to the type of emulsion on which the actinicity is based.

The filament of the Mazda C lamp operates at a higher temperature for a given life than that of the Mazda B (vacuum construction) and produces light containing a higher percentage of blue and violet rays. Although the light emitted by the filament of a Mazda C lamp has a higher percentage of green and red and a lower percentage of violet and blue rays than noon sunlight, there are enough of the latter to meet even the exacting demands of motion-picture photography; and, since the light is produced by incandescence, it gives the continuous spectrum which, as previously explained, is essential in an illuminant that is to be of general use in photography. Furthermore, the Mazda C lamp

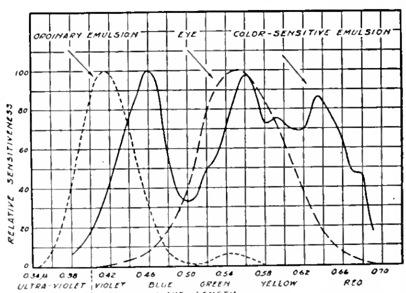


Fig. 1. *Relative Sensitiveness of Eye, Ordinary Emulsion, and Color Sensitive Emulsion to Rays of Equal Engery Value

*Luckiesch, M., The High Efficiency Tungsten Lamp in Photography, *Electrical World*, July 18, 1914.

has those merits which are common to all Mazda lamps. It is portable and will operate on alternating or direct current. It gives a steady light of constant quality, whose candle-power is well maintained throughout life as shown by Fig. 2. It is simple, noiseless, and reliable in operation. It is sturdy in construction, and its design is such as to permit the direction of its light to be efficiently controlled by reflectors and the intensity by resistors. Its installation and operating costs are both low; and the user may readily avail himself of new developments as they are made from time to time.

The curves of Fig. 3 show how the amperes, watts, candle-power, and ordinary-emulsion actinic intensity of a Mazda C lamp vary with changes in voltage. It will be seen from these curves that with an increase in voltage the candle-power increases at a faster rate than the wattage, and consequently, for a given consumption of electricity, a greater quantity of light is obtained by operating at a voltage higher than normal. For example, if a Mazda C lamp is operated at a voltage 10 per cent higher than the voltage rating appearing on the lamp, the electrical consumption is increased only 16 per cent while the candle-power is increased 37 per cent. Of even greater importance is the accumulative effect on the ability of the light to reduce the silver in an emulsion; for not only is the total quantity of light increased, but, of the total a higher percentage is actinic. As seen from the curves, an increase in voltage to 10 per cent above normal produces an increase in actinic intensity of 50 per cent.

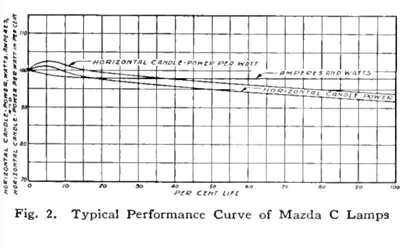


Fig. 2. Typical Performance Curve of Mazda C Lamps

In general, multiple Mazda C lamps have an average life of 1000 hours when operated at their rated voltage. When lamps are operated at a voltage 10 per cent higher than normal, their life is decreased to approximately 300 hours. It is obvious, therefore, that the advantage of operating lamps overvoltage to secure greater actinic intensity is tempered by the disadvantage of having to make more frequent lamp renewals. The fact should not be overlooked that the lighting service conditions for which lamps are, in general, rated are entirely distinct from those which obtain in studio lighting. In portraiture, where compactness of equipment is of minor importance and where the operator

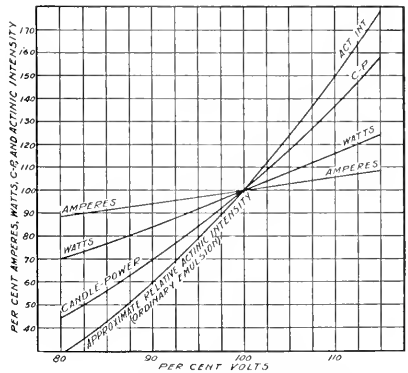


Fig. 3. Characteristic Curves of Mazda C Lamps

may desire a source of considerable area, the use of a larger number of units operating at normal voltage may be preferred to the use of fewer units operating overvoltage. On the other hand, in many classes of work, as, for example, in home portraiture, overvoltage burning, permitting the use of a less bulky and less expensive outfit, is a distinct advantage. In motion picture photography, where short exposures are necessary for successful results, overvoltage burning becomes essential.

The short exposures required in portrait and motion picture photography demand a high intensity of actinic light. At the same time, in order that the reproduction of facial expressions may be natural, the brightness of the light should not be such as to cause the subject to squint. These contrary requirements led to the development of a special blue-glass bulb for 1000-watt Mazda C lamps, which is known as the "photographic-blue" bulb. This bulb screens out about two-thirds of the light emitted by a Mazda C filament, but it transmits, as shown by the spectrograms in Fig. 4, all those rays which are actinic to ordinary emulsions and nearly all those rays which are actinic to those green and yellow sensitive emulsions that are usually called orthochromatic.

Furthermore, the light from photographic-blue-bulb Mazda C lamps appears like daylight, and its ordinary-emulsion actinicity per candle-power is so nearly equal to that of daylight that it may be mixed with daylight without any allowance being made in judging the proper time of exposure. This is an important quality, for it enables the photographer to estimate amounts of exposure by the brightness of the subject in accordance with his usual practice. Obviously, these advantages, namely, the reduction in brightness and likeness to daylight, can be utilized to the fullest extent with ordinary emulsions, and since most portrait and motion picture photographs are made on such emulsions, the photographic-blue-bulb Mazda C lamp is particularly adapted to the illumination of the usual studio. A glance at the spectrograms, Fig. 4 shows, moreover, that these blue-bulb lamps should also prove satisfactory for use with color sensitive emulsions—a fact which is borne out in practice.

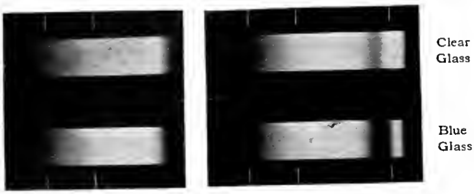


Fig. 4. *Spectrograms Showing the Effect on Typical Emulsions of Light from a Mazda C Lamp when Screened by Photographic-blue Glass which Transmits 35 per cent of the Incident Light

The unusual studio is that in which red-sensitive emulsions, commonly called panchromatic, are used. Such emulsions render color brightness values with approximate correctness instead of rendering blue like white and red like black, as do ordinary emulsions. Consequently, whereas considerable retouching must be done on ordinary emulsions to make the skin of the subject appear natural, portrait negatives on panchromatic emulsions, in general, require retouching only for idealization, and render color values of hair, eyes, clothing, etc., in the proper gradation of brightness. But these advantages are offset in the case of studios illuminated with daylight because of the fact that a yellow filter, which increases the exposure several times, must be used to screen out part of the violet and blue rays to produce a light the rays of which are distributed in such proportions as will best render brightness of color values. However, the distribution of rays in the spectrum of light from clear-bulb Mazda C lamps is so nearly the same as that obtained by passing daylight through a "four times" filter, that for a practical degree of accuracy of color brightness rendition no filter is required, while for true rendition only slight filtering is necessary. The same general principles apply, of course, in color photography. Therefore, when correct rendering of color-brightness values or of actual colors is desired, the use of clear-bulb Mazda C lamps will be found an advantage, the degree of advantage depending on the ability of the plate to record true values. In those studios where most of the work is done with ordinary emulsions and blue-bulb lamps are employed, the use of a ray filter enables the operator to work with color-sensitive emulsions without recourse to clear-bulb lamps.

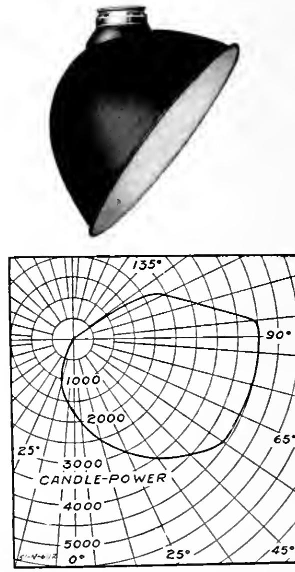


Fig. 5. Type and Distribution Curve with 1000-watt Mazda C Lamps of Angle Reflector Suitable for Portrait and Motion Picture Studios

*Luckiesch, M., The Application of the High Efficiency Tungsten Lamp to Photography.

Portrait studios lighted with Mazda C lamps have these additional advantages over those lighted by daylight: the actinic intensity of the light is constant; the intensity and direction of the light with reference to the subject can be controlled more readily; the floor space required is less; the studio may be located without regard to natural light, and may be operated any time of day or night.

In general, the equivalent of at least one 1000-watt Mazda C lamp is necessary for portrait work, and two such lamps properly equipped make it possible to produce first class negatives with the same exposures as are required under the usual skylight. From three to five lamps are advisable for lighting large groups. The location of the lamps with respect to the subject varies with the type of lighting desired and with the limitations of the studio. The photographer's training in the control of light and shade enables him to arrange his lamps in the way which will best meet his requirements.

For the sake of convenience, the lamps may be mounted on portable, adjustable stands equipped with suitable reflectors and diffusing screens. A type of porcelain-enameled steel angle reflector that is especially satisfactory for use on such stands is shown with its distribution curve in Fig. 5. Two arrangements of stands which have proved satisfac-

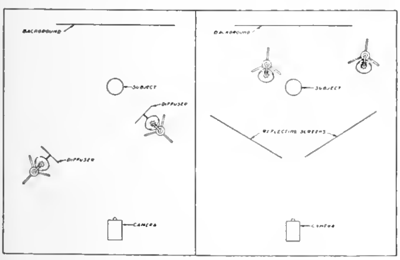


Fig. 6. Typical Arrangements of Mazda Lamp Stands in Portrait Studios

tory in practice are given in Fig. 6. When the subject faces the lamps the light should be diffused by some material such as ordinary tracing cloth.

A number of studios throughout the country have installed what may be called artificial skylights, utilizing several photographic-blue-bulb Mazda C lamps. Fig. 7 shows a rear view of such a "skylight" which consists of five lamps equipped with suitable angle reflectors mounted on a portable frame. About a foot in front of the units is stretched a sheet of tracing cloth which serves to diffuse the light. Near the center of the tracing cloth is a "window" of oiled paper which is more transparent than the tracing cloth and therefore produces a highlight on the subject.

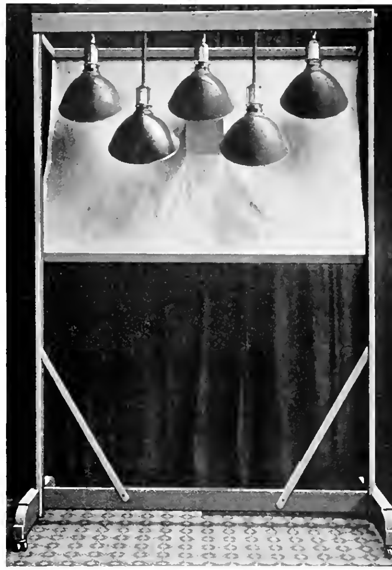


Fig. 7. Rear View of Mazda Lamp Artificial "Skylight"

The light reaching the subject is controlled by means of diffusing screens and reflecting surfaces in the same manner as daylight. An additional lamp on a portable stand enables the operator to produce with ease special artistic lightings difficult to obtain with daylight.

Another studio which is located in a basement on a prominent business street is equipped with ten 1000-watt photographic-blue-bulb Mazda C lamps. The position of the units is such that the direction and intensity of the light may be largely controlled by switching individual lamps on or off.

No matter how the lamps are mounted, in wiring them it is important to remember that a general ruling of the inspectors calls for a separate 10-ampere switch for each 1000-watt lamp. In this connection, it should also be borne in mind that the voltage at which the lamp operates is an essential consideration in photography, and good practice calls for wiring of such size that less than 2 volts drop will occur between the lamp and the service connection. No. 12 wire will usually meet this requirement. If a pair of

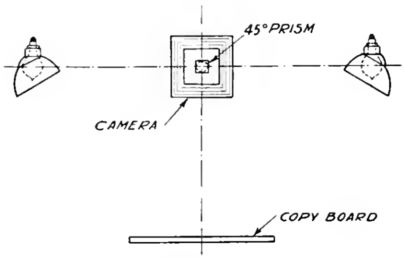


Fig. 8. Arrangement of Mazda C Lamps for Lighting of Copy Board of Bromide-paper Copying Machine

lamps is connected to an ordinary lamp socket, the drop in voltage may be from 5 to 10 volts. Unless lamps of correspondingly low voltage rating are used, the actinic intensity of the light is likely to be too low. Therefore, care must always be exercised to provide proper wiring for a minimum voltage loss so that the lamps can be operated at a voltage fully up to their rating.

Excellent photographs of large and small interiors may be conveniently made with Mazda C lamps. The character of work done with three 750-watt clear-bulb Mazda C lamps in photographing the lobby of a large hotel is shown on page 164. An exposure of 20 minutes with a lens aperture of f-32 was required. The lamps were attached to portable cords and equipped with reflectors. In order to soften the shadows, the position of the units was occasionally changed during the exposure. Such uniformity of illumination and rendering of detail would have been difficult to obtain by daylight even if windows had been so located as to admit enough light. Mazda C lamps are likewise of considerable advantage in photographing machinery, paintings, etc., which it is undesirable to move. The lamps may be carried with ease and supplied with electricity from the usual lighting circuits. The fuse capacity of the circuit should, of course, be investigated when the lamps to be used on it require a total of 750 watts or more.

The copying of prints and drawings, and the making of lantern slides demand a copy board that is uniformly illuminated. Such illumination may be obtained on the usual size of board from two bowl-frosted Mazda C lamps equipped with steel angle reflectors. These should be placed several feet out and away from the sides of the board, and for apparatus in which the distance between the board and camera is likely to vary through a considerable range adjustable supports should be provided for the lamps. For large boards, four reflector-equipped lamps located opposite the corners of the board, are required. The size of lamps that should be used necessarily depends upon the type of paper or plate used in the camera and the speed of operation desired. Fig. 8 shows a method of lighting the copyboard of a bromide paper copying machine by means of two 400-watt bowl-frosted Mazda C lamps. The illumination produced is such that a black and white tracing two feet square may be reduced to a bromide paper print one foot square with an exposure of 10 seconds at a lens aperture of f-11.

Photographic printing, with the exception of work on emulsions such as are used in blue printing and bichromate printing, may be done to advantage with clear-bulb Mazda C lamps. In view of their higher efficiency, printing may be done with greater speed and greater economy of operation by substituting these lamps for the Mazda B lamps used in the numerous printing machines which were designed prior to the introduction of the Mazda C lamp. The wide range of sizes obtainable makes it possible to select the lamps best fitted to individual requirements.

The process of enlarging consists in projecting the light transmitted by a uniformly illuminated negative through an objective lens upon a light-sensitive surface, such as bromide paper. The part of the process demanding the most attention is the illuminating of the negative. This is usually most efficiently and satisfactorily accomplished by means of a small but intense source of light, part of whose rays are collected and projected through the negative by a condenser lens system consisting of one or more single lenses. A diagram of the optical system of such an apparatus is shown in Fig. 9. As shown by this diagram, the light rays projected through the negative form a cone having its apex at the optical center of the objective lens. The function of the objective lens is to bring all of the rays of light emanating from a point on the negative, and entering the lens, to a focus at a point in the plane of the sensitive paper. The enlargement factor or number of times a dimension on the negative is increased on the positive, is equal to the ratio of the distance F to the distance f. The size of the enlargement may, therefore, be varied by varying the position of the objective lens with reference to the negative and copyboard. When this is done, it is necessary to adjust the position of the lamp with respect to the condenser in order that the cone of light projected through the negative may focus at the optical center of the objective lens. In many cases the change in the position of the objective is so slight as to render unnecessary any change in the position of the lamp.

Because of the constancy and high actinic intensity of light from Mazda C lamps and the wide range of sizes in which these lamps are available, they are particularly adapted to the process of enlarging. Since the smaller the source, the less apparent become defects in lens equipment, a source which approximates a point is desirable for use with condensing lenses. Consequently, concentrated-filament lamps should always be used for this type of enlarger. The possible advantages of operating lamps above their rated voltage apply as well to enlarging as to other photo-

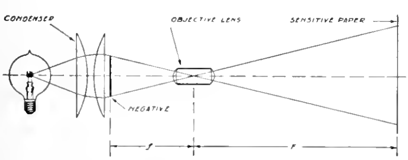
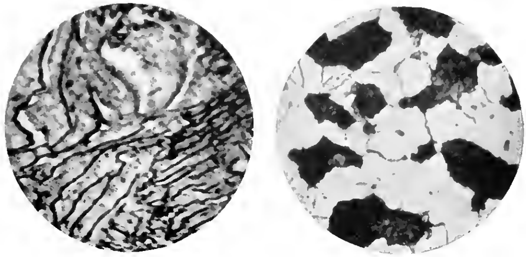


Fig. 9. Optical System of Condenser Enlarging Apparatus

graphic processes, and there is also an additional advantage from the projection standpoint in that the increase in volume and actinicity of the light is obtained without increase in the size of the source.

Although the use of condenser lenses greatly reduces the time of exposure, there are cases, mainly in amateur work, where so little enlarging is done as not to justify their purchase. For such work a diffuser, such as flashed-opal glass, may be used between the negative and the light source to secure uniform illumination of the negative. In this system the light rays are scattered and the amount of light brought to a focus on the paper depends upon the diameter of the lens aperture and its distance from the negative. The projected image from a negative lighted



Pearlite, 2000 Dia. Mag. **Medium Carbon Steel, 500 Dia. Mag.**
Fig. 10. Photomicrographs Made with 250-watt Mazda C Stereopticon Lamp

by diffusion will not, in general, be so sharp as that obtained with the condenser system. However, a high degree of sharpness may be obtained with the diffuser system by stopping down the lens. In many classes of work the softer images are desirable; this effect may be obtained with a condenser system by inserting a piece of ground glass between the condensing lenses, but when this is done the advantage of great speed is sacrificed. While Mazda C lamps are well adapted to enlarging with the diffuser system the lower voltage required for a given working speed by the condenser system makes this system more economical to operate and more generally satisfactory. That is, the saving in electricity affected by the use of condensers will more than offset the cost of the condenser in a comparatively short time.

The optical system used in photographing objects through a microscope is very similar to that of a condensing-lens enlarger. The distinction lies in the greater number, the finer adjustment, and the higher power of the lenses employed in photomicrography. The constancy and high intrinsic brilliancy of the light from Mazda C lamps make these lamps particularly suitable for this class of work. In general, concentrated-filament lamps should be used, the 250-watt size being best adapted to most instruments. Before the day of the Mazda C lamp, high-power photomicrographic instruments were usually equipped with carbon arc lamps. Mazda C lamps may be very readily adapted to such instruments by removing the ground glass and mounting the lamps so that the midpoint of one coil of a filament coincides with the working position of the arc. In adjusting the lenses, the filament should be focused on the diaphragm of the sub-stage condenser and then

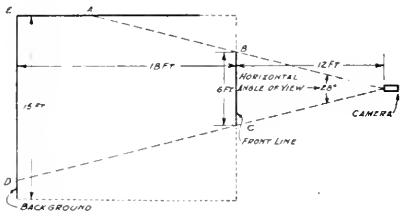


Fig. 11. Floor Plan of Typical Motion Picture Studio Stage

moved along the optic axis just enough to diffuse the image of the lamp in the field of the microscope. Fig. 10 shows photomicrographs of specimens of medium carbon steel and pearlite (alloys of carbon and iron). The photomicrographs were made with an instrument equipped with a 250-watt 110-volt Mazda C stereopticon lamp burning at rated voltage; the plates used were coated with a slow ordinary emulsion. Despite the loss of detail in half-tone reproduction it is apparent from the 2000 diameter magnification of pearlite that exceptional results may be obtained with the Mazda C lamp in photomicrography.

Motion picture photography demands, as previously stated, an exceptionally high intensity of actinic light because the exposure given to each picture is of the order of only one-fiftieth of a second. However, since the actors must face the light, its brightness should be kept as low as possible; and since the light from photographic-blue-bulb Mazda C lamps is visually only one-third as bright for a given ordinary-emulsion actinic intensity as that from clear-bulb Mazda C lamps, the blue-bulb lamps are particularly adapted to the illumination of motion picture production studios.

The lighting requirements of a studio vary according to whether only one size of set, or any size of set that a scenario may call for, is to be illuminated. For a single size of set the equipment may be fixed permanently in position. In some of the larger studios, sufficient equipment is provided to light one or more of the largest single sets that may be required and is so mounted that it may be readily moved from one set to another. Such an arrangement permits the greatest economy in equipment, for although it may require hours to rehearse a scene, only a few minutes are required to record it on the film; and it is only during these few minutes that a high intensity of illumination is required.

Sets commonly used are from 10 to 20 feet wide and from 10 to 30 feet deep; the depth is the distance between the background and the front line. The camera is placed from ten to fifteen feet back of this front line. Since the pictures are 1 inch wide, the horizontal angle of view with a lens of 2-inch focal length is 28 degrees. Although it might be assumed from the rectangular dimensions of the stage that it would be necessary to illuminate the area included by them, it is

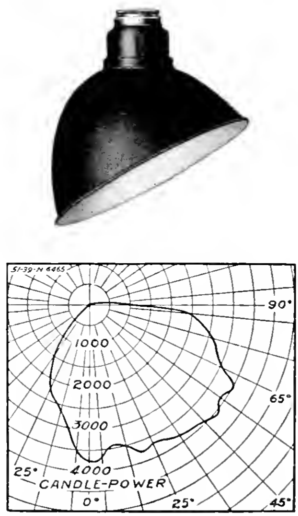


Fig. 12. Type and Distribution Curve with 1000-watt Mazda C Lamp of Reflector Suitable for Overhead Lighting in Motion Picture Studios

apparent from the diagram in Fig. 11 that light is actually needed only on the area ABCDE which is but two-thirds of the total area of the stage. Because of this and also because, as pointed out above, the ratio of area to illumination is not constant, the power requirements for motion picture stages should be expressed in terms of the total wattage needed rather than in watts per square foot of their rectangular area. On this basis from 15 to 100 kilowatts are required for lighting the range of sets given above. All, or nearly all of the power should be expended in 1000-watt photographic-blue-bulb Mazda C lamps, the number of lamps required depending upon the degree of overvoltage burning. In some cases it is desirable to provide from one to four high current arc lamps for giving emphasis to the most important part of a set, more character to the faces of the actors, or to produce the effect of daylight shining through a window. These arcs usually take from 3 to 4 kilowatts, and the number used in a given set depends on its size and the emphasis desired.

The proportion of the light emitted by the lamp filament which reaches the set depends upon the design of the reflectors used and the arrangement of the reflector-equipped lamps. In general, porcelain-enameled steel angle reflectors utilize the light to the best advantage. These reflectors are sturdy and have a reflecting surface which may be cleaned, without appreciable impairment of its reflecting qualities, as frequently as the collection of dust may demand. The arrangement of the units depends on the size of the set and the lighting effect desired. Small sets should, as a rule, be lighted entirely from lamps arranged along the front and sides, while large sets or sets of medium size should be lighted from above as well. For greatest economy of operation, overhead lamps should be used sparingly and placed well toward the front of the scene. They should be equipped with reflectors of the type shown in Fig. 12, which distribute the light according to the curve shown, and suspended about 12 feet above the floor, at which height they will not interfere with the scenery. Front and side lamps should have reflectors such as shown in Fig. 5. In addition to the above, several Mazda C lamps equipped with angle reflectors and connected to flexible conductors should be provided for lighting fireplaces, tables, and for other special purposes.

Lamps for lighting from the sides and front may be mounted on portable floor stands or on frames supported by overhead trolleys. The trolley system is particularly commendable in that its use eliminates the annoyance to the actors resulting from heavy cables strewn about the floor. However, even where trolleys are used, one or more floor stands should be provided for lighting those parts of a set which are inaccessible to the trolley-supported lamp.

The voltage rating appearing on Mazda lamps is chosen with due consideration to the more common uses to which the lamps are to be put. When lamps are applied to special service where there is a departure from normal conditions, the voltage rating is of interest only as a basis upon which the performance

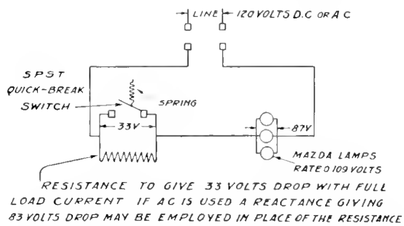


Fig. 13. Connections for Obtaining 120 and 87 Volts on 109-volt Mazda C Lamps from 120-volt Circuit. The reactance drop is higher than the resistance drop because of phase relations

of the lamps may be predicted. As previously explained, more actinic light per watt may be obtained by burning the lamps at a voltage higher than their rating. In general, motion-picture studios may be illuminated to the best advantage by burning the lamps 10 per cent above their voltage rating during the exposure of the film, and about 20 per cent below their rating when light is needed for rehearsing. The fact that the voltage on Mazda C lamps may be readily varied is important since it makes available for rehearsals a light of comparatively low intensity which gives the same character of lighting as that produced during exposure. Figs. 13 and 14 show diagrammatically how the voltage may be varied on typical alternating and direct current circuits. The voltage values as given will result in a voltage at the lamps 10 per cent above their rating with the switch closed, and 20 per cent below their rating with the switch open. If the line voltage is sufficiently high, the necessary variation in voltage can be obtained with lamps rated at any particular voltage within the range of 105-125 volts by inserting a reactance in the line as shown in Fig. 13; a short-circuiting switch, so controlled by a spring or weight that it will stay closed only when so held, should be connected across the reactance or resistance so that the higher voltage may be conveniently thrown on the lamps. When the line voltage is below 116 volts, it is necessary, in order to obtain the desired increase in voltage of 10 per cent above normal with regular lamps, to use an auto-transformer if the supply is alternating current as shown in Fig. 14, or a motor-generator in case of direct current. An auto-

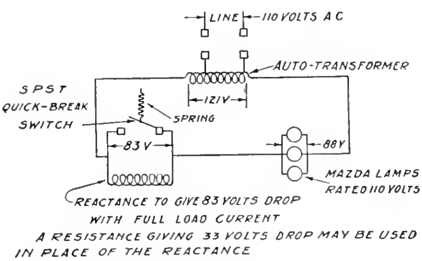


Fig. 14. Connections for Obtaining 121 and 88 Volts on 110-volt Mazda C Lamps from 110-volt A-c. Circuit

transformer is a simple and inexpensive device, whereas the cost of installing a motor-generator would seldom be justified

In motion picture studios, it is often desirable to vary the intensity of illumination in imitation of sunrise, sunset, or an approaching storm, or to produce the "fade-away" effect. This can best be accomplished by placing a dimmer in the circuit. The various steps of the dimmer should consist of resistance grids of sufficient capacity to carry the total current of the circuit.

An example of motion picture photography with Mazda C lamps is furnished in Fig. 15 which shows a section of the film of a large set taken at a lens aperture of f-4.5 with eighty-three 1000-watt photographic-blue-bulb Mazda C lamps and one high-current arc arranged as shown in Fig. 16. The fact that light from the blue-bulb lamps is so nearly like daylight that it may be used in conjunction with daylight has resulted in the installation of these lamps in a number of sunlight studios. With the aid of the lamps these studios can operate regardless of weather conditions. Mazda lamps are likewise in extensive use in studios relying entirely on artificial light. One large studio has just installed 600 1000-watt photographic-blue-bulb Mazda C lamps and expects to increase

Fig. 15. Section of Film Taken with Eighty-three 1000-watt Photographic-blue-bulb Mazda C Lamps and One Arc Lamp

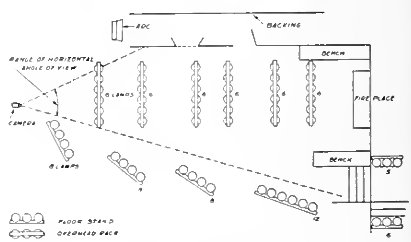


Fig. 16. Arrangement of Lighting Equipment for Set Shown in Fig. 15

the installation to a total of 1300 lamps in the near future.

GOVERNMENT REGULATION AND OUR TRANSPORTATION SYSTEMS *

HOW THE PUBLIC IS PAYING FOR THE INCREASED COST OF MONEY FOR RAILROAD PURPOSES. EFFECT OF INSUFFICIENT EARNINGS ON SAFETY—FORTY-NINE MASTERS INSTEAD OF ONE

By Oscar W. Underwood

United States Senator from Alabama

There are many problems that confront the American people to-day that must be solved justly to all concerned in order that the solution determined upon may be accepted by the country as final.

The history of the North American Continent indicates that we have settled the problems that have confronted our people in eras that were measured by the centuries. The first century after Columbus discovered America was devoted to exploration and adventure. The next century to the clearing away of the wilderness, the settlement of the country. Then came a century devoted to the determination as to which of the European civilizations should dominate the North American Continent. The work of the next century was that of building and development. It saw a fringe of civilization along the Atlantic and Pacific coasts spread and develop until we had builded a nation and developed our civilization in every part of continental United States.

A Destiny Which Must Be Accomplished

The destiny of our country is not yet accomplished. The work ahead of us for the century in which we live must be the solving of the great governmental and economic problems under which our people will grow into a homogeneous race, with fixed principles and policies that will guide our destiny in the centuries yet to come.

We cannot decide and determine all of these problems rightly in a day, in a year, or even in a decade, but we must approach them with a fair and unbiased mind, with the earnest desire to seek after the truth, with a determination to stand only for the right, and with a fixed purpose to reach a conclusion that will be of lasting benefit not only to the people of to-day, but to the generations that come after us.

There is no more important question now pending before the American people that awaits proper solution than the settlement along just and economic lines of the vexed problems of transportation.

We have recently solved the banking and currency problems of the country by passing legislation that seems to have met with almost universal approbation. This legislation was only accomplished after full and careful investigation by a commission appointed by the President of the United States.

The President of the United States in his recent message to Congress has recommended that a commission should be appointed to give a thorough investigation to all the problems that confront us in the field of transportation.

What President's Recommendation Means

As I understand the purpose of this investigation, it is not to hold an inquest on what has happened in the past. If errors have been committed or injuries have been done, that is a question for the courts and not a question of legislation. The real purpose to be accomplished by the investigation is to give an opportunity for all concerned—the farmer, the merchant, those directly engaged in transportation, the Interstate Commerce Commission and the railroad managers to appear before a committee of Congrees and state their views in reference to the solution of this great problem with the view in mind that in the counsel of many we shall find wisdom to guide our legislative course.

You may ask me, why the need of an investigation at all? There may be those present who believe that the transportation companies of the United States are engaged in private business and that they should not be interfered with by Government regulation. To them I can only say that the transportation of the commerce of this country by the carriers is so closely allied to the healthy growth and the economic business development of the nation that its regulation was inevitable from the beginning.

Government Regulation or Government Ownership

More than that, revolutions do not move backward, and if we are unable to successfully

* An address delivered at the dinner of the American Electric Railway Association, and American Electric Railway Manufacturers' Association, Chicago, Feb. 4, 1916.

and fairly regulate the transportation systems of America, the country will demand that we go forward and the next step ahead is the Government ownership of the railroad lines. I think a step in that direction would be most unfortunate. It would lead to many evils that we dream not of today; to avoid which, we must work out a satisfactory system of Government regulation, both for those engaged in the shipment of freights, and those who have their money invested in the means of transportation. It is, therefore, a matter of great importance that we should earnestly endeavor to reach a fair and reasonable solution of the problem of regulation at as early a date as possible.

It has been said a nation is an organism, not unlike a living individual, wherein the channels of transportation are arteries and veins; if the flow in these be sluggish, industrial disorders are indicated, if it be clogged, industrial diseases follow, if it be stopped national disaster results.

Something long has been, is, and will apparently continue to be wrong in the relation between the people and those who are engaged in the transportation business—something so wrong as at times to border on open hostilities. Drastic remedies spasmodically applied—and ill-considered and misapplied laws—have not reached but have rather more deeply rooted the essential wrong.

The capital invested in transportation is about one-sixth of all the wealth of the country and about one-twelfth of all our people depend for their livelihood on the wages paid by transportation corporations.

Seventeen thousand million dollars of the people's savings are invested in transportation securities.

Why the Railroad Problem is Difficult

In almost all countries the railroad question is one of first importance and has been met in foreign lands either by Government regulation or Government ownership. In other countries the problem has not been as difficult of solution as in our own, due primarily to two causes. Our large population and vast natural resources located far inland and at great distances from water transportation make railroad carriage indispensable and industrial freedom could be guaranteed only by just regulation. The most serious difficulty that has in the past prevented the solution of the problem here and is not met abroad, is a political one. Our system of government, under which the States possess certain inherent governmental rights and the Federal Government the great powers that were delegated to it in the beginning by the States, increases the difficulties and uncertainties that surround the problem before us.

Divided Authority over Railroads

It has been said that "No man can serve two masters," and under the regulation of today the transportation companies of America must obey the mandate of the Federal Government and at the same time the orders of each State through which the railroad line makes its way. All of the important railroad lines run through two or more States and are subject to different laws and regulations whenever a train crosses a State line. Go into the baggage car of an express train leaving Chicago and you will find a package that will reach its destination within the State of Illionios resting against a parcel whose destination is beyond the State line. Consider for a moment that the one package is subject to the rule of one master and the other must obey the mandate of at least three masters. Our courts have held that under the protection of the Federal Constitution the right of the railroads to charge rates that will produce a reasonable income on invested capital must be held inviolable; then how can we successfully determine what is a reasonable charge to be allowed for invested capital when you leave the determination to three or more sovereignties, each acting in its individual sphere?

Low rates and adequate facilities are demanded by the public, but the granting of one is often the denial of the other. Adequate facilities very often require the expenditure of large sums of money, but low rates prevent the accumulation of surplus capital and lessen the borrowing power of the roads.

Without new railroad facilities our commerce can not be expanded beyond our present limitation and trade has met a permanent barrier to its future development.

Increase in Cost of Railroad Money

Two decades ago the great trunk lines of the country were able to borrow in this country and abroad the money necessary to increase their facilities at four and four and a half per cent interest. Railroad bonds were considered by the investing public a first-class investment. How is it today? It is often with great difficulty that the best transportation systems in the United States are able to renew their old loans or place new ones. Practically none of these loans can now be placed at four per cent interest. A large majority of the bonds or notes sold in the last year earn above five and a half per cent interest and some are placed at rates as high as seven and seven and a half per cent. What is the effect of this condition on the shipping public? It must be borne in mind that on every dollar that is earned by the transportation companies of America, eighty-eight cents must go to pay wages, up-keep, and operating expenses, and only twelve cents goes to the capital account. It must also be borne in mind that there is no speculative enhancement in the value of the railroads that can be converted in the coffers of the company because the property of the railroad is needed for its operation and when the lines are once built the operation must continue in the interest of the public, and whatever their relative value may be does not affect the earning capacity of the company.

The sole source of revenue for the maintenance, development and expansion of our railroad systems must come from the men who ride on the trains as passengers and from the men who ship their goods over the railroad lines.

If you increase the interest rates, the transportation companies must pay. In the end you must get the money to meet the increases either by the reduction of wages, the curtailment of facilities or by an additional charge on the passengers and shippers of freight.

Increase of Rates Must Come

Practically speaking, the last alternative is the one we must adopt. Where a transportation company placed its bonds at four per cent interest twenty years ago, and renews them today at six per cent, so far as the public is concerned it is identically the same as if the company had increased its bonded indebtedness by one-half at the old rate of interest. And yet the public derives no benefit whatever from the increased charge.

It is, therefore, necessary in the solution of the problem before us in the interest of the public, even more so than in the interest of invested capital, that the credit of our transportation companies should be so good that they can secure the capital for their present maintenance and their future development at the lowest possible charge.

There may be many reasons to account for the changed status of railroad securities as investments in recent years. You may say that it is due to adverse legislation that has alarmed the investing public. Whether the legislation has been unwise and ill-considered, or whether it has been just and fair, there can be no question that the investing public has become alarmed as to the solvency of railroad securities. It is also true that recent legislation of Congress exempting state and municipal bonds from national taxation has invited capital into that field of investment. Again it is true that the past generation regarded industrial securities as a more or less speculative investment, but the development of the great industries of our country today along safe and conservative lines has opened a field for the use of capital at higher rates of interest than the transportation companies of America can afford to pay because there is no governmental limitation on the profits that can be made in industry and there is a hard and fast limitation, fixed by law, on the earning capacity of railroad securities.

The opening of new fields for investment has taken away from the transportation lines much of the market they enjoyed for their securities in the past.

The rates of taxation have increased in every State of the Union. Wages have gone up. The cost of equipment and supplies has greatly increased. If it had not been for economic managment, many of the railroads that are running today would have been forced into the hands of receivers.

Safety on American Railroads

There is yet another problem that we must consider and that is the safety of the employes, passengers, and freights that are carried over our transportation lines.

Statistics show that there are at least ten employes killed or injured on American lines to one on the railroads of Great Britain. It can not be truthfully said that the engineers who constructed these roads have builded them with less ability than the engineers who constructed the English roads. It can not be said that our iron and steel, our timber and rock are not as good building material as that which is found in the British Isles. It can not be said that the men who sit at the throttle, or watch the signal tower are less capable, sober and alert than the men who occupy similar positions in a foreign land. Then why should we face conditions in this country that endanger human life, and make a serious charge on transportation, that in the end the public must bear, if it is not due to the causes I have named? To my mind it is clear that the dangers involved in our railroad system are almost entirely due to the lack of proper transportation facilities.

We endeaver to run trains over a single track where the needs of business require double tracks. We load our freight on weak and defective cars where new cars should long ago have taken their place We rely on antiquated methods for the movement of our trains when our tracks should be provided with the latest and best signal devices.

In fact it cannot be denied that to adopt modern methods and provide proper facilities for transportation would be true economy in the end.

The Effect of Insufficient Earnings

Then why has it not been done? Largely because the transportation companies of America have been unable to earn sufficient capital to enable them to meet their operating expenses and interest charges, and accumulate a surplus with which to provide for betterments and improved facilities, and that their credit has been so seriously disturbed that they are unable to borrow money for the new improvements at reasonable rates of interest.

In fact I think it can be said without expectation of contradiction that taken as a whole the transportation system of the United States, so far as performing its proper functions in the transportation of our freights to their ultimate markets and the carriage of passengers to their destination with safety and economy, is breaking down.

What then must we do to solve the problem? To restore confidence in the minds of the investing public as to railroad securities? To insure rapid transportation of passengers and freights to their ultimate destination at reasonable rates, and to provide for the safety of transportation and the increased facilities that are necessary to transport the growing business of the Nation? These results can not be accomplished by moving backward or divorcing our transportation system from government control. Nor can it be accomplished without great danger and great cost to the people by progressing to the ultimate step in advance and accepting Government ownership of the transportation lines.

One Master Instead of Forty-Nine

In my judgment, we must find the golden mean. We must solve the problem along lines of private ownership and Government regulation. We must consider the wisdom of substituting one master for the forty-nine masters that regulate our commerce today. We must consider the wisdom of Government supervision of the issuance of all securities by our transportation companies with the assurance to the public that new capital will be invested to secure proper facilities and used for legitimate purposes—not for speculation. We must assure the public that when they invest money in railroad securities which are supervised by Government regulation we stand for a system of regulation which will allow the transportation companies to charge such rates for carriage as will enable them to promptly meet their interest account as well as their operating expenses. We must perfect a system of regulation that will recognize that the transportation lines of America are great public highways in which the people are as much interested as those who have invested their capital in them, that every shipper in America must have equal rights in the transportation of his goods along those highways; that rebates and discriminations of all kinds must be of the past and prohibited in the future, and we must recognize that the man who is willing to invest his money at a moderate rate of interest in railroad securities is not exploiting the public but is a public benefactor.

What Adequate Transportation Means

In my opinion an adequate transportation system means:

1. Road beds must be made more secure and more permanent.
2. Trackage must be enormously increased and many roads double tracked.
3. Safety equipment must be sufficient to satisfy requirements at any and all times.
4. Terminal facilities must be greatly improved and largely increased.

Stated briefly, then, our question is whether the American people are willing to put up with an unsafe, inferior, and inadequate transportation system or have the intelligence to pay for one that will supply their needs and protect the lives of the people.

The main trouble with the regulation of our railway system is that corporate law has been destructive, not constructive; has been piecemeal, not comprehensive.

To solve these problems, it is proposed that a Committee of Congress shall give a thorough and complete hearing to all who desire to present their views. Let us hope that the result of the investigation will be productive of wise legislation—legislation that will build up and not destroy—legislation that will be helpful and not hurtful—legislation that will bring lasting and complete prosperity to the people of America.

THE BRUSH-SHIFTING POLYPHASE SERIES MOTOR

Part II

By W. C. K. Altes

Induction Motor Engineering Department, General Electric Company

In the February issue of the Review we published the first installment of this article. It presented in detail the theory of both single-phase and polyphase brush-shifting series motors. The article below is the concluding installment of the series and it describes the motor's characteristics, applications, mechanical design, single-phase operation and testing.—Editor.

Operating Characteristics

Broadly speaking, the application of the direct current series motor is limited to railway, crane and hoist work. There are a number of applications, such as blowers, pumps, etc., where a direct current variable speed series motor would have been used, if we had not possessed in the direct current shunt motor with field control a more efficient variable speed motor. With alternating current, conditions are different. We have the multi-speed motor, wound with several different numbers of poles, which particularly in the squirrel cage type is a highly desirable motor when only a few definite speeds are required. The slip ring motor with polar wound armature and secondary resistance control will, as heretofore, continue to be applied to

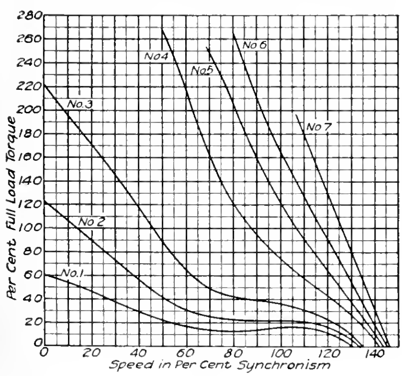


Fig. 1

a variety of drives. However, both motors are deficient as soon as we want efficient speed regulation with a large number of steps.

Judging by present developments it would seem that efficient speed regulation with a large number of steps can be more easily obtained with an alternating current motor having series characteristics than with one having shunt characteristics. Hence it becomes necessary to determine, in a number of instances, whether the a-c. series motor can take the place of the d-c. adjustable speed shunt motor.

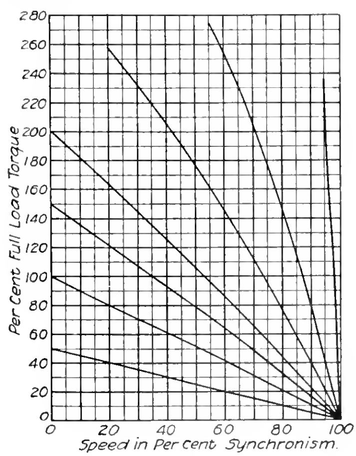


Fig. 2

The speed-torque characteristics of such a series motor for different positions of the movable brush yoke have been shown in Fig. 1.* They resemble the characteristics of the polyphase induction motor with secondary resistance control shown in Fig. 2; the principal difference being that in Fig. 1, at no load, the speed considerably exceeds the synchronous speed. In fact the no-load speed would reach excessive values if the saturation of the iron of the series transformer

* I desire to acknowledge Mr. R. P. Walton's assistance in the preparation of the curves of this article.

did not limit it. It will further be noticed that for low values of torque the curves of the series motor, between 70 and 100 per cent speed, are even notably flatter than those of

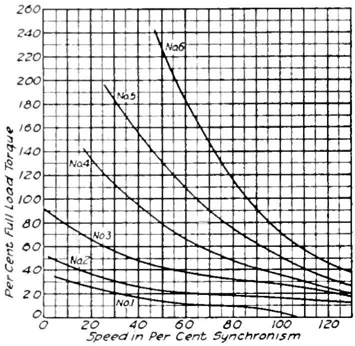


Fig. 3

the induction motor; which means that if the torque required remains constant over the speed range particular care should be taken in selecting a motor that is not too large for the application. Over motoring, in general undesirable from an efficiency standpoint, becomes particularly objectionable where a-c. series motors are used

The speed-torque characteristics at light load can be improved by reducing the number of primary turns of the transformer. The transformers for standard motors used for constant torque drives are therefore provided with a lower tap, by means of which speed-torque characteristics as shown in Fig. 3 can be obtained. A comparison of Fig. 1 and Fig. 3 will show that while the motor of Fig. 1 becomes unstable with 20 per cent torque as soon as the speed exceeds 70 per cent, the motor of Fig. 3 is stable over the entire range. Nevertheless, the latter motor will be very sensitive as regards brush position when operating at light loads and at speeds exceeding 70 per cent speed, and these conditions ought to be avoided as much as possible. The power-factor of the motor in that case will be lower for reasons explained in the preceding article.*

The induction motor with resistance control has a definite number of speed-torque characteristics, corresponding to the available number of resistance and controller points. This is a source of trouble, for sometimes with a given load certain desired speeds can not be obtained and it becomes necessary to readjust resistance and controller. The alternating current series motor has an infinite number of steps and by shifting the brushes far enough back the desired speed can always be obtained which is a decided advantage.

So far this motor has only been applied in a limited number of cases.

As an example of the successful application of the a-c. series motor where the d-c. shunt motor is commonly used, the cloth printing machine may be mentioned. The torque on a printing machine is determined by the number of color rolls and the pressure applied to these rolls, it is therefore clear that this torque stays practically constant over the entire speed range. A very low speed is required when the printer is adjusting the

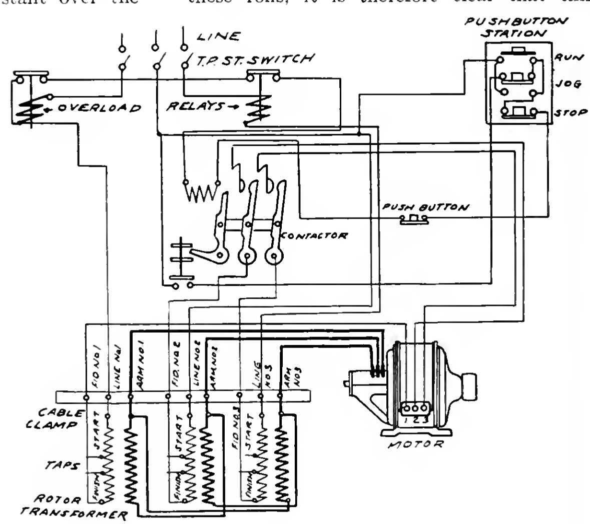


Fig. 4

* See General Electric Review, February, 1916, page 122.

rolls, while the printing speed is determined by the pattern. The series motor has filled the requirements of this service satisfactorily.

The diagram of connections of such an outfit is shown in Fig. 4. The brush yoke can be shifted by means of a controller (see Fig. 5), which is connected by a double chain to the yoke. By means of a push-button station, located together with the controller next to the printing machine, a double-pole line contactor can be operated, which connects the motor to the line. Before starting the motor the operator puts the controller in the starting position which is located between the highest and lowest speed positions. After having pushed the button "start" the line contactor is held in by its interlock until the "stop" button has been pressed for disconnecting the motor from the line. By pushing the "jog" button the line contactor will be held in only as long as the button is pushed, and thus the rolls of the printing machine can be turned over a small amount. Motors for this service are being designed to operate continuously between 1350- and 600-r.p.m. and intermittently down to 450-r.p.m. For short periods they can even be run at still slower speeds.

If the controller is shifted back to the lowest speed position, and there is considerable pressure on the rolls, the motor will come to a standstill. In that case the operator should either disconnect the motor from the line by pushing the "stop" button, or advance the brush-shifting controller so as to have the motor develop more torque. In case of neglect on the part of the operator, the commutator will be subject to damage due to the short-circuited currents (induced by the rotating flux) in the coils short-circuited by the brushes. This current will cause local heating of the commutator, and will often result in a rough commutator or loose soldered connection. In order to avoid these commutator troubles a centrifugal device has been developed which disconnects the motor from the line as soon as the speed is less than the lowest permissible operating speed.

This centrifugal switch is connected in series with the interlock of the contactor. The "start" button when closed (see Fig. 6) short circuits both interlock and centrifugal switch, and the contactor will stay in if the push-button is released after the motor speed exceeds the minimum speed for which the switch has been set. The centrifugal switch makes the "jog" button superfluous, as by pushing the start button for short intervals only, during which the motor can not reach the minimum speed for which the centrifugal switch has been set, the jogging operation can be obtained.

Several of these motors have been applied to cloth tenter frames. In this case a hand-operated switch instead of the contactor control is generally used. Both switch and rotor transformer are combined in a single unit, in a frame similar to a starting compensator. In Fig. 7 we have shown the diagram of connections of a quarter-phase tenter motor, the rotor transformer having a six-phase secondary which is connected to the brush studs. The switch has two positions, in which it is held by the no-voltage release. In the heavy load position the motor has a high power-factor but unstable characteristics at light loads, while in the

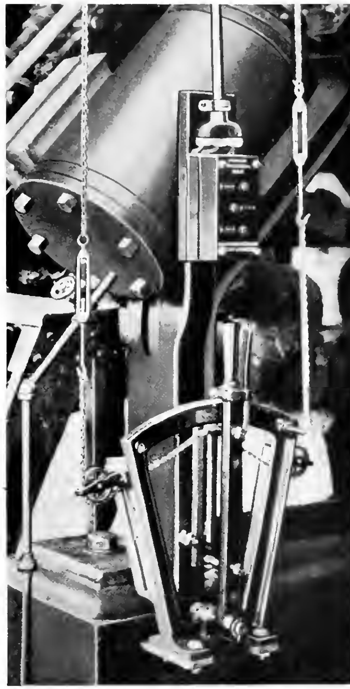


Fig. 5. Push-Button Station and Brush-Shifting Lever for a 550-Volt Motor in a Cloth Printing Works

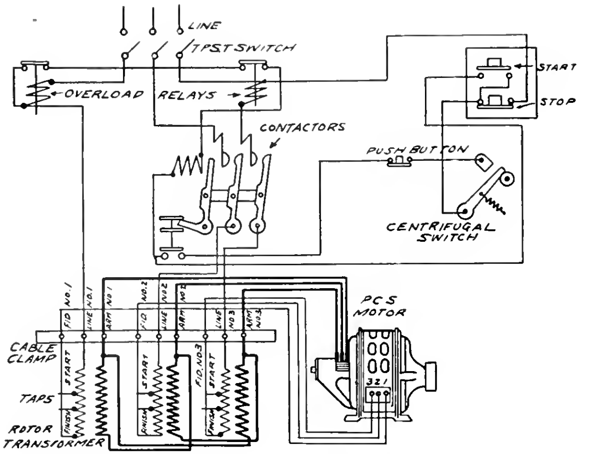


Fig. 6

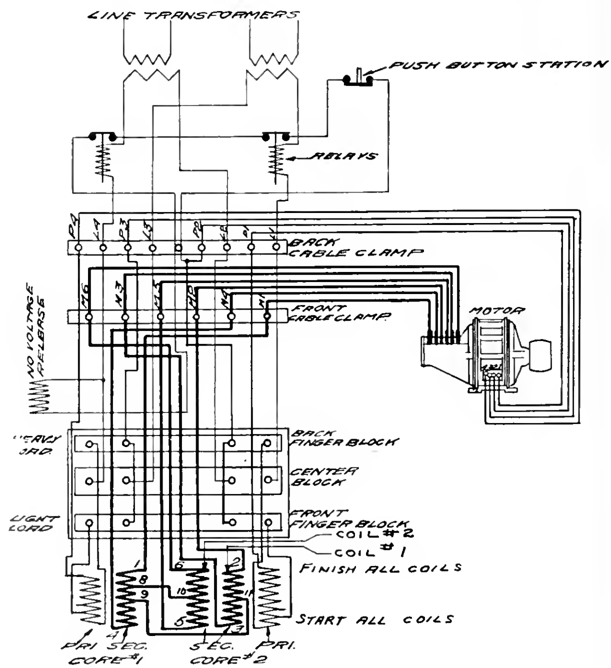


Fig. 7

light load position the power-factor is lower with increased stability at light loads due to the reduction of the primary turns of the transformer. If the size of the motor has been properly selected for the drive, the motor is always operated with the switch in the heavy load position; the "light load" position having been provided simply to help out in cases of over motoring.

In order to make it possible to determine merely by means of a tachometer and amperemeter the approximate power requirements of a drive to which a brush-shifting motor is applied, we have prepared curves showing, for different values of line current in percentage of the full-load current at synchronous speed, the horse power output at different speeds. These curves have been shown in Fig. 8. As the power-factor and efficiency differ somewhat for brush-shifting motors of different ratings, these curves can only be used for obtaining approximate values. For more accurate power readings the efficiency and power-factor of the motor with which the readings have been made should be used.

A broad field of application of the alternating current series motor is found in mine fans and water and sewerage pumps. The characteristics of centrifugal pumps and fans are such that the required motor torque falls off rapidly with decreasing speed, and therefore less attention need be paid to the proper selection of the size of the motor in view of the speed-torque characteristics, although also in this case the best efficiency will be obtained if proper care is taken to determine the output. In Fig. 9 we have shown an eight-pole, three-phase, 25-cycle brush-shifting motor rated 150-h.p. at 375-r.p.m. In Fig. 10 the efficiency and power-factor of a motor of this type have been plotted for different values of speed in percentage of synchronous speed for constant torque, and the torque decreasing proportionally as the square of the speed. In Fig. 11 similar curves have been shown for a slip ring induction motor with resistance control. It will be noted that the largest saving in power is obtained when the motor is regulated with constant torque, as required by piston pumps. Bearing in mind that many blowers and pumps have to be in operation almost continuously, it will often be found that the saving in power pays within a short time for the additional expense incurred by the application of the polyphase bursh-shifting series motor.

When speed regulation over a large range is required with low torque at slow speed it becomes advantageous to connect both motor and transformer in delta when running at the high speed, and in Y at the slow speed. Fig. 12 shows a three-phase, six-pole, 1200-r.p.m., 15-h.p. brush shifting motor used for driving a ventilating fan in a school building; the speed of this motor can be varied between 1350- and 400-r.p.m. The motor has been furnished with a rotor transformer with self-contained double-throw switch having an "off" middle position, which is held by the no-voltage release either in the Y or in the delta position, depending on the speed required. Below 70 per cent of synchronous speed the motor should be run in Y and above this value in delta.

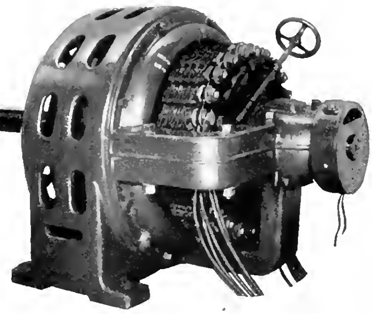


Fig. 9. A 440-Volt Three-Phase Brush-Shifting Motor

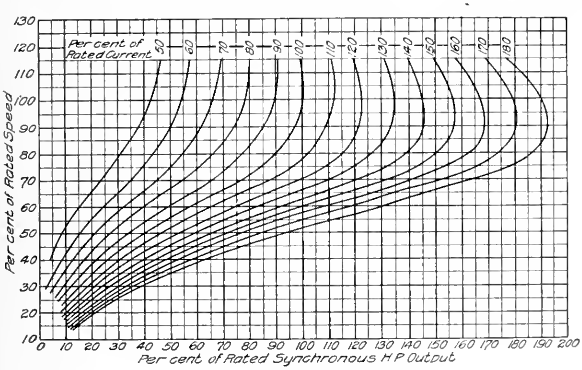


Fig. 8

Mechanical Design

The stator of the brush-shifting polyphase series motor of the General Electric Company is similar to the stators of standard induction motors, and in many cases the stator of the induction motor of the same rating can be used. The smallest motors can be wound up to 550 volts and the larger up to 2200 and 6600 volts. The smallest motors have riveted frame construction, the medium sizes skeleton frame and the largest motors open or closed box frames.

The armature resembles a d-c. armature, the commutator having in general larger dimensions than the direct current motor of the same rating, as the voltage is necessarily low.

The brush yoke is designed for 3, 6, 9 or 12 phases, requiring as many studs for every two poles as there are phases. In motors having a series wound armature or a multiple armature with equalizing connections to every commutator bar brush studs can be omitted and such motors require no more brush studs than there are phases. The 15-h.p. motor shown in Fig. 12 has a series armature and six brush studs arranged for six phases.

Single-phase Operation

It is generally known that the polyphase induction motor will continue to run after the motor is up to speed with one line open. This is also true of the polyphase series motor. In this case not only is the output reduced, which is demonstrated by the fact that in the

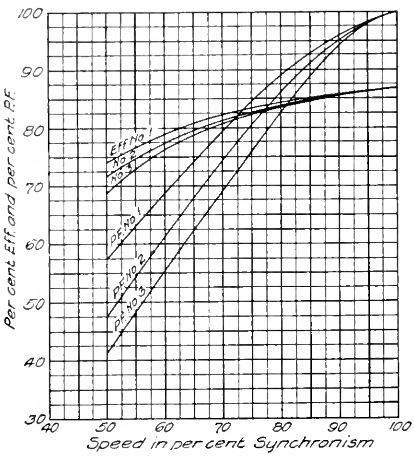


Fig. 10

same brush position the motor drives the load slower, but also the commutation is noticably inferior.

It is known further that the induction motor does not start when switched on to single-phase. In this respect the polyphase series motor shows a different behavior. In the preceding article we have shown how the theory of the quarter-phase series motor can be derived from the theory of the single-phase series motor, by considering the former as the superposition of two single-phase series motors. Hence if we run this quarter-phase series motor single-phase, we have only one of the two superimposed series motors left and the laws of the single-phase series motor apply. This means that the quarter-phase series motor will develop starting torque when single-phase current is applied. In Fig. 13 we have shown the normal connection diagram of the quarter-phase two-pole series motor, without transformer, the brushes being shifted clockwise over an angle α from the "live neutral" position. It is clear that the motor will have the same starting and running characteristics as a single-phase motor, no matter whether we connect either phase 1 or phase 2 to the line. In Fig. 14 we have shown the same motor, only we have incorrectly connected S5 of phase 2 of the stator winding to stud 2 instead of stud 5. If we connect phase 1 only to the line, then the characteristics will be the same as before. The conditions for phase 2, however, have been changed, the angle of brush-shift being equal to $180-\alpha$ deg. counter-clockwise from the live neutral. This means that if α is small, the motor will start with a powerful torque clockwise when phase 1 is connected to the line and with a weak torque counter clockwise when phase 2 is connected to the line.

When α equals 90 deg., the torque for both phases is equal and opposite. By connecting both phases to the line the motor will develop no torque for that of one phase counteracts that of the other.

The motor starts clockwise as long as α is less than 90 deg. and counter-clockwise when α is greater than 90 deg. This means that the direction of rotation is reversed when the brushes are shifted over 90 electrical deg.,

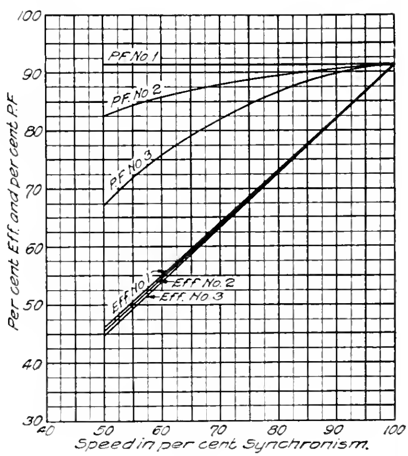


Fig. 11

while when the motor is connected up correctly, a change of direction of rotation occurs after the brush yoke has been shifted over 180 electrical deg. Further, it will be impossible to find a brush position in which the current in *both phases* is low; while with the motor normally connected we have found that the current, with the brushes on dead neutral, is only a fraction of the full-load current.

Similar conditions appear in the three-phase motor. In order to make sure that the motor is wired correctly, we should therefore open each line in succession to see whether the motor develops the same single-phase torque with the brushes in the same position.

Putting in Operation

After the motor has been connected up in accordance with the diagram furnished with each polyphase series motor, the single-phase test can be made if there is any doubt about the connections being correct.

For this purpose the brushes are advanced from dead neutral position to the point where the motor starts. They are then left stationary and the other phases are successively connected to the line, to see whether the motor starts up in the same direction with the same torque and current. If this is not the case then the wiring is wrong. After the single-phase test has proved that both motor and transformer have been connected up correctly, we still have to determine whether the line terminals have been properly connected. We have already explained in the preceding article that the direction of rotation of the motor merely depends on the brush position and not on the way in which the line terminals have been connected, as is the case with the induction motor. Nevertheless, we want the electrical field in the motor to rotate in the same direction as the mechanical rotation of the armature, in order to obtain good power-factor and commutating characteristics. In order to test out this point we should start the motor polyphase, watching the ammeter when the motor is coming up to speed, with the brushes kept stationary. If the line current decreases with increasing speed the motor has been connected up correctly. If the line current stays constant with increasing speed, or increases, this indicates that the motor is running against its field; the large line current being due to the magnetizing current required for exciting the transformer flux, which is large when the motor is running against its field and increases with increasing speed. If the line current stays constant two line leads should be interchanged, for instance, No. 1 and No. 2, of the diagram of Fig. 4 and not 1 and 2 of the motor terminal board.

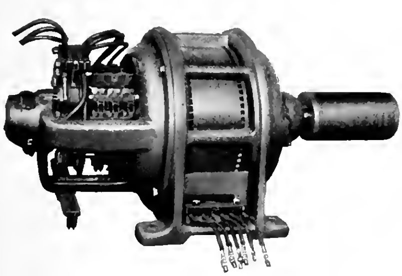


Fig. 12. A 220-Volt Brush-Shifting Motor

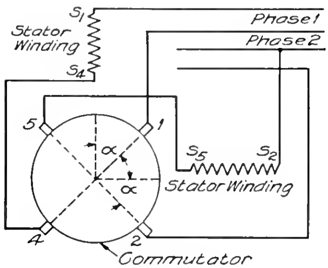


Fig. 13

After the single-phase and line current tests have given the correct results, the motor can be safely operated.

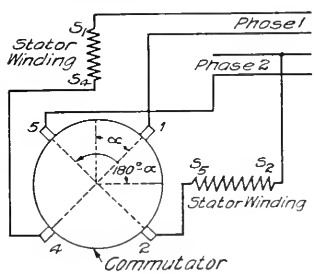


Fig. 14

Testing

The efficiency of small brush-shifting polyphase series motors built by the General Electric Company is directly determined by measuring the output by brake.

On larger motors the efficiency is calculated from the determinable losses. These losses are:

a I^2R losses of the stator winding and the primary of the transformer

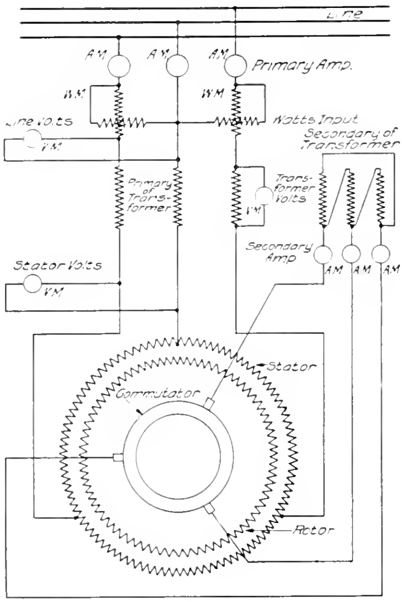


Fig. 15

b I^2R losses of the armature winding and the secondary of the transformer

c Brush contact loss

d Brush friction, friction of bearings and windage

e The iron losses in the motor

f The iron losses in the transformer

The determination of the efficiency is made as follows:

The resistance of the windings of both motor and transformer are measured and corrected for 75 deg. C.

The motor is run free with the brush studs short-circuited and a variable voltage of normal rated frequency applied to the stator, the watts input and the current being read. The brush friction, friction of bearings, and windage, are equal to the watts input at the lowest voltage at which the motor will rotate at synchronous speed. It is assumed that these losses decrease proportionally to the speed. This is not absolutely correct, as the windage loss will decrease more rapidly than the speed. The motor core loss for different applied voltages is found by subtracting from the watts input the no-load copper loss, brush friction, bearing friction, and windage. The transformer core loss is determined by applying to the primary of the transformer with open secondary, a variable voltage of normal rated frequency and reading the watts input and current. The core loss is obtained by subtracting the copper loss from the watts input.

The motor is then loaded with normal connection, and connected to a circuit of normal rated frequency and voltage, and run at the speeds for which the efficiency has to be determined; and the speed, watts input, applied voltage and frequency, primary current, secondary current, voltage across the stator winding of the motor, and the voltage across the primary of the transformer are read. In Fig. 15, we have shown the complete wiring diagram of a three-phase series motor with three-phase secondary and transformer showing the location of the different instruments. The calculation of the efficiency can be conveniently tabulated, as shown below. The power-factor for the calculated output follows directly from the test.

In order to investigate whether this method of determining the efficiency gives a value

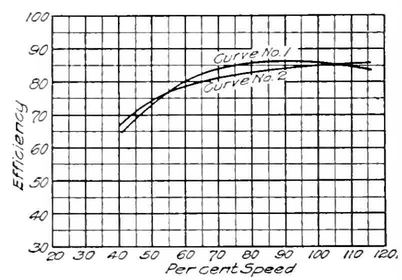


Fig. 16

corresponding to the directly determined efficiency, tests have been made on several motors on which the actual output was accurately determined by means of a dynamometer. A comparison of both methods has been shown in Fig. 16. It will be noted that between 55 and 105 per cent speed, the directly determined efficiency is higher that the efficiency determined from the losses. This is partly due to the fact that the temperature of the motor during the brake test was 50 deg. instead of 75 deg. C., but also to the fact that too large values for the core loss have been used, as we do not subtract the impedance drop from the voltage measured across the stator of the motor and the primary of the transformer. At 40 and 115 per cent speed the directly determined efficiency is lower than the calculated efficiency, which fact must be attributed to the increased commutation losses which escape accurate determination.

Readings

Per cent speed	115	100	91	82.5	66.66	51.5
Prim. amps	28.8	24.5	22.7	21.5	23	28.3
Sec. amps	247	209	193	187	163	166
Watts	25900	22000	19650	18300	15050	13150
P.F.	98.5	96.4	92.1	86	96.6	52
Line volts	550	550	550	550	550	550
Motor volts	432	520	546	580	572	522
Transformer volts per phase	79.5	34	26	50	98	129

Calculation

Primary C^2R	690	500	428	383	436	664
Sec. C^2R	604	445	378	356	270	280
Brush contact loss	927	785	723	705	612	623
Brush friction, bearing friction and windage	965	840	765	693	560	432
Motor core loss	390	620	700	840	810	630
Transformer core loss	1170	40	25	50	270	640
Total loss	3746	3230	3019	3027	2958	3269
Watts input	25900	22000	19650	18300	15050	13150
Watts output	22154	18770	16631	15273	12092	9881
Eff.	85.6	85.3	84.7	83.3	80.3	75.3

THE CHARACTERISTICS OF TUNGSTEN FILAMENTS AS FUNCTIONS OF TEMPERATURE

By Irving Langmuir

Research Laboratory, General Electric Company

The author, as is well known, has done most valuable work in the development of tungsten filaments for incandescent lamps, especially in the case of gas filled tungsten lamps. In the present article he deals with the characteristics of tungsten filaments in terms of their length, diameter and temperature. After citing the characteristics of "ideal tungsten filaments," he discusses actual filaments and then passes on to consider the cooling effect of the leads and corrections for lack of straightness. He also shows the effects caused by roughening of the surface, impurities in the metal and the presence of gases. Much useful data are given in tabular form concerning the characteristics of the "ideal tungsten filament." This article should form a valuable contribution to our knowledge of the behaviour of tungsten filaments in incandescent lamps.—Editor.

The relations between the current, candle-power and voltage in commercial tungsten lamps have frequently been determined. Middlekauff and Skogland (Bull. Bur. Stand. 11, 483 (1915) and Trans. Ill Eng. Soc., *9*, 734, (1914) have published equations and tables by which the candle-power, current, wattage, and watts per candle, of a tungsten lamp may be accurately calculated for any voltage, provided a value of the variable is known at some other voltage.

The estimation of the true temperature of tungsten filaments has been a matter of considerable difficulty. Pirani, by optical methods, measured the temperatures over a range of several hundred degrees, and thus obtained a relation between temperature and watts per candle. Pirani, and Corbino have also determined the ratio of "hot" to "cold" resistance corresponding to different temperatures.

As far as the writer has been able to determine, no data have been published giving the characteristics of tungsten filaments in terms of the length, diameter and temperature.

Users of tungsten lamps have little occasion to use data of this kind, but in the application of tungsten filaments in scientific research, or in applications such as the construction of electric furnaces, etc., the relation between temperature and the other variables is often of very great interest.

The present paper is a brief summary of some results obtained in the course of an extended investigation into the characteristics of tungsten filaments.

The complete data, together with a description of the experimental methods involved, and a general discussion of the results will be published elsewhere.*

The characteristics of filaments are related in a simple way, to the dimensions of the filament.

Let us consider the case of a very long straight filament of uniform circular cross-section with diameter d and length l. Let us imagine the ends of the filament connected to leads which have the same temperature as the filament itself, so that no heat is conducted away by the leads. We will further assume that the filament has been thoroughly aged† and consists of pure tungsten, having a definite specific resistance at a given temperature, and possessing a highly polished surface. A filament fulfilling these conditions we shall call an "ideal filament." Actual filaments may differ from the ideal in the following respects:

1. The leads conduct away heat.
2. The filament may not be straight.
3. The surface may be rough or contaminated, changing its ability to radiate both heat and light.
4. Impurities or mechanical strains in the wire may alter its specific resistance.
5. Gases around the wire may conduct away heat.

CHARACTERISTICS OF IDEAL TUNGSTEN FILAMENTS

We shall first consider how the characteristics of an ideal filament vary with the length and diameter.

Let

W = the total power consumed by the filament in watts.

C = candle-power of the filament in a direction perpendicular to its length, as seen through an ordinary lamp bulb. C = total lumens divided by π^2.

V = voltage between the ends of the filament.

A = amperes flowing through filament.

R = resistance of filament (ohms).

If the surface is uniform the power radiated and the candle-power are proportional to the surface. We may therefore place

(1) $$W = W' \, l \, d$$

(2) $$C = C' \, l \, d$$

where W' and C' are independent of the

* Probably in the *Physical Review*.

† This aging usually consists in heating the filament for 24 hours at 2400 deg. K. in a good vacuum.

dimensions of the filament, but depend on the temperature.

The total lumens radiated by a filament is equal to $\pi^2 C = \pi^2 C' l d$. The mean spherical candle-power of a filament is $\frac{\pi}{4} C' l d$.

In a similar manner, since the resistance of a filament is proportional to its length and inversely proportional to the square of the diameter, we may place

(3) $$R = \frac{R' l}{d^2}$$

From these relations we may now derive the following, since

$$V = \sqrt{WR} \text{ and } A = \sqrt{W/R}$$

(4) $$V = \frac{V' l}{\sqrt{d}}$$

(5) $$A = A' d^{3/2}$$

Equation 4 shows us, that, to maintain a filament at constant temperature while the length or diameter changes, we need to apply a potential proportional to the length, and inversely proportional to the square root of the diameter.

Similarly, by Equation 5, we see that the current needed to heat a filament to a given temperature, varies with the three-halves power of the diameter.

The quantities W', C', R', V' and A', may be called *specific characteristics* of the filament. They are numerically equal to the watts, candle-power, volts, etc., which would correspond to a filament 1 cm. long and 1 cm. in diameter.

The values of W', C', R', V' and A', for temperatures ranging from room temperature up to that of melting tungsten, are given in Table I.

In using these data it must be remembered that they apply to *ideal tungsten filaments*, and that the cooling effect of the leads, and in some cases other factors, must be taken into account before they can be applied with accuracy to actual filaments. The temperatures given in the first column of the Table are on the Kelvin or absolute (centigrade) scale ($T = t + 273$ deg.).

In the seventh column are given values of watts per candle. From equations 1 and 2, it follows that

(6) $$\frac{W}{C} = \frac{W'}{C'}$$

From the definition of C it is evident that W/C corresponds to watts per *mean horizontal* candle in case the filament is wholly vertical, and there is no absorption of light by the supports. The watts per mean spherical candle are equal to $\frac{4}{\pi} W/C$ or $1.27\ W/C$.

The eighth column gives the ratio of the "hot" to "cold" resistance. The "cold" resistance is taken at 20 deg. C. Thus R' (at $T = 293$ deg. K) $= 7.02 \times 10^{-6}$, so that

$$R/R_{20} = 0.1424 \times 10^6\ R'$$

In the ninth column are given data on the vapor pressures (p) of metallic tungsten in bars (or dynes per sq. cm.). To convert these pressures to mm. of mercury multiply by 0.00075. The tenth column gives the rate of evaporation of tungsten in grams per sq. cm. per second. These data are taken from previously published results (Langmuir, Phys. Rev. *2*, p-329 (1913). The eleventh column contains data on the electron emission from pure tungsten in high vacuum.* The values given represent the maximum current in amperes (saturation current) that can be obtained per sq. cm. of filament surface.

The twelfth column gives data on the thermal expansion of tungsten at high temperatures. The figures represent the ratio of the lengths of a filament at a given temperature to the corresponding length at room temperature (20 deg. C.).

Determination of the Diameter of Tungsten Filaments

For the large size wires a good micrometer may be used for measuring the diameter but for very small wires no micrometer is accurate enough. The most satisfactory way to obtain the diameter of such wires is to weigh a measured length. If w is the weight of the wire in milligrams per cm. of length then the diameter in cm. is given by

(7) $$d = 0.008186\sqrt{w}$$

This formula is based on a density of 19.0 for tungsten, a value obtained by measurements on filaments which have been run a considerable time in lamps.

CHARACTERISTICS OF ACTUAL FILAMENTS

The data given in Table I refer to an ideal filament. In order to apply these data to actual filaments it is often necessary to take into account the factors which cause departures from the ideal conditions.

* Traces of other substances which are often present in commercial tungsten filaments may cause an electron emission much greater than that given.

1. Cooling Effect of the Leads

Let us consider a single loop filament welded to two leads.

The leads cool the ends of the filament and thus lower its resistance and its total candle-power. Thus, with a given current passing through the filament, the voltage is *lowered* by an amount $\triangle V$ and the candle-power is *lowered* by the amount $\triangle C$. A mathematical analysis of the theory of the cooling effect of leads, together with an experimental determination of the heat conductivity of tungsten at high temperatures, has led to the following approximate equations.

(8) $\triangle V = 0.00034\ (T-300).$

(9) $\triangle C = 0.00087\ \frac{C}{V}\ (T-300).$

Here V is the total voltage of the filament, C the total candle-power, and T is the temperature of the central part of the filament. It should be noted that the diameter (d) does not occur explicitly in these equations. This is due to the fact that the cooling effect of the leads varies with the diameter in a manner simply related to that in which the voltage varies with the diameter.

The above equations give approximately the total changes in characteristics caused by *two* cooling junctions which are sufficiently large to cool the filament at its ends, practically to room temperature. These formulas must therefore be looked upon as giving the greatest possible effect that can be produced by the leads. In ordinary cases, even with moderately heavy leads, the coefficients in the equations should be less than those given. Under average conditions with a single loop filament having heavy leads, the following equations will be found to be of fairly general application.

(10) $\triangle V = 0.00026\ (T-300)$

(11) $\triangle C = \frac{0.00074}{V} C\ (T-300).$

2. Corrections for Lack of Straightness of the Filament

If a filament is bent into the form of a loop the characteristics are in general unchanged except that the distribution of light is altered. Thus the total lumens, or the mean spherical candle-power, remain the same but the mean horizontal candle-power is usually considerably changed.

The candle-power of the filament in a given direction may be calculated from the *projected area* of the filament in that direction.

The effect of lack of straightness becomes more serious if the filament is wound into the form of a helix or bent into any other form in which the free radiation from parts of the filament is prevented by the close proximity of other parts. Under such conditions the watts and even *mean spherical* candles of a given length of filament are decreased, but the resistance at constant temperature remains nearly unchanged.

3. Effects Produced by Roughening or Contamination of the Surface.

If a filament is heated in the presence of vapors of carbon compounds, this element is often taken up by the filament. This leads to an increase of emissivity so that, with the filament at a given temperature, the watts and candle-power may be considerably increased. An oxidation of the filament at lower temperatures may produce similar effects. Effects of this kind are also observed if the characteristics of a filament are measured before it has been thoroughly aged. In the case of a well aged filament in a good lamp vacuum the surface conditions of tungsten filaments seem to be remarkably uniform.

4. Effects Caused by Impurities in the Metal

Traces of carbon in a filament very greatly increase its specific resistance; one-tenth of one per cent of carbon sufficing to raise the resistance at room temperature by about five per cent.

5. Effect of Gases in Conducting Away Heat

The amounts of gas normally present in a good lamp vacuum do not conduct a perceptible amount of heat.

For low pressures of gases (less than 1000 bars or 0.7 mm. of mercury) the heat conducted from a hot filament by a gas may be calculated from the formula:

(12) $W_c' = \frac{W_c}{ld} = 0.00114 \frac{\alpha}{1-k} \frac{p}{\sqrt{MT_0}} (T-T_0)$

Here W_c = watts of heat energy conducted by the gas.

α = accommodation coefficient of the gas. This coefficient is always less than unity. For hydrogen it is 0.2 but for nearly all other gases it lies between 0.80 and 0.90.

k = ratio of the specific heat at constant pressure to the specific heat at constant volume.

For all monatomic gases such as argon, neon, and mercury vapor, k is equal to 1.666. For di-atomic gases like hydrogen, nitrogen, etc., k equals 1.40 and for tri-atomic gases like CO_2, k is about 1.29.

p = pressure of the gas in bars. The bar is the C.G.S. unit of pressure and is equal to 0.00075 mm. of mercury or ¾ of a micron pressure. One megabar (10^6 bars) is equal to 750 mm. which is more nearly average atmospheric pressure than the 760 mm. usually adopted as standard.

M = molecular weight of the gas.
T = temperature (deg. K) of the filament.
T_o = temperature of the bulb.

By calculating the values of the constants for the various gases the following formulas have been derived from the above. In each case the bulb temperature has been taken to be 300 deg. in calculating the expression under the radical.

For Nitrogen—

(13) $W_c' = 24.9 \times 10^{-6}\, p(T - T_o)$.

For Argon—

(14) $W_c' = 12.5 \times 10^{-6}\, p(T - T_o)$

For Mercury Vapor—

(15) $W_c' = 6.3 \times 10^{-6}\, p(T - T_o)$

For Hydrogen the corresponding formula is

(16) $W_c' = 24.6 \times 10^{-6}\, p(T - T_o)$

This last equation gives results agreeing with experiments only for temperatures up to about 1500 deg. K. At higher temperatures the hydrogen is dissociated* by the hot wire and the heat absorbed by the dissociating gas at very high temperatures reaches values as much as 20 times that calculated by equation 16

It is of interest to compare the heat conducted from a filament by a gas with that radiated. Let us consider a filament at 2500 deg. From Table I we see that $W' = 235$. If we have a pressure of one bar of gas

* Langmuir, J., Amer. Chem. Soc. 37, 417, (1915).

TABLE I

CHARACTERISTICS OF THE "IDEAL TUNGSTEN FILAMENT"

1	2	3	4	5	6	7	8	9	10	11	12
T	W'	C'	R'	V'	A'	W/C	R/R_{20}	p bars	m g/cm.² sec.	i amps./cm.²	l/l_o
273°K	—	—	6.37×10^{-6}	—	—	—	0.907	—	—	—	—
300	0.00034	—	7.24	0.00005	6.9	—	1.031	—	—	—	1.00000
400	0.0112	—	10 43	0.00034	33	—	1 486	—	—	—	1 00026
500	0.0424	—	13 76	0 00076	56	—	1 960	—	—	—	1.00053
600	0.1131	—	17.23	0 00140	81	—	2 454	—	—	—	1 00082
700	0.2606	—	20 83	0 00233	112	—	2 967	—	—	—	1 00111
800	0.5420	—	24 55	0 00365	149	—	3 497	—	—	—	1 00142
900	1.043	—	28.36	0 00544	192	—	4.040	—	—	—	1 00173
1000	1 885	0 0001	32.24	0 00780	242	13460	4 593	—	—	12×10^{-15}	1.00206
1100	3 225	0 0012	36 20	0.0108	298	2680	5 156	—	—	$1\ 48\times10^{-12}$	1 00240
1200	5.258	0 0074	40 23	0 0145	362	712	5.731	—	—	82×10^{-12}	1 00275
1300	8 207	0 0346	44 34	0.0191	430	237	6 316	—	—	2.56×10^{-9}	1 00311
1400	12.32	0 1325	48.52	0.0244	504	93.0	6.912	—	—	46.3×10^{-9}	1.00349
1500	17.87	0.4243	52 77	0.0307	582	42.1	7.517	—	—	$0\ 58\times10^{-6}$	1 00387
1600	25.17	1.179	57 13	0.0379	664	21.35	8 138	—	—	5.42×10^{-6}	1 00427
1700	34.55	2 928	61 61	0 0461	749	11.80	8 776	—	—	$37\ 8\times10^{-6}$	1 00468
1800	46 34	6 552	66 19	0 0554	837	7 074	9.429	—	—	214×10^{-6}	1 00510
1900	60.98	13.46	70.89	0 0658	928	4.530	10.10	—	—	0 00103—	1.00553
2000	78 87	25 90	75 67	0 0772	1021	3.045	10 78	8.60×10^{-9}	114×10^{-15}	0 0042	1 00597
2100	100.5	46 8	80.52	0.0900	1117	2.147	11 47	111×10^{-9}	$1\ 44\times10^{-12}$	0 0151	1 00642
2200	126.3	80 6	85.41	0 1039	1216	1 568	12 17	$1\ 13\times10^{-6}$	$14\ 4\times10^{-12}$	0.0483	1 00689
2300	157.1	133 3	90 41	0 1192	1318	1 179	12.88	$9\ 4\times10^{-6}$	117×10^{-12}	0 1377	1 00736
2400	193.2	209.8	95.39	0 1357	1423	0.921	13.59	$65\ 7\times10^{-6}$	798×10^{-12}	0 365	1 00785
2500	235.5	319.6	100 48	0 1538	1531	0.737	14 31	392×10^{-6}	4.67×10^{-9}	0 891	1.00835
2600	284.5	471	105.56	0 1733	1642	0 604	15 04	$2\ 02\times10^{-3}$	23.6×10^{-9}	2.044	1 00886
2700	341.1	675	110.69	0 1943	1756	0 505	15.77	9.27×10^{-3}	106×10^{-9}	4 35	1 00938
2800	406 3	944	115.83	0 2169	1873	0.430	16.50	0 0381—	429×10^{-9}	8 33	1 00991
2900	480.5	1290	120 9	0.2410	1993	0.372	17 22	0.141	1.57×10^{-6}	17.1	1.01046
3000	565.2	1729	126.1	0 2669	2117	0 327	17 96	0 483	5.23×10^{-6}	31 7	1 01101
3100	660 7	2272	131 2	0 2944	2244	0 291	18 69	1 52	$16\ 3\times10^{-6}$	57 2	1 01158
3200	768 8	2941	136 2	0.3236	2376	0.2615	19.40	4 45	$46\ 7\times10^{-6}$	101	1 01215
3300	889.6	3763	141.1	0.3543	2511	0.2364	20 10	12.1	126×10^{-6}	171	1 01274
3400	1025	4725	146 0	0.3868	2649	0.2169	20.80	31 2	320×10^{-6}	275	1 01334
3500	1176	5869	150 9	0.4213	2792	0.2004	21.50	76 3	769×10^{-6}	437	1 01396
3540	1241	6373	152.8	0.4355	2850	0.1948	21.77	107	0.00107	510	—

(0.00075 mm.), which is very much more than is present in a well exhausted lamp, the amount of heat conducted by the gas corresponds to

$W_c' = 0.055$ for nitrogen.
$W_c' = 0.028$ for argon.
$W_c' = 0.014$ for mercury vapor.
$W_c' = 0.054$ for hydrogen.

This result for hydrogen is calculated from equation 16. Actual experiment gives $W_c' = 1.0$ at one bar pressure. Even in the case of hydrogen with its abnormally great heat conductivity, the heat carried by the gas at one bar pressure is thus less than one-half of one per cent of that radiated.

For pressures above 500 bars the formulas given are not applicable. At higher pressures the heat conducted by the gas may be calculated by methods that have already been published. (Langmuir, *Phys. Rev. 34*, 401, (1912)].

Experiments have shown that the introduction of gases chemically inert towards tungsten does not alter the relation between resistance and temperature or that between candle-power and temperature.

WATTMETER CONNECTIONS IN UNBALANCED SYSTEMS

By Everett S. Lee

Union College, Schenectady, N. Y.

Methods of metering single-phase, two-phase, and three-phase electric power by wattmeters, connected according to standard diagrams, have been in vogue for years. Doubtless many engineers and operators, however, have taken the methods for granted. For them, the following analytical article will possess a distinctly educational value; and, for all, the latter portion of the article will possess a considerable interest for it contains a general proof of the correctness of metering power of *any* number of phases by the same fundamental methods. —Editor.

It is known by engineers that power in a balanced three-phase system can be metered with either three or two wattmeters. It is not generally known, however, that either of these two methods of power measurement may be applied to any three-wire system whether balanced or unbalanced and regardless of the degree to which the voltage, current, or power-factor relations depart from those of a balanced system. Indeed it is interesting to note that the power of any n-phase system having n wires may be metered in either of these two ways.

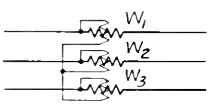


Fig. 1

(1) With n wattmeters, by connecting the current coil of each wattmeter into a separate line and the potential coil of each wattmeter from its own line to any desired common point or neutral, see Fig. 1.

(2) With $(n-1)$ wattmeters, by connecting the current coil of each wattmeter into one of the $(n-1)$ lines, and the potential coil of each wattmeter from its own line to the nth line which contains no meter, see Fig. 2.

The proof of these statements is given in the following.

First consider the particular case of three wattmeters metering a Y-connected three-phase unbalanced load, see Fig. 3.

The phase voltages are E_1, E_2, E_3.
The phase currents are I_1, I_2 and I_3.

The wattmeters are W_1, W_2, and W_3, one in each line, the potential coils being connected from each line to any point, a, that is common to the three, see Fig. 1. These connections made, a will assume a neutral

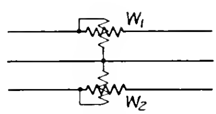


Fig. 2

potential which has been represented graphically by its position in Fig. 3. The voltage across the potential coils of each wattmeter is E_4 across W_1, E_5 across W_2 and E_6 across W_3.

With the wattmeters connected as described and the circuit unbalanced, it is practically a certainty that the neutral point a will not coincide with the neutral point O. Assume that the distance of separation is Oa, of which the horizontal and vertical components are

$-x$ and $-jy$* as shown by the small vector diagram in Fig. 3. Now assume the horizontal and vertical axes to intersect at the neutral point O.

Then,

$$\begin{aligned} \dot{E}_1 &= -e_1 - j\,e_1' \\ \dot{E}_2 &= e_2 + j\,e_2' \\ \dot{E}_3 &= -e_3 + j\,e_3' \end{aligned} \qquad (1)$$

and

$$\begin{aligned} \dot{I}_1 &= i_1 - j\,i_1' \\ \dot{I}_2 &= i_2 + j\,i_2' \\ \dot{I}_3 &= -i_3 + j\,i_3' \end{aligned} \qquad (2)$$

Similarly, remembering that the components of Oa are $-x$ and $-jy$.

$$\begin{aligned} \dot{E}_4 &= -(e_1 - x) - j\,(e_1' - y) \\ \dot{E}_5 &= (e_2 + x) + j\,(e_2' + y) \\ \dot{E}_6 &= -(e_3 - x) + j\,(e_3' + y) \end{aligned} \qquad (3)$$

If now, $\dot{E} = e + je'$ is the e.m.f. across a circuit and $\dot{I} = i + ji'$ is the current in the circuit, the power, P, in the circuit is given by the expression

$P = ei + e'\,i'$, which is obtained by "telescoping" the vectors, i.e., multiplying the horizontal components together and the vertical components together and adding the two products. This is a general expression and may be used anywhere to calculate the power when the e.m.f. and current are of the form indicated.†

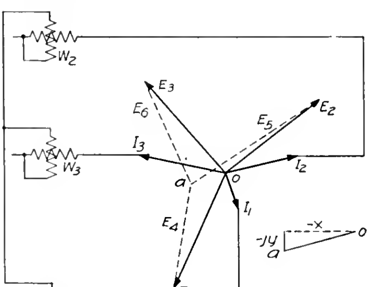


Fig. 3

* The symbol j before any quantity indicates that it is to be revolved 90 degrees in a counter-clockwise direction; the symbol $-j$ indicates a revolution 90 degrees in a clockwise direction. Also, in complex notation, $E = e + je'$ indicates that E is a vector whose two components are e and e'; e is the horizontal component and may have its direction to the right (+) or to the left (−) of an assumed vertical axis, and e' is the vertical component and may have direction upwards ($+j$) or downward ($-j$) from an assumed horizontal axis. Thus in Fig. 4

$$\dot{E}_1 = e_1 + je_1'$$
$$\dot{E}_2 = -e_2 - je_2'$$

† See Steinmetz's "Alternating-current Phenomena," p. 153 (Old Ed.).

Applying this principal to the expressions for the e.m.f. and current of each phase, the power in each phase is found to be,

$$\begin{aligned} P_1 &= -e_1\,i_1 + e_1'\,i_1' \\ P_2 &= e_2\,i_2 + e_2'\,i_2' \\ P_3 &= e_3\,i_3 + e_3'\,i_3' \end{aligned} \qquad (4)$$

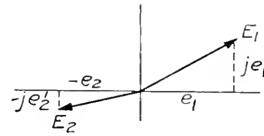


Fig. 4

and in exactly the same manner, the indication of each wattmeter is

$$\begin{aligned} W_1 &= -(e_1 - x)\,i_1 + (e_1' - y)\,i_1' \\ W_2 &= -(e_2 + x)\,i_2 + (e_2' + y)\,i_2' \\ W_3 &= -(e_3 - x)\,i_3 + (e_3' + y)\,i_3' \end{aligned} \qquad (5)$$

Adding the indications of the three wattmeters, the total power P is found to be

$$\begin{aligned} P &= W_1 + W_2 + W_3 \\ &= -e_1\,i_1 + i_1 x + e_1'\,i_1' - i_1'\,y + e_2\,i_2 + i_2 x + e_2'\,i_2' + i'_2\,y + e_3\,i_3 - i_3 x + e_3'\,i_3' + i_3'\,y \\ &= (-e_1\,i_1 + e_1'\,i_1') + (e_2\,i_2 + e'_2\,i_2') + (e_3\,i_3 + e_3'\,i_3') + x(i_1 + i_2 - i_3) + y\,(-i_1' + i_2' + i_3') \\ &= P_1 + P_2 + P_3 + x\,(i_1 + i_2 - i_3) + y\,(-i_1' + i_2' + i_3') \end{aligned}$$

Now, since the resultant of the instantaneous values of the currents in the lines of this system equals zero, the algebraic sum of the horizontal and vertical components respectively of the currents in the lines must equal zero. Hence, from (2), the horizontal components,

$$i_1 + i_2 - i_3 = 0$$

and the vertical components,

$$-i_1' + i_2' + i_3' = 0$$

and

$$\begin{aligned} P &= P_1 + P_2 + P_3 + x\,(o) + y\,(o) \\ &= P_1 + P_2 + P_3 \end{aligned}$$

Thus, the algebraic sum of the indications of the three meters is equal to the total power. If the common point a had been chosen in one of the lines, the meter in that line would have indicated zero, because there is no voltage across its potential coil. The total power of the system would then have been given by the sum of the two remaining wattmeters. Thus, a system of this type may be metered by 3 wattmeters connected as indicated in Fig. 1, or by 2 wattmeters connected as indicated in Fig. 2.

Consider now the general case wherein the phase voltages are:

$$\begin{aligned} \dot{E}_1 &= e_1 + j\ e_1' \\ \dot{E}_2 &= e_2 + j\ e_2' \\ \dot{E}_3 &= e_3 + j\ e_3' \\ &\ldots \\ \dot{E}_n &= e_n + j\ e_n' \end{aligned} \qquad (6)$$

The phase currents are:

$$\begin{aligned} \dot{I}_1 &= i_1 + j\ i_1' \\ \dot{I}_2 &= i_2 + j\ i_2' \\ \dot{I}_3 &= i_3 + j\ i_3' \\ &\ldots \\ \dot{I}_n &= i_n + j\ i_n' \end{aligned} \qquad (7)$$

and the power per phase is:

$$\begin{aligned} P_1 &= e_1\ i_1 + e_1'\ i_1' \\ P_2 &= e_2\ i_2 + e_2'\ i_2' \\ P_3 &= e_3\ i_3 + e_3'\ i_3' \\ &\ldots \\ P_n &= e_n\ i_n + e_n'\ i_n' \end{aligned} \qquad (8)$$

Since there are n phases and n lines, use n wattmeters connected according to the mode indicated in Fig. 1. Assume that the common or neutral point, a, of the wattmeter potential coil connections in this case be displaced from the neutral of the system by a distance m having a horizontal component a and a vertical component b.

Then, the voltages across the respective wattmeters are:

$$\begin{aligned} \dot{E}_4 &= (e_1 + a) + j(e_1' + b) \\ \dot{E}_5 &= (e_2 + a) + j(e_2' + b) \\ \dot{E}_6 &= (e_3 + a) + j(e_3' + b) \\ &\ldots \\ \dot{E}_n &= (e_n + a) + j(e_n' + b) \end{aligned} \qquad (9)$$

and the individual wattmeter indications are:

$$\begin{aligned} W_1 &= (e_1 + a)\ i_1 + (e_1' + b)\ i_1' \\ W_2 &= (e_2 + a)\ i_2 + (e_2' + b)\ i_2 \\ W_3 &= (e_3 + a)\ i_3 + (e_3' + b)\ i_3 \\ &\ldots \\ W_n &= (e_n + a)\ i_n + (e_n' + b)\ i'_n \end{aligned} \qquad (10)$$

The total power is:

$$\begin{aligned} P &= W_1 + W_2 + W_3 \ldots\ldots + W_n \\ &= (e_1\ i_1 + e_1'\ i'_1) + (e_2\ i_2 + e_2'\ i_2') + (e_3\ i_3 + e_3'\ i_3') \ldots\ldots + (e_n\ i_n + e'_n\ i'_n) + a\,(i_1 + i_2 + i_3 \ldots\ldots + i_n) + b(i_1' + i_2' + i_3' \ldots\ldots + i_n') \\ &= P_1 + P_2 + P_3 \ldots\ldots + P_n + 0 + 0 \end{aligned}$$

since the algebraic sum of the horizontal and vertical components respectively must equal zero.

Thus the algebraic sum of the individual wattmeter indications is equal to the total power. If, as before, the neutral point, a, is taken in any one line, the wattmeter in that line will indicate zero power, and the total power will be equal to the algebraic sum of the indications of the $(n-1)$ wattmeters.

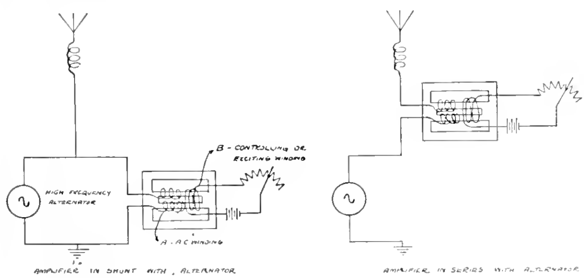
MAGNETIC AMPLIFIER FOR RADIOTELEPHONY

By E. F. W. Alexanderson and S. P. Nixdorff
Consulting Engineering Department General Electric Company

The magnetic amplifier described in this article is a new device which has been developed in order to make possible radiotelephony and high speed radiotelegraphy on a large scale. The magnetic amplifier has been developed as an accessory to a high power high frequency alternator. The magnetic amplifier is of the nature of a magnetic valve throttling the flow of power from the alternator so that the flow can be modulated by a telephone current. Oscillograms are given showing an output of 72 kws. radiofrequency energy, and also oscillograms showing the output of the alternator controlled by the human voice. This paper was read before the Institute of Radio-Engineers on February 2, 1916—Editor.

The name of magnetic amplifier has been given to a device for controlling the flow of radiofrequency currents because this name seems more than any other to describe its function when it is used for radiotelephony. As the same device can be used for a variety of other purposes the above name may in some cases not seem so appropriate. However, the essential part of the theory that will be given refers to the amount of amplification which is possible of attainment and the methods of securing a higher rate of amplification than would be given by the device in its simplest form.

The fundamental principle of varying an inductance by changing the permeability of an iron core is suggested in the early work of Fessenden as a means for changing the tuning of a radio antenna. The magnetic amplifier constructed as shown in Figs. 1 and 1a was, on the other hand, developed as an accessory to an alternator in order to take advantage of the better mechanical construction of a solid steel rotor and yet produce the results that could be obtained by field control in a machine with completely laminated magnetic circuit. The aggregate of the constant field alternator and the stationary controlling device has, as will be shown, the effect of a machine with variable field excitation. This analogy refers not only to the proportionality between excitation and electromotive force but to such phenomena as self-excitation and instability.



Figs. 1 and 1a. Combination of Alternator and Amplifier in its Simplest Forms

If two windings are related to each other and a common magnetic structure as shown in Fig. 1, it is apparent that there is no direct transformation possible from one winding to the other. Each turn in the controlling or exciting winding B includes both the positive and negative branch of the flux produced by a-c. winding, A, and hence there is no voltage induced. The current in either winding, on the other hand, influences the permeability of the common magnetic material and, therefore, changes the inductance of the other winding. If a current flows in either winding sufficient to saturate the iron, it is thereby rendered practically non-magnetic and the inductance of the other winding is reduced to the value it would have if the coil included only air. If, on the other hand, a current flows in the other winding which gives a magnetomotive force equal and opposite to the first, the iron is rendered magnetic again. Inasmuch as the two branches of winding A are relatively opposite to winding B, one branch will oppose the ampere-turns of winding B on one half cycle and the other branch during the next half cycle. In order to have any large flux variation in winding A, the opposing ampere-turns must be at least equal to the ampere-turns in winding B. The relation of currents is substantially the same as in a transformer between the primary and secondary current although in this case one is an alternating and the other a direct current, or a current of different frequency. It is thus obvious how current flow in winding A can be regulated proportionally to a controlling current in winding B. When the magnetic amplifier is used in shunt to the alternator (Fig. 1), it has the immediate object of controlling the voltage rather than the current. The combined characteristics can be derived from the characteristics of the alternator when operating on an antenna and at the same time controlled by a variable shunt across its terminals, as shown in Fig. 4.

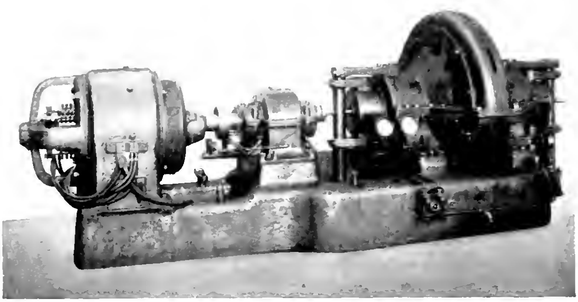


Fig. 2. High Frequency Alternator Used for Tests

As indicated in Figs. 1 and 1a, it is possible to connect the amplifier either in series or in shunt to the alternator. Of these two arrangements the shunt connection is preferable because the effect of the amplifier on the alternator is the same as if the electromotive force of the alternator in the antenna circuit had been reduced, whereas, the amplifier in the series connection does not influence the electromotive force in the antenna circuit but changes the tuning of the antenna. The result of this change in antenna tuning has an undesirable effect upon the speed characteristics of the alternator because it is found upon further analysis that the control does not become effective unless the alternator is operated on the upper or unstable side of the tuning curve of the antenna. If the alternator, on the other hand, is operated on the stable side of the tuning curve, the change in tuning partly neutralizes the intended controlling effect.

Ratio of Amplification

The method of arriving at a theory for the ratio of amplification can be perhaps best explained by a mechanical equivalent:

A throttle valve in a steam pipe may be designed so that it is perfectly balanced and it might move on ball bearings so that an infinitely small effort would be sufficient to throttle an infinitely large power flow. If, on the other hand, the valve were to be opened and closed 1000 times in a second, the inertia of the moving parts would absorb considerable energy. Although this would be wattless energy inasmuch as the energy consumed in accelerating would be given back in retarding, the device which would perform this movement must control considerable power. In analogy with this we must ask ourselves, what is the corresponding inertia in our magnetic valve which we must overcome in opening and closing it at the rate of a telephone current. The answer is: The inertia is the energy stored by the change of the magnetic field. This energy is the integrated area of the saturation curve between the points where the changes take place. The energy of the controlling field is not necessarily equal to the

Fig. 3. Amplifier Coil Used for Tests

energy of the high frequency field but of somewhat the same magnitude. The wattless flow of energy is proportional to the energy per cycle and the number of times per second the energy must be delivered and returned. It can, therefore, be said that the ratio of amplification is proportional to the ratio between the frequencies of the radio current and the controlling current.

However, the assumption that the energy per cycle is the same in the high-frequency and the controlling circuit is only a first approximation. The object of design and improved arrangements is evidently to make this energy ratio as favorable as possible; in other words, to produce a maximum flux variation in the high-frequency circuit for a minimum variation in the controlling circuit.

In order to understand these relations it is necessary to make a further study of the laws for change of permeability. The object of the magnetic amplifier when used for radiotelephony is not only to control the radio energy but to produce a telephone current in its true shape. An important part of the analysis is, therefore, a study of the conditions that lead to linear proportionality between the controlling and the controlled current.

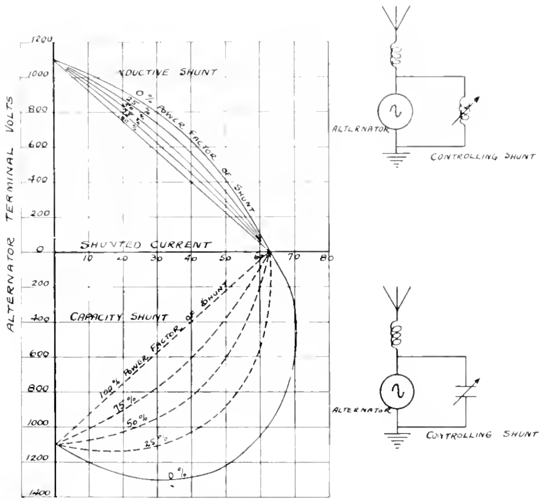


Fig. 4. Characteristics of Alternator when Controlled by Variable Shunt Impedance

Magnetic Theory and Characteristics

The magnetic amplifier can be operated in two ways, as indicated by the diagram of Fig. 5. In one case when the two a-c. windings are in series, the current in both windings is definite and the flux in the corresponding branches of the core adjusts itself accordingly. In the second case when the two a-c windings are connected in multiple the current in each winding is not immediately obtainable because a cross current of a strength not yet defined may flow between the two windings. We know on the other hand that the flux variations in the two branches of the core must be identical inasmuch as they produce the same terminal voltage in the multiple connected windings.

The characteristics of the amplifier winding in series and multiple connection as obtained from tests is shown in Fig. 6. The upper curve represents series and the lower multiple. The curves are plotted in ampere-turns and volts per turn so as to make the conclusions independent of the number of turns. Both curves represent the same d-c. excitation. These curves, as well as theoretical consideration, show that the multiple connection gives a lower curvature and a lower impedance. For zero d-c. excitation it is evident that the volt-ampere curves for these two connections must be identical. It thus follows that the change of impedance corresponding to a given d-c. excitation is greater with the multiple connection. The multiple connection is, therefore, altogether more advantageous because a lower impedance with a certain control excitation means greater sensitiveness, and a lower curvature means that large currents can be carried without causing instability as will be shown later. While thus the second mode of operation with multiple a-c. winding appears to have better characteristics, there are some other considerations which must be taken into account before it can be concluded that this connection could be used.

Object of Short-Circuit Condenser

In the multiple connection the flux variations are forced as already explained by the short-circuit that is formed between the two multiple coils. The induced current in this short-circuit tends to oppose any changes in the average flux, and thus a telephone current in the controlling winding would simply cause a corresponding short-circuit current between the two a-c. coils without producing the desired flux variations. This difficulty can, however, be overcome by taking advantage of the fact that the a-c. winding needs to operate only at radio frequencies, which are very much higher than the fre-

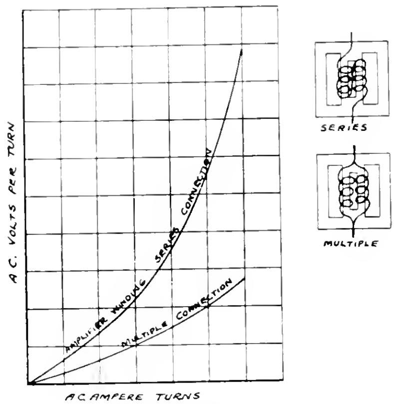


Fig. 5. Comparative Volt-ampere Curves with the same D-c. Excitation

quency of the telephone current. It is, therefore, possible to find a value of a condenser such that it acts as a short circuit for the radio currents and an open circuit for the telephone current. Accordingly a condenser is introduced in series with each of the a-c. coils as shown in Fig. 8.

Combination of Alternator and Amplifier

In order to demonstrate how the magnetic amplifier can be used for controlling the voltage of an alternator, reference may again be made to the alternator characteristics, as shown in Fig. 4. The alternator voltage is plotted against the current in the shunt circuit. The magnetic amplifier is used as this shunt circuit and the volt-ampere characteristics of the amplifier can, therefore, be directly combined with the volt-ampere characteristics of the alternator. The volt-ampere characteristics of the amplifier are shown in Fig. 6. Fig. 7 shows the alternator and amplifier characteristics superimposed. The intersections between the sets of curves give the alternator voltages at the corresponding amplifier excitations and thus another curve can be plotted between alternator volts and amplifier excitation. This curve as obtained from test is the upper curve in Fig. 8, which approaches the X axis asymptotically with increasing excitation of the amplifier. It is possible in this way to reduce the voltage practically to zero without using an excitation which is excessive from the point of view of heat capacity of the exciting winding. A magnetic amplifier may be used as a controlling device for radiotelegraphy. However, in this form, it is not well adapted for telephony because as shown by the curves the relation of volt-amperes and amperes excitation departs too far from the desired linear proportionality. Such proportionality can be obtained by the introduction of a series condenser, as shown in Fig. 8, while at the same time the sensitiveness of the amplifier is greatly increased so that a much smaller control current is needed. If the condenser is chosen so that it exactly neutralizes the inductance of the amplifier winding at some definite value of excitation, the resulting impedance at this excitation becomes a minimum and the impedance at any lower excitation is determined by the difference between the inductive reactance

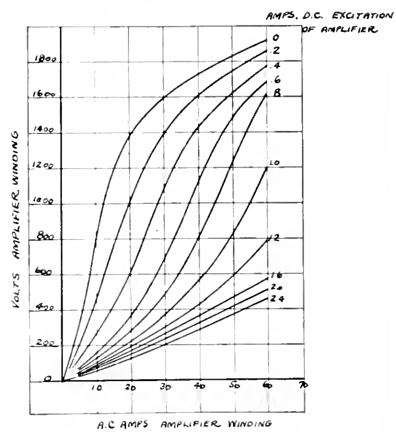


Fig. 6. Characteristics of Amplifier Coil Windings in Multiple

of the amplifier coil and the capacity reactance of the series condenser. The smaller this difference, the lower will be the amplifier excitation that gives minimum impedance, and the corresponding minimum of the alternator voltage. This means that the sensitiveness of the amplifier is increased because a smaller excitation is needed to reduce the alternator voltage. The increase of sensitiveness that can be obtained in this way is, however, not unlimited. If the minimum impedance is obtained as a result of a large inductive and a large capacity reactance the core loss due to hysteresis and the eddy currents becomes appreciable and appears as an equivalent resistance which can not be neutralized. Fig. 8 shows from result of test the variations of alternator voltage that can be obtained by different values of series condenser and the corresponding increase of the sensitiveness of the amplifier. The sensitiveness is represented by the steepness of the curves. It can be seen from the shape of these curves that the increased sensitiveness is gained at the expense of range of control or difference between maximum and minimum voltage. However, all the curves show a practically linear proportionality between excitation and voltage over almost the whole range available. The difference in sensitiveness with various series condensers is also illustrated by oscillograms, Fig. 9. The upper curve represents alternator voltage. The two lower curves represent amperes and volts, respectively, impressed upon the amplifier controlling winding, the frequency of the controlling current being 500 cycles. The effect of departure from linear proportionality and the consequent distortion of wave shape is shown in Fig. 14.

The amplification ratio is defined as the difference between the maximum and minimum kilowatts output divided by the effective alternating volt-amperes supplied to the controlling winding. The ratio of amplification can be derived directly from the oscillograms with reference to the calibration of the oscillograph curves. The ratio of amplification for operation suitable for telephone control ranges from 100:1 to 350:1.

Instability

The voltage which results from the combination of alternator and amplifier can be determined as has been explained by the intersection of the alternator and amplifier characteristics. When the curves have a definite and sharp intersection point a definite alternator voltage results from each excitation of the amplifier. If, on the other hand,

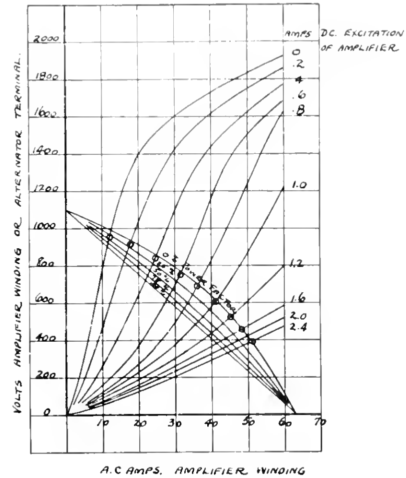


Fig. 7. Alternator and Amplifier Characteristics Superimposed

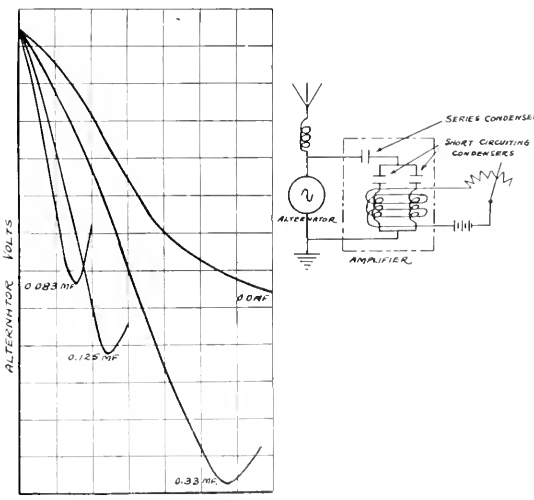


Fig. 8. Curves Obtained from Test Showing Sensitiveness of Alternator Voltage Control with Different Series Condensers

the curves should have such a shape that the alternator and amplifier characteristic curves become parallel in some place, the intersection becomes indefinite and the result is instability and generation of self-excited oscillations. This is a condition that must be

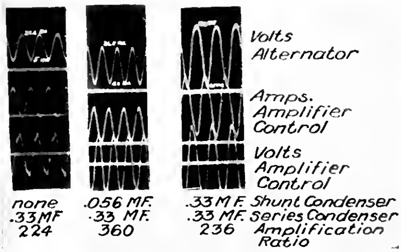


Fig. 9. Oscillograms Showing Ratio of Amplification with Different Series Condensers

avoided for telephone control, whereas, it may have useful applications for other purposes. The conditions that lead to instability can be graphically analyzed as shown in Figs. 10 and 10a. The left-hand diagram corresponds to a series condenser of ⅛ mf. which leads to instability at higher generator outputs, whereas, the right-hand diagram corresponds to a series condenser of ⅓ mf. and represents a condition which is stable at voltages at which a generator can be operated. The upper curve in each diagram is the volt-ampere curve of the amplifier coil and the straight line through origin represents the series condenser. The lower curve is the difference between the volts amplifier coil and volts series condenser, which is for the present purpose sufficiently close approximation of the volt-ampere curve of the combination. This resultant volt-ampere curve in Fig. 10 rises to a maximum, then falls again and crosses the zero line. The crossing of the zero line means change from inductive to capacity impedance.

With reference to any circuit which has a volt-ampere characteristic with a bend in it, it can be said that as long as the volt-ampere curve is rising, the circuit is stable where it is applied to a constant potential, and wherever the volt-ampere curve is drooping, the circuit is unstable on a constant potential. The rising part of the curve corresponds to a

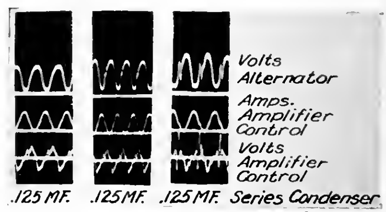
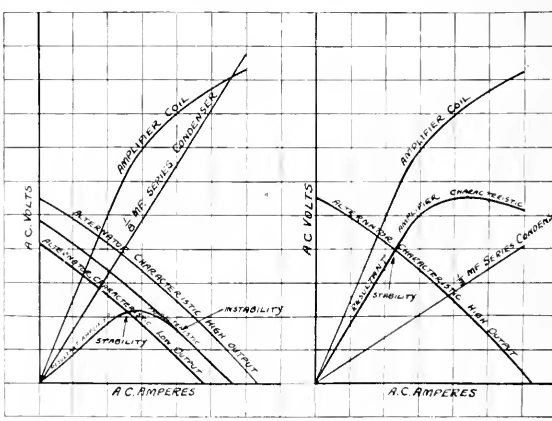


Fig. 11 Oscillograms Showing Instability at Higher Alternator Volts

positive resistance and the drooping side to a negative resistance. Well-known types of negative resistance are electric arc or series commutator generator. A circuit of this character is stable only when operated on a



Figs. 10 and 10a. Graphic Analysis of Instability

source of potential which has characteristics equally or more drooping than the drooping volt-ampere curve. These same curves (Figs. 10 and 10a) show the volt-ampere characteristics of the alternator. In Fig. 10a the resultant characteristic is only slightly drooping at the end, whereas, in Fig. 10 the condition for instability is indicated by the place where the volt-ampere curve of the amplifier is more drooping than the volt-ampere curve of the alternator. Fig. 10 also shows that the alternator curve corresponding to low output intersects the amplifier by curves at the stable portion and the characteristics for increased output reaches the unstable portion of the resultant amplifier curve. This change from stability to instability is shown by the series of oscillograms on Fig. 11. The instability as shown by the self-excited oscillations reoccur at the same place of the wave which is the place where the characteristic curves are tangent as shown on Fig. 10.

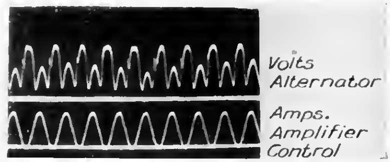


Fig. 14. Oscillograms Showing the Effect of Departure from Linear Proportionality and Consequent Distortion of Wave Shape

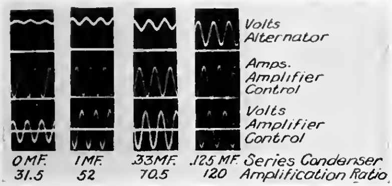


Fig. 13. Oscillograms Showing Effect of Different Shunt Condensers

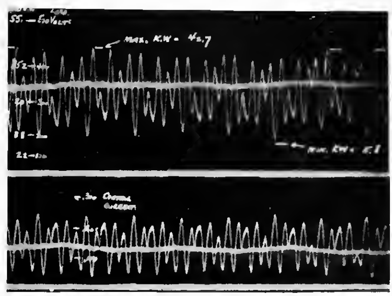


Fig. 15. Oscillogram Showing Telephone Control

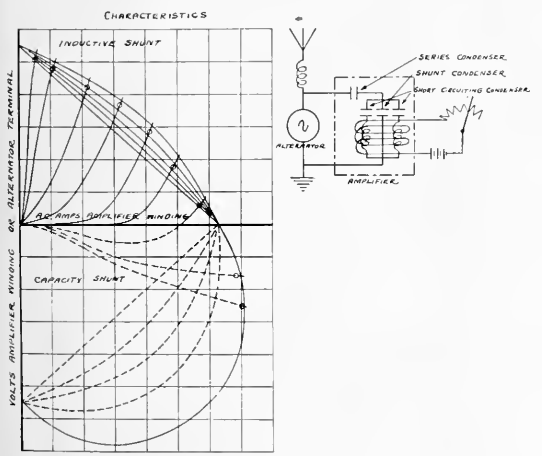


Fig. 12. Volt-ampere Characteristics of Amplifier with Shunt and Series Condenser Showing Intersection with Alternator Characteristics

Shunt Condenser

A further improvement in sensitiveness can be obtained by using a combination of shunt and series condenser. The shunt condenser is so porportioned as to make the amplifier take leading instead of lagging current at low excitation. Complete characteristic curves of amplifier with shunt and series condenser and the superimposed alternator characteristics are shown in Fig. 12. The series of oscillograms, Fig. 13, show the effect of different amounts of shunt condenser. While the series condenser is used within the limits of stability to increase the sensitiveness, the shunt condenser has the object of allowing the alternator to assume its full maximum voltage. The last oscillogram, Fig. 15, shows an alternator output of 72 kw.

Applications of the Amplifier

Oscillogram, Fig. 15, shows telephone control of the alternator output. The two curves on the oscillogram which are relatively upside down show that the variation of the alternator voltage is in all details an almost exact reproduction of the controlling telephone current.

While a specific method of adapting the magnetic amplifier to an alternator as described above has been worked out both theoretically and experimentally in greater detail, there are obviously a variety of possibilities for adapting the same devices and theories to other conditions. Outside of telephony, the magnetic amplifier will probably be found of value as a non-arcing key for telegraphy and particularly will make possible high-speed telegraphy at the same rate and with the same means as high-speed automatic telegraphy on land lines. Oscillograph records have been taken of telegraphic control from 500 to 1500 words per minute.

The structure and the mode of operation of the magnetic amplifier which has been described is such that there appears to be no limit to the power that might be controlled in this way if apparatus are designed with suitable dimensions. The 72-kw. control which has been demonstrated may be sufficient for most purposes but there would be nothing surprising if several times this amount of energy were to be used in transatlantic radiotelephony or high-speed telegraphy in order to make the service thoroughly reliable.

SWITCHING LOCOMOTIVES FOR THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By L. C. Josephs, Jr.

Railway Locomotive Department, General Electric Company

The adoption of 3000 volts for locomotive equipment, with the purpose of realizing high efficiency on long hauls, and powerful locomotives, has imposed hardships on the designer of the smaller locomotives used for switching on the same system. In this service the hauls are short and the loads relatively small. The switching locomotive described in this article, which has only one-fourth the weight of the main line locomotives, is a small high-voltage unit that is the equal in reliability and performance of the standard 600-volt switching locomotive. Wherever possible its equipment has been made the same as that of the road locomotives, in this way keeping down spare parts to a minimum.—Editor.

In attacking the problem of the electrification of steam railroads, the foremost thought has been to secure electric locomotives of enormous power that would be capable of performing service beyond the natural limitations of the steam locomotive. This secures one of the chief economies of electrification. In working out systems of electrification the problem of getting a suitable electric switching locomotive has generally been lost sight of for the reason that the switching load is only a very small part of the total power requirements, and for the further reason that the assumption has usually been made that, if the large road locomotives could be successfully worked out, there would then be very little trouble in securing a satisfactory switching locomotive. The road locomotives of an electrified system often require a capacity of several thousand horse power, while on the other hand the average switching service seldom requires a locomotive with a capacity of more than a few hundred horse power. For this reason the choice of a system of electrification is made with a view to meeting only those conditions imposed by the road locomotives and after the system has been chosen the switching locomotive must be designed to meet existing conditions. From the foregoing it will be seen that the design of the switching locomotive to be used on an electrified system may become almost as difficult a problem as the design of the main road locomotives themselves.

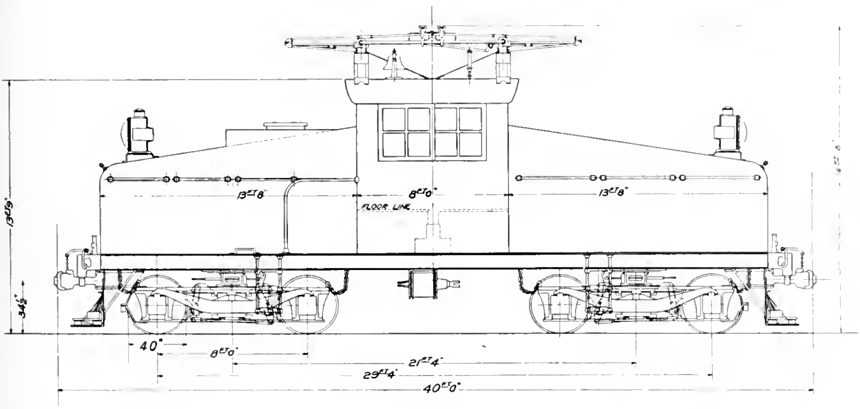
In the case of the Chicago, Milwaukee & St. Paul Railway there is being installed an electrification of 440 miles of main line over which is operated a very heavy traffic. This condition as well as the heavy grades encountered required the choice of a 3000-volt direct current system, with provision for regenerative braking on the road locomotives. The use of 3000 volts has made the design of the electric switching locomotive somewhat difficult and in fact when using regenerative braking on the road locomotive the voltage imposed on the switching locomotives may be even higher than 3000 volts. It is a well known fact that for simplicity, reliability, and low cost it is difficult to surpass the standard type of 600-volt switching locomotive. There is every indication, however, that in the design of the new 3000-volt switching locomotives which are now building for the Chicago, Milwaukee & St. Paul Railway, there has been secured a locomotive which will be in every way as satisfactory as any switching locomotive ever built. There is the still further advantage in this accepted design that a great majority of the electrical parts used will be interchangeable with parts of the road locomotives, thus simplifying the work of the railway company's store-keeper.

The two electric switching locomotives now in process of construction are known as Type 404-E-140-4GE255-3000-volt locomotives and are shown in outline in the accompanying illustration. As the above classification indicates the locomotive is an eight-wheel, swivel truck type weighing 70 tons and is equipped with four geared motors. The general features of the locomotive are approximately as follows:

Length inside knuckles	40 ft.
Height over cab	13 ft. 10 in.
Height, trolley down	16 ft. 8 in.
Width over all	10 ft.
Total wheel base	29 ft. 4 in.
Rigid wheel base	8 ft.
Diameter of wheels	40 in.
Diameter of axles	7 in.
Main journals	6 by 11 in.
Minimum clearance under locomotive	4⅞ in.
Weight—locomotive complete	140,000 lb.
Weight mechanical equipment	85,000 lb.
Weight electrical equipment	55,000 lb.
Weight per driving axle	35,000 lb.

The running gear of the locomotive consists of two swivel equalized trucks, these trucks being of the standard type used on all small switching locomotives. Each truck is formed of steel bolster and side frames bolted together and carried on semi-elliptic springs. Steel tired wheels are used consisting of 3-in. tires shrunk on cast steel centers. The axles are of the usual type designed for mounting an electric motor and are provided with outside bearings of MCB collar design.

The platform superstructure carried by the swivel trucks is built up of longitudinal steel channels stiffened laterally with cross sills and brace plates and over the whole platform is laid a steel floor. The end frame, attached to this platform, consists of a heavy steel casting designed to distribute the severe shocks met with in switching service. The draft gear, which is attached to the end frame and platform, is of the standard friction type and is provided with the usual MCB coupler.



Seventy-ton Switching Locomotive for Chicago, Milwaukee & St. Paul Railway

The cab necessary for housing the electrical apparatus and providing for the motorman's position is of the usual steeple type which has been found especially applicable to switching locomotives, on account of the sloping end providing an opportunity for the motorman to see clearly along the track in either direction. This cab which is built entirely of steel is divided into three portions consisting of one main cab approximately eight feet long by ten feet wide and two sloping end cabs each approximately fourteen feet by six feet wide.

On account of the advantages of a steeple cab as mentioned above only one operating position for the motorman is provided, and in order to assist further in giving the motorman a clear view in all directions the floor of the main cab has been raised approximately two feet above the floor of the platform. Thus with the exception of the electric cab heater and necessary controller and air brake apparatus, the entire space within the main cab is unobstructed. This plan of raising the motorman's position as high as possible is new on this type of locomotive, and besides affording the motorman a better view of the track this arrangement has the added advantage that all the electrical apparatus is located out of the way, either in the end cabs or under the floor of the main cab, where there is no possibility of injury to persons due to accidental contact with high voltage parts.

The electrical apparatus provided on this locomotive is in general very similar to the apparatus found on any small switching locomotives, but is novel to the extent that this is the first time such high voltages as 3000 volts have been applied to a small locomotive of this type. In order to simplify maintenance much of the apparatus used is similar in its details to the apparatus required on the road locomotives.

The motors, of which four per locomotive are used, are known as the GE-255 railway motor. This is a box frame commutating pole single-geared motor designed for operation on 3000 volts when connected with two motors permanently in series. This motor is mounted in the usual manner by a suspension on the axle and by the motor nose resting on the truck transom. The motor is provided with forced ventilation, the air being furnished by a blower in the cab from which the air is led through a duct in the platform down through a hollow center plate and hollow transom into a sliding duct connected to the motor.

The control apparatus furnished is a type M single-unit equipment providing ten steps with motors connected all in series and nine steps with motors connected two in series and two such groups in parallel. The apparatus provided in this equipment is of the most rugged type designed to stand severe service. The fuse compartment, main switch and contactors are of the same type as used on the large 3500-h.p. road locomotives. The transition from series to parallel is accomplished by means of a large electro-pneumatically operated switch, which also serves as a motor cutout switch.

The air brake furnished is of the usual locomotive type providing straight and automatic braking features. The air compressor provided affords a displacement of 150 cu. ft. per minute, this amount being much larger than necessary on a switching locomotive. It was, however, thought expedient to provide this extra large compressor so as to have the parts interchangeable with those furnished on the 282-ton road locomotives.* This compressor operates directly on 3000 volts and has already demonstrated its rugged qualities on those road locomotives now in service.

With regard to the other details of auxiliary apparatus provided on the locomotive, these are arranged to conform as far as possible to the equipment of the road locomotive; for example, all small switches, headlights, cab heaters and the pantograph trolley are exactly similar on both locomotives. On the switching locomotives, however, a small 3000-volt motor-generator blower set is furnished to provide forced ventilation for the motors and to provide energy for operating the control and headlights. In the case of the road locomotives this set is, of course, much larger on account of the greater requirements in the way of forced ventilation and energy for control purposes.

The locomotive has a nominal rating of 542 horse power. The horse power rating of a switching locomotive, however, is not altogether a satisfactory measure of its capacity for service. This locomotive will develop a tractive effort as high as 42,000 lb. for short periods providing rail conditions are suitable. The locomotive, is, moreover, capable of developing 13,480 lb. tractive effort continuously at a speed of 13.2 miles per hour, or 18,400 lb. tractive effort for one hour at a speed of 12 miles per hour. Both of these ratings are on a basis of forced ventilation. These locomotives will take the place of the present steam locomotives in operation in the yards of the electrified system, and will be capable of handling the same service.

* For description of these locomotives, see General Electric Review, July, 1915, page 600.

A MODEL STREET LIGHTING INSTALLATION

By H. A. Tinson and D. M. Diggs

General Electric Company

The following article comprises an interesting and well arranged description of a recent installation of Edison Mazda series lamps for street lighting. Pertinent details of the cost, layout, construction, operation, and appearance of the installation are included. This lighting system in Port Jervis has proved so satisfactory that it will afford a good typical pattern for other towns having similar requirements.—Editor.

Since the introduction of the Edison Mazda lamp in high candle-power sizes and more efficient types, there has been created a great amount of interest in regard to street lighting on the part of the layman. In practically all cities and towns there is more or less demand for better street illumination and very many of them have been provided during the past year with new street lamps and equipment. A larger number are either in process of making changes or actively considering the subject.

It is of timely interest, therefore, to record in detail what has just been accomplished in Port Jervis, New York—a city that has made such improvements in a very complete manner.

Port Jervis is a typical city of New York State, of about 10,000 inhabitants, situated far enough away from the metropolis to have ideas and standards of its own. It is a very progressive city in many ways, has well paved brick and macadam streets, and many local manufacturing enterprises. The city government is conducted on the "Commission" plan and the cordial relations and co-operation which existed between the city commissioners, the local lighting company (Port Jervis Light & Power Company) and the manufacturers and installation contractors for the new street lighting equipment, have resulted in the best and most approved units of the correct sizes and types being employed and installed at relatively proper spacings and correct heights.

General Layout

The business district of Port Jervis is more or less divided into two distinct sections. On referring to the plan, Fig. 1, it will be noted that the ornamental system of lighting is installed in what might be termed the "down town" section, with units extending on Pike Street to East Main Street. Pike Street itself for some little distance is residential, but it leads to another business street where trading is done so that the ornamental units are installed throughout the part of this street connecting the two trading sections. The fixtures installed in this district comprise ornamental novalux units with 600-c-p. 20-ampere Edison Mazda lamps mounted on ornamental iron standards. (See Fig. 2.)

On Main Street a smaller amount of retail business is carried on, but as this street is important as the principal thoroughfare connecting to Kingston Ave. (one of the main roads of travel in and out of town) it is lighted with 400-c-p. Edison Mazda novalux pendant units, suspended on span wires over the center of the street.

The principal main roads leading to the city are Kingston Avenue, Jersey Avenue and Fowler Street, the two latter being lighted by means of 250-c-p. Edison Mazda lamps, on center span suspensions. A typical illustration of this type of unit is shown in Fig. 3.

All other streets in the city are illuminated by 60-c-p. Edison Mazda lamps; some on center span suspensions and some on brackets fastened to the wooden poles.

There are now installed in Port Jervis a total of 460 units, made up as follows:

- 59 600-c-p. units on ornamental posts.
- 8 400-c-p. units on span suspensions.
- 19 250-c-p. units on span suspensions.
- 374 60-c-p. units on span suspensions and brackets.

Character of Streets

The streets in general are well paved and well kept. In the main business sections the paving is of brick and on the main thoroughfares macadam. The retail area is typical of a city of this size, the buildings being of brick and of moderate height. In the residential sections of town the houses are mostly of frame construction with grass plots in front. The foliage is dense in many cases and, therefore, the span suspension system adopted is well chosen to meet this condition.

In the "down town" section, where the ornamental units are installed, the maximum width between curbs is 44 feet and the minimum 32 feet, with an average of about 37 feet. From building line to building line the width runs from 75 to 55 feet. In the other sections of the city the average width is approximately 50 to 55 feet between building lines. Parts of the city are hilly and, as will be noted from the plan, Fig. 1, the general layout is somewhat irregular, which made it necessary in many instances to vary the spacing of the lighting units.

There are a few points of general interest that might be noted; i.e., at the junction of Jersey Avenue and Front Street, and the intersection of Pike and East Main Streets are located drinking fountains for horses. At both these places ornamental iron posts were mounted on top of the fountains, which illuminate the surrounding spaces at these points. The ornamental posts are located with special reference to the local conditions of traffic, rather than to secure equal spacing. A number of posts of various descriptions were removed from the business section and thus helped to clear the street and make it appear more attractive.

With the exception of the ornamental post installation, all the units are provided with prismatic refractors.

Ornamental Post Units

The ornamental post units comprise a cast iron pole, finished in bronze, made from a special design by the Mott Iron Works of New York, and a Novalux unit equipped with an Edison Mazda series lamp of 600-c-p. The lamp is of the 20-ampere type, operated through an auto-transformer (or compensator) mounted in the casing of the unit. The height to the center of the diffusing globe is 14 feet 6 inches.

The posts are staggered, the spacing on one side varying between 110 to 150 feet, with an average of 130 feet. Each post is provided with an absolute cutout. The posts were made in two pieces and are 12 feet in length from the ground line to the lamp casing holder. In the base a door 10½ by 20 inches is provided and inside are provided two lugs on which the cutout is mounted. The posts were especially designed so as to

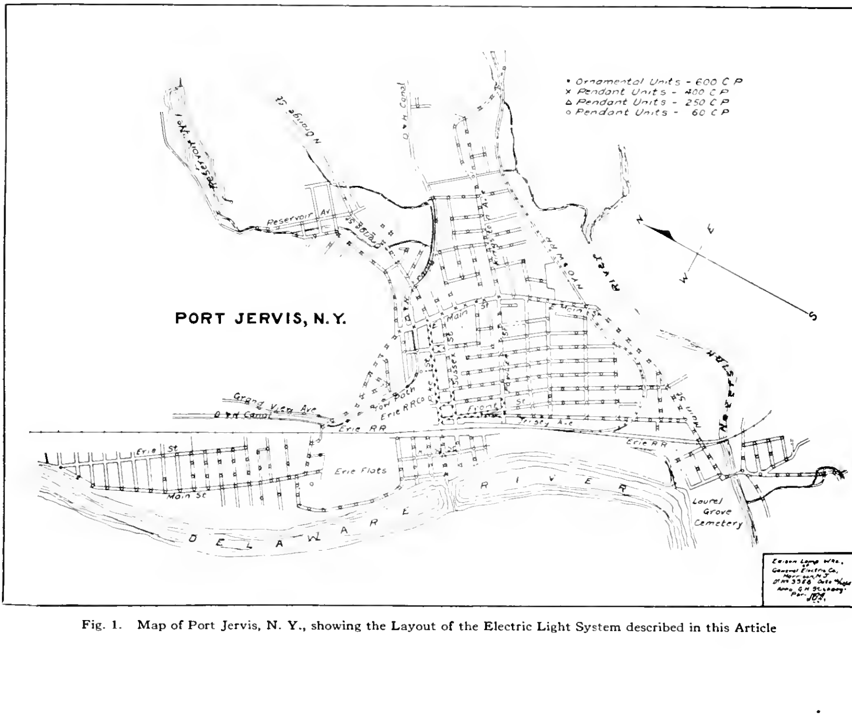


Fig. 1. Map of Port Jervis, N. Y., showing the Layout of the Electric Light System described in this Article

appear slim and ornate, and after they were set they received a second coat of red lead and then two coats of dark Venetian bronze, the high lights being finished in copper bronze. The posts were all mounted in position so that the door faced squarely towards the building line. The concrete foundations are 16 by 18 inches, and not less than 24 inches in depth, depending on the soil conditions.

Underground Construction

The series line is carried overhead to the ornamental system and is then taken underground. A No. 8 B.&S. solid gauge armored cable is used, insulated with 30 per cent Para rubber which is secured with overlapping rubber filled cotton tape of 0.012 in. in thickness, and over this is a $\frac{1}{16}$-in. lead sheath. The cable is then served with a layer of jute yarn asphalted and wrapped with two layers of steel tape. Over this again is laid more jute yarn and it is then thoroughly saturated with asphalt compound and coated with soapstone to prevent sticking when reeling or handling. The cable is laid in a trench 12 inches below the surface of the ground immediately behind the curbing, but where it enters the conduit elbows, set in the concrete foundations of the posts, the depth is increased to avoid too short bends. In crossing the intersecting streets the cable is laid in a duct. The total amount of underground cable used approximated 5000 feet. The leads from the cutout to the lamp are of No. 8 B.&S. gauge stranded wire, being two conductor, $^4/_{32}$ inches 30 per cent Para rubber covered and double braided; a water loop is made at each cutout.

Fig. 2. Day View in Port Jervis, showing Novalux Units equipped with 600-c-p., 20-amp., Edison Mazda Series Lamps

Fig. 3. Day View in Port Jervis, showing an Eye Suspension Unit with 20 In. Concentric Reflector, Prismatic Refractor, and 250-c-p. Edison Mazda Series Lamp

The underground system is bonded together with bare copper wire in the base of each post, bonding both the steel armor and the lead sheath; the pole being also properly grounded. The armored conductors, at the

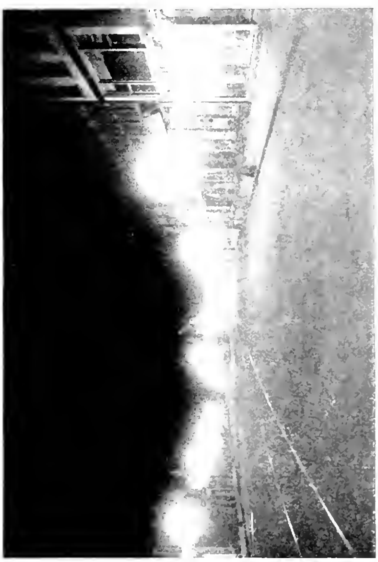


Fig. 4. Night View of Main Street, showing Novalux Ornamental Units equipped with 600-c.p., 20-amp., Edison Mazda Series Lamps

Fig. 5. Night View of Pike Street, showing Novalux Ornamental Units equipped with 600-c.p., 20-amp., Edison Mazda Series Lamps

Fig. 6. Night View of Jersey Avenue, showing Eye Suspension Units, equipped with 20 In. Concentric Reflectors, Prismatic Refractors and 250-c-p Edison Mazda Series Lamps

Fig. 7. Night View of Fowler Street, showing Eye Suspension Units, equipped with 20 In. Concentric Reflectors, Prismatic Refractors, and 250-c-p. Edison Mazda Series Lamps

points where they are joined to the overhead system, are continued to the pole carrying the overhead system and then run up a 2-inch lateral to a height of 20 feet.

The contractors for the installation of the underground work and the ornamental posts assumed responsibility for one year after completion of the work for any defects occurring in the setting of the posts or settling of the street paving, if the cause should be attributable to work done on the installation of this system.

A typical night view looking towards the junction of Front Street and Jersey Avenue is shown in Fig. 4. The illumination on the street surface is very uniform and the general appearance of the street after dark is quite attractive. The fronts of all the buildings are illuminated from the ground line to roof and appear to stand out prominently against the dark background of the night.

In Fig. 5 is shown another night view taken on Pike Street, looking towards the business section. Here the spacing is somewhat wider, owing to the residential character of the street. The use of medium density glassware has resulted in the elimination of excessive glare without too great an absorption of light.

Pendant Units

For the lighting of a section of East Main Street, which, as previously described, is partly a business section, eight novalux pendant units are installed. These are equipped with 20-in. concentric porcelain enameled steel reflectors, prismatic refractors and 400-c-p. 15-amp. Edison Mazda series lamps. These units are installed on span suspensions at a height of 20 feet above the roadway, and spaced approximately 200 feet apart.

For some distance leading from the center of the town, Jersey Avenue and Fowler Street are lighted with 250-c-p. units similarly suspended and spaced. The unit used comprises a span suspension fixture equipped with a 20-inch concentric porcelain enameled steel reflector and prismatic refractor. In Fig. 3 is shown a day view of Jersey Avenue with one of these units in the foreground. These lamps are spaced approximately 200 feet apart and placed about 20 feet high. Figs. 6 and 7 depict night views taken with this unit. The former is on Jersey Avenue, which is paved with brick, and the latter is a view of Fowler Street, which is macadam paved.

It is very interesting to record how even the illumination appears on the street surface with these relatively low power units, and for the size of the unit employed, the illumination is of high intensity. The buildings, even between the units, stand out quite prominently. The lower parts are well illuminated, so that persons can very easily and safely approach their homes after dark. At the height these lamps are placed the cut-off is such that relatively little light is projected towards the upper story of the residences. It is a fact that any person or moving object can be quite readily perceived on any part of these streets for a distance of five or six blocks. To view this installation after dark affords a striking demonstration of the effective application of the prismatic refractor to this class of street lighting.

With the exception of the streets specifically mentioned and described above, all the other streets and thoroughfares within the city limits are lighted by 60-c-p. Edison Mazda series lamps. The equipment used is similar to that provided for the 250-c-p. lamps, except that 18-inch reflectors and the smaller size of prismatic refractor are used with these smaller lamps.

The spacings average 200 feet and the majority of the units are installed on span suspensions at about 15 feet above the roadway. In some instances, however, brackets are used affixed to the poles, at a height to bring the lamps about 15 feet above the ground. All of these lamps are operated from constant current transformers, which formerly were used to operate a-c. enclosed carbon arc lamps

The replacing of the lamps and cleaning of the refractors on all the pendant units is accomplished by lowering the units on a cord permanently run to the pole for the purpose.

The entire ornamental installation, including all the necessary equipment and labor, was paid for by the city at a cost of about $100 per unit. The construction work was done by the Central Station Equipment Company of New York. All the pendant type units were provided and installed by the Port Jervis Light & Power Company.

In concluding this description of the street lighting at Port Jervis, it can be said that the satisfaction and appreciation shown by people of that city over this civic improvement is evident to any visitor. The utilization of street lighting equipment that has been scientifically designed and installed, is an important factor in the case, but co-operation between all the parties concerned has been of equal importance in securing these results in this installation.

THEORY OF ELECTRIC WAVES IN TRANSMISSION LINES

Part III

By J. M. Weed

Transformer Engineering Department, General Electric Company

Previous installments of this article consider the waves and reflections which would be produced in a line of zero losses from a generator of zero impedance. The present installment treats of the effects upon these waves of inductance in the generator, and of capacity, and combinations of capacity and inductance, concentrated at the generator terminals.—Editor.

We have so far considered the generator or source of voltage from which a charging wave is admitted to the line as of zero impedance, giving a wave of abrupt front. This condition would be obtained only with a charged condenser for generator, and the voltage would be maintained at its initial value only with infinite capacity. Practical generators possess resistance and inductance. Where a transformer is used, its resistance and inductance should be added to those of the generator.

If a line were thrown suddenly on a generator with resistance alone, the effect of the resistance would be merely to reduce the voltage of the charging wave, without affecting its abruptness. The voltage consumed by the resistance would be IR_g, and that appearing in the line would be

$$E_g - IR_g = IZ \qquad (70)$$

whence

$$I = \frac{E_g}{R_g + Z} \qquad (71)$$

where E_g is the total voltage of the generator and R_g its resistance. The resistance of the generator and the wave impedance of the line thus are added arithmetically for calculating the current of the charging wave. The voltage of this wave is

$$E_{ch} = IZ = E_g \frac{Z}{R_g + Z} \qquad (72)$$

The resistance of the generator is very small in comparison with the wave impedance of the line, and its effect on the charging wave may therefore be neglected. We will now consider the effect of the inductance of the generator.

If the line is suddenly thrown on a generator with inductance L_g, the voltage E_g is impressed upon the inductance L_g and the wave impedance Z in series. The current grows from zero at the first instant to the value

$$I = \frac{E_g}{Z} \text{ (at infinite time)} \qquad (73)$$

Since the wave impedance is of the nature of a resistance, the equation for the growth of this current is

$$i = \frac{E_g}{Z}\left(1 - \epsilon^{-\frac{Z}{L_g}t}\right) \qquad (74)$$

and the voltage of the charging wave is

$$e_{ch} = i\,Z = E_g\left(1 - \epsilon - ^{-\frac{Z}{L_g}t}\right) \qquad (75)$$

In order to plot this charging wave in terms of distance along the line, we may substitute for t the value

$$t = \frac{x}{V} = x\sqrt{LC} \qquad (76)$$

whence

$$i = \frac{E_g}{Z}\left(1 - \epsilon - ^{-\frac{L}{L_g}x}\right) \qquad (77)$$

and

$$e_{ch} = E_g\left(1 - \epsilon - ^{-\frac{L}{L_g}x}\right) \qquad (78)$$

The time constant for the charging of the line in accordance with equations (74) and (75) is $\frac{L_g}{Z}$. The voltage at the entrance of the line will therefore be

$$e_{ch} = 0.632\ E_g$$

at the time

$$t = \frac{L_g}{Z} \qquad (79)$$

after the closing of the switch. The corresponding value of x is

$$x = \frac{L_g}{L} \qquad (80)$$

The charging wave corresponding to this condition, for $x = \frac{L_g}{L}$ is plotted in Fig. 12. In fixing the scale of miles for this figure, the values of L_g and L must be assumed. Thus if $L_g = 0.5$ henry and $L = 0.00265$ henry, the voltage at the entrance of the line will have reached the value 0.632 E^g only after the tip of the wave has traveled 188 miles, and since the velocity is 186,000 miles per second, this will be at the end of about 1000 microseconds. This is based upon the assumption that the length of the line exceeds 94 miles so that the tip of the wave will not yet have returned to the generator end of the line after reflection from the farther end.

The time 1000 microseconds can, of course, be calculated directly from equation (79), if

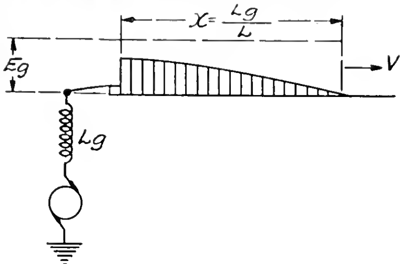


Fig. 12

we know the value of Z. This must correspond to the value $L=0.00265$ henries, which has been assumed. For any aerial line the velocity being approximately 186,000 miles per second, the capacity of one mile of line corresponding to $L=0.00265$ is found from equation (9), whence

$$C=\frac{1}{LV^2} \qquad (81)$$

substituting the values of L and V, we have

$$C=\frac{1}{0.00265\times(186000)^2}=0.0109\times10^{-6}=0.0109\ m.f.$$

From equation 15 we then have

$$Z=\sqrt{\frac{0.00265}{0.0109\times10^{-6}}}=494 \text{ ohms}$$

Substituting this value in equation (79), we again find the value

$$t=\frac{0.5}{494}=0.00101 \text{ seconds.}$$

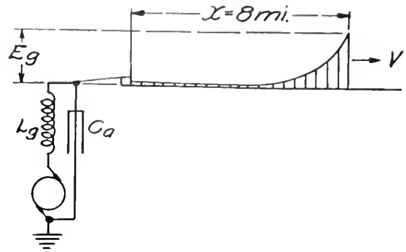


Fig. 13

The values of inductance and capacity used here are intended to be those of a single conductor line against ground.

We have pointed out above that when the line is switched on to a charged condenser, an abrupt wave front will be produced, whereas, if switched on to a practical generator of considerable inductance, the wave front will be very much tapered. In practice we usually find some capacity at the generator terminals, in the form of busbars, switches, etc We will therefore consider the wave

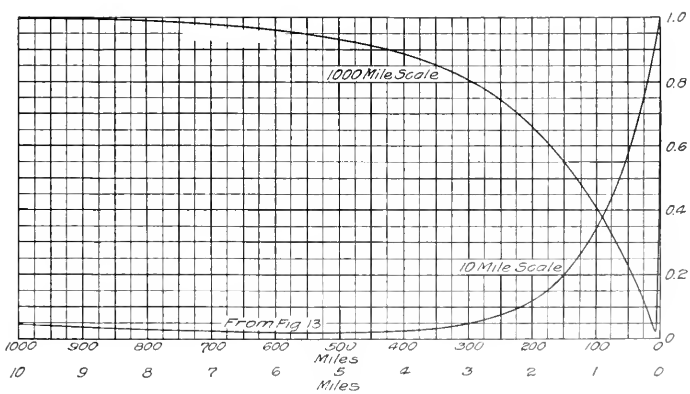


Fig. 14

which will enter the line when switched on to a combination of this sort.

The condenser, assumed to be on the generator side of the switch in Fig. 13, is charged to the voltage E_g before the switch is closed. An abrupt wave front of voltage E_g is therefore produced, current being supplied by the condenser. Current begins to grow in the inductance of the generator only after the voltage of the condenser, and consequently also that of the wave at the entrance of the line, has been reduced. The generator current then grows until it supplies the entire current of the wave, when the condenser and line voltage ceases to fall. Moreover, since this voltage is now less than E_g, the generator current continues to grow, re-charging the condenser and increasing the current and voltage in the line. When this voltage reaches the value E_g, the current flowing from the generator will be that taken by the line, plus that, if any, which is flowing into the condenser. If the condenser is large this will result in an oscillation, since the condenser current can be checked only by the building up of an excess voltage in condenser and line, which is counter to the generator voltage. When the generator current is reduced to that taken by the line, this voltage will be maximum, but so long as it is in excess of the generator voltage it will continue to cause reduction of the generator current, the condenser supplying the deficiency to the line. When the condenser and the line voltage are again reduced to E_g, therefore, the generator current will be deficient. We have thus traced one complete cycle of a heavy damped oscillation, which began with the closing of the switch.

With any value of capacity which may be found at the generator or transformer terminals in practice, the oscillation will be entirely damped out at the end of the first half cycle. The voltage of the wave front will be reduced rather suddenly from its initial value E_g, and then merely grows gradually to its original value (see Fig. 14).

The equation from which the wave of Fig. 14 is plotted was obtained as follows:

Considering the voltages of the generator and the line, we have

$$E_g = L_g \frac{di_g}{dt} + Z\ (i_g + i_c) \qquad (82)$$

where i_g and i_c are the currents supplied to the line by the generator and the condenser respectively. Considering now the voltages of the condenser and the line, we have

$$E_g = \int \frac{i_c dt}{C_a} + Z\ (i_g + i_c) \qquad (83)$$

from these equations, we have

$$\int \frac{i_c dt}{C_a} = L_g \frac{di_g}{dt} \qquad (84)$$

whence

$$i_c = C_a\, L_g \frac{d^2\, i_g}{dt^2} \qquad (85)$$

Substituting (85) in (82), and rearranging, we have the differential equation

$$\frac{d^2 i_g}{dt^2} + \frac{1}{Z\, C_a} \frac{di_g}{dt} + \frac{1}{C_a\, L_g} i_g = \frac{E_g}{Z\, C_a\, L_g} \qquad (86)$$

Substituting herein

$$i = i_g - \frac{E_g}{Z} \qquad (87)$$

we have

$$\frac{d^2 i}{dt^2} + \frac{1}{Z\, C_a} \frac{di}{dt} + \frac{1}{C_a\, L_g} i = 0 \qquad (88)$$

This is solved by

$$i = \epsilon^{-at}(A_1 \epsilon^{bt} + A_2 \epsilon^{-bt}) \qquad (89)$$

where

$$a = \frac{1}{2\, Z\, C_a}\ and\ b = \sqrt{\left(\frac{1}{2\, Z\, C_a}\right)^2 - \frac{1}{C_a\, L_g}} \qquad (90)$$

and the constants A_1 and A_2 must be determined.

For $t = 0$, as already stated the current i_g from the generator is zero. We have, therefore, from equation (87)

$$\text{For } t = 0,\ i = -\frac{E_g}{Z} \qquad (91)$$

These values, substituted in (89), give

$$A_1 + A_2 = -\frac{E_g}{Z} \qquad (92)$$

Also, as already stated, the current does not begin to grow in the generator until after the voltage of the condenser has been reduced, so that

$$\text{For } t = 0,\ \frac{di_g}{dt} = 0 \qquad (93)$$

From equation (87) we see that

$$\frac{di}{dt} = \frac{di_g}{dt} \qquad (94)$$

so that,

$$\text{For } t = 0,\ \frac{di}{dt} = 0 \qquad (95)$$

We may therefore differentiate (89) and equate it to zero. Thus,

$$\text{For } t = 0,\ \epsilon^{-at} [-(a-b) A_1 \epsilon^{bt} - (a+b) A_2 \epsilon^{-bt}] \qquad (96)$$

whence

$$A_1 = \frac{a+b}{b-a} A_2 \qquad (97)$$

From (92) and (97) we now have

$$A_2 = \frac{a - b}{2b} \frac{E_g}{Z} \tag{98}$$

or

$$A_2 = \frac{\frac{1}{2\,Z\,C_a} - \sqrt{\left(\frac{1}{2\,Z\,C_a}\right)^2 - \frac{1}{C_a\,L_g}}}{2\sqrt{\left(\frac{1}{2\,Z\,C_a}\right)^2 - \frac{1}{C_a\,L_g}}} \frac{E_g}{Z} \tag{99}$$

and

$$A_1 = -\frac{\frac{l}{2\,Z\,C_a} + \sqrt{\left(\frac{1}{2\,Z\,C_a}\right)^2 - \frac{1}{C_a\,L_g}}}{2\sqrt{\left(\frac{1}{2\,Z\,C_a}\right)^2 - \frac{1}{C_a\,L_g}}} \frac{E_g}{Z} \tag{100}$$

Considering now the voltage of the charging wave entering the line, we may write

$$e_{ch} = Z\,(i_g + i_c) \tag{101}$$

Substituting the value of i_c from equation (85), and that of i_g from equation (87), we obtain

$$e_{ch} = E_g + Zi + Z\,C_a\,L_g \frac{d^2 i}{dt^2} \tag{102}$$

Introducing the expression for i from equation (89) this becomes

$$e_{ch} = E_g + \epsilon^{-at}\left[\left\{l + C_a\,L_g\,(a-b)^2\right\} Z\,A_1\,\epsilon^{bt} + \left\{l + C_a\,L_g\,(a+b)^2\right\} Z\,A_2\,\epsilon^{-bt}\right] \tag{103}$$

Substituting here the values of a, b, A_1 and A_2, and reducing, we obtain

$$e_{ch} = E_g - \frac{1}{\sqrt{1 - \frac{4\,Z^2\,C_a}{L_g}}}\,\epsilon^{-\frac{1}{2\,Z\,C_a}t}\left\{\epsilon^{\sqrt{\left(\frac{1}{2\,Z\,C_a}\right)^2 - \frac{1}{C_a\,L_g}}\,t} - \epsilon^{-\sqrt{\left(\frac{1}{2\,Z\,C_a}\right)^2 - \frac{1}{C_a\,L_g}}\,t}\right\} E_g \tag{104}$$

The current of this wave is

$$i_{ch} = \frac{e_{ch}}{Z} \tag{105}$$

Equation (104) gives

$$\text{For } t = 0,\; e_{ch} = E_g \tag{106}$$

and the charging wave may be looked upon as a wave of the voltage E_g with abrupt front upon which is superposed an exponential wave, which becomes oscillatory when

$$\left(\frac{1}{2\,Z\,C_a}\right)^2 < \frac{1}{C_a\,L_g}, \text{ or } C_a > \frac{L_g}{4\,Z^2} \tag{107}$$

For the values of $L_g = 0.5$ and $Z = 494$ assumed in connection with Fig. 12, the superposed wave becomes oscillatory only when the capacity of the condenser in Fig. 13 exceeds

$$\frac{L_g}{4\,Z^2} = \frac{0.5}{4 \times (494)^2} = 0.515 \times 10^{-6} \text{ or } 0.515 \text{ m.f.}$$

This capacity is very much larger than any which we will have to consider. For the purpose of calculating the charging wave for such a case, it would be necessary to transform equation (104) to the trigonometric form. This gives

$$e_{ch} = E_g - \frac{2}{\sqrt{\frac{4\,Z^3\,C_a}{L_g} - 1}}\,\epsilon^{-\frac{1}{2\,Z\,C_a}t}\,\sin\sqrt{\frac{1}{C_a\,L_g} - \left(\frac{1}{2\,Z\,C_a}\right)^2} \tag{108}$$

For plotting waves represented by equations (104) and (108) with respect to distance in the line, it is again convenient to substitute for t the value $x\sqrt{LC}$, as given in equation (67). The wave of Figs. 13 and 14 is plotted in this manner from equation (104) for the values $L = 0.00265$ hen., $C = 0.0109$ m.f., $L_g = 0.5$ hen. and $C_a = 0.01$ m.f.

The front end of this wave is the same as that which would be produced by the capacity C_a alone. The effect of the condenser practically disappears within a very short time, and the subsequent growth of current and voltage is almost the same as that which would occur with the inductance L_g and no capacity.

If we have a small amount of capacity at the terminals of the generator, and an additional large inductance connected between this capacity and the line, the charging wave will not differ materially from that obtained with no capacity, shown in Fig. 12. This condition is represented in practice by the capacity of low voltage busses, switches, etc., the large inductance of the step-up transformers intervening between this capacity and the line.

Including the inductance of the transformer with that of the generator, we ordinarily find not only the capacity of high voltage busses, switches, etc., between this inductance and the line, as considered above, but also an additional small inductance between this capacity and the line, in the form of choke coils for lightning protection. If this inductance is very small, its principal effect will be a reduction in the steepness of the initial wave front. If larger values of inductance are used, this case will require separate investigation.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

HIGHER HARMONICS OF INDUCTION MOTORS DUE TO WINDING DISTRIBUTION

It has been found that induction motors with squirrel cage rotors sometimes tend to stick at a sub-synchronous speed. This tendency to stick is caused by higher harmonics in the rotating field.

In order to produce a field which shall have a sine wave distribution, the magnetomotive force producing the field, or in other words, the magnetizing current must have a sine wave distribution. Such a distribution of magnetizing current is not obtained with the windings used in the primary of induction motors. It is more closely approximated in three-phase windings than in quarter-phase windings and more closely in quarter-phase windings having a fractional pitch than in those having a full pitch.

By making an analysis of the current distribution, it can be determined which harmonics are present and what their values are. Although the current is not uniformly distributed over the surface of the primary but is concentrated in slots, it has, however, been found to be sufficiently accurate to assume a uniform distribution. This is especially true for the larger harmonics, such as, the third and the fifth which seem to be the only ones of any importance. The current per phase in a quarter-phase winding having 100 per cent pitch can then be represented by a rectangular wave such as shown in Fig. 1. The analysis of such a wave into sine waves is represented by the following series:

$$\sqrt{2}\, y = \frac{4\, y}{\pi}\left[\sin x - {}^1/_3 \sin 3\, x - {}^1/_5 \sin 5\, x + {}^1/_7 \sin 7\, x + {}^1/_9 \sin 9\, x - \text{etc.}\right]$$

It will be seen from the above that all the odd harmonics are present and that the value of the third is one-third of the fundamental, and of the fifth is one-fifth of the fundamental, etc. The fundamental and the higher harmonics up to the seventh are shown in Fig. 1. These sine waves are standing waves and all have the same frequency, that is, the frequency of the voltage impressed on the primary. The higher harmonics are not higher harmonics with respect to time but with respect to space. It is assumed that the current in the line and, therefore, also the current in the winding follows the sine law with respect to time. The waves shown in Fig. 1 represent the analysis of one phase and that of the other phase is, of course, the same so that the two sets of sine waves produce traveling waves which are shown in Fig. 2 for the instant when the currents in the two phases are equal. Again the waves as shown in Fig. 2 can be expressed by a series which is:

$$y = \frac{4\, y}{\pi}\left(\sin x + {}^1/_3 \sin 3\, x + {}^1/_5 \sin 5\, x + \text{etc.}\right)^*$$

The third and seventh harmonics travel in a direction opposite to that of the fundamental

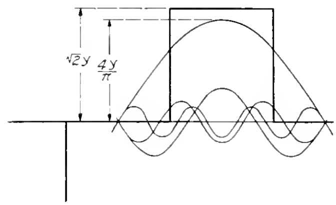


Fig. 1

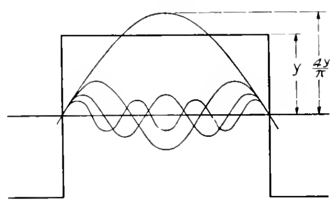


Fig. 2

and the fifth and ninth harmonics in the same direction as the fundamental; thus the third and seventh harmonic fields will rotate in a direction opposite to the fundamental field and the fifth and ninth harmonic fields in the same direction as the fundamental field. From this it follows that the third and seventh harmonics will cause no trouble in starting a quarter-phase induction motor from rest since their synchronous speeds are at a point where the slip is more than 100 per cent, being at $133\frac{1}{3}$ per cent slip for the third harmonic and at $114^2/_7$ per cent slip for the seventh harmonic. If, however, it is desired to reverse the direction of rotation of the motor by applying power with reversed phase rotation, then the third and seventh harmonics may cause trouble. The fifth and ninth harmonics may cause sticking at speeds

* See "The Magnetic Circuit," by Karapetoff, p. 125.

between 100 per cent slip and synchronism since the fifth harmonic has its synchronous speed at 80 per cent slip of the motor and the ninth at $88^8/_9$ per cent slip. The synchronous speeds of the higher harmonic fields are determined by their frequency and number of poles, the frequency as already stated is the same as that of the fundamental field but the number of poles of the third harmonic field is three times the number of poles of the fundamental field and the number of poles of the fifth harmonic field is five times the number of poles of the fundamental field, etc.

These higher harmonic fields produce torques which come to a peak value near the points of synchronism of these fields and if these peak values are larger or nearly as large as the torque produced by the fundamental field at these points, sticking will result. Only the third and fifth harmonics are apt to cause trouble since the torques produced by the other harmonics are not large and in general negligible. The higher harmonic torques decrease in value if the resistance or reactance of the secondary of the motor is increased or if the magnetizing current is increased.

So far this discussion applies only to a quarter-phase winding having 100 per cent pitch, but it can easily be applied to a quarter-phase winding having any value of pitch. Let the analysis as shown in Figs. 1 and 2 be only for the currents in the upper half of the slots, then for the currents in the lower half of the slots there will be a similar set of sine waves but there will be a phase displacement between these two sets of waves equal to the amount that the pitch lacks of being 100 per cent. These two sets of sine waves can then be combined into a resultant set of waves. The relative values of the resultant fundamental and resultant higher harmonics for any value of pitch is given by the following equations:

$$\text{Fundamental} = \cos\,[90 \text{ deg. } (1 - F.P.)]$$

$F.P.$ = fractional pitch

$$\text{Third harmonic} = \tfrac{1}{3} \cos 3\,[90 \text{ deg. } (1 - F.P.)]$$

$$\text{Fifth harmonic} = \tfrac{1}{5} \cos 5\,[90 \text{ deg. } (1 - F.P.)]$$

$$\text{Seventh harmonic} = \tfrac{1}{7} \cos 7\,[90 \text{ deg. } (1 - F.P.)]$$

It will be seen from the above equations that if a $\frac{2}{3}$-pitch winding is used, the third harmonic will be entirely eliminated and if a $^4/_5$-pitch winding is used, the fifth harmonic will be entirely eliminated. Thus with a $^4/_5$-pitch winding there should be no trouble in bringing a quarter-phase induction motor with a low-resistance squirrel cage rotor from standstill to full speed.

A three-phase motor is not so apt to have sub-synchronous speeds as a quarter-phase motor. Fig. 3 shows the analysis of the current of one phase of a three-phase winding having 100 per cent pitch up to the seventh

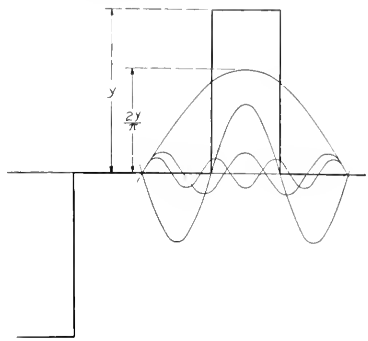


Fig. 3

harmonic, and this analysis is given by the following series:

$$y = \frac{2\,y}{\pi}\,[\sin x - \tfrac{2}{3} \sin 3\,x + \tfrac{1}{5} \sin 5\,x + \tfrac{1}{7} \sin 7\,x - \tfrac{2}{9} \sin 9\,x + \text{etc.}]$$

When this set of standing sine waves is combined with those of the other two phases, it will be found that there is no third harmonic, but, there is a fifth and seventh harmonic and the ninth, as the third, is not present. The value of the fifth is one-fifth of the fundamental and of the seventh is one seventh of the fundamental. The fifth harmonic field rotates in a direction opposite to the fundamental field and the seventh harmonic field in the same direction as the fundamental field. The fifth harmonic will, therefore, cause no trouble in starting a three-phase motor from standstill as its synchronous speed is at 120 per cent slip of the motor but the seventh will cause sticking between standstill and full speed if it has a sufficient value of peak torque since its point of synchronism is at $85\,^5/_7$ per cent slip of the motor.

If a fractional pitch winding is used, the equations given above for the relative values of the fundamental and the higher harmonics in a quarter-phase winding can also be used for a three-phase winding with the exception of that for the third harmonic, the third harmonic not being present in a three-phase winding. Then with a $^4/_5$-pitch winding the fifth harmonic will be eliminated and with a $^6/_7$-pitch winding the seventh harmonic will be eliminated. From this it follows that there should be no trouble in bringing a three-phase induction motor with $^6/_7$-pitch winding and having a low-resistance squirrel cage from standstill to full speed.

A. H. Mittag.

GENERAL ELECTRIC LECTURE SERVICE

By John Liston

Publication Bureau, General Electric Company

The practical value of the series of lectures referred to in this article is due very largely to the unique facilities available for their production. They embody in a readily assimilable form the results of much experimental research and commercial work carried on by the General Electric Company with its exceptional manufacturing equipment, and they also present the accumulated experience of engineers who have specialized in various classes of electrical apparatus for power and industrial applications—Editor.

Recognizing the high educational value of illustrated lectures and the practically universal interest which they arouse when the lecture subjects are selected and treated with due regard to the composite nature of different audiences, and their mental attitude toward technical subjects, the General Electric Company has prepared a number of popular, semi-technical and technical lectures dealing with various phases of the electrical industry.

These written lectures, together with the necessary lantern slides, which are in certain cases supplemented by motion picture films, are intended for use by schools, colleges, boards of trade, associations of central station employees and various educational societies. They are loaned without charge, when available, to be used in the interest of commercial development, education, welfare work or other purposes of a similar nature, on the understanding that the borrower is responsible for any damage to the films other than that caused by such wear as is incident to their normal use.

The success which attended the early development of the Lecture Service, when only a limited number of lectures were available, resulted in a consistent increase in the number of lecture subjects, and this in turn gave a constantly widening field of usefulness. The subjects selected include those of interest to the engineer, the student, central station employees and the general public. Some of the lectures deal with facilities and processes in the manufacture of electrical apparatus, motor applications, together with generating, transmission, distribution, and control systems and electrical railway operation, while others give information which is of interest to the non-technical audience on such matters as lighting and the numerous applications of electricity on the modern farm and in the household.

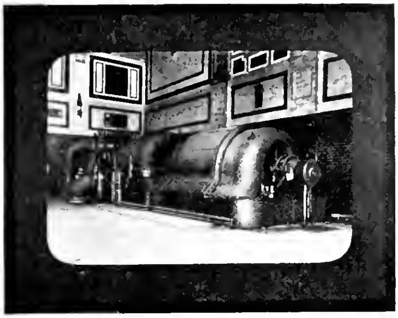
The present scope of the G-E Lecture Service can be best indicated by the following list, which comprises the lectures available at the beginning of the year. Additional material will be largely devoted to the subject of electric power application in a number of important industries, and new lectures, as soon as they are ready for distribution, will be listed in later editions of Catalogue Y-359.

THE ELECTRICAL INDUSTRY

14 Development of the Electrical Industry.

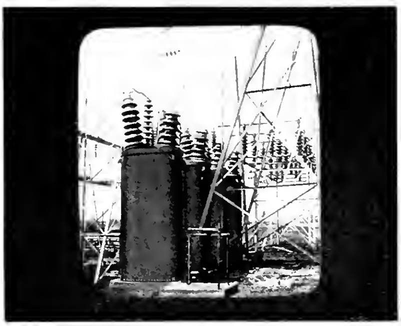
LIGHTING

8 The Inventor and the Lamp—Edison and the development of electric lighting by incandescent lamps. (Popular.)
9 Evolution of Electric Lighting—Arc and Incandescent. (Popular.)
11 The Light House, or the Lighting of Our Homes by Electricity. (Popular.)
17 Light and Safety—The importance of correct lighting as a safety factor, with particular reference to industrial plants. (Popular.)
18 MAZDA—The recent types of high efficiency incandescent lamps and their application. (Semi-technical.)
50 Electricity and the Farmer. (Central Station.)
19 Light as a Salesman—Electricity in advertising sign lighting, show window lighting (?) (Popular.)
24 Searchlights and Their Uses. (Popular.)
21 Sign Lighting—Covers general subject. (Popular.)
22 Lighting of Streets and Parks. (Popular.)
23 Modern Lighting of Meeting Places. (Popular.
49 Elementary Principles of Light and Lighting. (Semi-technical.)
39 Ornamental Street Lighting.
41 Floodlighting. (Popular.)

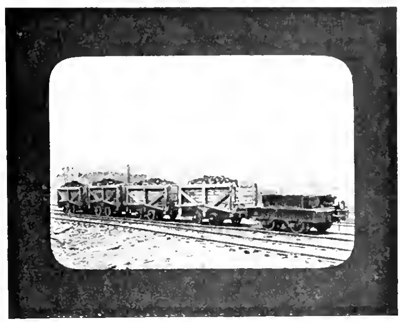


Lantern Slide—Lecture No. 2. Interior of New York Edison Company Power Station

Lantern Slide—Lecture No. 14. Generators in Hydro-electric Plant at Keokuk, Ia.



Lantern Slide—Lecture No. 26. Typical Outdoor Transformer Installation



Lantern Slide—Lecture No. 44. Storage Battery Locomotive Hauling Coal Cars in Mine Service

Lantern Slide—Lecture No. 14. General View of Hydro-electric Power Station and Dam at Keokuk, Ia.

Lantern Slide—Lecture No. 39. Typical Arrangement of Ornamental Street Lighting System

HEATING

7 Cooking by Electricity, the Various Devices and Applications. (Popular.)

POWER

Station Apparatus

2 The Steam Turbine in Electric Light and Power Stations, with special reference to the Curtis Turbine. (Popular.)
3 Alternating Current Generators and Synchronous Motors. (Technical.)
4 The Static Transformer—Its design and use. (Technical.)
28* Synchronous Converters. (See Transmission.)
15 The Circuit Breaker—Its function, design and application. An interesting subject treated popularly.
16 The Oil Switch—An important factor in handling high potential currents. (Popular.)
51 Panama Canal and Its Electrification. (Semi-technical.)

TRANSMISSION

1 Protection—By means of the lightning arrester. (Technical.)
27 Substation—The function of, both stationary and portable. (Technical.)
28* Converters—Synchronous converters, their characteristics, etc. (Technical.)
15 Circuit Breakers. (See station apparatus.)
48 Switchboards.

MOTOR APPLICATION

20 The Electric Motor—Design, construction and applications. (Popular.)
29 The Electric Motor in the Paper Industry. (Popular.)
13 The Electric Fan Motor—Where and how they are made and why half a million are sold annually. (Popular.)

INDUSTRIAL CONTROL

5 At the Wheel—The electric control of industrial machinery. (Popular.)
12 How Electricity Operates the Panama Canal—The Panama Canal Switchboards.

TRACTION

6 Electrical Railways—Electric railway traction. (Popular.)

AGRICULTURE

10 Electricity on the Farm—How it assists the progressive farmer. (Popular.)

The Lecture Service motion picture films have in most cases been made under most favorable conditions, and by a process of elimination have been made to combine, in a series of scenes, a condensed but comprehensive idea of the subject so that they can, with equally good results, be used alone or in conjunction with the written lectures constitute an effective supplement to the lantern slide views.

No effort has been spared in making these motion pictures attractive in themselves, and where the nature of the subject permits, acting has been utilized to inject the element of human interest through the interpretation of scenarios that are interesting, and in which the plots are so arranged as to form a pleasing combination with the purely instructive features.

The following brief synopses will serve as an indication of the character of the motion picture films procurable at present, and, as in the case of the lectures, future additions will be listed in Catalogue Y-359.

Film No. 3. 1 Reel

Electrification of the Butte, Anaconda and Pacific Railroad completely equipped with 2400-volt direct current apparatus furnished by the General Electric Company.

Picture shows working of electric locomotives and station apparatus as well as smelters and views of Butte and vicinity.

Film No. 4. 1 Reel

Every Husband's Opportunity—An interesting photo-play showing domestic happiness disturbed by difficulties in the kitchen. Electric heating appliances finally replace the old style cook stove and cooking utensils, and happiness is permanently restored.

Film No. 6. 1 Reel

Panama Canal Lock Control Board—Panama Canal lock control switchboard showing construction and operation. (Technical.)

Film No. 7. 1 Reel

Motor Construction and Direct Motor Drive—Manufacture of Induction Motors—A mill owner whose mill is equipped with the old style belt-drive has a vision of tangled belts and uneconomical production, and he calls on the General Electric Company for advice.

After visiting the Works and seeing how motors are built and tested, he equips his factory with an eminently satisfactory G-E direct motor drive.

Film No. 8. 1 Reel

Si Smith's Conviction—Incandescent Lamp Manufacture—A farmer who is opposed to the placing of electric wires in front of his home, visits the Edison Lamp Works. He is so impressed with the wonderful process of manufacture that he withdraws his objections and equips his home with Mazda lamps. The film is instructive and at the same time includes several amusing incidents.

A few sections of Lecture Service Films indicating the variety of subjects illustrated by means of motion pictures

Film No. 9. 2 Reels

The Panama Canal—Showing the world's greatest achievement in canal construction· the operation of the locks; the switchboard and the interlocking control system, etc.

Film No. 10. 2 Reels

Schenectady Works of the General Electric Company—A two-reel picture of unusual interest, showing the Schenectady Works of the General Electric Company, the largest electrical plant in the world, including many scenes such as a trip through the main avenue of the Works, the manufacture of generators, wiring supply devices, porcelain, etc., also views of the restaurant, Chinese Commercial Commission, ball games, regatta, Quarter Century Club Outing and some twenty-thousand employees leaving at the close of the day.

Film No. 11. 1 Reel

The Home Electrical—This picture shows a young man who has become interested in a central station window display and who is invited to visit the Home Electrical, which is completely equipped with electrical devices and which are demonstrated to him, with the result that he decides to equip his home with these wonderful conveniences and labor savers. The picture is worked out along educational lines and suggests an ideal home made possible by the use of electrical devices.

Film No. 12. 2 Reels

Pittsfield Works of the General Electric Company—These reels show the manufacture of heating devices, fan motors and transformers; also, exterior views of the Pittsfield factory, employees leaving, etc.

Film No. 13. 2 Reels

Back to the Farm—A two-reel picture full of human interest, depicting a farmer involved in labor difficulties. The ultimate solving of his troubles is brought about by the farmer "Seeing for himself" how electricity is made and applied to the farm.

The picture was staged in California and shows many beautiful, typical scenes.

Film No. 14. 1 Reel

Manufacture of Curtis Steam Turbines—This picture shows the handling of pig iron with magnetic crane, pouring castings, machining operations and construction of a 35,000-kw. turbine; also its installation in the generating station.

The activities of the Lecture Service are not limited to those already referred to, but cover also a number of special lectures, either technical in character or requiring, on the part of the lecturer, a detailed knowledge of certain classes of apparatus or of particular installations.

In order to provide the best possible presentation of lecture material of this class to the audience as a whole, and also to insure adequate answers to questions when additional information on specific points is requested by individuals in the audience, the special lectures are delivered in each case by an experienced speaker from the Lecture Service Staff.

ERRATUM: The Saline Method of Water Flow Measurement as Used in the Acceptance Test of a Pumping Plant.

By W. D. Peaslee

On page 133 the equation given as

$$Q=\left[\frac{S_2}{S_0}\right]q-q$$

should read

$$Q=\left[\frac{S_0}{S_2}\right]q-q$$

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 Company, Schenectady, New York.

ARC LAMP: CHOKE COIL

(161) Why is a choke coil used in connection with an arc lamp when operating on a constant potential circuit but not when operating on a constant current circuit?

Why is the choke coil wound on an open core instead of a closed core?

An arc lamp which operates at constant potential requires a choke coil (on an alternating-current circuit) or a resistance coil (on a direct-current circuit) because of the following well-known characteristic of an electric arc. The voltage drop across an arc at constant length decreases as the current increases; or, in other words, the resistance of the arc becomes lower as the current increases. This results in the arc being inherently unstable on constant potential, although stable on constant current. Consequently, when the lamp is operating on the latter type of circuit no choke coil or resistance coil is required.

For constant potential operation, the arc is commonly made stable by using enough series resistance on direct current, or series reactance on alternating current, to make the total resistance or impedance of the arc *plus its "ballast"* rise with increasing current, and vice versa.

In order to best produce this condition of stability, it is essential that the iron in the choke coil shall run well below its magnetic saturation. The most economical means of securing this low magnetic density is to increase the reluctance of the iron circuit by means of an air gap. S.H.B.

SYNCHRONOUS MOTOR: OPERATING VOLTAGE *VS.* LOAD CAPACITY

(162) What effect has a voltage higher or lower than normal on the available output of a synchronous motor, all other factors being held constant?

There are two factors to be considered; they are "heating" and "break-out," either of which will limit the amount of load the motor can carry. Under normal voltage conditions, the load which will cause a standard design synchronous motor to break out of synchronism is considerably in excess of the load it will carry continuously without exceeding the specified heating limit. The effect of changing the voltage impressed on a motor is to cause the operation of the machine to approach one or the other of these limiting factors, depending upon whether the voltage is raised or lowered.

If the supply voltage is lowered (and normal armature current is maintained, which will result in the heating remaining the same, neglecting the fact that the core loss is somewhat less) the available output will decrease in proportion to the decrease in voltage until that point is reached at which the motor will no longer continue in synchronism, i.e., until the break-out limit is reached.

If the supply voltage is raised (and normal armature current is maintained as previously described) the heating increases very rapidly due to saturation of the iron and the limit of safe temperature is soon reached. Under this condition consideration need not be given to the break-out limit, for this is raised by the increase in voltage.

Ordinarily, the percentage that the supply voltage can be lowered before the break-out point is reached (other factors remaining the same) exceeds that which the voltage can be increased without exceeding the safe heating limit.

E.S.H.

CRADLE AND SUBSTITUTES: APPLICATION TO CROSSING LINES

(163) Is it considered good practice to use a well-grounded cradle between a power transmission line and a telephone line that cross? The particular transmission line under consideration is one of 33,000 volts, three-phase, grounded neutral. At about 20 feet beneath it and crossing it at right angles is a two-wire electric interurban dispatching telephone line. Wooden poles support the power line, the telephone line is not protected by insulating transformer outfits; and lightning and violent wind storms are prevalent.

A grounded cradle or network between a 33,000-volt power line and a telephone line, where the two cross, would be an effective safety device only when it is developed into practically a bridge structure and is completely independent of the pole line. If the net is suspended from the same poles as support the conductors, its additional weight on the poles is more than likely to cause additional troubles and therefore increase the hazards. For these reasons the use of a cradle is now considered to be obsolete.

At such a crossing span, it is considered better by modern practice to omit the cradle and adopt the following construction:

Power wires above the telephone wires.
Short span for power wires.
Poles very firmly set and strongly guyed.
Cross-arms and insulators reinforced.

Although the construction as just described is considered to offer sufficient protection to telephone wires that cross beneath, an additional safeguard can be installed at slight cost. This may take the form of the one illustrated in Figs. 1 and 2 or that shown in Figs. 3 and 4.

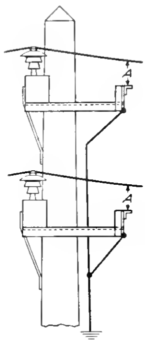
The wire which grounds the device as shown in Figs. 1 and 2 (also that in Fig. 3) can of course be omitted if the line is supported on steel poles or towers.

Figs. 1 and 2 show how the device is applied to a wooden pole power line; it is of course equally applicable to a steel pole or steel tower line by using a different method of attachment. Two of these should be installed facing each other, one on each pole at the end of the crossing span. (In Fig. 1 the bracket guard device is shown arranged for a crossing of the power and telephone wires on the right-hand side of the pole shown.) Pipe or angle-iron may be used for the material. The device should be connected to ground through a low resistance, and it should be located near enough (see *A*, Fig. 1) to the wire to guarantee the two touching, should the wire break, before the wire falls as far as the telephone line. Thus the broken wire becomes grounded. If the neutral of the system is grounded, the grounding of one transmission wire produces a current that will result in the opening of the generating station oil switch. If the neutral is not grounded, the generating station oil switch would or would not open depending upon whether the charging current and leakage current to ground is sufficient to overload the system. In either case, the grounded transmission wire will be harmless since there is no voltage between it and the ground. Conditions of maximum sag, due to temperature, sleet and wind, should of course be taken into consideration when installing the device in order that it be a sufficient distance below (see *A*, Fig. 1) the power wire to prevent flashes to ground while the wire is continuous.

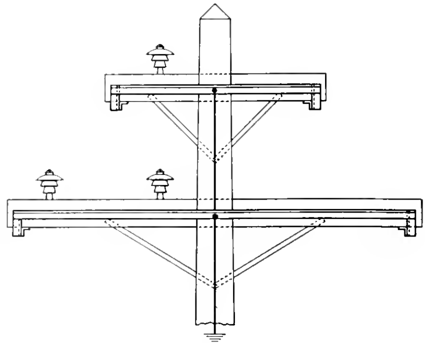
Figs. 3 and 4 illustrate a simple scheme of protection that can be applied to the telephone pole line. It consists of two thoroughly grounded wires between the two telephone poles adjacent to the crossing. The proper location of the guard wires is shown in Figs. 3 and 4 in which is also illustrated an inexpensive support. It is of primary importance that these guard wires be larger in size than the power wires, in order that a falling power wire may not burn its way through the guard wire and eventually reach the telephone line.

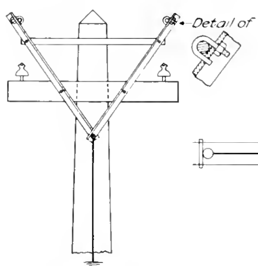
There are on the market several patented protective devices regarding which the makers issue their own claims as to effectiveness. In one such type the crossing span is hooked in at both ends near the poles and a wire upon breaking completely leaves the live circuit before falling the distance of several feet to the telephone wires below.

J.B.T. and T.A.W.

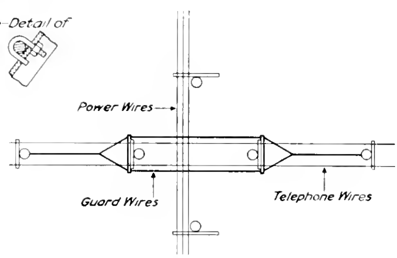


(163) Fig. 1


(163) Fig. 2



(162) Fig. 3



(163) Fig. 4

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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(See page 319)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

In this issue we again record some of the scientific advances during 1915, this time in the realm of physics. As we have mentioned previously, it is our belief that physical research is to play an increasingly important part in the industrial progress of the future. This being the case it may not be out of place to devote one editorial to a few remarks on the Spectrum which, by the way, we have always regarded as the holy of holies of physical science, and to try to see wherein the Spectrum holds its fascination for the investigator. Our remarks may seem almost childish to those who have made a study of physics, but we find that many are handicapped by having no conception at all concerning it.

We imagine that the first case of spectrum analysis (if the term analysis can be applied to what now seems so trivial an experiment) was made when the immortal genius of Newton led him to close the shutters of his chamber and place a glass prism in the path of a beam of sunlight coming through a crack.—"Behold the Specter!" for this is his term for the brilliant band of many colors that was revealed, and is indeed where we get our modern word "Spectrum." At that instant a new realm was opened to the imagination of man, a realm that we have explored with such marvelous results in the last half century. It is from this beginning that we have built up so much of our modern knowledge of the laws of nature that had hitherto been a sealed book. It proved in one instant that the particular kind of energy that radiates from the sun in the form of light and strikes our planet, in common with innumerable other spheres, is no simple thing, but rather is a composition of the seven colors—violet, blue, peacock, green, yellow, orange, red.

Subsequent investigations have shown that the Spectrum of visible light embraces almost exactly one octave, that is to say, the violet light at the extreme end of the visible Spectrum is energy vibrating in ether at the rate of 750 billion vibrations per second, with a wave length of 16 millionths of an inch, and the extreme red light at the other end of the visible Spectrum is energy vibrating in ether at half this frequency with double the wave length, or 32 billionths of an inch in length.

This is our starting point; but energy vibrates in ether with a multitude of vibrations and corresponding wave length—continuing from the violet end we now know that there are two whole octaves of ultra-violet light, followed by seven octaves of unknown characteristics, and that these are followed by an unknown number of octaves of X-rays, which are proving such a rich field for investigators.

Returning to the red end of the Spectrum, there are seven known octaves of dark heat vibrations, and then fourteen octaves of Hertzian waves, again followed by five octaves of wireless waves. This, roughly speaking, accounts for energy vibrations in ether ranging from those of 300,000 billion vibrations per second with a wave length of 0.39 millionths of an inch, to those of only 246,000 vibrations, with a wave length of 4000 ft. Our knowledge is gradually increasing concerning the characteristics of energy within these limits—and who can foretell the wonders yet unknown beyond these limits. It is a combination of what has already been learned by the investigations of the Spectrum and the rich field of infinite possibilities that makes us believe that the discoveries of the future will be many fold greater than the discoveries of the past.

The investigations of the visible Spectrum have aided in the development of many forms of commercial lighting units; researches in the region of the ultra-violet have greatly increased our knowledge of photography, and X-rays have been brought to the service of man, both as a most valuable aid to research work and as a means of curing disease. Again the wireless waves, besides making travel at sea safer than was before possible, have opened up possibilities before unthought of in the transmission of intelligence both in the field of wireless telegraphy and wireless telephony. And so we see that the investigations of the Spectrum, which may seem purely academical today, lead to the commercial achievements of tomorrow.

It is a fascinating thought that light, radiant heat and electricity, besides a host of other physical manifestations of energy, are all one and the same thing with simply a difference in their rate of vibration and wave length.

Our industrial efforts are largely focused on converting mechanical energy to some form of physical energy, heat, light and power, and sometimes, generally in the case of power, to its reconversion to mechanical energy. The efforts of the physicist, besides those in many other fields of activity, are constantly being exerted to obtain higher efficiencies in the process of these conversions, and we venture the opinion that enormous progress will be made as patient investigations enable us to read the chapters of the Spectrum at present unread, because unreadable by the light of our present knowledge.

TRANSFORMER CONNECTIONS

Part I

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

and Louis F. Blume

Transformer Engineering Department, General Electric Company

The wide application of transformers and the large number of connections that are possible to fulfill given operating conditions, demand a thorough understanding not only of the characteristics of the transformer, but also of the relations of the currents and e.m.fs. of the different phases. These may often be of a rather puzzling nature, and it is with a view to make clear some of these points and to bring out the advantages and disadvantages of the different connections that this article was written.—Editor.

Primary and Secondary

In regard to the use of the terms high-voltage, low-voltage, primary and secondary the A.I.E.E. Standardization Rules read as follows:

Before proceeding with a description of transformer connections it is essential for the reader to have a clear understanding of the meaning of such terms as ratio, primary, secondary, etc. These are commonly given quite different meanings, and a failure to understand how they are used will lead to confusion.

"The terms 'high-voltage' and 'low-voltage' are used to distinguish the winding having the greater from that having the lesser number of turns. The terms 'primary' and 'secondary' serve to distinguish the windings in regard to energy flow, the primary being that which receives the energy from the supply circuit, and the secondary that which receives the energy by induction from the primary."

Ratio

The A.I.E.E. Standardization Rules also state that "The *voltage ratio* of a transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary terminal voltage under specified conditions of load." It also defines "the *ratio of a transformer*, unless otherwise specified, as the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding: i.e., the *turn-ratio*."

The two ratios are equal when one of the windings is open and the transformer does not carry any load. When loaded, the resistance and inductance of the windings cause a drop in the voltage, thus modifying the ratio of transformation slightly.

The ratio of a transformer refers, of course, to the turns which are connected in series, high-voltage as well as low-voltage. In many instances it is desirable for the sake of interchangeability and standardization to split up the windings in groups or sections which may be connected either in series, parallel or series-parallel. This is almost always the case with distributing transformers, where the low-voltage winding may be connected for 110-220 volts. This makes possible the following connections:

HIGH-VOLTAGE		LOW-VOLTAGE		
Connection	Voltage	Connection	Voltage	Ratio
	2200	Parallel	110	20:1
	2200	Series	220	10:1

For transformers of very high voltage it is often requested that the high-voltage winding be designed for series-parallel connection. So, for example, by designing a transformer with a high-voltage of say 110,000-55,000 volts, it is possible to operate the system at the lower voltage until the load has increased to a point necessitating a change-over to the higher transmission voltage.

Single and Polyphase Transformers

Transformers are made either as single or polyphase units, the latter being generally of the three-phase type. The single-phase design is by far the most flexible, as by different connections any combination can be obtained. Economical considerations are, however, often the determining factor in deciding on what type to use.

Three-phase designs may be connected either in delta or Y, and the units may be either of the shell or the core type construction. In delta-connected shell-type transformers, should one phase be damaged, it is possible to operate the remaining two phases in open-delta at 58 per cent of the combined capacity, by simply disconnecting the damaged unit of the three single-phase transformers, or in the case of three-phase shell-type units by disconnecting and short-circuiting the damaged phase, both high and low-voltage. This will reduce the flux passing through the part of the core surrounded by these windings and limit the current in the damaged winding to a fraction of the normal full-load current.

Y-connected shell-type transformers of both the single- and three-phase types can not be operated with one phase damaged, except where the neutral is grounded, in which case they may be operated at 58 per cent of their total capacity by short-circuiting

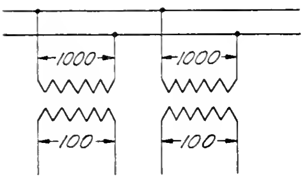


Fig. 1

both the high and low-voltage windings of the damaged phase. Such a scheme is, nevertheless, not very satisfactory for motor operations on account of the unbalancing of the phases and the reduced voltage. Lights can, however, be operated successfully by connecting them between the live single-phase wires and the neutral.

In the case of three-phase core-type transformers, even though the windings are delta-connected, it is impossible to operate when one phase becomes short-circuited. This is due to the fact that the three phases are magnetically interlinked in such a manner that any one phase is a return path for the fluxes in the other two phases. This means that when one phase is short-circuited the short-circuit is transmitted magnetically to the other two phases in such a manner that when the two phases are excited large short-circuit currents flow, the short-circuit phase acting as secondary and the remaining phases as primary. In the three-phase shell-type transformer this does not occur, because the fluxes in the three phases are independent of each other, and, therefore, the flux in one phase can be reduced to zero without affecting the other.

However, if the damaged winding can be open-circuited or removed from the core the transformer will operate satisfactorily when connected open delta.

Rating

A transformer should be rated by its kilovolt-ampere (kv-a.) output. It is simply equal to the product of the voltage and current, and is therefore the same whether the different coils are connected in series or parallel. If the load is of unity power-factor, the kilowatt output is the same as the kilovolt-ampere output; but if the power-factor is less, the kilowatt output will be correspondingly less. For example, a 100-kv-a. transformer will have a full-load rating of 100 kw. at 100 per cent power-factor, 90 kw. at 90 per cent power-factor, etc.

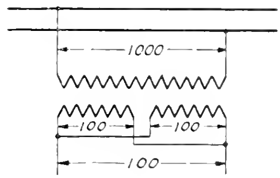


Fig. 2

Connections

Among the great variety of transformer manipulations in power and general distribution work, either for straight voltage transformation or for phase transformation, the following are the most generally used:

- Voltage transformation:
  - Single-phase.
  - Two-phase
  - Three-phase, delta—delta.
  - Three-phase, delta—Y, and vice versa.
  - Three-phase, Y—Y.
  - Three-phase, open-delta.
  - Three-phase, T.
- Phase transformation:
  - Two- or three-phase to single-phase.
  - Two-phase to six-phase.
  - Three-phase to six-phase.

SINGLE-PHASE

The windings may be divided into sections and variously connected to meet different requirements. So, for example, are most standard distributing transformers made with two low-voltage coils.

Fig. 1 represents the straight connection of two transformers to 1000-volt mains, the transformer consisting simply of single high- and low-voltage windings.

Figs. 2, 3 and 4 represent different connections of transformers which are provided with two coils. So, for example, in Fig. 2 the two low-voltage coils are connected in parallel to supply 100 volts.

In many instances it is deemed advisable to operate a three-wire circuit from the low-voltage side of transformers, and thereby reduce the cost of copper for the feeders. Such a connection is represented in Fig. 3, where the low-voltage coils are connected in series and their junction connected to the neutral wire. This method of connection is used very extensively and is known as the Edison three-wire system. When used for combined power and lighting load, the motors are usually connected to the two outside wires, and the lights between the outside and neutral.

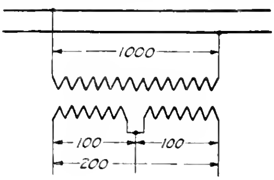


Fig. 3

The neutral wire generally carries less current than the outside wires, except in the case where the entire load is on one side. The neutral wire should for this reason be of sufficient cross-section to safely carry a current which will blow out the main fuses in case of short-circuit on one side of the system.

Fig. 4 shows the three-wire distribution where a grounded neutral wire is employed, this system also being widely used for general distribution, lighting, small motors, etc.

The four terminals of the low-voltage coils are, as a rule, brought outside the case in such proximity that they can readily be connected in any desired manner by joining adjacent terminals. Connection blocks are seldom used for the low-voltage winding of distributing transformers, because of the large current-carrying capacity required.

The voltage stress on the windings naturally depends on the voltage of the mains to which they are connected, and also on abnormal operating conditions such as accidental grounds, lightning surges, etc. For the arrangement shown in Fig. 2 it is obvious that under normal conditions the maximum voltage stress between the high-voltage leads is 1000 volts, and to ground 500 volts. If a ground should occur at one of the high-voltage connections to the mains, the stress will be 1000 volts.

In the case of the low-voltage winding, if the two coils are connected in series and non-grounded, the stress to ground under normal conditions is 100 volts, which is also the maximum stress if the junction point or neutral is grounded. If not, and with one lead grounded, the stress becomes 200 volts. The stress between the two windings is equal to the high voltage plus or minus the low-voltage, depending on the arrangement and connections of the coils.

In order to avoid the danger of excessive voltages being impressed on the low-voltage circuits, caused by crosses between the high-

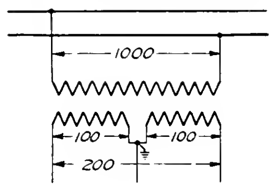


Fig. 4

voltage and low-voltage lines or windings, grounding of the low-voltage circuit is now generally advocated for all voltages up to 250 volts. No point of the circuit can then, except under unusual conditions, rise above its normal potential, and such grounding therefore prevents accidents to persons and damage by fire to property. If the low-voltage side, on the other hand, is not grounded, and the transformer breaks down, the high voltage may be impressed on the low-voltage circuit, and a person touching any bare part of the low-voltage circuit is liable to receive the full shock of the high voltage, if he were grounded by contact with, for example, a gas fixture, etc. Furthermore, if the low-voltage side is not grounded and there is a ground on the high-voltage circuit, the high voltage impressed on the fittings of the low-voltage circuit might cause a fire.

For a two-wire 110-volt circuit it is common practice to connect the ground to one side, while with a three-wire Edison circuit the neutral wire is grounded, limiting the potential from either outside wire to ground to 110 volts. On a 220-volt single-phase power circuit the middle or neutral point of the transformer winding should be grounded.

To prevent any increase of the potential stress between ground and either low-voltage

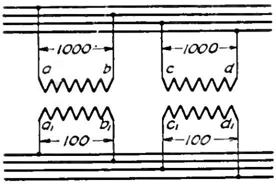


Fig. 5

wire, the ground should be well made so that it cannot readily be broken. It should not be fused and should consist of a conductor which without overheating can carry a current sufficient to blow the main fuses.

TWO-PHASE

This system practically consists of two separate single-phase circuits, the two e.m.fs. and currents being 90 electrical degrees or one-fourth of a cycle out of phase with each other; Fig. 6.

Two single-phase transformers are mostly used for two-phase systems, and the most common connection is that shown in Fig. 5. The high-voltage windings of the two transformers are connected respectively to the two phases of the supply mains.

It is sometimes also desirable to operate a three-wire two-phase distribution, as shown in Fig. 7. In this case the voltage across the

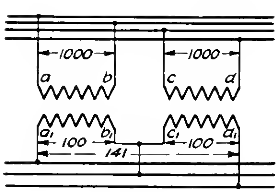


Fig. 7

outside wires is $\sqrt{2}$ or 1.41 times the voltage of each individual transformer. This is clearly understood by a reference to the vector diagram in Fig. 8, and is due to the 90 deg. phase difference between the two e.m.fs.; so that instead of adding them numerically, they must be added vectorially. The current in the neutral wire is also 1.41 times the current in either of the outside wires, provided the load is balanced.

Transformers in two-phase work are sometimes interconnected as shown in Fig. 9,

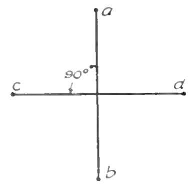


Fig. 6

where a common return is used on both high- and low-voltage sides. Very few systems are, however, operated on this plan.

By connecting together the middle points of the low-voltage windings, as shown in Fig. 10, two 100-volt main circuits *ac* and *bc* are obtained. Also four 70-volt ($50\times\sqrt{2}$) side circuits *ab*, *bc*, *cd* and *da*.

This method of connection is used when the neutral is to be brought out in connection with Edison three-wire service with rotary converters. If the converter is started from the transformer with one-third and two-third voltage taps, provision must be made for opening the neutral connection when starting, so as to avoid short circuit.

Another two-phase arrangement is shown in Fig. 11, and is comonly called the five-wire system. It is accomplished simply by connecting the low-voltage windings at the middle

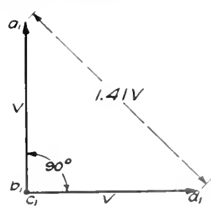


Fig. 8

and bringing out an extra wire from the middle point of each.

With the connections shown in Fig. 5 the maximum insulation stress in case of a permanent ground is 1000 volts on either phase of the high-voltage side, but a simultaneous grounding of lines a and d, a and c, b and c, or b and d or their connection, causes insulation stresses $\sqrt{2}$ times this value or 1414 volts. On the low-voltage winding the corresponding stress would be 141 volts.

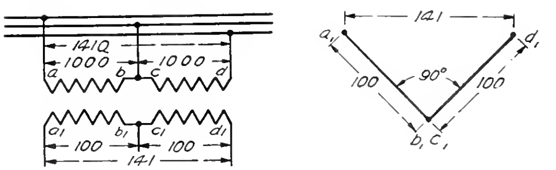


Fig. 9

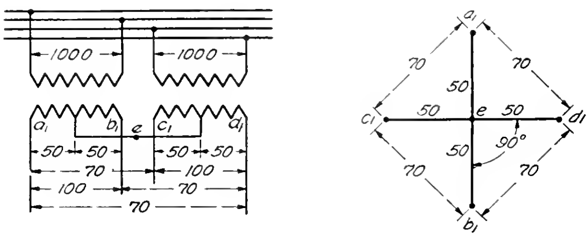


Fig. 10

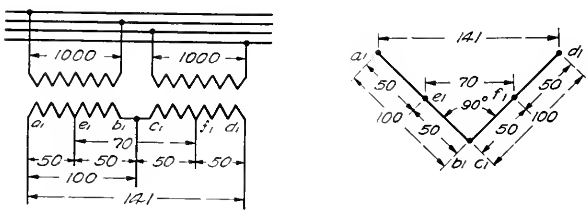


Fig. 11

With the two low-voltage windings connected for a three-wire distribution, as in Fig. 7, the maximum stress when one of the outside wires becomes grounded is 141 volts, while if the junction or neutral point is grounded it is limited to 100 volts.

Some systems are supplied with two-phase generators in which the neutral points of each winding are connected together. In this case simultaneous grounding or connection of any two lines from the generator causes a short-circuit on one-half the generator winding.

For grounding two-phase systems several methods are employed. With a four-wire distribution the mid-point of each transformer winding should be independently grounded unless the motor windings served are inter-connected so as to prevent it. In that event the neutral of one transformer only should be grounded. With the three-wire system the neutral point should be grounded and the same applies to the systems shown in Figs. 10 and 11.

THREE-PHASE

The following are the most common methods in which transformers may be connected for a three-phase system:

Delta—Delta.
Delta—Y, or vice versa.
Y—Y.
Open-delta.
T-connections.

Delta-delta

With the delta — delta system the leads of three-phase transformers are connected to the mains as shown in Fig. 12. The e.m.fs. and currents differ in phase 120 electrical degrees, and the line voltage is equal to the individual transformer voltages. This voltage is commonly denoted as the "delta voltage" to distinguish it from the "star or Y voltage" in the star connected combination. Similarly the line current must be distinguished from the current flowing in the closed delta winding.

The voltage and current relations are easily explained by reference to the vector diagram in Fig. 13.

If we denote:

E = delta voltage, or voltage between phases.
e = Y voltage, or voltage between phases and neutral.
I = Y current or line current.
i = delta current or current in delta winding.

Then:

$$E = e\sqrt{3} \text{ or } e = \frac{E}{\sqrt{3}}$$

and

$$I = i\sqrt{3} \text{ or } i = \frac{I}{\sqrt{3}}$$

When speaking of the voltage and current or line voltage and line current of a three-phase system, without further qualifications, the delta voltage and the Y current are understood.

Delta-connected transformers must be wound for the full line voltage but for only 58 per cent line current. The windings must therefore have a greater number of turns than for star connection, while they can be of smaller conductor.

The maximum insulation stress in case a permanent ground occurs does not exceed the normal voltage stress, provided the ground is at the transformer terminals. When, however, the ground occurs on the transmission line at some distance from the transformer terminal the reactance drop due to the charging current adds to this stress. On this account on long distance high voltage transmission lines operating on the delta—delta system a dead ground of one wire may cause the other two wires to rise above ground considerably above normal potential, thereby increasing the insulation stress. This increased stress may exist both at the generating and receiving ends of the transmission line.

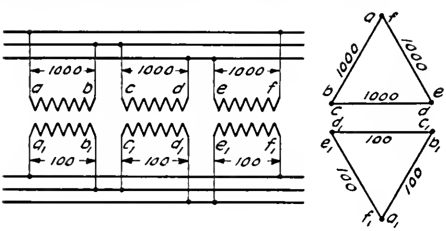


Fig. 12

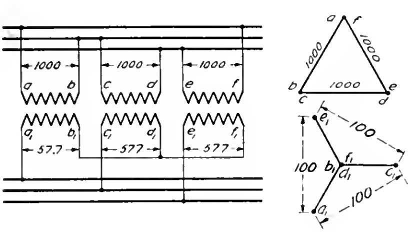


Fig. 14

With a delta-connected 220-volt distributing system the ground connection should be made to the mid-point of the winding of one transformer. This gives 110 volts to ground from the phase wires next to the ground connection and about 200 volts from the other phase to ground.

Where 2200/220 volt transformers are connected delta—delta for three-phase power service one of the units is occasionally made larger than the other two, and a tap from the middle point of the low-voltage winding brought out so that a 110/220-volt single-phase three-wire service may be obtained for lighting purposes.

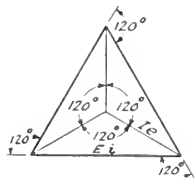


Fig. 13

If one transformer or one phase of a three-phase transformer is disabled, the other two may then be used in open delta.

The capacity of a group of delta-connected transformers is equal to $\sqrt{3} \times E \times I$ kv-a., where E represents the transformer or line voltage and I the line current. The current in the transformer windings is equal to $\frac{I}{\sqrt{3}}$.

Delta—Y

Delta—Y connection or vice versa, as shown in Fig. 14, is used to a great extent, and it is especially convenient and economical in distributing systems, in that a fourth wire may be led from the neutral point of the low-voltage windings.

The current and voltage relations in the delta side are the same as in the delta—delta connection. On the Y-connected side, however, one end of each winding is connected to a common neutral point and the other three ends to the lines. With this connection the number of turns in a transformer winding is 58 per cent of that required for delta-connected transformers, but the cross-section of the conductors must be correspondingly greater for the same output. For high voltages the currents are, however, generally so small that in many cases the size of wire in the high-voltage winding must be governed by mechanical considerations, and the size of wire may have to be the same for either system. The delta connection is therefore sometimes somewhat more expensive.

If the neutral point of the Y-connected system is ungrounded, the transformer insulation must be capable of standing the stress of the full line voltage, since a ground on any line will throw full voltage on parts of the transformers. With grounded Y the stress is, of course, limited to the Y voltage. This is, however, only true for step-up transformers at the generating end of transmission line, and also only when the neutral is solidly grounded. When the neutral is grounded through a resistance the insulation in transformer may be subjected to full voltage stress and under any conditions the step-down transformers may be subjected to full voltage stress.

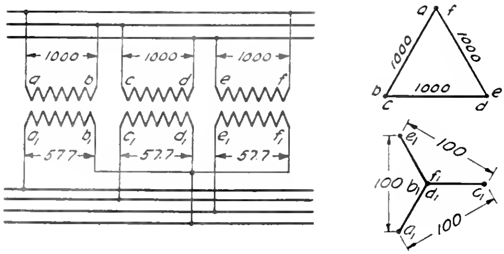


Fig. 15

For distributing service, as previously stated, the transformers often have their low-voltage windings Y-connected and the neutral brought out, forming a four-wire system, as shown in Fig. 15. The single-phase service is then obtained by tapping between any line and the neutral, while for three-phase work the line wires are tapped directly, the voltage between these being $\sqrt{3}$ times the single-phase. This system results in a copper saving of 56 per cent, assuming that the four wires are of the same cross-section.

If the main three-phase line potential is fixed, this method offers no saving; on the contrary, it requires 33 per cent more copper. In any case, however, the use of the four-wire system gives increased flexibility, and the neutral wire carries all unbalanced currents.

This system is mostly used for a combination of motor and lighting loads. The lighting service is operated from the 2300-volt phase voltage and the power service from the 4000-volt line voltage.

Transformers are sometimes designed so as to be suitable for either delta — delta or delta — Y connection, in order to permit the user to increase the capacity of a transmission line by raising the line voltage, which can be accomplished by changing the connections from delta to Y on the high voltage side. Such transformers are necessarily more expensive than they would be if designed for straight delta—delta, and used at the lower voltage only, because they must be insulated to withstand the higher line voltage.

The rating of a group of delta—Y-connected transformers is the same as for the straight delta—delta connection.

Where power is transmitted with delta—Y step-up and Y—delta step-down transformers, service may be maintained with one step-down transformer cut out, the connections being made as shown in Fig. 16.

A' B' C' represents the Y-connected high-voltage winding of the step-up transformers and *a b c* the high-voltage winding of the step-down transformers, of which the phase *c-d* is out of service. A three-phase open-delta connection *a' b' c'* is thus obtained on the low-voltage side.

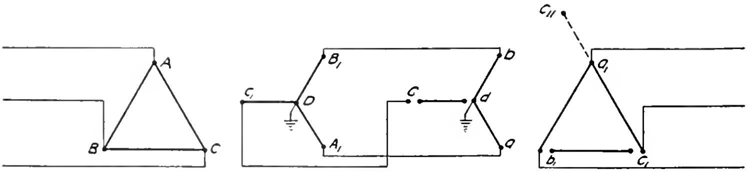


Fig 16

The capacity is reduced to 58 per cent of the original value, and care must be taken not to connect *a′ c′* in the position *a′ c″*, since this will not give a three-phase relation. The neutral connection on the high-voltage side should preferably be made through a wire, tional magnetism in the transformer, which, superimposed on the magnetic cycle, would tend to raise the magnetic induction beyond saturation, and thus cause excessive exciting current and heating, except in cases where the unbalanced current is comparatively small.

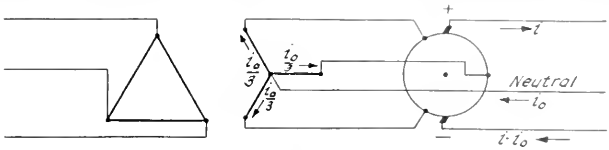


Fig. 17

but can be made by solidly grounding the neutral of both transformers. The system will, however, be electrostatically and electromagnetically unbalanced, and the usual disturbances characteristic of such a condition will be observed, the severity depending on the circuit characteristics.

Synchronous converters are frequently installed in connection with Edison systems, where three-wire direct-current is required. The three-wire feature is readily obtained by connecting the neutral wire directly to the neutral point of the low-voltage winding of the step-down transformers. In such a case Such a connection is shown in Fig. 17 which represents a delta—Y-connected step-down transformer with the neutral brought out. It is evident that in this case each transformer low-voltage winding receives one-third of the neutral current, and if this current is not small, as compared with the exciting current of the transformer, it will cause an increase in the magnetic density.

A system with a distributed Y or "zigzag" connected low-voltage winding, as shown in Fig. 18, has, however, been devised and will eliminate the flux distortion due to the unbalanced direct current in the neutral.

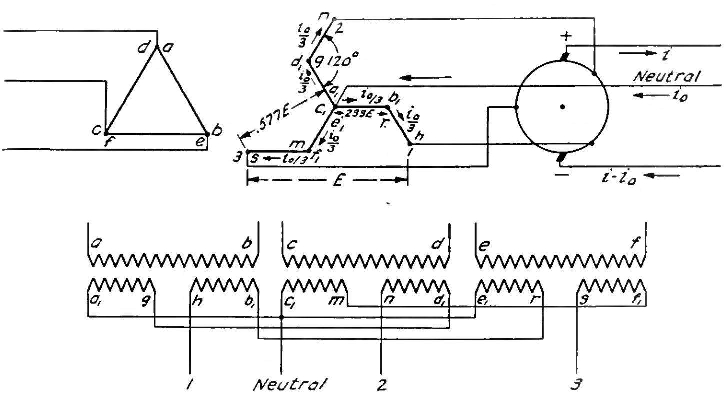


Fig. 18

care should be taken to use only such connections as will cause the transformer to act as an auto-transformer, i.e., so that the direct current in each transformer divides into two branches of equal m.m.f. If this is not done, the direct current will produce a unidirec- Two separate interconnected windings are used for each leg of the Y. The unbalanced neutral current flowing in this system may be compared in action to the effect of a magnetizing current in a transformer. The effect of the main transformer currents in the high-and low-voltage windings is balanced with regard to the flux in the transformer core, which depends upon the magnetizing current. When a direct-current is passed through the transformer, unless the fluxes produced by it neutralize one another, its effect on the transformer iron varies as the magnetizing current. For example, assume a transformer having a normal ampere capacity of 100 and, approximately, six amperes magnetizing current, and assume that three such transformers are used with Y-connected low-voltage windings for operating a synchronous converter connected to a three-wire Edison system. Allowing 25 per cent unbalancing, the current will divide equally among the three legs giving 8.33 amperes per leg, which is more than the normal magnetizing current. The loss due to this current, however, is inappreciable, but the increased core losses may be considerable. If a distributed winding is used the direct current flows in opposite directions around the two halves of each core, thus entirely neutralizing the flux distortion.

Whether the straight Y or the interconnected Y connection it to be used is merely a question of balancing the increased core loss of the straight Y connection against the increased copper loss, and the greater cost of the interconnected Y system. The straight Y connection is much simpler, and it would be quite permissible to use it for transformers of small capacities where the direct current circulating in the neutral is less than 30 per cent (10 per cent per transformer) of the rated transformer current.

When three-phase core-type transformers are used, it is not necessary to resort to the zig-zag connection, as in such transformers the direct current flows along the core from end to end in the same direction on all three legs, and since the direct magnetism must find its return path through the air and the case outside of the core, its effects are practically negligible.

On account of the 30 deg. displacement between the voltage from line to neutral and that across each half of the transformer legs of the zig-zag connected windings, the low-voltage side operates only at 86.6 per cent of the normal capacity, which it would have if operated straight Y.

Y—Y

This connection ordinarily is not to be recommended for a bank of three single-phase transformers or a three-phase shell-type unit, if their neutrals are ungrounded. This is due to the fact that the triple frequency component of the exciting current necessary for normal magnetization cannot flow, which results in a third harmonic and its odd multiples appearing in the e.m.f. from line to neutral, thus causing an excessive stress on the windings. No triple frequency harmonic appears, however, in the line voltage, which remains normal, because the third harmonics across the three transformers are in phase with each other.

The triple frequency component does not exceed 75 per cent of the fundamental and with densities commonly used has an average value of 50 per cent of the fundamental. An exception to this, however, is the case when the transformers are operated with grounded neutral and connected to a transmission line possessing electrostatic capacity. In such a case the induced triple harmonics may be intensified to values as high as two or three times normal.

To obviate this increase in voltage, it is necessary to make neutral connections in such a manner that the triple harmonic exciting currents necessary for sine wave excitation can flow, thereby eliminating the triple harmonic voltage. This is accomplished first, when the transformer neutral is grounded, and a Y delta bank of transformers with grounded neutral of sufficient kv-a. capacity is connected to the line; second, when the primary neutral is connected to the neutral of the generator, this case only being possible for step-up transformers. It should be noted that by grounding the high voltage neutrals of both step-up and step-down transformers the danger from triple voltage intensification is not eliminated.

It should be kept in mind, however, that when such ground connections are relied upon for eliminating triple harmonic voltages, such voltages are restored by disconnecting any ground connections, and also that the third harmonic ground currents are liable to subject parallel telephone or telegraph systems to serious interference.

The above does not refer to three-phase core-type transformers, which owing to their construction are not subject to these additional strains.

No stable neutral can be maintained on a bank of transformers with both high and low-voltage windings Y-connected when ungrounded, since it may shift to any position.

Open-delta

When single-phase or three-phase shell-type transformers are used, it is possible to maintain operation if one phase is damaged. Such a combination is shown in Fig. 19, and is termed the open-delta or V connection. It is not possible with the three-phase core-type design, as it is impossible to isolate the damaged phase, due to the interlinked magnetic circuits. With V-connected three-phase shell-type transformers the damaged phase should be short-circuited to prevent stray fluxes from the other phase from inducing voltages in the damaged windings.

With the V connection the current in each transformer is 30 deg. out of phase with the transformer voltage, so that each transformer under non-inductive load operates at only 86.6 per cent power-factor. Based on a three-phase load, the cutting out of one transformer would therefore reduce the current-carrying capacity not to two-thirds of 100 per cent which equals 66.6 per cent, but to two-thirds of 86.6 per cent which equals 58 per cent.

Assuming that each transformer shall have a capacity of $\frac{3\,EI}{2} = 1.5\,EI$, it must be capable of carrying 1.73 EI kilovolt-amperes, because the transformer voltage is equal to the line voltage E, and the transformer current equal to the line current 1.73 I. Therefore, the single-phase rating of each transformer must be $\frac{1.75}{1.5} = 1.55$ or 15½ per cent greater than one-half the group rating.

Sometimes it is desired to parallel a number of transformers in such a way that certain of the transformers will form a delta group while the others may be connected in open-delta or V. Such a combination may be desired

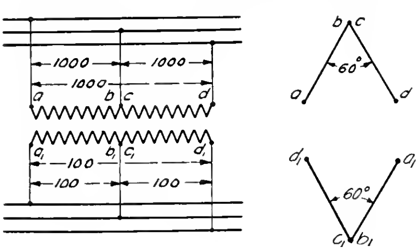


Fig. 19

to increase the capacity by adding spare transformers of insufficient number to form a group of complete deltas, or through the failure of one or more units originally installed. It is not, however, generally realized that such an arrangement will, in general, prove either uneconomical as to capacity if all the units are kept to rated currents, or disastrous to the units on the legs having the smaller numbers, if it be attempted to work all units at overloads guaranteed for single-phase operation. Not only is this because of the additional 15½ per

Number of Transformers	Connection	Three-phase Capacity of Group in per cent of Single phase Rating
3	Δ	100
2	Λ	86.6
2	T	86.6
6	Δ Δ	100
5	Δ Λ	80
4	Λ Λ	86.6
4	Λ ∠	82
9	Δ Δ Δ	100
7	Δ Λ ∠	91
7	Δ Λ Λ	72
8	Δ Δ Λ	88

Fig. 19a

cent capacity required on units for open-delta service, but a further increase in current takes place in the V-connected transformers due to change in phase relations, and for this reason when delta and V groups are operated in parallel the resultant capacity is not the sum of the individual delta and V ratings. More than one V group cannot be used advantageously with a delta group of transformers nor with two or more paralleled delta groups. Three delta-connected transformers when added to another delta group will give an increase of capacity which is 50 per cent greater than if four transformers, connected in two V groups, were added to the same delta group. This is because the four transformers, which would form two V groups, can be rearranged to form a delta group (one transformer remaining idle), and the delta group will have the capacity of three transformers while the two V groups will add the capacity of only two transformers. The addition of two transformers, connected in V, in parallel with a delta group adds the capacity of only one transformer to the capacity of the total group. Although two V-connected groups should never be used in parallel with a delta group, they may be paralleled with one another and in this case will give a greater capacity than three units connected in delta. The capacity of the two V groups would be 0.866 times four or 3.46 as agains three, the corresponding rating of three transformers connected in delta.

The table of Fig. 19a gives the transformer capacities available with various combinations of open and closed delta groups.

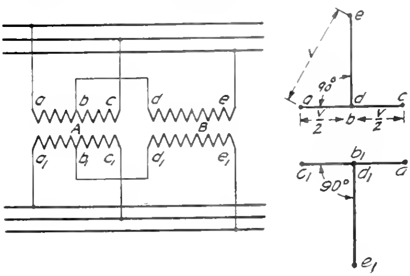


Fig. 20

T—T

As with open-delta arrangement, the T—T connection requires only two single-phase transformers, Fig. 20 representing the diagram of connections. *A* is called the main transformer and is provided with a 50 per cent voltage tap to which the teaser transformer *B* is connected. This transformer may be designed for only 86.6 per cent of the line or main transformer voltage, but generally it is made identical with the main transformer and operated at reduced flux density. It should be noted that although the teaser operates at 86.6 per cent of line voltage it is unnecessary to provide an 86.6 per cent tap as is often supposed. On this account it is possible to operate two identical transformers connected T—T as well as open delta, when one transformer of a delta-delta bank burns out, the only requirement for the T—T connection being a 50 per cent tap. Although interlacing is not required between halves of the main winding, nevertheless each half of the primary winding must be properly wound with respect to the corresponding half of the secondary winding. The three-phase capacity of the T connection as is shown in the table is the same as for the open delta connection, that is, 86.6 per cent of single-phase capacity, but on account of the fact that the teaser operates at a lower flux density, the efficiency of the T connection is somewhat greater than in the open delta or V connection.

Two ordinary transformers may also be used with T connection provided a 50 per cent tap is available. It is also more economical to operate with T connection than with V connection, when one transformer has burned out.

The T connection, as shown in Fig. 21, can also be used for three-phase synchronous converters, and the neutral point can readily be brought out for Edison three-wire service. The neutral is then brought out from a point at one-third the height of the teaser winding and the m.m.f. of the direct current i will balance as shown in the diagram.

For T connection with ungrounded neutral the voltage stress is the same as for the delta system, and with grounded neutral the voltage stress between line and ground is limited to 58 per cent of normal.

Assuming again that as with the open-delta connection the two transformers shall be capable of supplying a load equal to $\frac{3EI}{2} =$ 1.5 EI, the kv-a. rating of the main transformer must therefore be equal to 1.73 EI, while the kv-a. of the teaser transformer only is equal to $1.73\, I \times 0.866\, E = 1.5\, EI$. The two transformers are, however, designed to carry the same currents and are generally made identical, so that the single-phase ratings of either transformer must also here be $\frac{1.73}{1.5} =$ 1.155 or 15.5 per cent greater than one-half the group rating.

PHASE TRANSFORMATION

Of the connections for transforming one polyphase system into another with a different number of phases, the following are the most commonly used:

Two or three-phase to single-phase.
Two-phase to six-phase.
Three-phase to two-phase.
Three-phase to six-phase.

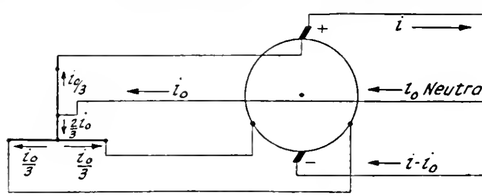


Fig. 21

Two or Three-phase to Single-phase

It is practically impossible to transform from polyphase to single-phase by means of static transformation with balanced conditions. Various schemes have been proposed and investigated, but none of the combinations give better results than can be obtained by simply using a transformer across one phase.

The reason for this is explained by Dr. Steinmetz (A.I.E.E. 1892) to be as follows:

Single-phase power changes from a maximum to zero and back to maximum every half cycle, while polyphase power is delivered at a constant rate. Therefore, any system capable of transforming from balanced polyphase current to single-phase current must be capable of storing energy during the interval of time when the power delivered to the single-phase side is less than the power received from the three-phase side. The transformer is incapable of fulfilling this requirement. Nevertheless, it is desirable to know the most desirable method of taking single-phase power from a three-phase system and often ingenious although complicated connections are proposed with the idea of more uniformly distributing a single-phase load. Most of these schemes do not present a single feature that is superior to the placing of the single-phase load directly across two wires. When there is one feature which is apparently superior, there are generally undesirable features which more than offset it. The four schemes shown in Figs. 22, 23, 24 and 25 are ones commonly suggested and the tabulation on page 258 give the characteristics of these connections and show that they are inferior to straight single-phase transformation. All values except for power are given with reference to straight single-phase as unity. The total value of power delivered is the same in all cases. By straight single-phase is meant connecting one transformer between two wires of a three-phase system. The only condition under which there seems to be an advantage is in schemes 1 and 3 where it will be noticed that a delta-connected generator has a maximum current of 0.577 as against 0.667 for the straight single-phase. To offset this, both schemes 1 and 3 require two transformers possessing greater total capacity and also impose upon the line a greater maximum current.

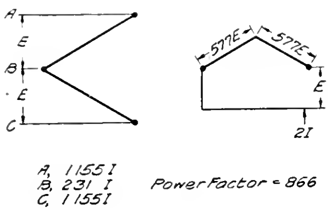


Fig. 22

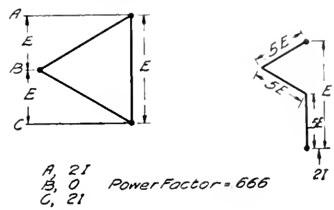


Fig. 23

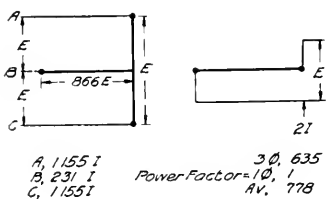


Fig. 24

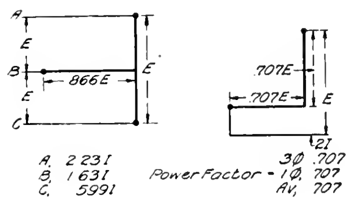


Fig 25

Two-phase to Six-phase

The double-T connection, as shown in Fig. 26, is generally used in cases where a six-phase synchronous converter is to be operated from a two-phase supply system, and where the two-phase voltage requires some transformation in order to obtain the correct alternating current voltage for the converter. The cost of double-T-connected transformers and

Scheme No.	No. Trans.	Capacity: Trans. Each	Capacity: Cap. Total	Power-factor for Non-Inductive Load	Generator Y-Connected: Current	Generator Y-Connected: Watts	Generator Delta-Connected: Current	Generator Delta-Connected: Watts
1	2	0.577	1.155	0.866	0.577 1.155 0.577	1/6 2/3 1/6	0.577 0 0.577	1/2 0 1/2
2	3	0.500	1.500	0.666	1.0 0 1.0	1/2 0 1/2	1/3 2/3 1/3	1/6 2/3 1/6
3	2 P	1.000 0.577	1.577 †	P 0.635 S 1.000	0.577 1.155	1/6 2/3	0.577 0	1/2 0
		S1.000 0		Av. 0.817	0.577	1/6	0.577	1/2
4	2 P	0.707 0.557 * 0.150 *	1.821*†	P 0.707 S 0.707	1.115 0.815	0.622 0.333	0.644 0.172 0.471	0.622 0.045 0.333
	S	0.707 0.707		Av. 0.707	0.300	0.045		
Straight Single-phase	1	1.00	1.00	1.00	1.0 0 1.0	1/2 0 1/2	1/3 2/3 1/3	1/6 2/3 1/6

* One half of main has capacity of 0.557; other half 0.150; total capacity computed on basis that both halves are alike and of large capacity.

† On basis of primary capacities when there is a difference between primary and secondary.

a standard six-phase rotary converter will occasionally be less than that of two-phase transformers and a special two-phase converter. T connection, however, requires specially designed transformers, and the complication of starting taps and switches is a disadvantage.

The system requires two transformers of the same impedance, each equipped with two low-voltage windings, connected in such a way that they are displaced 180 deg. from each other, thus producing the six-phase relation.

The voltages are the same as for the T-connected three-phase system, and each transformer must be 15 per cent greater than half of the power required for the rotary.

The neutral can also be brought out on the six-phase side, although this furthermore increases the complication of the connections.

Three-phase to Two-phase

A number of schemes for three-phase to two-phase transformation, and vice versa, have been devised, but the most commonly used method is the T connection for either balanced or unbalanced service.

Balanced-T

The connection is shown in Fig. 27 and requires two transformers which on the three-phase side are connected in T, the number of effective turns in the teaser winding being 86.6 per cent of the number of turns in the main winding. On the two-phase side both mains and teaser windings are identical and pendent, when supplying a two-phase, four-wire system. Generally, the main and teaser transformers are made identical for the sake of interchangeability, in which case the three-phase winding is provided with both a 50 per cent and an 86.6 per cent tap, as shown by the dotted lines in Fig. 27, so that when used as a main the 50 per cent tap is used and when as a teaser the 86.6 per cent tap is used, the 13.4 per cent winding being left idle. Each of the two halves of the three-phase winding should furthermore be distributed over the entire winding length of the core in order to prevent flux distortion and poor regulation. The T connection requires 6 7 per cent more copper than single-phase transformers delivering the same power on account of the idle copper in the teaser and also on account of the fact that wattless currents flow in the three-phase side of the main winding.

The neutral of the three-phase side, which is one-third the height of the teaser winding, can be brought out for four-wire operation, although the transformer construction is somewhat complicated thereby. When operating without the neutral point grounded on the three-phase side, the maximum insulation strain, if a permanent ground occurs, is equal to the line voltage V.

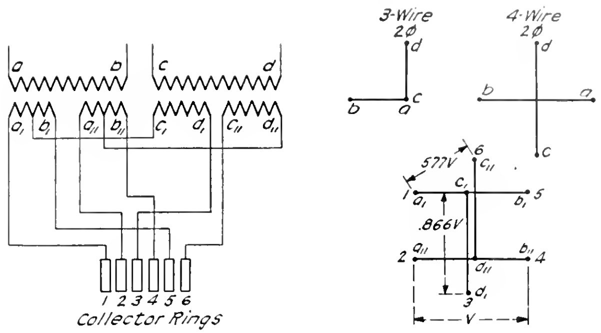


Fig. 26

Unbalanced-T

This connection may sometimes be of use in emergency conditions where a transformer with an 86.6 per cent tap is not available and a teaser transformer of the same voltage as the main transformer must be used.

In this connection two transformers of exactly the same capacity and voltage are used. The phases, however, are no longer strictly 120 degrees apart, and it is assumed that the same connection is used at each end of the line. As it is not a true three-phase system, any attempt to operate in multiple with a three-phase system or three-phase apparatus will cause seriously unbalanced currents.

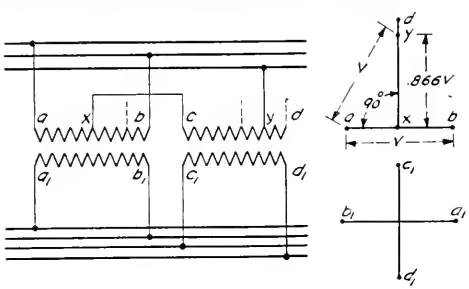


Fig. 27

The unbalanced T connection occurs when voltage is applied from the two-phase side. When balanced three-phase voltages are applied the voltages on the two-phase side will be unequal.

The connections and voltage relation of this system are shown in Fig. 28. With equal currents in the two-phase system, the currents in the three transmission wires will be the same as in the coils, namely: $a = 112$ amperes, $b = 112$ and $d = 100$, with the voltages as indicated in the diagram.

An unbalancing of the two-phase distributing network affects the currents in the three transmission wires, in that an increase of the load on phase V further increases the unbalancing, while if phase E be loaded in the neighborhood of 15 per cent in excess of phase D, the transmission line currents become practically balanced.

With no neutral the maximum insulation stress under all conditions arising from a permanent ground would be 1.12 times V.

Symmetrical

In the two previous T-connected methods, the two-phase windings are electrically distinct. There are, however, a number of schemes in which the windings on the two-phase side are electrically interconnected in one way or another.

Such a system of connections is shown in Fig. 29. It consists of three windings, one for each phase. Two of the phases are identical, each consisting of two coils, wound for 0.577 times the two-phase line voltage and having a current capacity of 0.577 times the

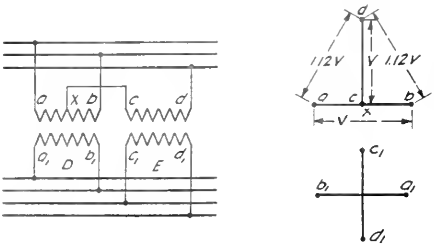


Fig. 28

two-phase line current. The third phase consists of three coils, one being wound for 0.577 times the line voltage and the other two being identical and wound for 0.212 times the line voltage. The respective current capacities are 0.421, 1, 1 times the line current.

One advantage of this system is the fact that voltages and currents do not exceed those which would occur in single-phase operation, giving an internal power-factor of the system of 100 per cent, whereas in the T connections the average power-factor is only 96.4 per cent. The three-phase side may be connected either delta or Y. This connection, requiring less copper and being slightly more efficient than the T connection, is recommended in place of the T connection for three-phase units, provided no taps are required on the two-phase side. If single-phase units are desired, the use of this connection becomes doubtful owing to the multiplicity of leads and coils on the two-phase side.

Three-phase to Three-phase/Two-phase

It is possible by means of transformer connections to derive from a three-phase primary circuit a four-wire secondary circuit, three

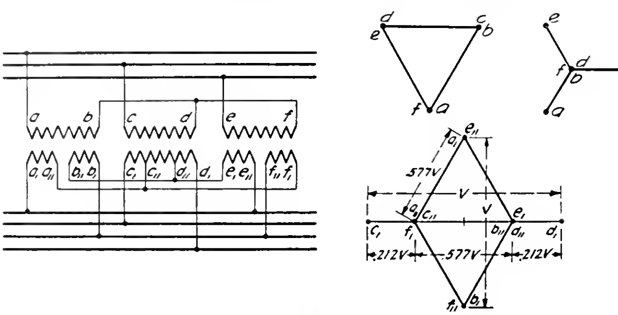


Fig. 29

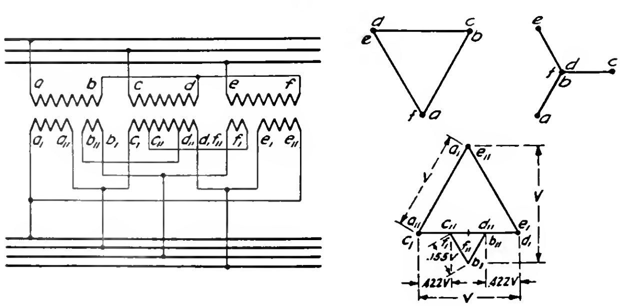


Fig 30

wires of which represent a three-phase system and the four wires making a two-phase system. From such a system independent three-phase or two-phase loads may be taken simultaneously. This may be accomplished by three single-phase transformers provided with special windings or by one three-phase transformer, as shown in Fig. 30. Primary winding may be connected either Y or delta and is in no wise different from an ordinary three-phase winding. The secondary, however, is provided with 15½ per cent coils in two of the phases and 15½ per cent taps in the other phase, which are interconnected as shown in Fig. 30.

This may also be accomplished by means of two transformers T connected as shown in Fig. 31.

The choice between the two methods given above of obtaining three-phase and two-phase on four wires depends for the most part upon whether the three-phase or the two-phase load predominates. Where the three-phase load is predominant, it is evident that the connection given in Fig. 30 is superior, but where the two-phase load predominates, the T connection is preferable.

Three-phase to Six-phase

In transforming from three to six-phase, there are four different connections, which may be used, namely:

Diamentrical.
Double-delta.
Double-Y.
Double-T.

Diametrical

The diametrical connection, as represented in Fig. 32, is the most commonly used of all three-phase to six-phase transformations, and there is very little reason for using any other connection for the operation of six-phase converters. It requires only one low-voltage coil on each transformer which is connected to diametrically opposite points on the armature winding. It furthermore gives the simplest arrangement of switches, trans-

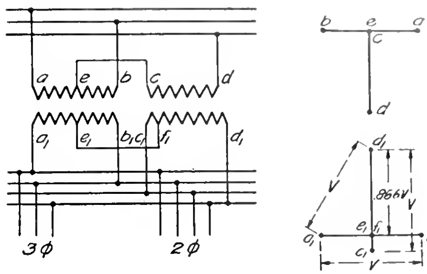


Fig. 31

former taps and connections for starting six-phase converters from the alternating current side, while on the other hand it is possible to operate a six-phase converter at reduced capacity with one transformer out of service, leaving the other two connected across their respective diameters.

With diametrically connected low-voltage windings, the high-voltage windings should preferably be connected in delta so as to avoid the triple frequency harmonics of the e.m.f., as described under Y—Y connection on page 254. With regulating pole converters, however, the high-voltage windings must be connected Y on account of the fact that the third harmonic voltage is made use of to obtain the direct-current voltage regulation, and in such a case the windings must be insulated for double line voltage to ground

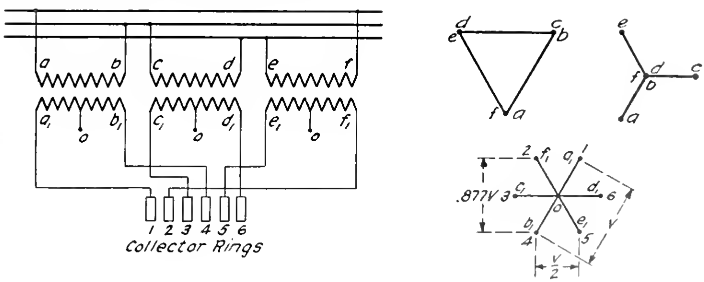


Fig. 32

and 3.46 times normal Y voltage across windings, due to the presence of the third harmonic e.m.fs. The middle points of the diametrical windings can readily be connected together and brought out for three-wire Edison service, the unbalanced three-wire direct current having no distorting effect. Arrangements should then be made for opening the neutral connections during starting to avoid short circuit. When used with regulating pole converters the neutral must be isolated.

1.73 times the diametrical voltage may be obtained by connecting the coils in Y, in which case the neutral should be grounded, and if the high-voltage windings are Y-connected the system is subject to the dangers of the third harmonic e.m.fs. as previously explained. It must also be ascertained if the insulation of the windings can withstand the increased voltage safely. If the secondary windings are made up of two distinct sections, which is not, however, standard practice, the connections may be made as in Fig. 33. The latter connection is, however, somewhat complicated and when three-phase operation with full output is desired and without change of voltage, the double-delta connection is generally preferable.

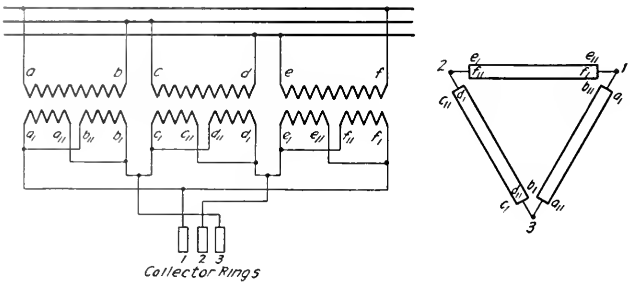


Fig 33

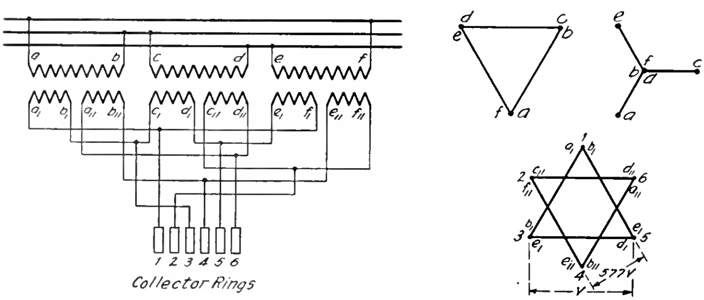


Fig. 34

The current in each coil on the low-voltage side is equal to $I = \frac{\text{output of transformer in watts}}{3 \times \text{diametrical voltage}}$ assuming the load is balanced and that the power-factor is unity.

With six-phase diametrical connection with common neutral, one-half the output can be taken from the low-voltage side for operating three-phase without change of diametrical voltage. If full three-phase output should be desired, the coils can be connected in delta, in which case the diametrical voltage is increased 14 per cent. The full three-phase output at

Double-delta

For the double-delta connection two independent low-voltage coils are required for each transformer, as shown in Fig. 34. The second set are all reversed, and then connected in a similar manner to the first set, so that the two deltas are displaced 180 degrees.

The high-voltage windings should preferably be connected delta, as it permits the system to be operated with only two transformers, in case one should be damaged

The current in each coil for double-delta is equal to $I = \frac{\text{output in watts}}{\text{delta voltage} \times 2 \times 3}$ and the current in each line equals $I \times 1.73$.

Full output, three-phase may also be obtained by connecting as shown in Fig. 33.

pole converters, but in this case the two low-voltage neutrals must not be connected together. Where the high-voltage windings are Y-connected the danger of Y—Y operation should be considered, and the neutral should be grounded.

The current in each leg is equal to $I = \frac{\text{output in watts}}{\text{Y voltage} \times 1.73 \times 2}$ and the line current has the same value.

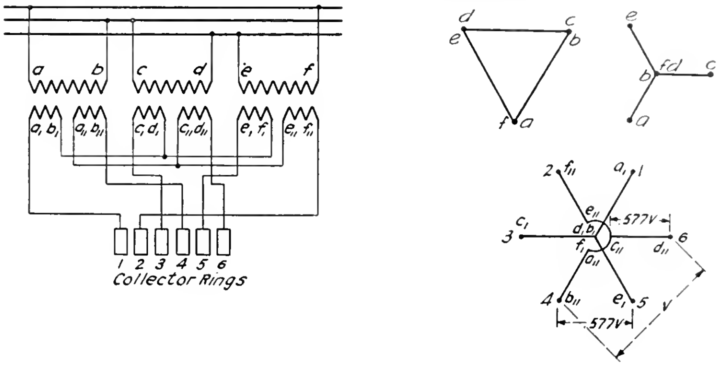


Fig. 35

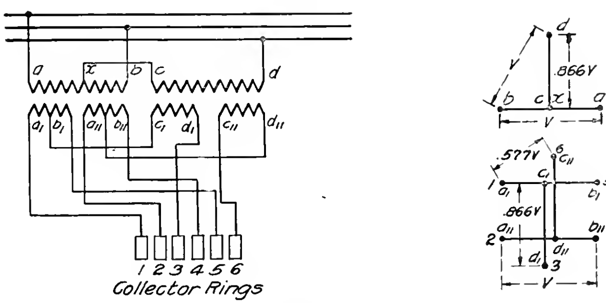


Fig. 36

Double-delta connection cannot be used with Edison three-wire service, as it has no neutral, and in such cases separate auto transformers would be required.

Double-Y

Like the double-delta, this system requires two sets of low-voltage coils, displaced 180 degrees, as shown in Fig. 35.

The high-voltage windings may be either delta or Y-connected, even with regulating

Double-T

Fig. 36 represents the double-T connection for transforming from three-phase to six-phase. The low-voltage connections are similar to the two-phase/six-phase system shown in Fig. 26, and the high-voltage windings are connected in T.

Figs. 33, 34, 35 and 36 are the connections of single-phase transformers used for six-phase operation, and they do not apply to three phase units. *(To be Continued)*

SOME MECHANICAL ANALOGIES IN ELECTRICITY AND MAGNETISM

By W. S. Franklin

This article was prepared especially for the Review by Professor Franklin, and the material was largely taken from Franklin & McNutt's two volumes, "Electricity" and "Advanced Electricity and Magnetism." We hope that these analogies will help to an understanding of some electrical problems that may often have seemed obscure. Professor Franklin urges every reader to try for himself the more important experiments, as an actual ocular demonstration is always more convincing than a written narrative.—Editor.

Certain fundamental equations in the elementary theory of electricity and magnetism are identical to equations in mechanics,* and this identity of mathematical forms carries with it a group of complete analogies between mechanics and electricity and magnetism. These analogies are familiar to everyone in a vague and incomplete way. The object of this article is to show the use of these analogies in their precise forms, especially in their bearing on alternating current phenomena.

Consider a heavy body which moves without friction. The effect of a force on such a body is to make its velocity increase at a certain rate. Indeed

$$F = M\frac{dv}{dt} \qquad (1)$$

where F is the force (expressed in suitable units), M is the mass of the body, and $\frac{dv}{dt}$ is the rate of increase of the velocity of the body.

Consider an electric circuit or coil which has no resistance. The effect of an electromotive force on such a circuit would be to make the current in the circuit increase at a certain rate. Indeed

$$E = L\frac{di}{dt} \qquad (2)$$

where E is the electromotive force, L is what is called the inductance of the circuit, and $\frac{di}{dt}$ is the rate of increase of the current i in the circuit.

From equations (1) and (2) it is evident that electric current i corresponds to velocity v in mechanics, and that what is called the inductance L of a circuit is exactly analogous to mass M in mechanics. Also it is evident that electromotive force E is analogous to mechanical force F.

Consider a helical spring. The effect of a force F is to stretch the spring; and the elongation q' is proportional to the stretching force F so that we may write:

$$q' = C'F \qquad (3)$$

where C' is a proportionality factor having a definite value for a given spring.

Consider a thin layer of insulating material between two large sheets of metal. Such an arrangement is called a condenser. The effect of an electromotive force E on such an arrangement is to draw a certain amount of electric charge q out of one metal plate and push it into the other metal plate, and q is proportional to E. Therefore we may write

$$q = CE \qquad (4)$$

where C is a proportionality constant which is called the capacity of the condenser.

From equations (3) and (4) it is evident that the electric charge q which has passed through a circuit is the analogue of distance moved, and that the capacity C of a condenser is the analogue of the elastic or yield constant C' of a spring.

THE FUNCTIONS OF THE CHOKE COIL IN THE LIGHTNING ARRESTER

The hammer exerts very large force on the ball for a very short time, and this force sets the heavy ball in motion very quickly. The ball then continues to move for a relatively long time, slowly compressing the elastic

When lightning strikes the trolley wire a very large electromotive force acts for a very short time between trolley wire and ground. This electromotive force sets up a current through the choke coil (an inductance) and

* A partial list of these equations is given in Franklin and Williamson's *Elements of Alternating Currents*, pages 15-16.

cushion and exerting a comparatively small force on the wall for a comparatively long time. Thus the ball and cushion convert the very large and short-time force of the hammer blow into a comparatively small and long-time force as exerted against the wall

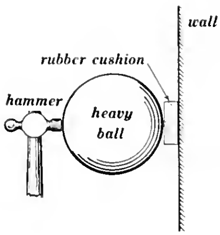


Fig. 1

If the cushion is replaced by a rigid block, and if ball and wall are assumed to be entirely rigid then the force exerted on the wall would be exactly as if the ball were not there.

this current continues to flow for a relatively long time, slowly charging the condenser and building up a comparatively small electromotive force across the condenser terminals and across the generator terminals. Thus the choke coil and condenser convert the very large and short-time electromotive force due to the lightning stroke into a comparatively small electromotive force of long duration, as acting across the generator terminals.

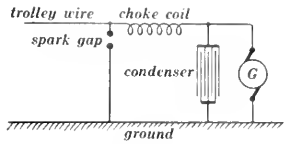


Fig. 2

If the condenser is disconnected, if there is no condenser effect in the end turns of the generator, and if the generator inductance is very large, then the electromotive force exerted across the generator terminals would be exactly as if the choke coil were not there.

ANALOGUE OF LEADING WATTLESS CURRENT IN A CONDENSER

A flat spring is clamped in a vise, and the free end of the spring is moved back and forth by the hand. *The end of the spring moves at its maximum velocity in the positive direction one-quarter of a cycle before the maximum pull in the positive direction is exerted upon it.* Similarly, the maximum positive value of current in a condenser occurs one-quarter of a cycle before the maximum positive value of alternating electromotive force is exerted on the condenser.†

ANALOGUE OF LAGGING WATTLESS CURRENT IN AN INDUCTIVE CIRCUIT

A heavy weight is attached to the free end of a flat spring the other end of which is clamped in a vise. The weight is set oscillating back and forth and the spring by its bending serves to visualize the force (alternating force) which acts on the oscillating weight. *The weight moves at its maximum velocity in the positive direction one-quarter of a cycle after the maximum force in the positive direction is exerted upon it.*

Receiver of High-Power Factor

A light spoon is used to stir stiff pancake batter by a rapid to and fro motion. The force exerted on the spoon by the cook's arm is nearly all used to overcome the resistance of the batter thus doing useful work, and only a negligible portion of the force exerted by the cook's arm is used to start and stop (accelerate and decelerate) the spoon.

Receiver of Low Power-Factor

Imagine a cook trying to stir pancake batter with a heavy iron coupling pin by a rapid to and fro motion. The force exerted on the receiver (the coupling pin) would be nearly all used to accelerate and decelerate the pin, and only a small part of the force would be used to overcome the resistance of the batter.

Alternator with High Internal Inductance

The spoon (or coupling pin) is the receiving device in the above examples, and the cook's arm is the alternator. If the spoon were to fly out of the cook's hand we would have the analogue

† The student of physics who is content with a verbal statement is hopeless; let the thing be actually done. The above statement in italics is not to be taken on authority; get a spring and see for yourself. If this article is to be understood all of the experiments must be seen, or, what is infinitely better, done by the reader.

of dead short-circuit on the alternator (perfect freedom of movement corresponds to perfect freedom of flow of current). Why, under such conditions does not the cook's hand move back and forth with indefinitely large velocity values corresponding to the very large current values in a short-circuited alternator and wreck the kitchen?

Because, even supposing the muscular effort to be entirely unaltered by the "short-circuit" condition, the mass of the cook's arm limits the velocity values in the same way that the internal inductance of an alternator limits the current values on short-circuit even if the electromotive force induced in the armature windings were to be entirely unaltered by the short-circuit condition.

A Horse That Can be Fed by Driving Him Down Hill

One of the most troublesome things in mechanics is to understand the work or energy aspects of the stirring of pancake batter with a heavy coupling pin. Anyone can understand that very little work is done on the batter, but everyone knows that a great deal of work is done by the cook. The case of the alternator, however, is different; very little work is done by a low power-factor receiver, and *correspondingly little work is done by the alternator*. The important difference between the cook and the alternator is that the cook is not a pure mechanism. The cook's arm cannot be put into condition to do work by forcibly bending it. Or, in other words, to forcibly bend a man's arm is not equivalent to giving the man food. To understand completely the energy relationship between an alternator and a low power-factor receiver one must get far enough away from homely experience to realize that there is a kind of horse that can be fed by driving him down hill. Let our coupling pin be connected to a spring of proper stiffness to accelerate and decelerate the pin, and let the cook exert only the force necessary to overcome the resistance of the batter, then all forcible bending of the cook's arm is eliminated and taken care of by the spring, and the spring *can* be "fed" by forcible bending.

INDUCTANCE AND CAPACITY IN PARALLEL

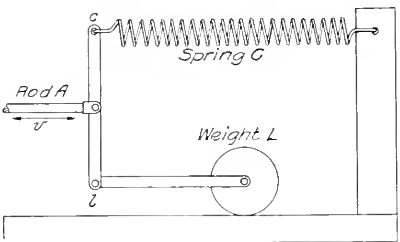


Fig. 3

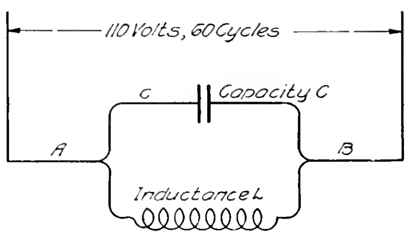


Fig. 4

An alternating force is applied to the rod A so as to give to it a to and fro velocity v.

This velocity divides between the ends c and l of the lever

An alternating electromotive force produces an alternating current i through A and B.

This current divides between the two branches c and l of the circuit.

The following experiments can be performed with the mechanism shown in Fig. 3.

(1) Move the rod A back and forth at low frequency; then the weight L will move but the end c of the lever will not move perceptibly. *Low-frequency alternating current will flow almost wholly through the inductance L in Fig. 4.*

(2) Move the rod A back and forth at high-frequency; then the end c of the lever will move, but the weight will not move perceptibly. High-frequency alternating current will flow almost wholly through the condenser *C in Fig. 4.*

(3) Move the rod A back and forth at a low-frequency with a high-frequency movement superposed thereon. The low-frequency movement will show itself almost wholly in the movement of the weight, and the high-frequency movement will show itself almost wholly in the

movement of the end c of the lever. This action corresponds exactly to the action of the arrangement for using a single telegraph wire for telegraph and telephone service simultaneously.‡

(4) At a certain critical frequency a very small to and fro movement of rod A sets up and maintains very large rocking movement of the lever, so that the to and fro velocity of end c and the to and fro velocity of end l are both very much larger than the to and fro velocity of rod A. *A small alternating current of critical frequency at A and B in Fig. 4 divides between the two branches c and l, and the current in each branch is much larger than the current at A and B.* This effect is called the multiplication of current by resonance.

(5) Hold end c of the lever so that it cannot move, and move rod A back and forth (preferably at the resonance frequency as described under (4), above). Then release end c of lever and note great reduction of motion of rod A for given to and fro movement of weight. This experiment shows how the alternating current in a transmission line (movement of rod A) can be reduced by connecting a condenser in parallel with a low power-factor (inductive) receiver.

INDUCTANCE AND CAPACITY IN SERIES

A weight attached to the end of a flat spring, the other end of the spring being clamped in a vise, is exactly analogous to inductance and capacity in series. Take hold of the weight and move it back and forth thus bending the spring. Then:

(1) At low-frequency nearly the whole of the force exerted by the hand is used to bend the spring, the force required to accelerate and decelerate the weight is very small in comparison.

(2) At high-frequency nearly the whole of the force exerted by the hand is used to accelerate and decelerate the weight, the force required to bend the spring is very small in comparison.

(3) If a low-frequency alternator is connected in series with a high-frequency alternator we get from the combination a high-frequency electromotive force superposed on a low-frequency electromotive force. If such an electromotive force be connected to an inductance and capacity in series, the low-frequency voltage will show itself across the capacity and the high-frequency voltage will show itself across the inductance.

(4) At a certain critical frequency the force exerted by the hand overcomes the resistance only; the force required to bend the spring is at each instant supplied by the inertia reaction due to acceleration and deceleration of the weight, and the force required to produce acceleration and deceleration is at each instant supplied by the reaction of the bent spring. It is correct to say that the alternating force exerted by the hand divides into two parts (one acting on the weight and the other acting on the spring) each of which may be much larger than the whole force exerted by the hand. This phenomenon is called the multiplication of electromotive force by resonance.

Use a strip of window glass as a spring, clamp it in a vise and attach a weight to its free end. Touch the weight with a feather repeatedly at a frequency equal to the frequency of free oscillation of the weight, and a violent state of oscillation will be slowly built up. Eventually the force action on the strip of glass by the inertia reaction of the weight will be large enough to break the glass. This is exactly analogous to the building up of a high voltage across a capacity by resonance so as to break down the insulation of the condenser (capacity).

(5) The use of a stiff spring to accelerate and decelerate a coupling pin which is used to stir batter, so that the cook need only exert the force necessary to overcome the resistance of the batter, is an example of power-factor correction (reduction of low power-factor to unity power-factor) by connecting a condenser in series with an inductance. This arrangement is not used in practice.

THE TRANSFORMER

Every student of electrical engineering has no doubt wondered what might possibly be the relation between the familiar devices for multiplying force in mechanics and the devices for multiplying electromotive force. A steady force of 110 pounds is easily "transformed" into a steady force of 1100 or 11,000 pounds by means of a lever; but a steady electromotive force of 110 volts cannot be converted into a steady electromotive force of 1100 or 11,000 volts by a transformer. Therefore it would seem that the lever and the transformer are wholly unrelated. However, a lever with a heavy weight instead of a fixed fulcrum is entirely analogous to a transformer; and the equations of motion of such a lever can be reduced to forms identical to the equations of a transformer including such complications as magnetizing current and magnetic leakage.

‡ See Franklin's *Electric Lighting and Miscellaneous Applications of Electricity*, page 245.

An ideal lever consisting of a weightless bar with an indefinitely large mass as a fulcrum is the exact equivalent of the ideal simple transformer. The to and fro velocities of the ends of the lever correspond to primary and secondary currents, the force (alternating) applied to one end of the lever corresponds to the voltage applied to the primary of a transformer, and the force (alternating) exerted by the other end of the lever corresponds to the secondary terminal voltage of a transformer. The velocity values are directly as the lengths of the two arms of the lever (this corresponds to the fact that the primary and secondary currents of an ideal transformer are inversely as the respective numbers of turns of wire), and the two forces are inversely as the lengths of the two arms of the lever (this corresponds to the fact that the primary and secondary voltages of an ideal transformer are directly as the respective numbers of turns of wire).

When the working end of the lever is rigidly fixed, we have a condition corresponding to open-circuited secondary. In this case the hand-end of the lever will not move perceptibly if the fulcrum mass is very great; but if the fulcrum mass is moderate, the hand-end of the lever will move as the fulcrum mass is accelerated and decelerated. This motion of the hand-end of the lever corresponds exactly to the magnetizing current of a transformer.

If the beam of the lever were without mass the forces at the ends of the lever would be in exact inverse proportion to the lengths of the arms of the lever; but if the mass of the lever beam is considerable or if there are weights attached to the ends of the lever then the lever acts like a transformer with magnetic leakage. Part of the force exerted by the hand is used to accelerate and decelerate the weight at the hand end, the *remainder* of the force exerted by the hand is transmitted to the other end of the lever (being multiplied in exact inverse proportion to the lengths of arms of lever); a portion of the force so developed at the working end of the lever is used to accelerate and decelerate the weight at the working end, and the *remainder* is exerted on the receiving device.

In all of the above the lever is supposed to be frictionless and the transformer coils are assumed to have zero resistance. There is no need to trace out the analogies between mechanical friction and electrical resistance, because, to make the analogy complete, one has to assume that the force of friction is proportional to the velocity of the moving body.

LOOSE AND CLOSE COUPLING

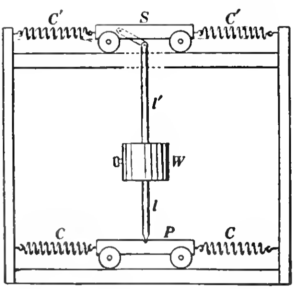


Fig. 5

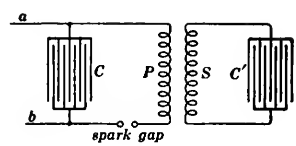


Fig. 6

Fig. 5 shows a mechanism which is exactly analogous to the inductively coupled (transformer connected) circuits in Fig. 6. Two cars S and P in Fig. 5 are each tied by coiled springs C' C' and C C as shown, and the cars are free to oscillate back and forth on friction rollers. The cars are connected by the vertical lever l l' as shown. Car P with its connecting springs represents the primary circuit in Fig. 6, and Car S with its connecting springs represents the secondary circuit in Fig. 6.*

If the weight (mass) W is large as compared with the mass of either car we have what is called *close coupling*. If the mass W is small as compared with the mass of either car we have what is called *loose coupling*.

* The double pendulum arrangement which is described by Professor F. R. Lyle in the *Philosophical Magazine*, Vol. 25, pages 567-592, is the exact equivalent of two circuits inductively coupled, but the details of the correspondence are not so simple. The usual double pendulum arrangement is not theoretically exact as a representation of coupled circuits.

If either car in Fig. 5 is held fast so that it cannot move, we have what is equivalent to open circuited primary or open circuited secondary as the case may be.

Four modes of oscillation are to be distinguished in the mechanism shown in Fig. 5 (or in the electrical arrangement in Fig. 6) as follows:

Part of System held fast	(*a*)	Oscillation of car *P* (primary) when car *S* is held fast (when secondary is open).
	(*b*)	Oscillation of car *S* (secondary) when car *P* is held fast (when primary is open).
Entire system free	(*c*)	Steady oscillation of entire system at high frequency *c* with velocities of cars opposite at each instant (primary and secondary currents opposite in phase).
	(*d*)	Steady oscillation of entire system at low-frequency *d* with velocities of cars in same direction at each instant (primary and secondary currents coincident in phase).

These four modes of oscillation are easily shown by the mechanism of Fig. 5.

The most general type of motion of the system consists of modes *c* and *d* together; and in this general type of motion the two circuits oscillate by turns, and the energy is handed back and forth from one circuit to the other repeatedly. This is easily shown by the mechanism of Fig. 5.

In order that all of the energy of the system may be handed back and forth, from primary to secondary and back again, the two frequencies *a* and *b* must be equal. The adjustment for bringing these frequencies to equality is called tuning. Tuning may be accomplished in the mechanism of Fig. 5 by placing weights on car *P* or on car *S*. With this adjustment made, car *P* may be set oscillating and it quickly comes to rest because it gives all its energy to *S;* then *S* quickly comes to rest because it gives all its energy back to *P;* and so on.

If frequencies *a* and *b* are not equal and car *P* is set oscillating, it quickly loses part of its energy as it sets *S* oscillating; then it takes all of the energy back again and *S* comes to rest; and so on repeatedly.

In the coupled circuits of the older type of wireless telegraphy, it is desired to get all of the energy from the primary into the secondary. Therefore the primary and secondary should be adjusted to make frequencies *a* and *b* equal. When the energy has been handed over to the secondary it must be prevented from being handed back to the primary by open-circuiting the primary by means of the quenched spark. The effect of the quenched spark may be shown by tuning the system in Fig. 5, setting car *P* oscillating, and suddenly grabbing car *P* and holding it fast the moment it loses all its energy and comes to rest.

The above discussion takes no account of friction and resistance.

THE ELECTRIC DOUBLER

Two tin cans, *C* and *D* open at top, are supported on insulating stands as shown in Fig. 7. Can *C* has a small amount of positive charge and can *D* an equal amount of negative charge, as indicated by the ten lines of force which diverge from *C* and converge upon *D*. Two metal balls *A* and *B* with insulating handles are placed in contact with each other between *C* and *D* as shown, and *a certain fraction of the lines of force from C to D converge upon A and diverge from B as shown.* This fraction is equal to ½ in the figure.

The balls *A* and *B* are separated from each other and (1) Ball *A* is carried to and into can *D* and touched to the interior of *D*, and (2) Ball *B* is carried to and into can *C* and touched to the interior of *C*. The result of operation 1 is to string the five lines of force from *C* to *A* clear across from *C* to *D*, and the result of operation 2 is to string the five lines of force from *B* to *D* clear across from *C* to *D;* balls *A* and *B* being left in neutral condition. The original ten lines of force from *C* to *D* have evidently been increased to 15, that is the charges on *C* and *D* have been multiplied by 1.5 by the above described operation, and by repeating the operation over and over again the charges on *C* and *D* can be multiplied by 1.5 over and over again (leakage on account of imperfect insulation being ignored). Therefore extremely minute initial charges on *C* and *D* can be quickly brought up to very large values by 50 or 60 repetitions of the above described operation, because, if the insulation is good, 60 repetitions will multiply the initial charges about one hundred thousand million times, and of course the initial voltage between *C* and *D* is multiplied to the same extent.

This experiment must be seen to be appreciated. Support the two cans C and D on clean blocks of paraffin in a warm dry room. Use best hard rubber or quartz tubes (closed at one end) for insulating handles for balls A and B. Attach a vertical strip of metal to the outer face of each can C and D, and hang several strands of fine

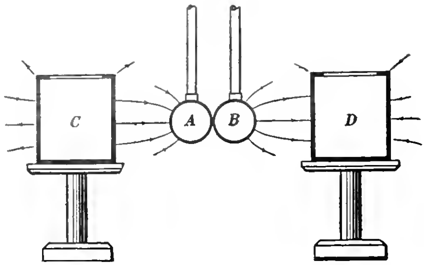


Fig. 7

cotton thread over the top edges of these strips of metal. These threads will stand approximately vertical at first, but as the charges on C and D increase they will stand out more and more nearly horizontal.

There is, perhaps, no mechanism which multiplies mechanical force in a manner strictly analogous to the multiplication of electromotive force by the electric doubler. A slight modification of the doubler to give a series of increasing charges (and voltages) which constitute an arithmetical progression instead of a geometrical progression is shown in Fig. 8. The opposite charges on plate A and hollow vessel B are to be multiplied (and thus the voltage between A and B multiplied). A metal ball with an insulating handle is touched to the battery terminal as shown in Fig. 1 and a certain number of lines of force form from ball to plate. Four lines are shown in the figure. These lines are then strung across from A to B by carrying the ball to and into B and touching it to the interior of B as shown in Figs. 2, 3 and 4.

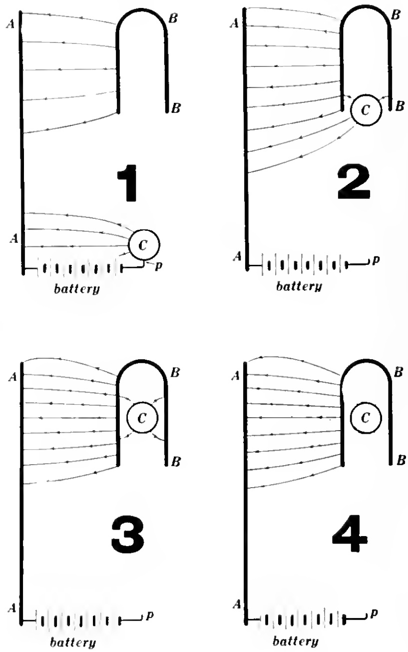


Fig. 8

The nearest approach to a mechanical analogue of the doubler as shown in Fig. 8 is to produce an increasing compression on a pack of cards by winding around the pack a string under tension.

ELECTRICITY OR ENERGY: WHICH?

When water is pumped through a pipe it is usually the amount of water delivered in a given time that is important, whereas the amount of power represented by the stream of water is not important except that it must be enough to carry the water where it is needed. But one might conceivably use a pump to drive water through a pipe for the sake of the heating effect of the moving water in the pipe or to drive a water motor placed somewhere in the circuit of pipe. In such a case one would be interested primarily in the amount of power represented by the stream of water because the desired effect (heating or motor driving) would depend upon the amount of power.

So it is in the use of the electric current. It is not electricity (whatever that is) that one uses, it is work or energy; and the important thing about an electric generator (such as a battery or dynamo) is its power output. The almost universal misunderstanding of the matter may be beautifully illustrated by considering the mechanism shown in Fig. 9. A wheel A drives another wheel B by belt. A person knowing nothing at all about machirery, and *especially a person having no available words to use in describing such an arrangement*, might look at the continuous stream of leather coming off wheel A at point p and decide to call wheel A a leather generator, and wheel B a leather motor. Everyone knows, however, that a driving wheel does not generate leather; it gives of work or energy, and the work is transmitted to the driven wheel by the belt.

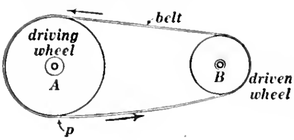


Fig. 9

It seems very ridiculous to speak of a belt wheel as a generator of leather, and it is equally absurd to speak of a battery or dynamo as a generator of electricity. One must be careful not to take electrical terms and phrases too literally.

To speak of a dynamo as an electric generator is common usage and it is therefore not seriously objectionable, but to speak of electricity as a motive power indicates a very serious misunderstanding. When it is proposed to drive a machine by a leather belt it is always understood that something must drive the belt, but when it is proposed to drive a machine by "electricity" it is not always understood that something must drive the "electricity." Electricity as applied in the arts is merely a go-between like a leather belt, and no one ever thinks of leather as a motive power, at least not in the engineering sense, however vivid our memories may be of the motive power of leather in homely sense.

This discussion of mechanical analogies is intended to illustrate the important use of sense material in the building up of physical ideas; indeed the understanding of any principle or relation in physics is a structure which is built up in the mind out of just stuff, like a house is built of wood or stone. Many teachers, especially teachers of mathematics, seem to think that ideas can be built up in a young man's mind by a sort of hocuspocus, out of nothing; but ideas, like everything else in this world must be made of something, and the problem of the science teacher is, by suggestion or by manipulation and experiment, to drag sense material into the young man's field of consciousness where it may be organized into a structure of ideas.

EFFICIENCY

By H. M. Hobart, M. Inst. C.E.

Consulting Engineer, General Electric Company

The physicists' definition of efficiency is "the ratio between the useful energy obtained from a particular machine and the energy put into it." In the author's article it is shown that it is important that the engineer should not lay undue stress on the physicists' definition, but that he should keep prominently in mind the broader conception expressed as follows by the late Professor E. J. Houston: "Efficiency is the ratio between the effect produced and the expenditure required to produce that effect." Although the Diesel engine's "energy" efficiency is much greater than the steam turbine's "energy" efficiency, the latter's "cost" efficiency, that is to say, its efficiency by Professor Houston's definition, will be greater, except sometimes for very high fuel costs (especially when associated with a high load-factor) than the Diesel engine's "cost" efficiency—Editor.

While high efficiency is a desirable attribute of a machine or of a system, it is usually only one of several attributes which are all desirable if they can co-exist in the system. If they cannot so co-exist, then one or more of these in themselves desirable attributes must be sacrificed, at any rate in degree. The true worth or value of a system may often be increased by sacrificing the, in itself, desirable attribute of high efficiency for a lower efficiency. Indeed, the problem may, and often does, consist in designing the system to have that particular efficiency which will give to the system its greatest worth or value. This is the principle underlying Kelvin's Law.

In these statements the term "efficiency" is employed in its most general sense of the ratio of power or energy output to power or energy input. With these considerations in mind, it will be agreed that engineers can rarely complete a thorough study of a machine or of a system without finding it necessary to give careful consideration to the efficiency aspects.

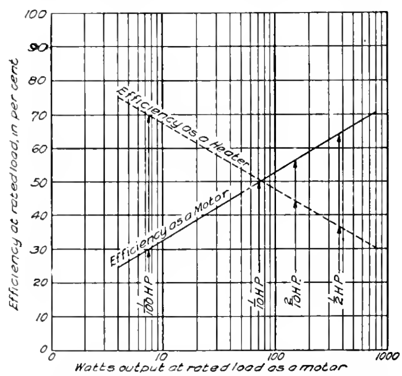
Efficiency of Electrical Machinery

High efficiency is commonly regarded as a distinctive attribute of electrical machinery and of electrical methods as distinguished from alternative methods of providing for our needs. Broadly this is correct but it might be better to express ourselves more guardedly and to the effect that *in many instances* electrical methods are characterized by higher efficiency than alternative methods, or possibly to put it that the efficiency associated with electrical methods is often *less low* than that associated with other methods.

Let us take a concrete instance. It is probably no exaggeration to state that as regards the efficiency of an electric motor of unspecified rating there present themselves to our minds, figures of the general order of magnitude of at least 85 per cent. The full-line curve in Fig. 1 is a typical curve of the rated-load efficiencies of 60-cycle single-phase high-speed fractional-horse-power motors. The curve does not refer to any particular line of motors, but is typical for all single-phase motors designed to meet competition. The dotted curve in Fig. 1, shows the corresponding efficiencies of such machines as heaters.

In Fig. 2 are given two curves respectively typical; the one, of the rated-load efficiencies of small high-speed d-c. motors and polyphase squirrel-cage 60-cycle motors, and the other of single-phase 60-cycle motors. No significance should be attached to the exact values of the efficiency since the influence of rated voltage, speed, and degree of enclosure occasion variations of several per cent.

The 10-h.p. values in the two curves in Fig. 2 are respectively 87 per cent for d-c. and for polyphase squirrel-cage motors and



Fog. 1. Efficiencies of Fractional Horse Power Single-phase High-speed Motors of Commercial Proportions

80 per cent for single-phase motors. While the ratio of the higher of these two efficiencies to the lower is only $\left(\frac{87}{80}=\right)$ 1.09, the ratio of the *losses* corresponding to the lower efficiency to the *losses* corresponding to the higher efficiency is $\left(\frac{20}{13}=\right)$ 1.54. Consequently

for the same temperature rise, and with the same design as regards ventilation, the 80-per-cent-efficiency motor would have to be a matter of some 50 per cent larger than the 87-per-cent-efficiency motor. This is rarely the case in practice; the handicap of the lower efficiency design in respect to size is usually reduced, partly by resorting to more effective ventilating means and partly by designing closer to the permitted temperature limits and by decreasing margins in all directions. Were resort made to similar extremes in the 87-per-cent-efficiency motors, their size would be reduced to some two-thirds of that of the 80-per-cent-efficiency motors, but the evolutionary stimulus being less acute, the greater margins are retained.

The *natural* influence exerted on the efficiency of a motor by the rated speed is rarely prominent in commercial lists, since there have come into existence preconceived ideas of acceptable efficiencies, in which the rated speed has but little influence. An example of a study of the *natural* relation between the rated speed and the efficiency of designs for 10-h.p. direct-current motors is shown in the curve plotted in Fig. 3 from data given by Dr. Rudolf Goldschmidt at p. 16 of his valuable little book entitled "Die Normalen Eigenschaften elektrischer Maschinen."

An investigation by the present author led to the results shown in the lower curve of Fig. 4 as the "natural" relation between

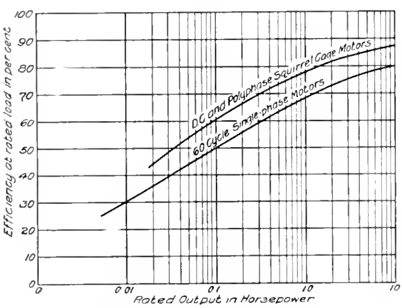


Fig. 2. Efficiencies of Small High-speed D-c. and Polyphase Motors and of 60-cycle Single-phase Motors

efficiency and rated speed for designs for 50-cycle squirrel-cage induction motors for a rated output of 10 horse power. The upper curve in Fig. 4 relates to an actual line of 60-cycle 10-horse-power squirrel-cage induction motors. In Fig. 5 are given curves showing results estimated by the author for the "natural" efficiencies of 375-r.p.m. squirrel-cage induction motors for various rated periodicities and for rated outputs of 10 h.p., 100 h.p. and 1000 h.p.

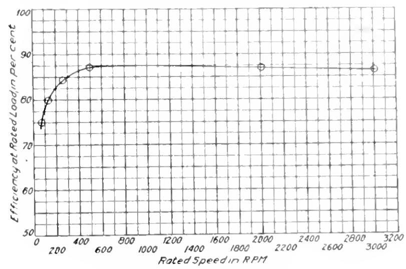


Fig. 3. Efficiencies of 10-h.p. D-c. Motors as a Function of the Rated Speed

A superficial consideration would incline one to believe that a high-speed machine would usually have higher efficiency than a low-speed machine, since it would be smaller, and (for a given permissible temperature rise) would have lower losses. Occasionally, however, the reverse is the case. As a notable instance may be mentioned direct-current motors, the design of which at high-speeds becomes very unfavorable, particularly with reference to commutation. In the process of contending with the designing difficulties at high rated speeds the efficiency suffers. The

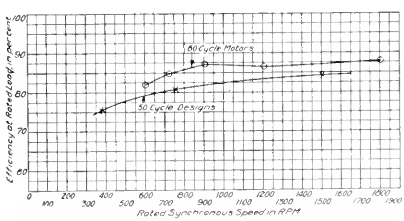


Fig. 4. Efficiencies of Some 50-cycle 10-h.p. Squirrel-cage Designs Indicating the Influence of the Rated Speed on the "Natural" Values, and the Actual Efficiencies of Some 60-cycle 10-h.p. Squirrel-cage Motors

present author once made a study of two groups of 150-h.p. motors, the one group being of the squirrel-cage induction type, while the other group related to direct-current designs of motors. There were five designs in each group and the rated speeds ranged from about 70-r.p.m. to about 1200-r.p.m. The efficiencies at rated load and at half load are shown in Fig. 6. It will be noted that the efficiencies of the induction motors increase considerably with increasing rated speed

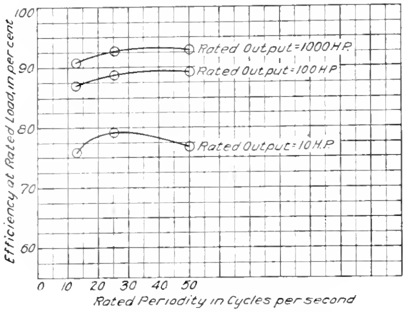


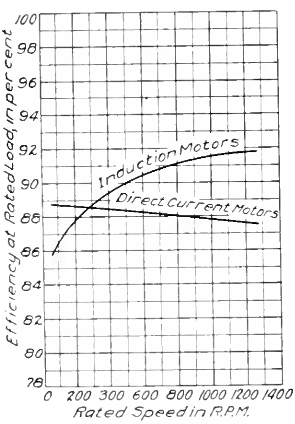
Fig. 5. Curves Showing the Influence of the Rated Periodicity on the Efficiency of Squirrel-cage Induction Motors

while there is a marked decrease in the efficiencies of the direct-current motors with increasing rated speed. The underlying premises for the designs were chosen with every effort to give full play to the "natural" tendencies. In practice these "natural" tendencies are apt to be obscured by prevalent conceptions with regard to the appropriate efficiency.

The low-speed induction motor suffers from other poor attributes besides low efficiency. Amongst these may be mentioned its lower stalling load. It also has a worse power-factor the lower the rated speed. The product of the power-factor and the efficiency used to be called the "apparent" efficiency and this expression is too valuable as a useful criterion of the quality of a machine to be permitted to fall into disuse, since for a given *true* efficiency, the lower the *apparent* efficiency the larger is the machine and the larger must be the conductors over which it is supplied and the larger must be the size of the electric generators supplying the system.

If from a 60-cycle three-phase 1000-volt supply it should be required to drive a tool at 240-r.p.m., and if 50-h.p. is necessary, we could drive direct from a 30-pole squirrel-cage induction motor or we could drive through 5:1 gearing from a six-pole motor. The two outfits have the efficiencies and power-factors shown in Table I.

The results show that in addition to the better efficiency of the geared drive, there is the important advantage that it consumes 25 per cent less current at rated load and 35 per cent less current at half load. The great lagging current of the low-speed motor is very objectionable from the standpoint of the supply company and its low stalling load makes it less reliable for the consumer. Furthermore the cost and size of the high-speed motor including its gearing are less than for the low-speed motor.



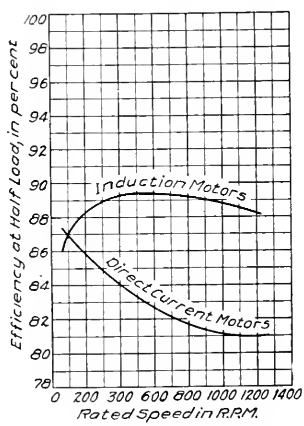


Fig. 6. Curves of Rated-load (left) and Half-load (right) Efficiencies of 150-h.p. Motors for Various Rated Speeds

Conventional Efficiency

In the latest edition (July, 1915) of the American Standardization Rules for Electrical Machinery, the subject of efficiency is approached in a very conservative manner. Formerly there was a good deal of confusion as to whether the I^2R losses should be based on the cold or on the hot resistance. If the parties concerned in a transaction decided that the cold resistance was not suitable then there arose a question as to whether the loss at various loads should be estimated on the basis of the particular temperature which would ultimately be attained at each particular load. Lack of agreement in these respects sometimes led to considerable confusion. 75 deg. C. has now been adopted as a standard reference temperature for efficiency specifications. Some parts of the windings of some machines will, at no load and at light loads, run at temperatures very much lower than 75 deg. But in other kinds of machines and at loads approaching the rating, the windings of some parts (for example, the windings on the rotors of turbo-alternators) will run at temperatures very much above 75 deg. But simplicity and definiteness are the chief requirements in a matter of this sort, and it is believed that the general acceptance of this reference temperature of 75 deg. for efficiency specifications marks a valuable advance in standardization. The present Rules set forth conventional values for certain classes of losses (such as brush-contact losses) and conventional methods of measurement for obtaining values which shall be regarded as the stray load-losses. The efficiency obtained by conforming with these various Rules is termed the Conventional Efficiency. Since the values introduced for all losses whose amount is uncertain are in the direction of being decidedly liberal, and since the I^2R losses are estimated at 75 deg. C., and since field rheostat losses are included, the Conventional Efficiencies are usually materially lower than the efficiencies heretofore set forth in tenders. It is important that

TABLE I

Number of poles		30	6
Type of motor		Gearless	Geared
Rated output		50-h.p.	50-h.p.
Speed of motor armature		240-r.p.m.	1200-r.p.m.
Speed of tool		240-r.p.m.	240-r.p.m.
Efficiency (including the gearing in the case of the 6-pole motor)	at rated load	83 per cent	87 per cent
	at half load	80 per cent	82 per cent
Power-factor	at rated load	0.72	0.91
	at half load	0.52	0.78
"Apparent" efficiency	at rated load	60 per cent	79 per cent
	at half load	42 per cent	64 per cent
Current input per phase	at rated load	36 amp.	27 amp.
	at half load	26 amp.	17 amp.

TABLE II

		NEW BASIS		OLD BASIS	
		Unity Power-factor	0.8 Power-factor	Unity Power-factor	0.8 Power-factor
36-pole, 312-kv-a., 200-r.p.m. three-phase, 2300-volt revolving field generator	Rated load	92.4 per cent	89.5 per cent	94.2 per cent	90.4 per cent
	3/4 load	92.3 per cent	89.4 per cent	94.0 per cent	90.3 per cent
	1/2 load	91.5 per cent	88.1 per cent	93.0 per cent	89.0 per cent
48-pole, 450-kv-a., 150-r.p.m., three-phase, 2300-volt revolving field generator	Rated load	93.2 per cent	90.6 per cent	94.2 per cent	91.3 per cent
	3/4 load	92.8 per cent	90.1 per cent	93.7 per cent	90.7 per cent
	1/2 load	91.7 per cent	88.6 per cent	92.8 per cent	89.5 per cent

there should be general conformance with these new standards for estimating the efficiency, since otherwise, superficial comparisons of competitive bids will reflect disadvantageously on the machinery whose specifications have been prepared in strict accordance with the American Standardization Rules for Electrical Machinery.

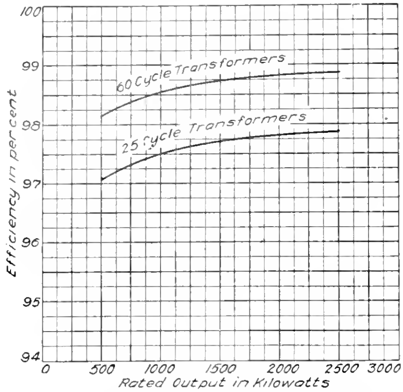


Fig. 7. Efficiencies at Rated-load and Unity Power-factor of Single-phase 60-cycle and 25-cycle Oil-immersed Water-cooled Transformers for a Primary Pressure of 40,000 to 50,000 Volts and a Secondary Pressure of Some 2500 Volts

The difference between the old and the new basis has been worked out for two typical alternators and the results are reproduced in Table II.

The lower efficiencies on the new basis are in part due to the inclusion of field-rheostat losses and in part to the employment of I^2R losses at 75 deg. C.; but the results are also materially affected by the rule that the stray load-loss shall be taken as the total extra loss at short circuit instead of at only one-third of this value as on the old basis. This greater conservatism is very desirable.

Transformer Efficiencies

In transformers of large capacity we find efficiencies sometimes approaching 99 per cent. In Fig. 7 are given curves of representative values for the full-load efficiencies of large 60- and 25-cycle transformers at their rated loads when these are of unity power-factor. Since the capacity of a transformer is determined by its kilovolt-amperes of output, the kilowatts output at lower power-factors is decreased. The losses for a given kilovolt-ampere load are, however, not decreased at the lower power-factors and consequently the efficiency suffers. Take the 60- and 25-cycle 2000-kw. transformers of the curves in Fig. 7. Since their efficiencies are 98.8 per cent and 97.8 per cent respectively their losses are:

$$\frac{2,000,000}{0.988} - 2,000,000 = 23,000 \text{ watts}$$

and

$$\frac{2,000,000}{0.978} - 2,000,000 = 43,000 \text{ watts.}$$

respectively. For the same kv-a. output, namely, 2000-kv-a., the kw. output at a power-factor of 0.80 (which is high, for example, for such work as supplying electricity to a single-phase railway) is reduced to only

$$0.80 \times 2000 = 1600 \text{ kw.}$$

and their efficiencies at their rated output of 1600 kw. at 0.8 power-factor are:

$$\frac{1,600,000}{1,600,000 + 23,000} = 98.5 \text{ per cent}$$

and

$$\frac{1,600,000}{1,600,000 + 43,000} = 97.4 \text{ per cent.}$$

The results are brought together in Table III.

There could be cited an almost endless number of interesting points relating to the efficiency of electrical machinery. Let us, however, now turn our attention to some more involved problems of efficiency.

Efficiencies of Steam and Electric Locomotives

If an electric locomotive is operated *at its rated load* the motors may deliver to the driving wheels of the locomotive a matter of 90 per cent of the electrical energy taken by the locomotive from the third-rail or overhead conductor. With its varying duties as regards speed, load, and number of stops, the *service* efficiency from pantograph to drivers will usually be at least 5 per cent lower, say 85 per cent, the precise value varying greatly with the conditions of working. If the weight of the locomotive were negligible in comparison with the weight of the train hauled, the "pantograph-to-drawbar" efficiency would be identical with the "pantograph-to-drivers" efficiency, say 85 per cent, the figure above suggested as typical. If the locomotive is not hauling any train, the "pantograph-to-drawbar" efficiency obviously falls to zero, as no work is performed at the drawbar.

If a 100-ton locomotive hauls a 900-ton train and if the tractive effort per ton of weight is the same for the locomotive as for the train, then 90 per cent of the output from the electric motors is expended behind the drawbar while 10 per cent is expended in propelling the locomotive. In this case, the "drivers-to-drawbar" efficiency is 90 per cent and the "pantograph-to-drawbar" efficiency is

$0.90 \times 0.85 = 76.5$ per cent.

If the tractive effort per ton of weight is, as will often be the case, greater or less for the locomotive than for the rest of the train, the efficiency from pantograph to drawbar will be lower or higher for the above composition of train than the stated result of 76.5 per cent.

Taking into account the various kinds of work required of locomotives, such as hauling all sorts of passenger and freight trains and carrying out shunting operations, we may fix ideas by taking 70 per cent as the overall efficiency from pantograph to drawbar for the locomotives on an electrically-equipped division of a hypothetical railway.

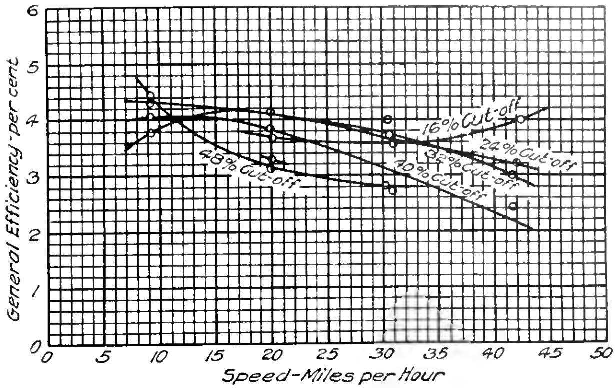


Fig. 8. "Coal-to-drawbar" Efficiency of a Characteristic Freight Locomotive

TABLE III

	EFFICIENCY AT RATED OUTPUT	
	60-cycle Transformer	25-cycle Transformer
Rated output = 2000-kw. at power-factor = 1.00	98.8 per cent	97.8 per cent
Rated output = 1600-kw. at power-factor = 0.80	98.5 per cent	97.4 per cent

Fig. 8 is reproduced from Bulletin No. 82 of the "Engineering Experimental Station" of the University of Illinois, and shows the relation between "fuel to drawbar" efficiency and speed, at various cut-offs, for Locomotive 958 of the Illinois Central Railroad, a consolidation type of steam locomotive. On page 7 of the bulletin it is stated that:

"Locomotive 958 is a characteristic freight locomotive of whose type there are about *twenty thousand* on American railways, or one-third of the total in service. Its weight and heating surface exceed the average values of these quantities for all consolidation locomotives by about twenty-five per cent. It is in most respects thoroughly representative of its type. Complete laboratory tests of simple consolidation locomotives are not common and include tests of only three different classes, all of which are somewhat smaller than the one here under consideration."

It is seen from the curves in Fig. 8 that the efficiency of this steam locomotive is about 4 per cent; that is to say, 4 per cent of the energy in the coal is delivered from the drawbar. Taking into account the varying conditions of actual service, and debiting the result with the coal consumed while standing and while performing non-earning operations, the efficiency will not be over 3 per cent. Let us keep it in mind as 3 per cent.

But we have not acquired any very useful comparative knowledge from the facts that, in the varied conditions of actual service, an electric locomotive will have an overall efficiency of 70 per cent while the corresponding efficiency of a steam locomotive is only 3 per cent. This is an instance of the uselessness of values of efficiency as criteria of worth of systems. The investigation must be pursued further. For propelling our electric train, coal is burned in an electricity-generating station. To ascertain, in the case of the electric locomotive, the efficiency from the coal to the drawbar we must examine the efficiencies of the remaining links in the transmission of energy from the coal to the train. Let us assume that from a large electricity-generating station, high-pressure three-phase electricity is sent over a 100-mile transmission line to substations from which the railway's overhead conductors are supplied with direct current. Of the energy in the coal burned in the electricity-generating station some 13 per cent* is delivered to the step-up transformers, which, in turn, deliver 97.5 per cent to the transmission line, which delivers 95.0 per cent to the 100-miles-distant step-down transformers, which deliver 97.0 per cent to the motor-generators in the substations, which deliver 87.0 per cent to the direct-current distribution system, which delivers 92 per cent to the locomotives, which (as we have already seen) deliver 70 per cent from their drawbars. The coal-to-drawbar efficiency is 6.5 per cent since:

$$0.13 \times 0.975 \times 0.950 \times 0.970 \times 0.870 \times 0.92 \times 0.70 = 0.065.$$

Thus from coal to draw-bar we have an efficiency of 6.5 per cent for electric operation as against 3 per cent for steam locomotive operation. But even these figures are utterly insufficient as criteria of the two systems. They suggest to us that, other things being equal, electrical operation of railways is the more attractive in districts and countries where coal is scarce and expensive. This, as we know, has proven to be the case. It will not be practicable in this article to complete this comparison of the two types of locomotives. Complete comparisons of this kind are formidable undertakings. But we can acquire a realization of some of the important factors involved, by confining our attention to the case of the *electric* locomotives. Instead of starting at the coal, let us start with the three-phase electricity delivered from the electricity-generating station to the step-up transformers. Let the cost of the electricity at this point be 0.60 cents per kilowatt-hour. The electricity's pressure is raised in the step-up transformers at an efficiency of 97.5 per cent. If the step-up transformers did not cost anything, and if the transformer attendants were not paid anything, and if no outlays were required for repairs, and if the transformers could be relied upon never to wear out or become obsolete, and if they were so indestructible as not to require to be insured, and if the investment were exempt from taxation, then the cost of the electricity delivered to the transmission line would be $\left(\frac{0.600}{0.975}=\right)$ 0.615 cents per kw-hr. As a matter of fact, proper allowances under the other heads increase the cost by a further 0.012 cents making it $0.615+0.012=0.627$ cents per kw-hr. as against the cost of 0.600 cents per kilowatt-hour prior to being stepped up. We can conceive of a "cost" efficiency which shall take all these factors into account so that, while the "energy" efficiency of the step-up transformers is 97.5 per cent, their "cost" efficiency is $\left(\frac{0.600}{0.627}\times 100=\right)$ 95.6 per cent. Similarly while the "energy" efficiency of the transmission line is 95 per cent its "cost" efficiency is 78.6 per cent bringing the cost of the electricity delivered to the step-down transformers up to $\left(\frac{0.627}{0.786}=\right)$ 0.797 cents per kw-hr.

Continuing this process up to the locomotive we arrive at results which are brought together in Table IV.

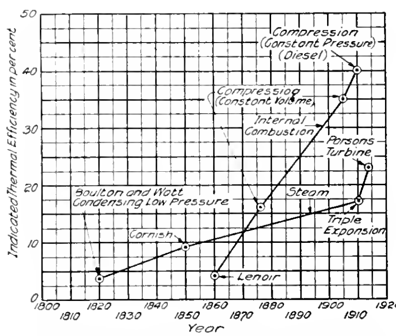


Fig. 9. Curves of Prof. Dugald Clark's Data Showing Progress in Increasing the Indicated Thermal Efficiencies of Steam Engines and Internal Combustion Engines

From the above table we obtain 71.8 per cent as the "energy" efficiency from generating station to trains (since $0.975 \times 0.950 \times 0.970 \times 0.870 \times 0.920 = 0.718$), and we obtain 39.6 per cent as the "cost" efficiency from generating station to trains (since 0.956×

* Indeed figures a couple of per cent better than this have lately been reported for the annual overall efficiency of large electricity-generating stations.

$0.786 \times 0.945 \times 0.706 \times 0.788 = 0.396$, and since $\frac{0.600}{1.51} = 0.396$).

This latter (the "cost" efficiency) is a true criterion; in other words, engineers should so take into account "energy" efficiency and cost as to arrive at the highest overall "cost" efficiency.

Efficiencies of Steam Engines and Internal-Combustion Engines

Interest also attaches to the progress being made *from year to year* in improving the efficiency of various kinds of machines. The curves in Fig. 9 relate to the improvement in the indicated thermal efficiency of steam engines and internal combustion engines. They are plotted from data given by Professor Dugald Clerk in the Thomas Hawksley lecture which he delivered in London last October before the Institution of Mechanical Engineers.

TABLE IV

	"Energy" Efficiency of:	"Cost" Efficiency of:	Increment of Cost (in Cents) Occasioned by:	Cost (in Cents per Kw-hr.) as Delivered From:
Electricity-generating station..			..	0.600
Step-up transformers...	97.5 per cent	95.6 per cent	0.027	0.627
Transmission line.......	95.0 per cent	78.6 per cent	0.170	0.797
Step-down transformers..	97.0 per cent	94.5 per cent	0.046	0.843
Substations...	87.0 per cent	70.6 per cent	0.350	1.193
Direct-current distributing system from substations to locomotives...	92.0 per cent	78.8 per cent	0.320	1.513
Overall "energy" efficiency .	71.8 per cent	. .		
Overall "cost" efficiency...	..	39.6 per cent		

We note from the final values of the curves that the Diesel engine has an indicated thermal efficiency of 40 per cent as against the steam turbine's indicated thermal efficiency of 23 per cent. The figure for the steam turbine must be multiplied by the boiler efficiency in order to make it comparable with the Diesel engine efficiency. Taking the boiler efficiency at 80 per cent we have, from fuel to mechanical energy developed in the cylinder, an efficiency of 40 per cent for the Diesel engine and $23 \times 0.80 = 18.4$ per cent for the steam turbine. Of the energy developed in the cylinder, only some 80 per cent will, in the case of the Diesel engine, be available as output of electricity from a direct-connected generator as against some 90 per cent for a steam-turbine-driven set.

Thus for rated-load efficiencies from the fuel to the outgoing terminals of the electric generator, we have for the two cases:

Diesel-driven generating set $40 \times 0.80 = 32.0$ per cent

Steam-turbine-driven generating set $0.80 \times 0.23 \times 0.90 = 16.5$ per cent.

Now although the Diesel-engine-driven outfit has practically twice as great an overall efficiency as the turbo-generator outfit, it by no means follows that it should be employed. The representative price of crude oil may be taken as a matter of 4 cents per United States gallon of 7.2 lb., or 0.56 cents per lb. One pound of crude petroleum has a calorific value of 18,000 British thermal units or (since a kw-hr. is equal to 3411 B.t.u.), a lb. of crude petroleum has a calorific value of $\frac{18,000}{3411} = 5.3$ kw-hr. per lb. Thus the fuel cost is:

$$\frac{0.56}{5.3} = 0.105 \text{ cents per kw-hr. of input}$$

or

$$\frac{0.105}{0.32} = 0.33 \text{ cents per kw-hr. of output from}$$

the electric generator.

For the steam turbine let us take as a basis a price of $4.00 per short ton of coal of a calorific value of 15,000 B.t.u. per lb., or $\frac{15,000}{3411} = 4.4$ kw-hr. per lb. One pound of this coal costs

$$\frac{400}{2000} = 0.20 \text{ cents.}$$

This reduces to a fuel cost of

$$\frac{0.20}{4.4} = 0.045 \text{ cents per kw-hr. of input}$$

or

$$\frac{0.046}{0.165}=0.28 \text{ cents per kw-hr. of output.}$$

So we see that notwithstanding that the steam-turbine outfit's efficiency is only half that of the Diesel outfit, the fuel cost per kw-hr. of output is actually lower (with the assumed prices of oil and coal) than for the Diesel outfit. If the comparison were modified to include the cost of lubricants the inferiority of the Diesel outfit would be still more marked.

But on top of these disadvantages we have those consequent upon the great weight, cost, and complexity of Diesel engines as compared with steam-turbines. We cannot enter upon a discussion of all these factors but it is of interest to point out that while the lightest designs of Diesel-engine-driven sets weigh some 300 lb. per kw. of rated output, steam-turbine-driven sets of large output weigh as little as about 30 lb. per kw. of rated output, or only one-tenth as much. In both cases, all auxiliaries (and in the case of the turbine plant, boilers and condensers) are excluded from the above weights, but after taking such auxiliaries into account the Diesel set with all its machinery costs at least three times as much as the steam turbine set with all its auxiliaries including boilers and condensing plant.

Attention has been drawn to these aspects of the comparison since they show conclusively that if the "cost" efficiency were worked out the result for the Diesel outfit, notwithstanding its very high "energy" efficiency, would be much below the "cost" efficiency of the steam-turbine outfit except for such conditions as very high priced coal or an exceptionally high load-factor.

The indicated thermal efficiency of 23 per cent credited by Professor Clerk to the Parsons turbine corresponds to a thermal efficiency of some 20.5 per cent when referred to the output from a direct-connected electric generator. Let us assume that this 20.5 per cent thermal efficiency is obtained with an admission pressure of 12 metric atmospheres (170 lb. per sq. in.), 50 deg. C. of superheat and a condenser pressure of 0.05 of a metric atmosphere (95 per cent vacuum). The total heat required to be imparted to one ton of feed water at 33 deg. C. to convert it into steam of the above temperature (187+50=237 deg. C.) and pressure is 770 kilowatt-hours. Of this amount, the convertible energy in an *ideal* engine when the condenser pressure is 0.05 of a metric atmosphere is only 236 kw-hr. Consequently the highest theoretically attainable thermal efficiency is

$$\frac{236}{770}\times 100=30.6 \text{ per cent.}$$

The ratio of the thermal efficiency actually obtained to that which is theoretically obtainable is usually termed the "efficiency ratio." For the case of the Parsons steam turbine

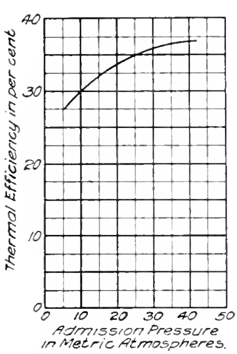


Fig. 10. Ideal Thermal Efficiencies of Steam Prime Movers with Various Admission Pressures, for an Admission Temperature of 300 deg. C and a Vacuum of 95 per cent in the Condenser

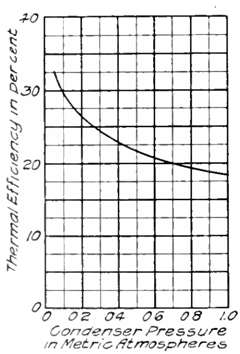


Fig. 11. Ideal Thermal Efficiencies of Steam Prime Movers for Various Condenser Pressures for an Admission Temperature of 300 deg. C. and an Admission Pressure of 16 Metric Atmospheres

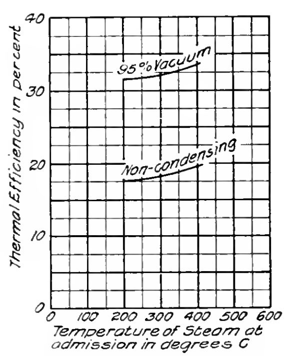


Fig. 12. Ideal Thermal Efficiencies of Steam Prime Movers for both 95 per cent Vacuum and Non-condensing, with Various Steam Temperatures at Admission, for an Admission Pressure of 16 Metric Atmospheres

cited by Professor Clerk the efficiency ratio referred to the output of a typical direct-connected electric generator is:

$$\frac{20.5}{30.6}\times 100 = 67 \text{ per cent.}$$

Efficiency ratios ranging to values of over 70 per cent are now obtained in large steam-turbine-driven generating sets of the leading manufacturers including Messrs. Parsons.

In Figs. 10, 11 and 12 are plotted the thermal efficiencies attainable in an ideal engine for various conditions of admission temperature and pressure, and of condenser pressure.

Man's Efficiency

In an article entitled "Wirkungsgrade" Dr. K. Schreber at p. 4 of vol. 20 (Jan 1, 1914), of the Zeitschrift fur Elektrochemie gives some very interesting data concerning Man's efficiency as a machine. The food consumed daily is stated to have a calorific value of about 4 kw-hr., and about 8 per cent of this (or one third of a kw-hr. per day) represents the mechanical output of which a man is capable. Averaged over 24 hours, this represents about 14 watts. A man can, of course, exert many times this power for a short time, as in climbing a hill, or in shovelling coal. If he compresses his efforts into one hour per day he presumably is capable of an output of about 340 watts, or nearly half a horse power; if he spreads it over four hours per day his output is reduced to about one-tenth of a horse power. If he and twenty-three other men work on a treadmill in relays of one hour each, they could drive a dynamo with a continuous rating of about 0.2 of a kilowatt and supply eight 25-watt tungsten lamps with its daily output of 1.8 kilowatt hours. If these men were each paid a dollar a day, their wages alone would amount to $5.00 per kw-hr. of output from the dynamo.

On the basis of an output of one-third of a kw-hr. per day as representative of a man's capacity as a machine, his total output in a working life of forty years would come to:

$$\frac{40\times 365}{3} = 4850 \text{ kw-hr.}$$

If we take this as worth 5 cents per kw-hr. the value of the man's life's work only amounts to $243 whereas his cost to the community during his whole life would be several tens of thousands of dollars. This amount of energy, 4850 kw-hr., could be delivered within a reasonable life, say ten years, from the generator of a motor-generator set, which, when completely installed, would only cost a matter of from $50.00 to $100.00.

If man's "energy" efficiency were 100 per cent, so that the 4 kw-hr. of energy input in one day's food should all be available as useful mechanical output, his life's work as a machine, on the basis of 5 cents per kw-hr. of his output, would only aggregate $3000. A man costs the community much more than this prior to attaining the average age of going to work.

In the light of these figures the wastefulness of employing animal power for plowing, stoking, lifting, etc., is clearly seen. Man's "energy" efficiency of 8 per cent from food to point of application is rather good, being twice that of a steam locomotive from fuel to drawbar. It is his low "cost" efficiency which utterly disqualifies him for usefulness in activities in which no mental effort or exercise of free will is required.

MOTOR DRIVE FOR STEEL MILLS

By F. B. Crosby

Power and Mining Engineering Department, General Electric Company

The following article on the applications of electric drive in the steel mill industry should be of widespread interest. The author states that the early installations were of direct-current motors but that the more recent ones have usually been of induction motors, because of the ability of the latter type machines to withstand excessive abuse. The employment of the induction motor, however, introduced the problem of developing a thoroughly satisfactory variable-speed control. The various methods that have been attempted in solving the problem—the ones that have been partially successful and the latest and most satisfactory developments—are clearly and comprehensively treated in this article.—Editor.

To many the story of iron and steel making affords one of the most fascinating chapters in the industrial growth of the United States. Few other branches of industry have shown as radical a departure from early methods or such expansion in commercial importance.

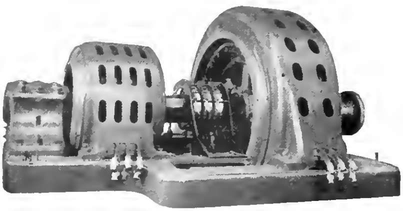


Fig. 1. 600 h.p., 514 r.p.m. Concatenated Induction Motor Set Arranged to Operate at Six Synchronous Speeds. Built for the Oliver Iron and Steel Company

Cause and effect have been closely related. Improved methods have cheapened production, this in turn has increased the demand and this again has stimulated further effort toward economy of manufacture.

Just as the advent of a practical steam engine made possible the development of industrial centers apart from natural sources of energy such as water-powers, so in even greater measure has the practical application of electric power increased the scope of human activity. Certainly, without the electric motor the steel industry could never have reached its present magnitude and marvelous efficiency.

Ten years ago the decision of the U. S. Steel Corporation to electrify its Gary plant gave an unprecedented impetus to the adoption of electric drive in steel mills. Single a-c. units of more than three times the normal capacity of any previously constructed were built with entire success, and while the aggregate installed capacity has never yet been equaled in a single plant, some conception of the growing importance of electric drive can be had from the fact that during the past year an aggregate of approximately 75,000-h.p. continuous rating have been added by a single manufacturer to the grand total of main roll drive in this country.

Although direct current motors for main roll drives were first in the field, the greater simplicity and unquestioned ability of the induction type to stand abuse soon left for

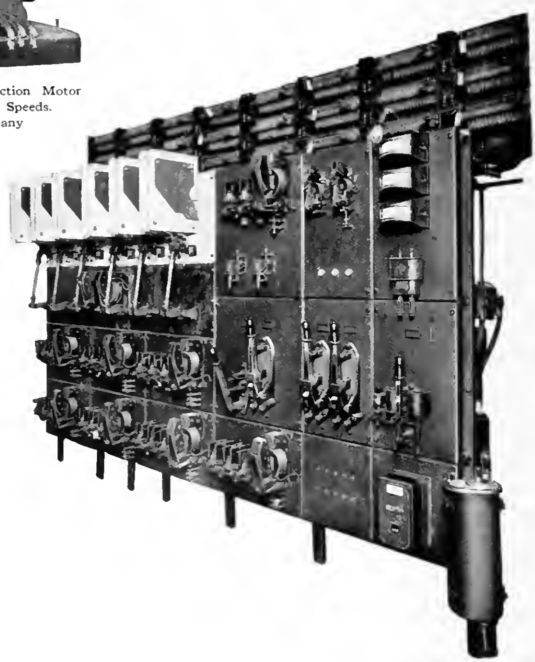


Fig. 2. Switchboard for Primary and Secondary Control Circuits of the Concatenated Induction Motor shown in Fig. 1

the direct current motor only a somewhat restricted application to reversing mills, and to those requiring adjustable speeds, constant under varying loads. Not content with the prestige already won by the induction motor in constant speed mill applications, greater effort was put forth to replace direct current for adjustable speed drives.

Several schemes, each a compromise, have been suggested and tried out in actual service where more than one speed was required. The most common arrangement is perhaps the multi-speed motor with one or two windings. Two speeds with a 2:1 ratio can be readily obtained with a single winding or a maximum of four speeds with two independent windings, each winding having leads brought out for two 2:1 speeds. In steel mill work it is rarely possible to select four synchronous speeds bearing the right relation to one another and to the mill requirements. Furthermore, while the efficiency of such a machine is good, the power-factor at the lower speeds, particularly for 60-cycle motors, is very poor and the cost very high.

A second method employs what is known as operation in concatenation. Two induction motors, one of which at least must have a phase wound rotor, are arranged on a common shaft and base. One or both of these machines may have either a double or a single winding and either may be operated independently of the other at its respective synchronous speed or speeds. Other speeds in concatenation, or cascade as it is sometimes called, may be obtained by connecting the secondary windings of the first motor to the primary of the second motor while the primary of the first is connected to the power circuits. The concatenated speed can be readily determined from the effective number of poles, $\frac{P_1 \pm P_2}{2}$, where P_1 equals the number of poles in the first motor and P_2 the number of poles in the second.

Fig. 1 shows a 600-h.p. set of this type installed by the Oliver Iron & Steel Co. Each motor has two independent windings, the machine at the right having a phase wound rotor and that on the left a squirrel-cage

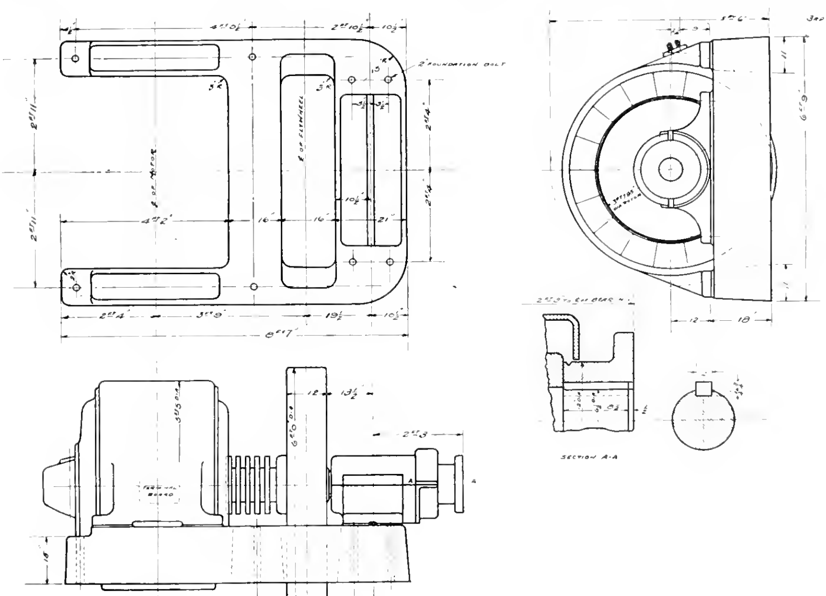


Fig. 3. Outline Drawing of 16/20/36 pole, 250/200/120-h.p., 300/240/133-r.p.m. Concatenated Induction Motor Set Installed by the Ludlum Steel Company. The two Motors are in one Frame

rotor. Six synchronous speeds are arranged for by the control.

Fig. 2 shows the combined primary and secondary control panels for the 600-h.p. concatenated set shown in Fig. 1. The master controller, main and pole changing oil switches,

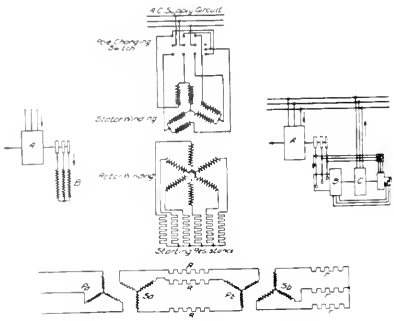


Fig. 4. Wiring Diagram of a Multispeed Motor, and also of a Concatenated Set

the air break primary reversing contactors, accelerating contactors, current limit relays, and starting resistance are all clearly shown. This equipment can be started, or stopped by reversing at full speed, from the master controller.

Fig. 3 shows the outline drawing of a 250-h.p., three-speed concatenated set installed by the Ludlum Steel Spring Co in which the two motors are combined in a single frame.

As with the multi-speed motor this method of obtaining adjustable speeds is open to the objections of high cost, complicated control, limited choice of speeds and low power-factor at low speeds.

Fig. 4 shows schematically the connection of a multi-speed motor and also of a concatenated set.

The third and simplest method of obtaining speed control is indicated in the sketch at the left of Fig. 4. It consists merely of inserting an adjustable resistance (*B*) in the secondary circuit of the induction motor (*A*). So long as the load remains constant the speed will remain constant for any given setting of the controller. Unfortunately, however, the average steel mill load is made up of a series of peaks interspersed with periods of friction load only. It should be obvious therefore that the series speed characteristic obtained with rheostatic control is entirely unsuitable for main roll drives.

Fig. 5 shows typical speed torque curves of a phase wound rotor induction motor with external resistance in the secondary, plotted from 100 per cent backward rotation to 100 per cent above synchronism. The similarity of the curves above and below synchronism will be referred to later. Assuming that sufficient external secondary resistance is in circuit to maintain 40 per cent speed with full load torque of 800 pounds at one foot radius as shown on curve No. 2, it follows that if this torque suddenly drops to 200 lb., corresponding to the friction load on the mill, the motor will accelerate along curve No. 2 to 85 per cent speed unless a prohibitive amount of resistance were cut in simultaneously with the change in load. In view of this simple fact, it is astonishing to note how frequently motor manufacturers are requested to quote rheostatic control for main line drives.

A second serious objection to rheostatic control for mill drives lies in the fact that for constant torque the input to an induction motor is constant irrespective of speed. To keep this point clearly in mind it is well to consider the machine under normal operation as combining two functions (Fig. 6), first, a pure motor action transforming electrical to mechanical energy and second, a simple transformation of electrical energy of primary frequency and voltage to a secondary frequency and voltage. At standstill the motor acts as a crude static transformer with maximum potential and line frequency at the slip rings. As the motor accelerates the slip ring frequency and voltage approach zero at synchronism with constant torque; therefore, at half speed, neglecting losses, 50 per cent of the input becomes useful work at the shaft and 50 per cent is dissipated as heat in the external secondary resistance. In other words, with rheostatic control the efficiency is reduced in proportion to the reduction in speed. No matter whether the torque increases, decreases or remains constant with change of speed, the secondary losses are always equal to

$$\frac{\text{slip}}{1-\text{slip}} \times \text{shaft horse power.}$$

It is evident, therefore, that both from the standpoint of speed characteristics and efficiency, rheostatic control is not desirable for rolling mill drives.

The first practical application of the adjustable speed a-c. drive was made in Europe.

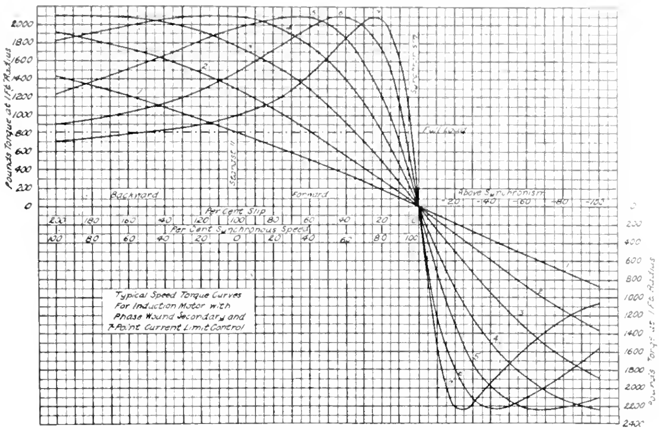


Fig. 5. Typical Speed-Torque Curves for Induction Motor with Phase-Wound Secondary and 7-point Current Limit Control

Out of a very considerable number of methods, more or less experimental, two, the so-called Kraemer and Scherbius systems, emerged on a commercial basis. In the early part of 1911 the General Electric Company began a careful and exhaustive study of the relative advantages and commercial possibilities of these and other systems. For reasons mentioned later, the Scherbius system received more favorable consideration and the first American speed regulating set was built similar to, but not identical with, the Scherbius motor. The results obtained with this first set so far exceeded expectations that negotiations were opened to secure the American rights to the Scherbius motor which, by the way, permitted with standard induction motor design a somewhat simpler control than did the experimental set as first built.

In the fall of 1912, so far as can be ascertained the first bona fide proposition to build a speed regulating set was made to the U. S. Steel Corporation in connection with the two speed 6500 h.p. universal plate mill motor at Gary.

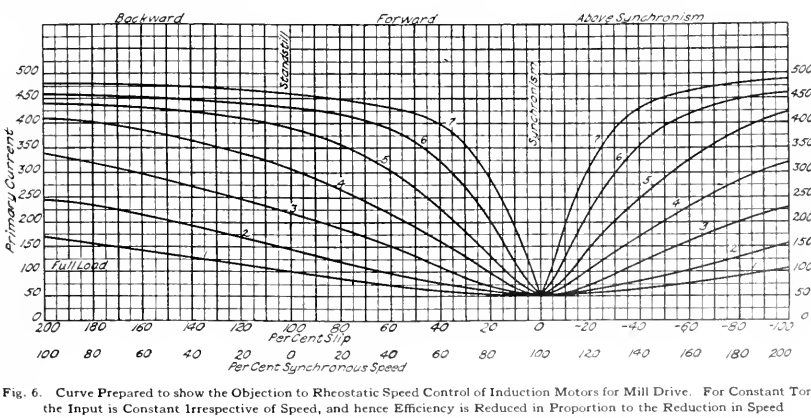


Fig. 6. Curve Prepared to show the Objection to Rheostatic Speed Control of Induction Motors for Mill Drive. For Constant Torque the Input is Constant Irrespective of Speed, and hence Efficiency is Reduced in Proportion to the Reduction in Speed

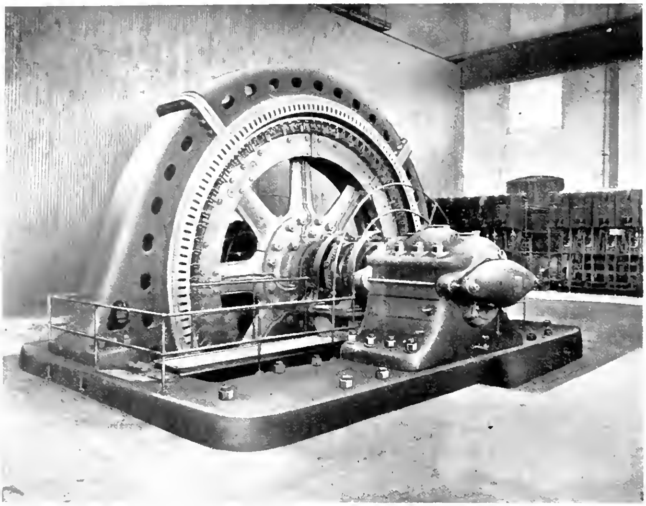


Fig. 7. 6500-h.p. 107 53-r.p.m., 6600-volt Induction Motor with Pole Changing Switch for Driving 60-inch Universal Plate Mill, Indiana Steel Company, Gary, Indiana

Fig. 7 shows this motor, rated I-28 56-6500-h.p. 107 53.5-M-6600 volts, which is the largest induction motor yet built for steel mill service. It has a continuous overload capacity of 8150 h.p. and a maximum torque corresponding to approximately 24,000 h.p.

It is of interest to note that many of the features incorporated in the Gary motors have since become recognized standard requirements in a-c. mill motor design. The massive frame and bearings, the steel rotor spider, breakable end thrust device and provision for sliding the stator parallel to the shaft to clear the rotor for examination, are all standard features.

The d-c. contactor control is shown in the background. Since this installation was completed a-c. contactors have been developed and are now almost universally used for large mill motor control.

Fig. 8 shows the 60-in. plate mill driven by the motor shown in Fig. 7. The vertical rolls are driven in this case through gearing from the main shaft.

Fig. 9 shows the general arrangement of equipment and connections proposed in 1912

Fig. 8. Main Rolls of Universal Plate Mill Driven by Induction Motor shown in Fig. 7

for obtaining continuous speed control from the lower synchronous speed of 53.5-r.p.m. up to approximately 86-r.p.m. That portion of the diagram to the left shows the motor and control as installed. At the time this proposition was made the Scherbius patent rights had not been secured and it seemed advisable to use what will be referred to as the rotary converter system of dynamic speed regulation. This is shown to the right and consists briefly of a suitable rotary converter taking the slip energy of the main motor at varying frequency and voltage and converting it to direct current at proportionate voltage. This direct current was to drive a motor-generator. The d-c. motor, on account of the large capacity involved, was laid out in two units with their armatures in series, the fields being separately excited. The driven unit is a standard induction motor. Hence when driven slightly above synchronism with its primary connected to the power system it operates as an asynchronous induction generator and returns to the system energy proportional to the reduction in speed of the main roll motor. Speed control is obtained by manipulation of the d-c. motor field. Strengthening the field of the d-c. motor reduces the speed, and weakening the field increases the speed of the main motor. The speed characteristic becomes practically that of a shunt wound d-c. motor with field control, the speed remaining constant for any given setting independent of variation in load.

Fig. 10 shows a diagrammatic arrangement of connections with distribution of losses as calculated for a definite condition.

A = 800-h.p. induction motor at 1200-r.p.m.
B – 160-h.p. kw. rotary.
C – 208-h.p. d-c. motor.
D – 150-kw. induction generator.

With 254-kw. (340-h.p.) at shaft and 422-kw. input to the motor at 720-r.p.m. there are 3.7-kw. loss in main motor, 10.8-kw. loss in

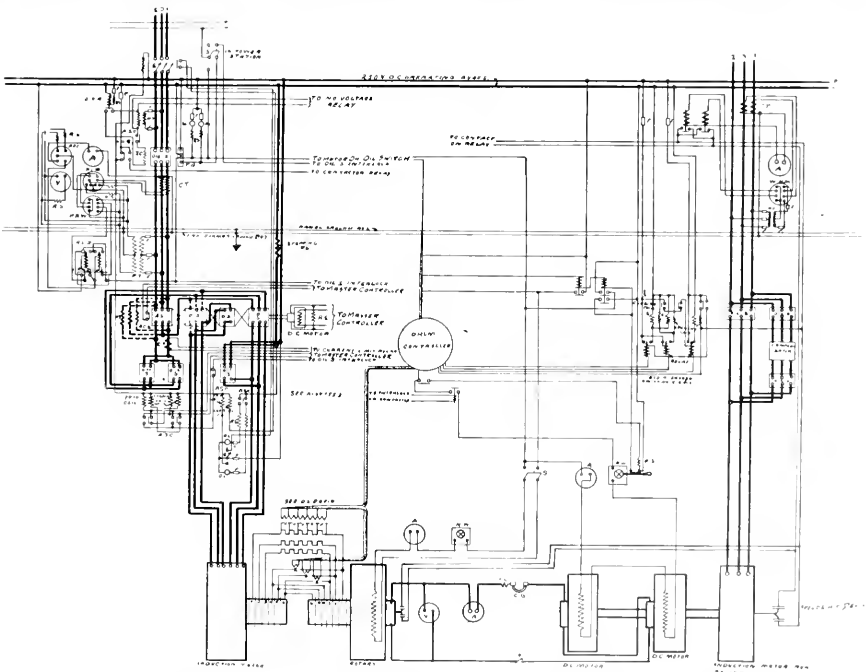


Fig. 9. Proposed Arrangement (1912) for Continuous Speed Control, ranging from 53.5-r.p.m. to 86-r.p.m.

rotary, and 29.3-kw. loss in motor-generator; leaving 125.2-kw. of slip energy to be returned to the system and showing an efficiency of 80 per cent with rotary regulating set as compared with 57.5 per cent for rheostatic control This also shows the original Kraemer

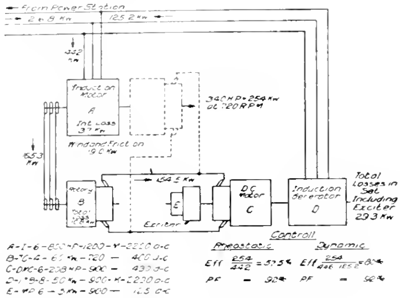


Fig. 10. A Rotary Converter Method of Speed Control for Induction Motors

idea of connecting the auxiliary d-c. motor to the shaft of the main motor and returning the slip energy mechanically.

Where the minimum speed of the main motor is sufficiently high and where constant power or increasing torque at reduced speed is required, this arrangement is sometimes used. Generally speaking, however, the slow speed direct connected d-c. motor will cost quite as much as or more than the higher speed d-c. motor and induction generator, since when forming a part of the mill unit it must be built sufficiently rugged to meet mill service, whereas if a separate set is employed the standard industrial construction is satisfactory. Furthermore, the separate set can often be placed in a room apart from the mill along with the control and better operating conditions can be maintained.

Fig. 11 shows the first rotary converter set with direct connected d-c. motor as built by the General Electric Company for the Union Rolling Mills. The 60-cycle motor rated 1400/950-h.p. at 600/405-r.p.m. with a 450-h.p. d-c. motor and a 325-kw. rotary is arranged to operate at constant h.p. at reduced speed. The contactor control panels for both primary and secondary are shown in the foreground.

Fig. 12 shows another view of this equipment.

Shortly after the Gary universal plate mill proposition was submitted, the American patent rights to the Scherbius system were secured and an order taken from the Forged Steel Wheel Company for one 1300-h.p. and one 600-h.p. motor, each with speed regulating sets of this type.

Fig. 13 shows one of these sets of 450-kv-a. capacity designed to give continuous speed control from 214 to 140-r.p.m. on the 1300-h.p. motor. The machine in the middle is a polyphase commutator regulating motor (PCR) which combines in a single unit the functions of the rotary converter and d-c. motor shown above. The machine on the left is a standard industrial type squirrel cage motor functioning as an asynchronous induction generator as described above. The small machine at the right is in design practically a duplicate of the polyphase commutator regulating unit and serves as an exciter, its function being strictly analagous to that of a d-c. exciter on a standard motor-generator. This latter exciter in turn receives its excitation from the slip rings of the main motor.

In European practice a special transformer with three independent phases is used, speed control being obtained by connecting different taps to the field winding of the polyphase commutator regulating unit. This arrangement has been used here in one or two instances, but Fig. 14, which shows such a transformer for seven running points, indicates the complexity of taps encountered if a large number of running points is required.

Fig. 15 shows the standard three-phase exciter field rheostat used with the polyphase exciter. These rheostats are easily made to give as many as 125 running points, which for all practical purposes gives continuous speed control. These rheostats are usually operated by means of a vertical lever very similar to the usual throttle control for engine drives, the full speed range being obtained by a single movement of the lever.

Fig. 16 shows the factory test of the 600-h.p. and 1300-h.p. motors and polyphase commutator regulating sets mentioned above.

In view of the apprehension which has been expressed in certain quarters relative to commutation difficulties with this type of machine it may be noted here that such fears are largely based on the sad results experienced with certain single-phase series a-c. commutator motors. The problem is much simpler with the three-phase com-

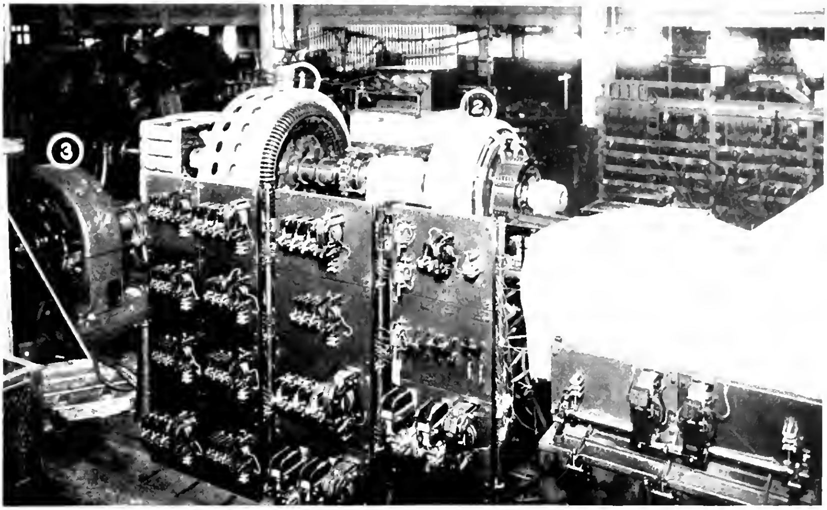


Fig. 11. Factory Test of a 12 Pole, 1400/950-h.p., 600/450-r.p.m., General Electric Mill Type Induction Motor with 0/450 h.p., 600/405-r.p.m. Direct-Connected Auxiliary Direct Current Speed-Regulating Motor and 325-kw., 750-r.p.m. Rotary Converter for Continuous Speed Control at Constant Horse-power Output Magnetic Control in Foreground. Installed at Union Rolling Mills, Cleveland

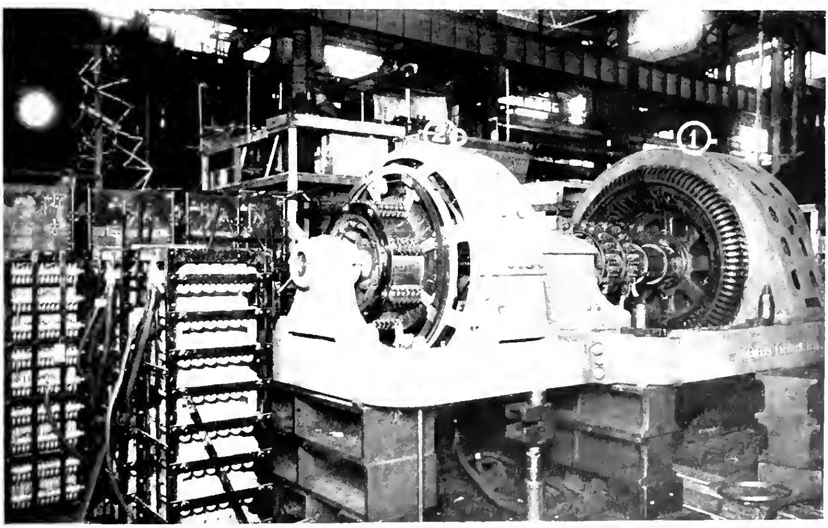


Fig. 12. Another view of the equipment shown in Fig. 11

pensated winding of the Scherbius design. In the second place, unless sparking is very severe, it is much less injurious with alternating current than with direct current due to the potential dying away to zero twice during each cycle. It may also be of interest to note that with the 600-h.p. motor driving a d-c. generator connected to a water box load of 900-kw., or practically 100 per cent overload on the motor, absolutely *no* sparking could be detected at any brush on the polyphase commutator regulating motor when the load was suddenly relieved by a circuit breaker or thrown on by closing a knife switch.

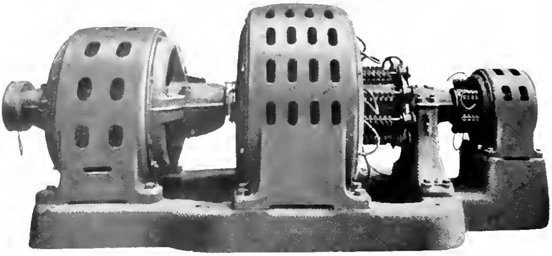


Fig. 13. 400-kv-a. Speed Regulating Set for 1300-h.p. Induction Motor, giving a Range of Speed Control from 214 to 140-r.p.m.

Fig. 17 shows schematically the general character of punchings and connection of windings. The main interpole compensating and armature windings are clearly indicated. The secret of perfect commutation lies largely in the proper design of the compensating winding, which is fully covered by the Scherbius patents. The polyphase commutator regulating motor is in effect a shunt wound machine with a series speed characteristic, due to the effect of increasing the armature voltage while maintaining constant excitation. It is this series speed characteristic which renders possible the induction generator action of the squirrel-cage motor referred to above.

Fig 18 shows the stator of a polyphase commutator regulating motor. The interpole as well as the main and compensating winding is clearly seen. The cost of these machines is relatively high, due to the fact that by comparison they consist of an induction motor stator and a d-c. armature, the most expensive parts of each type of machine.

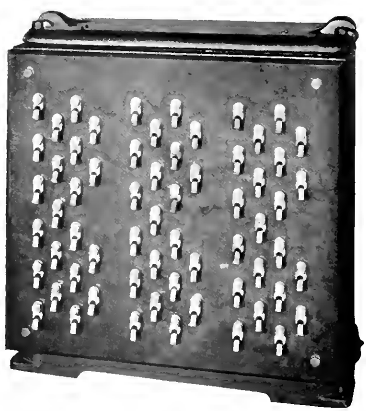


Fig. 14. Special Three-phase Transformer for Effecting Speed Regulation, Showing Complexity of Taps

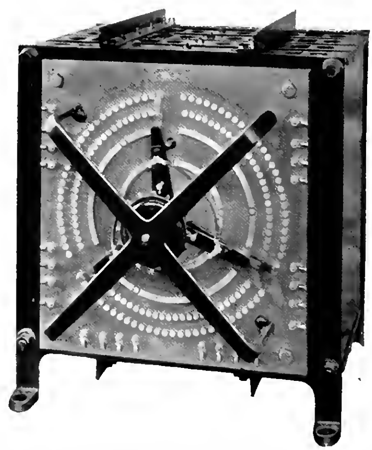


Fig. 15. Standard Three-phase Exciter Field Rheostat for use with Polyphase Exciter

Seven of these polyphase commutator regulating sets were sold on one order to the American Iron & Steel, all of which were put into operation without difficulties of any sort. This installation (Fig. 19) is of especial interest in that the motors replaced old steam engines and it was put into service by men accustomed to engine characteristics. Production has been increased fully 25 per cent over that obtained with engine driven units and now it is proposed to obtain a further 25 per cent increase by increasing the length of the cooling beds to permit handling larger billets.

In making the change from steam to electrical drive the American Iron & Steel Company made a clean sweep and have put in a strictly up-to-date equipment in every respect.

The type of motor house adopted can be seen in Fig. 19. This particular house contains the motor and control for the 8 in. roughing and 10 in. finishing trains. The structural work was done by David Lupton Sons Company. Re-enforced wire glass is used, the lower tier being transparent, thus affording the motor attendant a clear view of the mill.

Fig. 20 shows in another room, a 400-h.p. motor at 107-r.p.m. and a 200-h.p. motor at 375-r.p.m., each being provided with a polyphase commutator regulating set.

Fig. 21 is a view of the interior of the motor room for the 10-in. and 12-in. mill showing the direct connected 300-h.p. motor (500-r.p.m.)

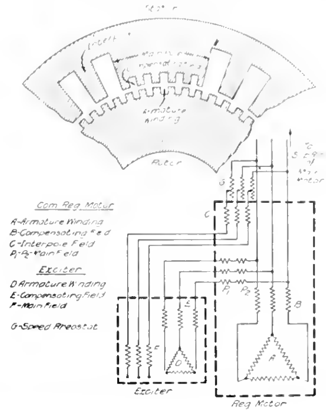


Fig. 17. Diagram of Punchings and Connections of Polyphase Commutator Regulating Set

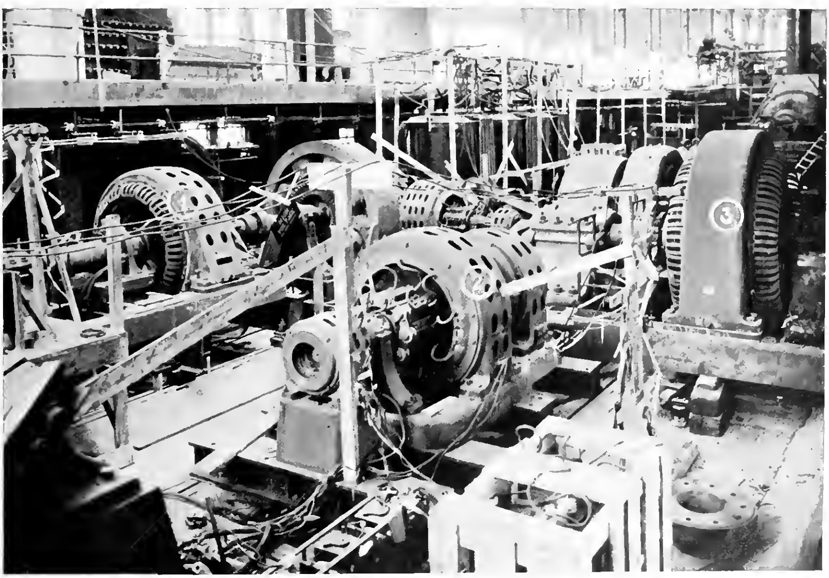


Fig. 16. Testing a 600 h.p. Rolling Mill Motor (1) with Regulating Set for 44 per cent Speed Regulation (2), and a 1300-h.p. Rolling Mill Motor (3) and Regulating Set for 35 per cent Speed Regulation

and flywheel for the finishing train, the polyphase commutator regulating set at the right and the control panels for the 300-h.p. motor and also for the 200-h.p. motor on the roughing mill.

Fig. 18. Stator of a Polyphase Commutator Regulating Motor

Fig. 22 is a shop view of the automatic controller for one of these sets, showing the primary reversing contactors, accelerating contactors, current limit relays and the notching back relay for producing the automatic slip of the flywheel. By opening the three-pole switch and throwing the five-pole switch down, the polyphase commutator regulating set is cut out and the motor run as a normal induction motor with or without rheostatic control.

The regulating set is started first by means of a standard hand-operated compensator. The main motor is then started and the polyphase commutator regulator set put into commission by a single movement of the master controller. Necessary interlocks insure the proper sequence of action and prevent possible mistakes on the part of the operator. The motor may be plugged in emergency by simply throwing the master controller to full reverse position, the polyphase commutator regulating set being automatically cut out. The desired speed reduction is secured by means of the three-phase rheostat shown in the preceding view (Fig. 6).

Particular mention should be made of the fact that the use of the PCR set adds practically nothing to the standard General Electric automatic current limit contactor control which has been in use for years with large steel mill induction motors.

Fig. 23 shows efficiency curve "*B*," and power-factor curve "*A*," for a single speed motor and polyphase commutator regulating set as compared with efficiency curve "*C*" and power-factor curves "*D*" and "*E*" for two speed motor with rheostatic control.

Fig. 24 shows power-factor and efficiency curves for the general case with torque decreasing, increasing, and constant. Note that as the total required regulation increases the efficiency curve becomes slightly lower.

Fig. 25 shows a typical excitation curve for the PCR exciter. While the slip ring potential varies uniformly the field resistance increases slowly at first with increasing field current and then more rapidly until at a point corresponding to about 5/6 of the total range the resistance becomes infinite, the exciter current zero, and the polyphase commutator regulator is excited directly from the slip rings of the main motor. Beyond this point the exciter current is reversed and the field resistance rapidly reduced.

Fig. 19. Motor House in the Plant of the American Iron and Steel Company Containing the Motor and Control for 8-inch Roughing and 10-inch Finishing Frames

Fig. 26 shows one type of relay actuated by the line current for automatically reducing the speed of the motor and flywheel as the load comes on, thus making available a portion of its stored energy for reducing the peaks. This same relay works equally well with the motor on rheostatic or dynamic control. This effect is shown in the graphic ammeter curve of Fig. 27.

It is of interest to note that the speed may be automatically increased instead of reduced where it is essential that the inherent tendency of any asynchronous machine to drop slightly in speed under load be strictly neutralized. Two 2000-h.p. equipments are under construction at the present time for the Jones & Laughlin Co. which contemplate this arrangement in order to insure absolutely constant speed under varying load.

Seven of these polyphase commutator regulating sets have been installed for controlling the speed of mine fans and have shown very material savings over the old method of rheostatic control. Fig. 29 shows a typical fan house of the Pittsburgh Coal Co.

Fig. 28 is a view of the standard belted 250-h.p. induction motor driving a mine fan, and Fig. 30 shows the incoming line panel, special drum controller and speed regulating rheostat. Fig. 31 shows another 250-h.p. belted fan drive. Note the extreme simplicity of the control panel with the speed controlling

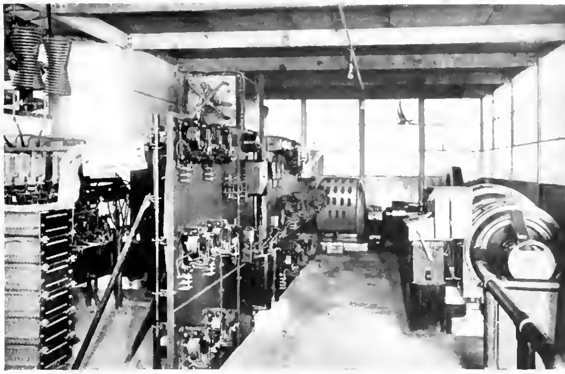


Fig. 21. Interior of Motor Room for 10-inch and 12-inch Mill showing Direct Connected 300-h.p., 500-r.p.m. Motor and a Polyphase Commutator Regulating Set (at right) and Control Panels

rheostat above and accelerating resistance for the main motor mounted on the ceiling where the use of a drum controller is permissible. Fig. 32 shows the polyphase commutator regulating set for use with the 250-h.p. fan motor shown in the preceding view.

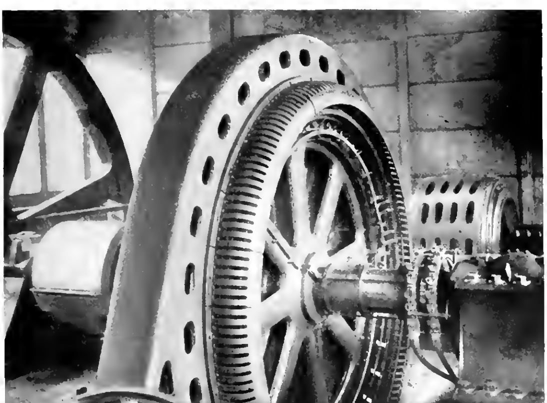


Fig. 20. 400-h.p., 107-r.p.m. Motor (foreground) and 200-h.p., 375-r.p.m. Motor (background) in the Plant of the American Iron and Steel Company. Each of these motors is provided with a Polyphase Commutator Regulating Set

Referring again to this curve shown in Fig. 5 it is evident that the speed torque current curves of an induction motor are practically the same above or below synchronism. Furthermore, the slip ring voltage and frequency increase uniformly above synchronism just as they do below, although, of course, the phase rotation is reversed. It is apparent, therefore, that the standard polyphase commutator regulating set will function equally well above and below synchronism. The difficulty has been to develop a practical commercial method of operation at and near synchronism *without sacrificing continuous speed control, torque, efficiency* or *other desirable* *characteristics* obtained below synchronism. Much effort has been expended abroad in this direction but so far as I can learn, without practical commercial results.

As compared with the polyphase commutator regulating motor the rotary converter system will always involve one more machine when the two systems are laid out on the same basis. If the separate motor-generator set is used the rotary converter system requires four machines, as against three, Fig. 19 with the polyphase commutator regulating. If the d-c. motor, Fig. 19, of the rotary converter system or the PCR motor are respectively direct connected to the main motor the rotary converter system will require *three* units and the polyphase commutator regulating but *two*.

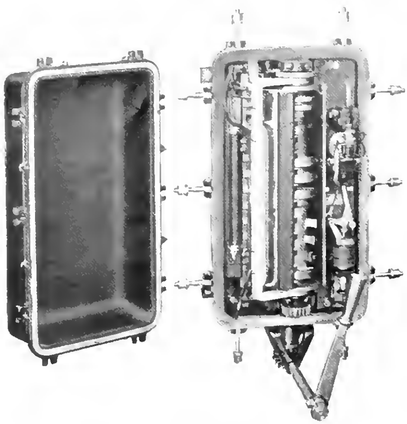


Fig. 22. Automatic Controller for Polyphase Commutator Regulating Set

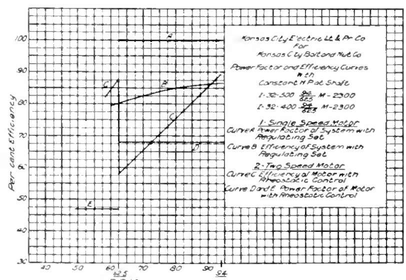
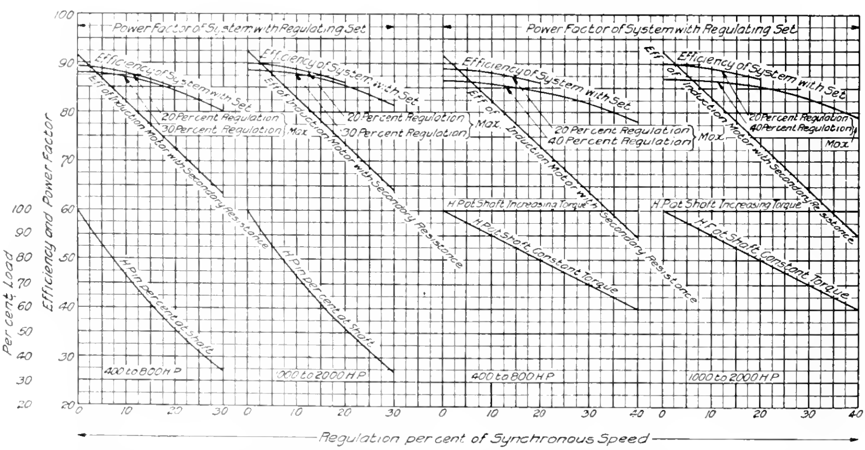


Fig. 23. Efficiency and Power-Factor Curves for Single Speed Motor and Polyphase Commutator Regulating Set, Compared with Similar Curves for two Speed Motor with Rheostatic Control



Overall 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

Overall Efficiencies of Induction Motors Operating at Constant Horsepower or Constant Torque at Different Speeds. Speed Control obtained by Speed Regulating Set and by Rotor Resistance.

Fig. 24. Typical Power-Factor and Efficiency Curves for Decreasing, Increasing and Constant Torque, with Regulation by Means of Polyphase Commutator Regulating Set and by Rheostatic Control

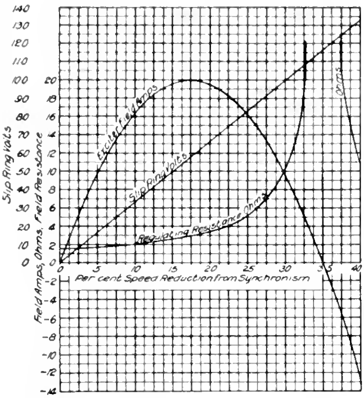


Fig. 25. Typical Excitation Curve for Polyphase Commutator Regulating Set

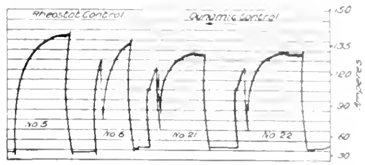


Fig. 27. Effect on Current Input to Motor Produced by Relay of Fig. 26

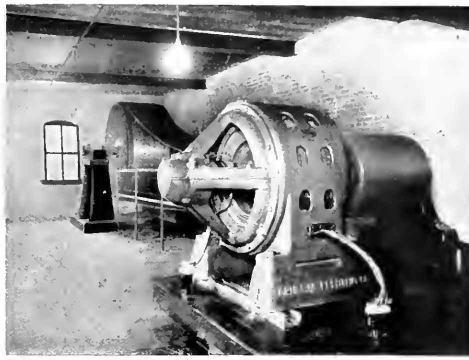


Fig. 28. 250 h.p. Induction Motor Driving Mine Fan, Pittsburg Coal Company

Fig. 26. One Type of Relay for Automatically Reducing Speed of Motor and Fly Wheel as the Load comes on. Its effect is shown in Fig 27

Fig. 29. Fan House of the Pittsburg Coal Company. Polyphase Regulating Sets are employed here for Regulating the Speed of the Mine Fans

From the standpoint of power-factor, it is generally considered poor practice to attempt correction with a rotary whereas the design of the polyphase commutator reglator readily lends itself to this end.

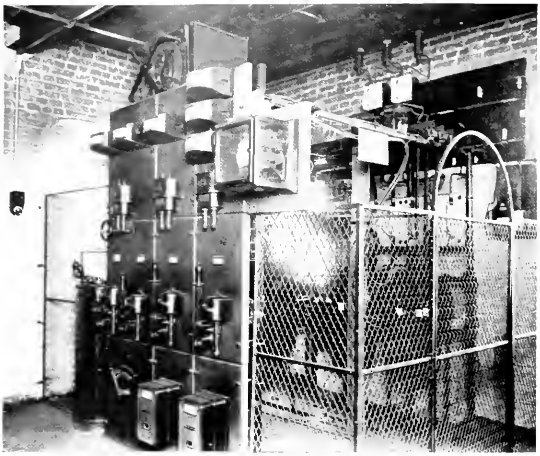


Fig. 30. Incoming Line Panel, Special Drum Controller, and Speed Regulating Rheostat

It is the established policy that the use of regulating sets shall in no wise handicap the desirable characteristics of the mill type induction motor as regards torque, heating, or efficiency and shall in every case improve the normal power-factor. The customary guarantee of 250 per cent maximum torque can readily be met with the polyphase commutator regulating set from maximum regulation to within a slip frequency of about one cycle, whereas with the rotary converter the tendency to fall out of setp at low frequency limits the 250 per cent torque guarantee to about 8 cycles slip frequency which on a 25-cycle circuit, means that 250 per cent torque can not be guaranteed at regulation less than about 30 per cent. In many cases, therefore, the maximum torque throughout the entire speed range required is greatly reduced except at prohibitive expense.

So far as I am aware, the total number of sets sold to date in this country is twenty-seven. Of these, five use the single range rotary converter system, twenty-one the single range and one the double range polyphase commutator speed regulating motor regulating set. With the present possibilities of the double range equipment, the polyphase commutator regulating system should show even greater gains due to its greater flexibility, better efficiency power-factor and torque characteristics.

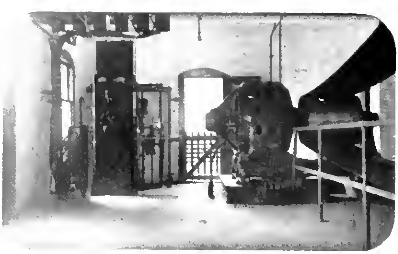


Fig. 31. 250-h.p. Induction Motor Belted to Mine Fan

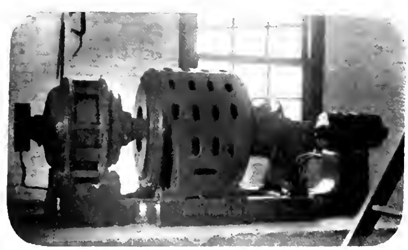


Fig. 32. Polyphase Commutator Regulating Set for Controlling Speed of 250-h.p. Fan Motor Shown in Fig. 31

THE HOT CATHODE ARGON GAS FILLED RECTIFIER

By G. Stanley Meikle

Research Laboratory, General Electric Company

The author gives a brief review of hot-cathode phenomena and then shows how through development work these phenomena have been made use of in obtaining practical results. The various types of gas-filled rectifiers are described in detail.—Editor.

It has been known for a number of years that a vacuum tube containing a hot and a cold electrode acts as a rectifier. The problem of applying this principle to a practical rectifier was, however, beset by numerous difficulties. The variation in the magnitude of currents was extremely erratic with a slight variation in the degree of the vacuum. The blue glow phenomenon accompanying the electron emission (indicating the presence of residual gas) caused a very rapid disintegration of the hot electrode, and made the tube inoperative after a relatively short period of life.

Early investigators had assumed that the electron emission was a secondary effect, due to the presence of gas. Dr. Langmuir[1], in his detailed investigation of the whole field of electronics demonstrated that all of the irregularities thought to be inherent in the hot cathode vacuum discharges disappeared with the elimination of all residual gas effects. It has been found possible to produce and maintain vacuums so high that no gaseous discharge occurs with voltages as high as 100,000 volts. This is particularly demonstrated in the kenotron[2], and in the Coolidge X-ray tube[3], both of which are commercial devices.

In these types of high vacuum apparatus, the current is more or less limited, due to space charge effect. The electrons emitted from the hot cathode produce an electrostatic field around it, which limits the motion of electrons towards the cold electrode. This space charge, however, is rendered less effective, and the current is increased, by raising the positive potential or by increasing the surface from which the electrons are evaporated. The kenotron, in its present commercial form, is made to supply currents as high as 250 milliamperes, at voltages up to 100,000 volts.

However, owing to the fact that the voltage drop in the kenotron when rectifying currents of the above order of magnitude is relatively high (100-500 volts) it is impracticable to use this device on low-voltage circuits.

In the presence of positive ions the space charge of electrons is partially or completely neutralized. When minute traces of gas are introduced into the kenotron under certain conditions, a sufficient number of positive ions may be formed to completely neutralize the space charge effects, and then the voltage required to draw a given current through the space is reduced many fold. The presence of the gas not only has an enormous effect upon the current carrying capacity of the space between the electrodes, but also may have a very marked influence upon the number of electrons emitted from the cathode. In the presence of oxygen, whether in a free state or contained in a gas (such as water vapor), the electron emission from a pure tungsten cathode is cut down to a small fraction of that in high vacuum. Inert gases and vapors apparently have no effect upon the electron emission from pure tungsten[4].

In the previous investigations, the work has been confined to the effects of minute traces of gas where the gas molecules are few in number, and where the ionized particles are thus enabled to move with comparative freedom under the influence of electric fields. Under these conditions, the positive ions acquire a very high velocity, and when they strike the cathode actually cause a chipping off of atoms of the metal, until the function of the cathode is destroyed. The disintegration becomes very much more rapid as the voltage is increased.

A very careful investigation was made to determine the effect of gases at higher pressures upon the cathode filament. (By higher pressures is meant pressures exceeding 50 microns). It was found that the nature of the gas had much to do with the rapidity with which the cathode was disintegrated. Certain impurities, even though present in very minute traces, cause the formation of volatile compounds with the cathode material

[1] Dr. Langmuir, Phys. Rev. *2*, 450-86, 1913.
[2] Dr. Dushman, G. E. Rev. *18*, 156-67, 1815.
[3] Dr. Coolidge, Phys. Rev. *2*, 409-30, 1913.
[4] Dr. Langmuir, Phys. Zeih. *15*, 348-53, 1914.

in the presence of high temperatures, which ultimately effect destruction.

At pressures smaller than several millimeters, the effect of positive bombardment is still very troublesome. As the pressure of the gas is increased from vacuum condition the number of molecules increases very rapidly, limiting the free movement of the positive ion, and therefore decreasing the velocity. The energy given up by the individual ion at impact is then very much less than under conditions when it moves at the higher velocities; but there are vastly more positive ions present, so that the effect of bombardment by positive ions is much more disastrous in gases at certain pressures than under conditions where only minute traces of gas are present. In order to prevent disintegration of the hot cathode it becomes necessary to isolate the causes, and produce a condition which would not only eliminate the principal agents of destruction, but also the many secondary effects which are present. During the investigation of conditions covering a period of several years, the properties of many gases at varying pressures have been studied, with particular reference to their adaptability for rectifying purposes. Many electrode materials have been investigated with reference to their size, shape, and indestructibility. By a proper adjustment of the pressure of a selected gas, we have not only been able to reduce disintegration to a minimum (practically eliminating it), but have also been able to secure conditions where the emission of electrons from the cathode has been sufficient to actually cool it when rectifying excessive currents.

As a result of these investigations it has been demonstrated that a rectifier filled with gas at pressures within a more or less definite range can be designed to rectify currents from a few milliamperes to exceedingly high values at voltages varying between several volts and several thousand volts.

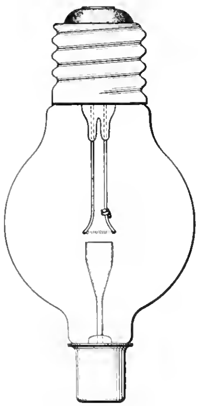


Fig. 1. Low Current Hot Cathode Gas Filled Half-wave Rectifier

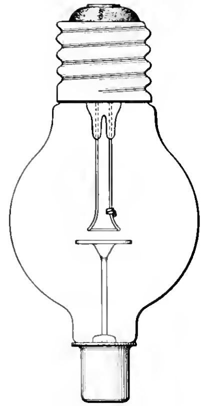


Fig. 2. Low Current Hot Cathode Gas Filled Half-wave Rectifier

The Hot Cathode Argon Gas Filled Rectifier

During the investigation, many observations were made which in themselves are worthy of elaboration. The object of this article, however, is not to present any of these noteworthy facts, or even to venture a scientific exposé of any phase of the investigation, but rather to refer to one of the several combinations of conditions which have given us a rather interesting type of low-voltage gas-filled rectifier for rectifying currents within a wide range.

Fig. 1 shows a sketch of a rectifier in which the cathode consists of a filament of small tungsten wire coiled into a closely wound spiral, and a tungsten anode of relatively large cross-section, with a comparatively smooth surface. The filament ends are welded to heavy tungsten wires, while the anode lead is swaged from, though is still a part of the anode. All leads are sealed directly through the high heat-resisting glass into 3-inch spherical bulbs of a similar glass. Although the anode of the tube shown consists of tungsten, other materials have been used with good results. Care, however, must be exercised in mounting all anodes, particularly where the material (such as graphite) can not be welded to the tungsten lead.

The rectifier shown in Fig. 2 differs only in the shape of its parts. The cathode is shown as a straight filament of small tungsten wire, which, if properly proportioned and mounted, consumes a minimum of energy for a maximum number of electrons emitted. The anode is shown in the form of a thin disk, made large in diameter, to give a big radiating surface, which is found to be desirable when such metals as copper are used.

Fig. 3 illustrates a gas-filled rectifier designed to rectify high currents at low voltages. Two cathodes are shown; one is in filament form identical to that shown in Figs. 1 and 2, used for starting; the other is a tungsten rod cathode with beaded tip, used during the operation of the tube. The construction between the bead and the lead suffices to prevent conduction of heat from the tip. The object of using such a cathode is to secure a long operating life. Any disintegration, unless very severe, has no appreciable effect upon the life and operation of a rectifier of this design. A graphite anode mounted on a heavy tungsten lead is shown, as graphite has been found to be a very desirable anode material for rectifying high currents. As before, all leads are sealed directly through the glass and, for currents between 20 and 45 amperes, into a 5-inch spherical bulb of a similar glass.

The rectifiers just described are constructed of high heat-resisting glass, since it is possible to seal the tungsten parts directly into the glass, and bulbs of small volume can be used for tubes of large energy consumption. Soft glass bulbs are used with very good results. It is then necessary, however, to use special sealing-in wires, or blended seals.

All tubes, whatever the material of which they are constructed, are carefully exhausted and filled with a gas in a high state of purity. As has already been stated in the introduction, certain impurities, even though present in small quantities, produce a very rapid disintegration of the cathode, and also have a very marked effect upon the voltage characteristics of the rectifier. It is advisable in certain types of gas-filled rectifiers to introduce substances which react chemically with such impurities as are introduced with the gas, or are given off by the parts during the operation of the rectifier. The reaction which occurs keeps the gas in a pure state. It is found convenient in certain types of the low-current rectifier to introduce the purifying agent in the form of an anode

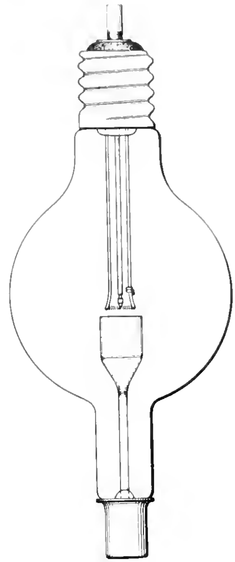


Fig. 3. High Current Hot Cathode Gas Filled Half-wave Rectifier

As the impurities are distilled from the anode or cathode, or from the overheated glass parts, the arc drop increases. The increased energy consumption automatically causes evaporation of the anode material until the high state of purity is re-established, when the evaporation ceases. In Figs. 1, 2 and 3, the purifying agent is shown as a coil wound around one of the leads. During aging it is evaporated, and redeposits on the sides of the bulb, carrying with it the impurities in their respective chemical combinations.

The experimental work with argon indicates that rectification is possible in all pressures of gas. With an increase in the gas pressure the potential at which the arc is established increases. At the higher pressures, the temperature of the filament is also a factor in determining the starting voltage. After the arc is formed, the arc drop increases very gradually for big increases in gas pressures. Between gas pressures of 10 and 15 centimeters, the nature of the arc changes from a sharp concentrated arc to one diffused in character, which at very low pressures assumes the characteristics of the blue glow. At the lower pressures, the filament temperature above 2200 deg. K. has little effect upon the characteristics of the arc.

For the low-voltage tubes of all current capacities a pressure is selected at which the effects of disintegration are a minimum and where the voltage condition for starting and operating are desirable. A pressure of argon between 3 and 8 centimeters (measured cold) gives very good results and is, therefore, the pressure used in this type of rectifier.

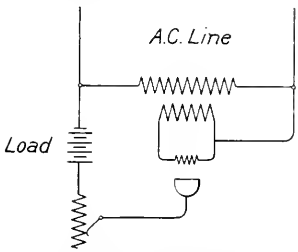


Fig. 4. Diagram showing Method of Connecting a Half-wave Rectifier in Circuit

Characteristics and Operation

The principles already briefly discussed are applied equally well to half-wave or full-wave rectifiers. The half-wave type shown in Figs. 1, 2, and 3, is very desirable, because of the simplicity of its construction and installation. A typical circuit for the half-wave rectifier, consisting of a 40-watt transformer for filament excitation, a load, and a means of regulation, is shown in Fig. 4. Where efficiency is not a serious consideration, regulation can be secured by placing resistance in series with the load. If efficiency must be considered, however, the line voltage is transformed to values where no regulation is required, so that the load can be placed directly between the terminals of the transformed source. Unless a sufficiently great number of these units controlling relatively large amounts of energy are placed in a power circuit in such a way as to badly distort its wave shape, the use of this type of tube is permissible. As a matter of fact, the half-wave unit of low-current capacity if generally installed will have no appreciable effect upon the power-supplying circuit. Should this feature, however, become objectionable to the central station when high current units are used, two half-wave rectifiers can be placed in circuit, as shown in Fig. 5. The compensator is designed to transform the voltage to values required for regulation, and to supply current for exciting the filament. It possesses as much or as little reactance as the characteristics of the load require for proper operation. Where it is possible to split the load into equal parts, or where the total load is divided into units, as for example the vehicle battery of a central charging station, the half-wave units, each with its individual battery load, are connected into the circuit in such a way that half of the tubes are

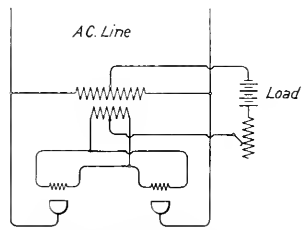


Fig. 5. Diagram showing Method of Connecting Two Half-wave Rectifiers in Circuit

rectifying one loop of the wave, while the other half rectify the remaining loop. The resultant effect upon the wave shape of the main circuit is similar to that when the full-wave rectifier is used.

The full-wave gas-filled rectifier shown in Fig. 6 consists of a tube into which are sealed two anodes and a common cathode. This type of rectifier is connected in a compensator circuit, Fig. 7, very much in the same way as the two half-wave units shown in Fig. 5. The energy consumed by the two cathodes in the former arrangement is somewhat greater than that consumed by the one filament of the full-wave unit. The effect upon the general efficiency is, however, relatively small, and is offset by other features, depending upon the service for which the rectifier is used.

A particularly desirable characteristic of the hot cathode gas-filled rectifier shown in Figs. 1 and 2 is the self-starting feature. When the alternating-current circuit switch is closed, the cathode filament is heated very much in the same manner as is the filament of an electric lamp by the turning of the snap-switch. A supply of electrons is liberated from the filament, and through the mechanism of ionization positive ions are produced, which, with the electrons, carry the unidirectional current of the arc. Normally the arc forms very rapidly upon the closing of the switch. This characteristic is particularly attractive to communities where the power-circuits are frequently broken during the night. The rectified current service is re-established automatically immediately after the power-circuit is completed, and continues to give service as long as desired.

In the low-current unit the cathode filament is excited continuously during operation. The apparent loss of energy, due to the excitation, is compensated for by a low loss of energy in the arc when the filament is excited from an external source, under which condition we have repeatedly observed arc potentials as low as 1 volt d-c. Once the arc is formed, the tube continues to operate as a rectifier even though the filament circuit is broken, except in instances where the rectified current is very low. The electrons are not so freely liberated from the unexcited cathode, and the deficiency of electrons results in the formation of a positive space charge. The voltage required to overcome this positive space charge and cause the electrons to be emitted by bombardment may be sufficient

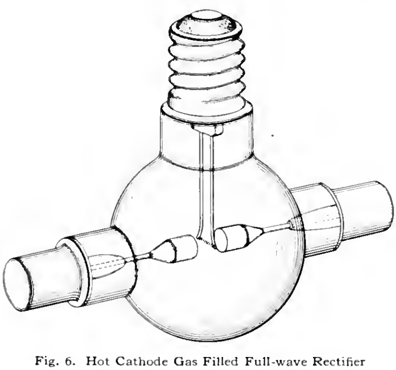


Fig. 6. Hot Cathode Gas Filled Full-wave Rectifier

to make the total loss within the tube greater than when the filament is excited by external means. With no filament excitation, the spot concentrates on a few turns and there is a tendency to shorten the life of the cathode by evaporation. It is therefore feasible in tubes of low-current and low-voltage capacity to continuously excite the cathode by external means. In the high current rectifier, the intensity of the bombardment is sufficient to produce electrons from the cathode with remarkable ease and the energy consumed

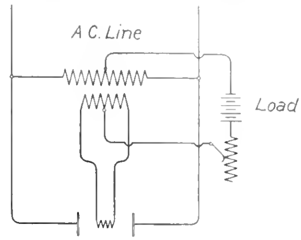


Fig. 7. Diagram showing Method of Connecting a Full-wave Rectifier in Circuit

is small. The filament is no longer necessary during operation. It functions in such tubes only as a starting cathode. A three-pole switch closes the filament-circuit, and also connects it with the anode. The gas is immediately ionized and the current begins to flow to the operating cathode, which is acting temporarily as anode until it becomes hot enough to emit electrons at which point the rectifying arc is established between it and the anode.

If conditions warrant, the tube is made to start automatically by placing a direct-current relay in the rectified current circuit. When the arc forms between the operating cathode and anode the three-pole switch is opened and is closed when the power-circuit is broken.

When a constant purity of the gas can be relied upon, the filament is used both as a starting and as an operating cathode even in the high current rectifier. Rectified currents as high as 80 amperes have been drawn from a tungsten filament 20 mils in diameter for short periods without any appreciable harm to it. The filament remains relatively cool and the spot moves toward the filament lead connected into the main circuit, as the current increases. The 20-mil tungsten filament in a low-pressure atmosphere of argon normally fuses at 31 amperes. Unless extreme precautions are taken to free all parts of the rectifier from gases which are later given up during operation, or unless purifiers are incorporated in the rectifier, it is advisable to use the point cathode. This is not noticeably affected by the irregularities inherent in a poorly treated tube.

In this as in all types of gas or vapor rectifiers, it is necessary to ionize the gas before the arc can be started. Furthermore, in order to prevent the arc from going out

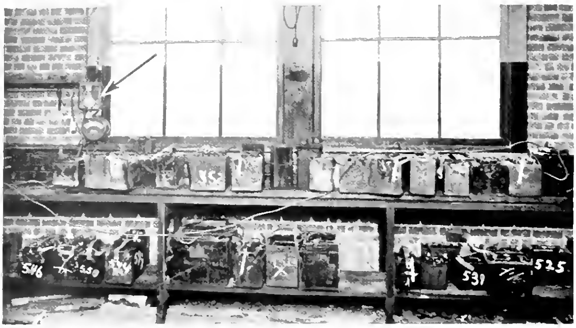


Fig. 8. Typical Half-wave Hot Cathode Gas Filled Rectifier Installation

permanently it is necessary to maintain the cathode spot and re-establish ionization at comparatively low voltage. As long as the arc exists it supplies its own ionization. During that portion of the cycle when the voltage is too low to maintain the arc, and is zero, the cathode cools only slightly due to its heat capacity, and with the aid of the residual ionization the arc reforms at low voltage without the starting anodes and other devices for overlapping the voltage waves. The rectifier is not only self-starting but also self-maintaining. The persistency of ionization in argon seems to be particularly marked and this makes it possible even without filament excitation to use the rectifier for supplying current for very low frequencies. For the same reason, it is possible to operate the tube on very low current when the cathode is not externally excited.

No auxiliary starting load is required when beginning a battery charge. The supply switch is closed and the charging current picks up immediately, giving a slightly tapering charge as the battery voltage increases. On a resistance load, the current is very constant due to the fact that the cathode spot does not wander.

The efficiency of the tube depends upon the supply voltage, increasing with it as the voltage become higher, and upon the energy consumed in the arc indicated by the arc drop. The arc drop of the low-current low-voltage rectifier in which the filament is externally excited is between 4 and 8 volts measured on a direct-current circuit. The energy consumed in keeping the filament cathode hot enough to produce initial ionization is less than 40 watts. Therefore for a 6-ampere tube the energy consumed by the arc and filament is equivalent to that of a rectifier having an arc drop of 10.66 to 14.66 volts. The actual drop in this tube without filament excitation is however somewhat higher than indicated by these values.

The tube operates satisfactorily on current ranging from a fraction to many amperes. With a properly excited cathode, the rectifying arc is started on alternating current supply voltages as low as 20 volts and is maintained on voltages as low as 14 volts.

The life of the low-current low-voltage rectifier, upon which the greater part of the work has been done, varies from nine-hundred hours to over three-thousand hours. Some of the high current half-wave tubes have a life of over a thousand hours and many others have a life of five-hundred hours or more. Most of the life runs have been made with resistance loads. Many of the low-current tubes have been in actual service for over eighteen months in several of the local central charging stations. Here they have been used to supply current for charging batteries. The life and characteristics in such service have proven to be very satisfactory. A typical central charging station installation is shown in Fig. 8. The outfit consists of a half wave rectifier screwed in a fuse block and a 50-watt filament transformer supported by a small bracket screwed to the window post to the left of the photograph. The direct-current meter placed in the load circuit is screwed to the sill just beneath the tube. The supply circuit is a 60-cycle, 236-volt alternating-current city power main. To secure flexibility, a variable resistance was placed in series with the battery load. In practice where efficiency must be considered, a variable transformer should be used

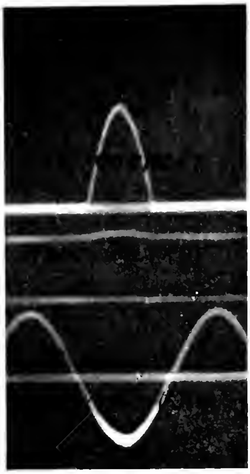


Fig. 9. Rectifier Charging Ignition Cells at 6.1 Amperes Direct-Current Voltage Across Battery

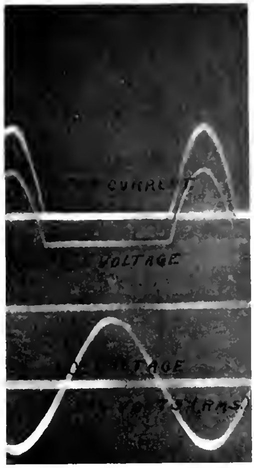


Fig. 10. Rectifier Charging Ignition Cells at 6.1 Amperes Direct-Current Voltage Across Battery and Regulating Resistance

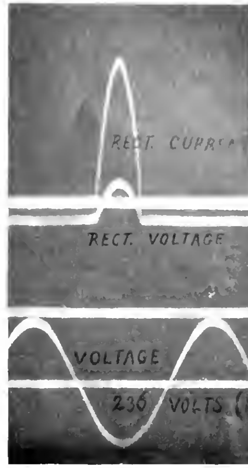


Fig. 11. Rectifier Charging Ignition Cells at 6.2 Amperes Direct-Current Voltage Across Battery and Regulating Resistance

Fig. 12. Rectifier Containing no Purifying Agent. Voltage Across Arc Gap 21 Amperes Direct-Current Flowing

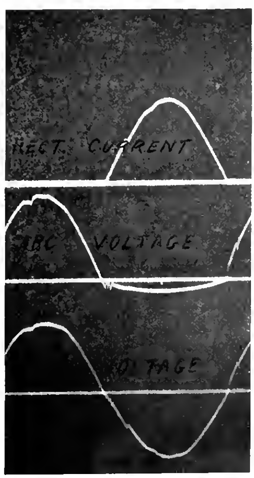


Fig. 13. Rectifier Containing an Active Purifying Agent. Voltage Across Arc Gap 29.6 Amperes Direct-Current Flowing

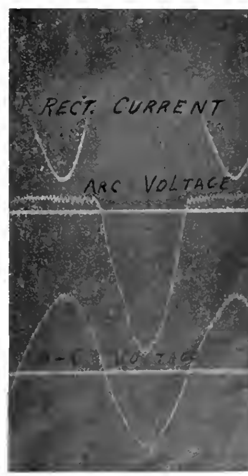


Fig. 14. Rectifier Containing a Purifying Agent as Anode Voltage Across Arc Gap 6.6 Amperes Direct-Current Flowing

in place of resistance. When the photograph was taken the rectifier was supplying a 6-ampere charging current to 15 batteries or 54 cells of miscellaneous character. At one period during the life run of this particular tube, all of the available batteries in the garage were coupled into a series circuit and the characteristics and oscillograms taken. During this period eighty-nine cells were in circuit being charged with a direct current of 6.2 amperes. The direct-current voltage over the total number of cells was 224 volts (average value) and the alternating-current voltage at this instant was 236 volts (root mean square value). The total direct-current voltage measured over the battery and variable series resistance was 236 volts (average value). It is evident that even a larger number of batteries can be charged by reducing the regulating resistance to zero value. The characteristics indicated above are typical.

Oscillograms

In order to study the characteristics of the rectifying arc, frequent oscillograms have been taken under varied conditions. Figs. 9, 10, 11, 12, 13, and 14 are typical of the half-wave low-voltage rectifiers. In all of the films, the lower curves represent the voltage of the supply circuit, while the upper curve gives the current passing through the rectifier. The middle curve represents the voltage measured either over the load where the curve does not cross the reference line, Figs. 9, 10 and 11, or over the arc gap where the curve traces below the reference line, Figs. 12, 13 and 14.

In Fig. 9, the middle curve represents the voltage taken at the battery terminals. The rises in the rectified voltage line are due to a voltage factor which is the product of the battery resistance and the charging current. Where a smaller number of cells are being charged, these rises are barely perceptible.

In Fig. 10. the voltage is taken over the batteries and regulating resistance; therefore these voltage rises are very much more pronounced due to the increased value of the resistance. As the regulating resistance of the charging circuit is replaced by a larger number of batteries, the counter electromotive force is increased and the time during which the current flows is accordingly decreased. Therefore for the same r.m.s. value of the current, the wave becomes very peaked, as shown in the upper curve of Fig. 11.

The middle curve of Fig. 12 represents voltage across the arc gap of a tube in which there are no gas purifiers. Note that the voltage for starting is rather high, but decreases as soon as the arc forms. There is a tendency for it to increase at the end of the half cycle. This is more pronounced at the lower current values. The middle curves of Fig. 13 represent the arc voltage of a tube which contains an active purifying agent, and Fig. 14, a tube in which the purifying agent is used as an anode.

In all of the oscillograms the current graph shows that the rectification obtained is absolutely perfect and that, by a proper use of purifying agencies, a very desirable voltage condition is established.

In conclusion, the writer wishes to express his indebtedness to Mr. J. H. Clough, who has assisted throughout these investigations, also to acknowledge the generous co-operation of Mr. G. M. J. Mackay and others of the Research Laboratory staff.

THE CAUSES AND EFFECTS OF TRAFFIC IN GOODS

By David B. Rushmore

Chief Engineer Power and Mining Department, General Electric Company

and R. H. Rogers

Power and Mining Engineering Department, General Electric Company

This contribution emphasizes in a most interesting manner the phenomenal growth of traffic and deals with the causes that lead to our modern complexity in traffic conditions. Increase in population is, of course, a large factor, but the increase in commerce per capita is still more striking: "The increase in commerce per capita for all the countries where data can be collected has been from about $2 in 1820 to $24 in 1912, while the present commerce per capita in this country is $42, or 75 per cent more than the average and is still going up rapidly."—Editor.

The intermingling currents of goods moving from place to place over the earth's land and water surfaces are among the most wonderful effects of the work of man and they indicate, in a sensitive and faithful manner, his activities and constantly advancing requirements. The individual threads of the streams are subject to every whim of fashion, weather, politics, taste and circumstance, yet the aggregate movement is ever increasing, both in quantity and rapidity, under the influence of more complicated methods of living and more ingenious means of transportation.

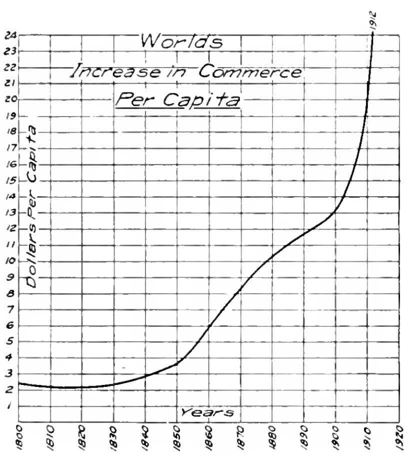


Fig. 1

Almost every human activity and every degree of progress is instantly reflected by an increase in exchange of goods and values. The most savage undeveloped peoples have the least traffic but still they have some. The most advanced nations have the greatest traffic, and the acceleration, due to the doubling back, reflecting and retroacting of every line of progress, is almost unbelieveable. As an illustration, take a given community; its normal increase in population naturally increases its traffic with neighboring communities and foreign countries, but the increase due to the advancing ideas of its individuals is of much more importance. Specializing in the production of the things easiest for that community to make and trading them for whatever they desire, has brought about an enormous increase in traffic over the day when each community was sufficient unto itself.

Changed tastes of individuals from corn, fish and rabbits to a table set with the best products of the entire world, has brought about the interchange of food stuffs of every variety in wonderful quantities. Refinement and culture as typified by music, art, literature and architecture, has added much to the burden of traffic.

Any line of endeavor affects traffic in many ways. This idea may be shown by following the publication of a book. Pulp from Sweden and spruce wood from Canada come together and are reshipped as paper. After printing—say in New York—the stock is shipped to Boston for binding. In the meantime leather from abroad is processed in Pennsylvania and shipped to the binder. The finished books are returned to New York for distribution and then are shipped broadcast. So the great tide of commerce and traffic have been augmented in many ways by so simple a thing as the publication of a book.

To bring out this impetus due to the advancement of individuals, note the curve, Fig. 1, which shows this phase only and does not consider the increase due to increased population. This shows that the increase in commerce per capita for all the countries where data can be collected has been from about $2 in 1820 to $24 in 1912, while the present commerce per capita in this country is $42, or 75 per cent more than the average and is still going up rapidly.

Man's requirements are now so complex and he works so indirectly toward the maintenance of his family that today all the food, clothing and housing materials have to be brought to him, together with the thousand and one articles that he thinks he needs to be happy. The exchange of work with neighbors and the community handworkers in wood, iron, leather and cloth are largely of the past. There was a time when an annual ox-cart pilgrimage of 80 miles to Utica sufficed to supply the pioneers of Jefferson County with their gun powder and tea. Today every individual in that county requires nearly an ox-cart load of materials every week. They burned wood from close at hand, we burn coal from Pennsylvania. They wore wool from their own sheep—spun, woven and sewed by their own fireside; we wear materials from every land, spun in one place, woven in another, cut and sewed in another and remarketed several times before we receive it. Their food was raised, caught or shot close at hand with only a minute portion such as salt, spices and tea from outside their little circle. Our tables and cupboard shelves daily bear the myriad products of fields, plantations, forests, jungles, deserts, isles, of shallow lakes and deep seas, from almost wherever latitude and longitude extend.

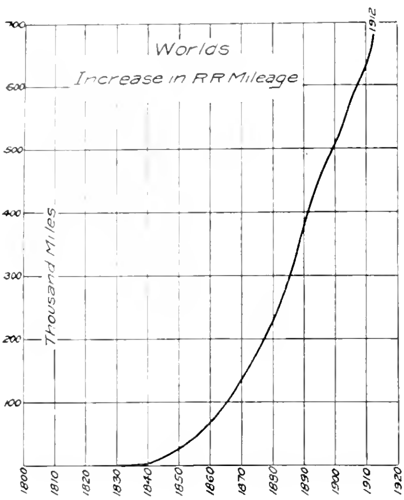


Fig. 2

Their lights were candles, their books were the Bible and an almanac, their papers none, their music little besides the human voice, their homes—unornamented—were of the logs cleared from their land. By contrast, what do you and I use or see in a day, above the ground itself, that has not been brought to where we use or see it from some other community or land, by who knows how many steps and transitions to reach its final place and form?

So much for the causes of traffic: now let us consider the effects that this constant ebb and flow of goods has had upon communities, individuals and the ways and means that have been created to make it possible.

Man carried the products of the chase to his cave on his back—that was the beginning of transportation. Rafts, dugouts, canoes and batteaux followed because streams and lakes were the natural highways. When trails could be made the animals took up their burdens. Putting wheels under loads must have been an epoch-making invention, necessitating a semblance of roads.

An evergreen bush was probably the first sail, and through a long, slow process of evolution the sailing ship was evolved and the craft became able to navigate across or into, as well as with, the wind. This was another great step that emboldened sailors to investigate unknown seas and to discover new routes and lands, because they could return against the trade winds.

The practicalizing of the steam engine and its use in boats and on locomotives were nearly simultaneous. Rails were laid and the principle of pulling many loads with a single power tractor was evolved.

Commerce was, and is, ever pushing transportation for more and better facilities to meet the pressure and pull of supply and demand. In 1830 railroads made a slow beginning but from 1840 on the increase in mileage has been steady. The railroad mileage curve, given in Fig. 2, shows this increase graphically—indicating that there are now 700,000 miles of railroads as one of the effects of the traffic in goods. At the same time sail and steam ships were added rapidly to meet the demands of overseas traffic. The curve of ships tonnage, Fig. 3, indicates that there are now 30,000,000 tons (spaces of 100 cubic feet) gross, or in other words, all the ships in the world together could carry 50,000,000 tons dead weight of cargo at once. While this seems like an enormous quantity, the railroads of the United States handle enough freight in a year to load every ship in the world twenty times.

Transportation facilities must include the power trucks, a very modern invention, and one of great importance. Their economy often lies in door-to-door service, i.e., for distances up to say 45 miles deliveries are made direct from shipper to consignee without rehandling as is necessary at docks or freight houses. In other words, every road and street is a "siding" for the commercial truck. This new distributor will be a large factor in the success of the New York State Barge Canal with its sixty or seventy terminals. Every street radiating from a terminal to wholesale or manufacturing districts becomes a feeder by virtue of the big rumbling power trucks.

To shorten routes and make them safer, cheaper and quicker, great canals have been constructed and railroad beds leveled and strengthened at heavy cost, all to cope with the ever growing impatience of traffic.

All things with which we deal have beginnings and endings; so it is with trade routes, and they are called terminals. At these places goods are received from shippers and delivered to consignees, goods are moved from one form of carrier to another as where railroads and ships meet. Another function is in connection with the transfer of goods from one ship or car to another to expedite delivery and to conserve space. Your telephone line goes with all others to the central board—not direct from you to the place you call—and traffic lines are much the same. At transfer terminals goods are reassembled into as nearly full car loads as possible in the general direction of their destination.

The needs of commercial traffic have brought into being a system of warehouses and grain elevators which are reservoirs standing between the intermittent movements of goods from supply sources and the practically constant movement toward the demand areas. They contain constantly varying quantities of constantly varying commodities from the far corners of the earth, often in astounding quantities, especially of those things that we ordinarily meet with only in very small parcels.

The magnificent showing of the railroads and steamship companies in equipment and facilities for transportation, together with the tremendous growth of traffic, have imposed a burden upon the terminals which are usually so located as to prevent extension. It is, therefore, necessary to intensively cultivate the terminal areas to avoid the

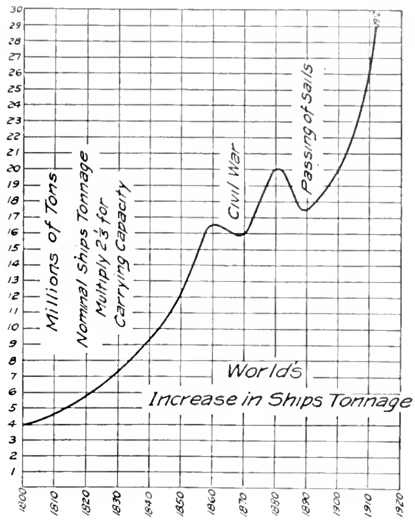


Fig. 3

disastrous congestions that are constantly recurring because of these conditions. The ways and means for safely and economically handling two tons of freight when only one was handled before, to double the tonnage per square foot or per string piece (water front) foot is the subject of much study at this time and much progress has been made along this line in the past few years.

There seems to be no reason to believe that the rate of acceleration of freight traffic per capita is going to fall off, as all the forces that have made the increase in the past are as strong as ever. The population of the United States is increasing, thereby adding to commercial traffic. The ocean, lake and river highways are capable of carrying freight far in excess of the present amount without congestion. The railroads by adding equipment can carry greatly increased quantities without reaching the limit of rails and roadbeds. Therefore, the limiting feature, clearly felt now and sure to become a further handicap, is the terminal. This then makes freight handling at least of equal importance with freight transportation as far as the necessity for study, careful design and wise expenditure of money is concerned, for freight traffic can be better expedited now by terminal improvements than by anything that can be done to or for the carriers.

*THE PUBLIC AND ELECTRIC RAILWAYS

By O. B. Willcox

Vice-President, William P. Bonbright & Co., New York, N. Y.

Transportation by electric railway has become an intimate and essential part of the life and industry of every American city; and although the fact is not always obvious to the unthinking, whatever acts to hamper or hinder efficient service, the extension of lines, or the adoption of improved methods, will prove to be of much greater harm to the community than to the investors in the railway property. The public is the party most deeply interested in the success of electric railway enterprises. Good service in any growing country can be maintained only through the increasing use of capital, and new capital can only be interested in those enterprises that show a reasonable return on the risk involved. Should unfair regulation impair the earning power of an electric railway system beyond this point, capital would turn to more promising fields of investment, the service would become inadequate and inefficient, and the public would be the principal sufferer from the acts of its own agents.—Editor.

Electric railways, from the standpoint of the public, are merely public utilities—properties built and operated by the capital of private investors, dedicated to serve the people in the vital business of local transportation, charged with the duty of giving adequate service to the community in the territory served, and of making such extensions as the demands of the public require, and such improvements as progress in the applied arts permit, and under obligation also to give such service at reasonable rates.

But from the standpoint of the investors who supply the capital required, electric railways are business enterprises offering opportunity for the employment of capital in a permanent business, with expectation of reasonably steady income and reasonable profit; they have become great financial institutions, requiring large capital. They can be operated successfully only by the keen appreciation by their managers of the fact that the foundation of the business is the capital invested and that the business must be conducted, while with due regard to its obligations as a public utility, always as a financial institution into which no capital will flow except upon an expectation of profit.

Profit cannot be expected, and of course no new money can be obtained for the properties, unless the financial records demonstrate the safety of the capital already risked in the enterprise, and earnings permitting the payment of a reasonable return upon it; and also the security of the additional capital required, and the promise of earnings on both the old capital and the new capital sufficient to justify a reasonable certainty of the payment of a fair return on both.

What Executives Must Do

The endeavors of the managers of the property in respect to its securities are therefore twofold; first, to protect the integrity of the investment already made and endeavor to earn and pay reasonable returns to the present investors; second, to show such security for further investment and such certainty and amount of future returns as will attract the additional capital required for extensions and improvements, through the sale of additional securities.

Legislation, regulation and management may affect the value of outstanding securities, and may facilitate or obstruct the sale of additional securities. Stocks and bonds already outstanding are evidences of property, and property itself is protected by the constitutional prohibition against taking without due process of law.

The legislation creating commissions for the regulation of public utilities has charged the commissions with the duty of permitting only just and reasonable rates for service rendered; and generally the orders of the Public Utility Commissions have involved either reduction of charges or improvements and extensions of service. A reduction in charges results, of course, in less income per unit of service and affects the earnings distributable to securities, while improve-

* Paper read before the mid-year meeting of the American Electric Railway Association, Chicago, Ill., February 4, 1916.

ments and extensions of service also usually involve expenditures of capital, to secure which new securities must be sold. The standard fare for street railways being five cents, often fixed by ordinance or contract, the regulation of electric railways has more often affected service than earnings.

Upwards of $5,000,000,000 are invested in electric railways in the United States and the magnitude of this financial interest of the people of the country is the measure of the obligation of Public Service Commissions to see that the charges for the service are not only just and reasonable to the passengers, but also to the investor.

What Electric Railways Are

The electric railways of the country serve every city and every town, every large industrial district, every seaport, extensive suburbs and country sides, resorts and amusement centers; the interurban lines connect cities with cities and provide the only transportation for great areas; they are the cheapest means of transportation; vast millions of our population depend on them daily between home and business and in the many activities of commercial life. An occasional failure of service because of fire, storm or flood brings instant inconvenience or loss or suffering to many thousands. Electric railways are a great national industry—a great national convenience—a great national necessity—a great national asset. That government function which interests itself in the economic welfare of the people can have few obligations greater than the preservation and protection of electric railway service for the present needs of the country, and the promotion and encouragement of its improvement and expansion, in quality and extent, to keep pace with its increasing use and meet the future demands of a country growing rapidly in population and tending as rapidly to undue concentration.

The trolleys, urban and interurban, permit concentration of workers in business and industrial centers, simultaneously with diffusion of residence in suburban and country districts, and are both the instruments and the cause of this tendency, which is of such great import to the social and industrial health and activities of a great people.

These active and interacting tendencies toward concentration and diffusion of population have put demands on electric railways not contemplated by the original investors, nor dreamed of by the most farsighted economist or financier. Lines originally running a few miles, operating on light rails, carrying passengers in small cars drawn by horses the length of the line for five cents, have expanded through the adoption of electricity, and responded both to the facilities available and to the increased demand, so that now big, handsome, well lighted and well heated cars with adequate equipment serve as easily and as quickly square miles of territory as their forerunners served city blocks. We may well point with pride to the expansion of street car service as one of the great accomplishments of this efficient age and race.

Public's Duty to Railways

No economist would hesitate to declare that the encouragement of this great industry to the full performance of the task it has set itself, and the promotion of its expansion and improvement to adequately meet the more exacting and dependent demands of its millions of industrial patrons, is one of the big tasks of this day and to-morrow, calling for the most intelligent cooperation of science, efficiency and finance, and of individual effort with Governmental support.

The problem is not that of so financing and operating a finished work as to conserve the interests of the investors while serving a static and satisfied demand. It is rather the constant and repeated rebuilding and expansion of a vast, economic, arterial system by the application of the latest achievements of science to the ever heavier and wider distribution of the energies of the very life and body of the community served; a system which grows, producing a redoubled new demand for every new facility afforded and which needs not only coal and steel and brains, but vast wealth to adjust its functions; and the moneys constantly required come ultimately from the pockets of the people.

Capital, the aggregate of funds free for investment, is sought by our own Government, offering the credit of this nation as security; by other great governments, which are offering now as high as 7 per cent; by States and cities, by railroads and banks, by the steel and other metal industries, by manufactories; and multifarious opportunities are offered with varying security and rate of return, and varying attractions real and sentimental. The capital required for electric railways must be sought in competition with all the securities appealing to investors for funds, and there is little hope that it will be available unless the usual requirements of investors are met. These requirements are, that capital already invested in electric railways be amply protected and made safe, and regularly pay a reasonable return; and that new capital be amply secured, and made safe, and a reasonable return on it not only promised but by the experience of the industry made dependable.

A "Reasonable Return" Defined

What constitutes a reasonable return is succinctly stated in the admirable *Report of the Railroad Securities Commission* to President Taft, November 1, 1911:

> We hear much about a reasonable return on capital. A reasonable return is one which under honest accounting and responsible management will attract the amount of investors' money needed for the development of our railroad facilities. More than this is an unnecessary public burden. Less than this means a check to railroad construction and to the development of traffic. Where the investment is secure, a reasonable return is a rate which approximates the rate of interest which prevails in other lines of industry. Where the future is uncertain the investor demands, and is justified in demanding, a chance of added profit to compensate for his risk. We cannot secure the immense amount of capital needed unless we make profits and risks commensurate. If rates are going to be reduced whenever dividends exceed current rates of interest, investors will seek other fields where the hazard is less or the opportunity greater. In no event can we expect railroads to be developed merely to pay their owners such a return as they could have obtained by the purchase of investment securities which do not involve the hazards of construction or the risks of operation.

Not only the protection of the present huge investment but the future of the industry depends on the ability of the electric railways to offer securities of such safety and promise as will attract the needed new money, in competition with all other securities offered in the money markets of the country, and those charged with the management and regulation of the industry may well inquire what course must be taken to secure this result. This responsibility rests quite as much on those regulating electric railways as on those who manage them.

Power of Regulation

The conditions inherent in the electric railway business give peculiar power to the people, acting through their representatives, the legislators, utility commissions and city councils; not only is the business a natural monopoly, competition bringing increased cost and decreased efficiency and service to the public, but both the location of the investment and the area of the market for the service rendered are definitely and immovably fixed. In this latter respect the industry differs from almost all others; the site of a factory can be moved, if subjected to unbearable conditions of whatever origin, without a necessarily total loss of the going business of merchandizing which in turn is conducted over areas without fixed limits, reaching markets where demand exists; and if one market is shut off, whether by tariffs, or transportation costs, or fashion's changes, another can usually be found or created by progressive management; and the goods dealt in may be changed, and in fact in all industries are constantly changing, to meet varying market conditions.

Not so a street railway; the plant is so rooted to the soil that it cannot be moved without total loss; its market is the territory served and no other can be reached; its output is transportation in that territory and cannot be varied. So is the industry peculiarly defenseless against oppression, whether through declared attempts at confiscation or throttling under the guise of regulation.

The dedication to the public service and the immobility of investment, plant and market, making attack easy and defense difficult, throw upon the public the concurrent obligation that the investment shall be protected in its entirety, and neither shall the rates be made too low nor service requirements too onerous to permit a reasonable return on capital invested and the new capital required for extensions and improvements.

Public's Selfish Interest

But beyond the responsibility to the investor, the public served have a greater interest—a selfish interest—much more concrete and material, if no less real and compelling, than the duty to be honest. The public has a greater interest in the electric railway than all the investors; because in every community the electric railway is a necessity and every day a greater necessity to the due course, order and progress of the community life.

It goes without proof that the loss to the public, in all but the most exceptional cases, would be much greater, were the electric railway totally destroyed, than the loss to the investor. In such a case, beyond the immense inconvenience, the lack of the speedy, safe and cheap transportation of passengers would instantly destroy values in real estate, buildings, leaseholds, going businesses, stocks of goods and means of employment, immeasurably greater than the value of the investment in the railway itself.

It may not be so instantly apparant, but reflection will bring conviction, that impairment of the ability of the railway to properly serve the public, while injurious to the owners, must react more severely on the public and the community. The investor feels it instantly in loss of income; the public does not see nor hear the loss of efficiency, the loss of time, the decrease in population, the loss in value of real estate, the stoppage of progress and the stunted growth; but is it not necessarily true, that if rapid transit brings growth, progress and enhanced opportunity and values, the lack of it will obstruct or prevent them?

Interests That Are Mutual

The public served and the investors then have an active interest in the prosperity of local transportation lines; the growing community, offering opportunity for successful and profitable business in all the activities of modern industry; factories, shops and new construction for the labors of the people; labor, market and profits for the employer; absence of undue congestion of population; homes in the nearby suburbs for small incomes and remoter and less crowded residences for the well-to-do; these usual conditions of the modern American City have followed the development of electric transportation, and are impossible without it. Find a dull, backward and inactive town and you will find an unprofitable street car system, unable to give modern service through the inability to secure and recompense the needed new capital. The community served and its transportation facilities are part of one whole, and the success, growth and prosperity of one is dependent upon like prosperity of the other. The security and sure and adequate return to the investor in electric railway securities react to give better transportation facilities to the community, and if oppressive regulation reduces the earnings so as to imperil the principal or the returns on the capital invested, the public will suffer for the lack of the facilities efficient transportation would give. There is no conflicting or divergent interest; the investor and the public prosper or suffer together. Each has a common interest in promoting the prosperity of the other.

Now the interest of the investor is concentrated in the management, which knows these things, while the interest of the public is diffused, and to each man is secondary to his own private affairs; so, upon the management of the electric railways rests the responsibility of making these aspects of their business clear to the public and those of the public servants who are responsible for the regulation of their common interest. It is no easy task; and while it is recognized and much discussed by every live management, too much emphasis cannot be laid upon the necessity of a new publicity—an insistence that the public learn and know the common interests of the traction lines and the community.

Communities' Vital Interest

The service demanded by the public requires that every right and so-called privilege be given to the transportation company, and these are used primarily in the service of the public and are essential to public service, while they are merely elective and incidental to the investor. Capital is the freest and most fluid of commodities; it may go where it pleases and it does go where security and return are best assured; while local rapid transit is an insistent necessity in every community. None of the incidents to transportation are necessary to capital. The corporate machinery for the concentration of investment funds, the stockholder's immunity from personal liability and his right to vote and to act through directors and officers, the franchise, the right of way, the use of the streets and the power of eminent domain, are the essential instruments of transportation, without which it cannot be had; they are not the only recourse of capital, which can seek employment in a thousand other attractive and profitable enterprises. They are the "special privileges" the demagogue so delights to shout of; they are in fact the essential facilities afforded by the public to provide itself with its necessity. Let them be taken back by the public—and while an enormous amount of capital will be destroyed and the investor will suffer tremendous loss, the public will suffer more.

Capital is proverbially timid; it refuses to venture again where it has been ill treated, deprived of a fair return, or suffered loss. Once diverted by losses from the enterprises to which it is accustomed to flow, and persuaded that repeated losses will follow its investment in a field become dangerous though previously profitable, capital would require long years of good records to induce it to return. It is far more important to the American public that its local rapid transit facilities grow and expand and bring in new population and multiply the wealth of the urban and interurban districts, than that American dollars be given a chance to earn a precarious return by investment in this particular business.

Investors Not Dependent

Deprived of expanding rapid transit, the American City will ingrow and strangle itself in unclean congestion; deprived of safe and profitable investment in rapid transit securities, the American dollar will earn a surer and a larger return in unregulated industries.

These truths must be shown, and by the managers of electric railways. The public is selfish; and uninformed, it may fatuously believe that it is benefiting itself by requiring extensions and improvements of service without also providing for a fair return. If the public is instructed in its own interest, it cannot long be blind to the profit of two dollars in convenience and efficiency and value to itself, for every dollar fairly earned for electric railway stocks and bonds—nor to its loss, if loss follows investments in public service.

Securities of electric railways will not be salable if constantly increasing mileage, involving new investment, is demanded for the same five-cent fare; if an ever greater share of the income must be expended to meet requirements for costly improvements in service without increased return; if higher costs of material and labor must be met out of shrinking earnings; if modern and expensive pavements, not used or injured by the cars, must be paid for out of earnings, while interest and dividends are left unpaid.

Unfair Demands Cannot Continue

Unless the public is prepared to assume the financial burdens and political evils of state or municipal ownership of these modern necessities, all unreasonable demands on the capital invested or required in electric utilities, and on their static or decreasing income, must be removed; the public must be made to recognize its own vital interest in the industry, and do its part by restraining unfair demands under the guise of regulation and by protecting investment and providing rates which will insure a fair return; and when these reasonable requirements of capital are met, electric railway securities will successfully compete with any in the world's markets.

The burdens on the managers in these essential utilities are great and to them is added their obligation to the investors and the public, to disclose frankly the real problems of local transportation in the precarious financial conditions of their properties. The recent reports tend to show a decrease in gross income per dollar of investment, and increase in operating expenses due to increased cost of materials and labor, the normal extensions and improvements in service, and the demands of regulating bodies; a large increase in taxes; large increases in non-remunerative investments, such as street paving; a constantly diminishing return on the capital invested; a shrinkage in the surplus applicable to depreciation and available for contingencies and periods of dull business. A further danger confronts the business in the tendency to still further limit the income through appraisements and valuations that do not recognize the true value of the properties, nor the vital interest of communities served in their prosperity, and by fixing a "rate of return" not adequate to meet the demands of modern service or permit earnings sufficient to justify investors in providing money for extensions and betterments and improved service, and for maturing obligations.

Attacks, whether ignorant or malevolent, must be met by frank and courageous disclosure of all the financial difficulties and dangers besetting the business, as well as convincing presentation of the results to the public of strangulation of electric traction, and the common sense and self-interest of the people must respond to these honest endeavors by assuring a fair policy of honest treatment and a just and reasonable reward.

SOME SCIENTIFIC ADVANCES DURING 1915

By Helen R. Hosmer

Research Laboratory, General Electric Company

The search into the laws of Nature is today being prosecuted with more vigor and interest than ever before. The discoveries and hypotheses of the past decade have created entirely new ideas respecting the structure of matter and the nature of energy; and important developments are now following one another so rapidly that a résume of the achievements of a single year requires much elimination and abbreviation. The author mentions some of the more important results of investigation into physical matters that have a bearing on electricity or the electrical industry.—Editor.

PHYSICS

There appears to be no doubt that we are living today in an epoch of physical science, and especially of that aspect of physical things for which the processes of evolution have adapted us only by endowment with reasoning powers which make it possible to supplement the scanty five senses with more delicate means of apperception.

The continued pursuit of the reason of things has led long since to the micro-physical and to the realms of things perceived only by artificial means of the greatest refinement which had to be devised before their possibilities were fully anticipated. Each new discovery has opened up a broad field for further inquiry, until in review of the progress of even a single year one has rather to eliminate than search for material worthy of mention. The developments of the last decade coming after a period of comparative quiescence have put a totally new face upon a subject which was generally conceded to have settled its major problems. And these developments have led in an increasing degree to new knowledge and new conceptions of the structure of matter and the nature of energy. Evidence has been drawn from this line of research and from that for the support of the various theories. The status of the different conceptions of the make-up of the atom for instance, in the light of each new publication of experimental data, is followed with keenest interest by the devotees of the subject.

The past year has added especially important details to the knowledge of the characteristics of X-rays. The constancy and ease of operation of the Coolidge tube has led to a number of investigations of the radiations produced by it.

Rutherford[1] has studied the relation of the energy of the X-rays to that of the cathode rays, exciting them for voltages of 48,000, 64,000 and 96,000 and has found it to be 0.59/1000, 0.74/1000 and 1.04/1000 respectively for the radiation emerging from the bulb under working conditions. As the glass absorbs nearly half the energy of the rays, the efficiency within the bulb should vary from about 1/500 for 96,000 volts to 1/800 for 48,000 volts. These values are not corrected for reflection or scattering of the cathode rays by tungsten, which may be very considerable at high voltages.

Duane and Hunt[2] using a storage battery as source of current have shown that homogeneous X-rays are not produced by a constant voltage. They determined by the ionization method the minimum wave lengths (maximum frequencies) produced at various voltages ranging from 25,000 to 39,000 and found that no radiations of a given wave length are produced until the exciting voltage has attained a certain minimum value, specific for the wave length in question, which wave length is produced, however, by all voltages exceeding this minimum. The minimum voltage V_o corresponding to a wave length λ_o is given by the quantum relation

$$V_o e = h \ \nu_o = \frac{hc}{\lambda_o}$$

where e is the charge of an electron, c the velocity of light, h Planck's constant, and ν_o the frequency $\frac{c}{\lambda_o}$. The maximum frequency attainable is then equal to the energy of a cathode particle divided by Planck's radiation constant. The average value of h calculated from the experimental data by means of this equation is 6.39×10^{-27}, agreeing closely with Planck's latest value of 6.41×10^{-27}. The work affords very strong evidence in favor of the quantum hypothesis.

Duane finds that the energy radiated as X-rays at any given voltage rises with increasing wave length from zero at a certain minimum wave length to a maximum and then falls again rapidly.

He also shows that the effective wave length, by which is meant the wave length having the same coefficient of absorption as the whole radiation at a given voltage, decreases as the rays pass through matter and the corresponding effective frequencies

[1] Rutherford, Phil. Mag. *30*, 361-7 (Sept., 1915).
[2] Duane, Hunt, Physical Review *6*, 166-71 (Aug., 1915).

at different voltages are not proportional but increase less rapidly than the voltage. Consequently the absorption method of measuring the energy radiated at any given voltage will show the maximum at shorter wave lengths than will the ionization method, and also a falling off of frequencies with increasing voltages.

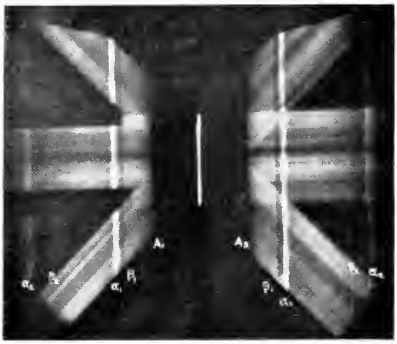


Fig. 1. X-Ray Spectrum of Tungsten showing only K lines

This last fact will account for the results obtained by Rutherford, Barnes and Richardson[3], when using the absorption method, which indicate that with increasing voltages the frequency and penetrating power reach a maximum at 145,000 volts and are not changed by increase of voltage up to 175,000, and that consequently the quantum theory only holds for wave lengths of low frequencies. The shortest wave length emitted by the Coolidge tube is stated to be 0.171×10^{-8} cm. with a penetration of about 3/10 that of the gamma rays from radium C. Dr. Hull of the Laboratory has recently observed a radiation with wave length of 0.117×10^{-8} cm. at a voltage of 110,000.

Hull[4] moreover found no indication of such limitation of the frequencies attainable. Working by the ionization method and with voltages from 24,000 to 95,000, he found that the frequencies accorded well with the quantum relation throughout and there was no indication of deviation above that range. The minimum wave length at 95,000 volts was 0.132×10^{-8} cm. Further, the intensities of all wave lengths increase with the voltage.

Hull's work was done with a voltage constant within less than 1 per cent, obtained by rectifying by means of a kenotron the 100,000-volt current from a transformer. His results agree very closely with those of Duane.

Barnes[5] studied the high-frequency spectrum of tungsten from a Coolidge tube by Moseley's method but found no evidence of a characteristic K line radiation for tungsten, even with 100,000 volts across the tube. A continuous spectrum was observed in the place where the K lines should appear.

Hull, on the contrary, has observed the K lines repeatedly in the course of work which is to be published in the near future.

Fig. 1 will serve to illustrate the methods employed and results obtained in the study of X-ray spectra. This is a photograph, taken by Miss Rice of the Laboratory, of the X-ray spectrum of tungsten at 110,000 volts, showing just the K lines, which have been demonstrated for the first time in the course of Dr. Hull's work here. The beam of X-radiations is resolved by reflection, during slow rotation about an axis of symmetry, from a crystal of rock salt whose action upon the ray is precisely that of a reflection grating with spacings equal to the intermolecular spaces (i.e., 2.81×10^{-8} cm.). The first and second order spectra of the K characteristic radiation of tungsten are shown in the two lines α_1, β_1 and α_2, β_2. The α line is a doublet. The width of the dark space on each side of the direct transmission line in the center (i. e., ½ the distance A_1 A_2) is proportional to the minimum wave length, 0.117×10^{-8} cm., which is excited by the voltage used. Measurement from the cut will show that the α and β lines of the K radiation occur at wave lengths of 0.209×10^{-8} and 0.185×10^{-8} cm. respectively. The repetition of the spectrum at the various angles is due to reflection from the several reflecting planes of the cubical crystal.

Bohr[6] discusses in great detail his theory of the structure of the atom, based on the quantum theory of radiation, in the light of researches published during the last two years. Recent investigations have furnished data tending to confirm his view that the single line spectra are due to oscillations produced by the return to their natural orbits of electrons which have been displaced by some external influence.

Thus McLennan and Henderson[7] have found that the vapors of cadmium, zinc, and

[3] Rutherford, Barnes, Richardson, Phil. Mag. *30*, 339-60 (Sept., 1915).

[4] Hull, Physical Review 7, 156-8 (Jan., 1916). Amer. Jour. Roentgenology *2*, 893-9 (Dec., 1915).

[5] Barnes, Phil. Mag. *30*, 368-70 (Sept., 1915).

[6] Bohr, Phil. Mag. *30*, 394-415 (Sept., 1915).

[7] McLennan, Henderson, Proc. Roy. Soc., *91*, 485-9 (Aug., 1915).

mercury emit single-line spectra when traversed by electrons possessing the proper amount of energy. The many lined spectra of these metals are obtained at minimum arcing voltages of 15.3, 11.85 and 12.5, respectively. Below these voltages there is what appears to be a definite range for each metal, over which the characteristic single-line spectra alone can be excited. Thus the conditions required for producing the two types of spectra are clearly differentiated and may well correspond to the energy emission produced in the simpler case by the return of one electron, and in the other case by the return of a complete ring of electrons to their original positions about the central nucleus.

In a later paper McLennan[8] notes the existence of a single-line spectrum for magnesium also, as well as of an absorption band analogous to those of mercury, zinc, and cadmium. The further results of the investigations are discussed in detail, and with reference to their bearing upon Bohr's theory of atomic structure.

Further experimental data bearing upon Bohr's atom have been published by Evans (Spectra of Helium and Hydrogen)[9], Allen (Series Spectrum of Hydrogen)[10], Fowler (Band Spectrum of Helium)[11] and others.

R. W. Wood[12] has demonstrated by means of a very simple experiment involving the bombardment in a high vacuum of reflecting surfaces of glass or mica with a small stream of mercury vapor, that the assumption that the number of gas molecules reflected in any given direction is proportional to the cosine of the angle of that direction with the normal to the surface is at least approximately correct. At angles greater than 80 deg. there appears to be practically no reflection. The conditions employed completely eliminated molecular collisions and lateral pressure.

That these phenomena may be due to other conditions than that of reflection has been indicated by work in the Laboratory which will be published in the near future.

J. J. Thomson[13] discusses in detail the bearing upon his theory of metallic conduction, as stated in "The Corpuscular Theory of Matter," of the fact, recently established by Kamerlingh Onnes, that the electrical conductivity of metals undergoes at certain perfectly definite transition temperatures in the region of the absolute zero, an enormous increase. He finds it difficult to account for this condition of super-conductivity from the point of view of the theory of free electrons and presents arguments to show that the presence in the atoms of electrical doublets whose orientation is so changed by an electrical force that the axes tend to point in the direction of the force, whereupon the electrons pass freely along the resulting chains thus formed. This would explain the phenomena involved quite adequately. He deduces mathematically the conditions which would result from his theory and shows that they correspond well with many of the well known properties of metals and alloys.

McLennan, Treleaven and Murray[14,15], working upon residual ionization in gases, have come to the conclusion that such ionization is not spontaneous but is due to alpha, beta, and perhaps gamma radiations emitted by the walls of the container, or by the land, water, etc., in the neighborhood. Experiments made upon the electrical conductivity of air confined in a vessel made of ice from the water of Lake Ontario, measured on the surface of that lake, gave a value corresponding to the generation of 2.6 ions per cc. per second, the lowest value yet obtained for air.

The old ideal of the absolute measure of light intensity in such a way as to eliminate the physiological and individual peculiarities of the human eye have been brought much nearer realization than ever before by the work of Ives and Kingsbury[16] upon a method of photometry which replaces the eye by a thermopile. A solution, whose composition has been so adjusted that its energy transmission corresponds very closely to the intensity values observed with the average human eye over the range of the normal equal energy spectrum, is used to screen out from the thermopile non-luminous radiations. The thermopile is then influenced only by such radiations as would be perceived by the eye, and has been shown to give readings which indicate the intensity of these with a precision better than one per cent. While this artificial eye is still to a certain extent in the empirical stage, awaiting a more exact determination of the luminosity curve of the spectrum, it is capable of measuring the color differences most commonly met with in practical photometry as accurately as is done by the methods of visual colored light photometry.

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[8]McLennan, Journal Franklin Inst., *181*, 191-207 (Jan., 1916).
[9]Evans, Phil. Mag. *29*, 284-97 (Feb., 1915).
[10]Allen, Phil. Mag. *29*, 140-3 (Jan., 1915).
[11]Fowler, Proc. Roy. Soc., *91*, 208-16 (Mar., 1915).
[12]Wood, Phil. Mag. *30*, 300-4 (August, 1915).
[13]Thomson, J. J., Phil. Mag. *30*, 192-202 (July, 1915).
[14]McLennan, Treleaven, Phil. Mag. *30*, 415-27 (Sept., 1915).
[15]McLennan, Murray, Phil. Mag. *30*, 428-34 (Sept., 1915).
[16]Ives, Kingsbury, Physical Review *6*, 319-33.

Observations made in the course of this work have led to a corrected value for the mechanical equivalent of light of

1 lumen = 0.00159 watt of luminous flux.

Ives[17] has further shown that for cases involving large amounts of light the absorbing solution may be replaced by a spectrometer whose spectrum is cut down to the wave lengths visible to the normal eye, or to any other sensibility curve desired, by passing through a template of the proper form, and then recombining, by means of a lens, upon a thermojunction.

A new method for estimating high temperatures has been subjected to preliminary tests and is described by Paterson and Dudding[18]. It consists in bringing a black body in the form of a carbon filament to such a temperature that its total luminous radiation is identical in color, as shown by a Lummer-Brodhun photometer, with that from the incandescent metal under observation. The lumens per watt and relation of lumens per watt to temperature having been already determined for carbon and tungsten filaments, the unknown temperature is easily computed. The possible sources of error were investigated, and the conclusion reached that the method as tested gives accurate results as long as the bodies being considered behave like grey bodies throughout the *visible* spectrum. Any deviation from such behavior will produce errors of the same magnitude. A grey body is defined as one which, while not radiating at any temperature as much energy as a black body at the same temperature, does radiate in any wave length an amount which is a constant fraction of the black body radiation of the same wave length.

In the hot-wire anemometer there has been perfected a simple portable instrument for measuring with great accuracy the velocity and velocity gradients of air currents under the most varied conditions without disturbance of the flow. Observations are made by determining the current required to keep a fine wire, stretched between suitable supparts, at a given temperature which is measured by the resistance of the wire.

A consideration of the heat convection from cylinders in a stream of fluid and the experimental determination of the convection constants of small platinum wires were necessary preliminaries. The details of construction of the "linear anemometer" as it has been termed, its calibration, and sources of error have been carefully studied.[19] A change of velocity as small as 10 cm./sec. can be detected in a distance of 1/800 mm. and velocity gradients as high as 80,000 cm./sec. per cm. can be measured.

The applications of this instrument should be many, as it offers a means of studying with great precision the problems of complex gas flow, of gaseous viscosity, and of thermal conduction in gases. Observations can be made very rapidly, and hence the instrument is suited for making studies of the distribution of air velocities in the neighborhood of various obstacles in connection with aeronautical studies where the need for a standard instrument has long been felt. It will thus be possible to analyze propeller wakes and measure the distribution of velocities over planes of different dimensions.

Among other technical applications should be the analysis of gas temperatures and gas flow in pipes, and particularly of steam flow in engines.

A study of the counter diffusion of various gases and vapors at low pressures led to the invention by W. Gaede[20] of a vacuum pump without solid or liquid pistons whose sucking action is due wholly to the diffusion forces. The gas being exhausted diffuses through small openings against a blast of mercury vapor which is immediately condensed by suitable coolers and returned to the vaporizer.

The pump is very slow in action, but the speed of evacuation is constant up to the highest vacuum it is capable of producing, which is better than can be obtained by any mechanical pump, or even by the use of charcoal at the temperature of liquid air.

It is of interest to note that Dr. Langmuir of the Research Laboratory has invented a vacuum pump based upon an entirely new principle of operation. The rate of evacuation is $1\frac{1}{2}$ to 3 times that of the molecular pump, accelerates as the pressure diminishes, and appears to be capable of unlimited increase. A liter bulb can be exhausted from 100 to 0.01 microns in 2 seconds. The construction involves no moving or breakable parts.

This review will serve as a very incomplete but possibly characteristic record of the achievements of a single year in the field of physics. For a true understanding of any of the problems mentioned a study of the originals is indispensible.

[17] Ives, Physical Review *6*, 334-44 (Nov., 1915).
[18] Paterson, Dudding, Proceedings of the Physical Society of London, *27*, 230-62 (April., 1915). Phil Mag. *30*, 34-63 (July, 1915).
[19] King, Phil. Mag. *29*, 556-77 (April, 1915).
[20] Gaede, Am. Phys. *46*, 357-92 (Feb., 1915).

APPARATUS FOR PRODUCING ULTRA-VIOLET RADIATION

By W. S. Andrews

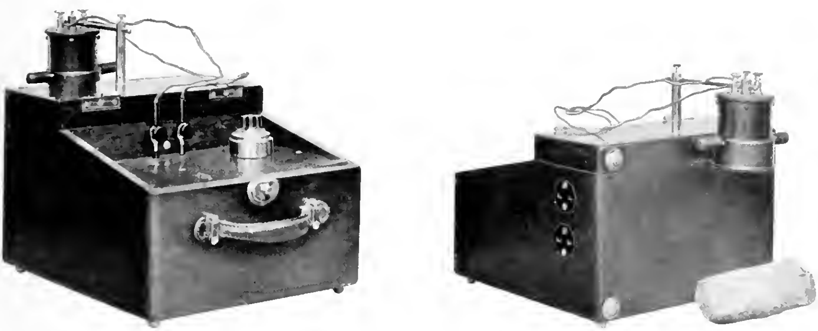
Consulting Engineering Department, General Electric Company

After briefly describing the characteristics of ultra-violet radiation, the author gives a description of apparatus recently designed for the production of such radiations.—Editor.

There is no distinct line dividing the visible spectrum from the invisible ultra-violet spectrum, as they melt one into the other like the various colors in the visible spectrum. The wave length of 4000 Ångström units may, however, be taken as the approximate wave length at which visibility ceases for the average eye, and at which the invisible ultra-violet spectrum may be said to begin.

The chemical power of ultra-violet radiation as evidenced in the reduction of silver nitrate, etc., has been known for many years, but its wonderful property of exciting fluorescence and phosphorescence in certain mineral and organic compounds is not so commonly understood and recognized. Roughly speaking, the ultra-violet spectrum may be said to extend about two octaves beyond the visible spectrum, say from 4000 A.u. to 1000 A.u. When the invisible radiation somewhere within these limits of wave length falls upon a substance that possesses the property of fluorescence, the waves are absorbed by some atomic mechanism which we do not understand, and they are reflected or emitted again as light waves of greater length, thus dropping for the most part within the limits of the visible spectrum so that the substance in question, although excited by a beam of *invisible* light, glows with one of the colors of the visible spectrum.

Different substances require different wave lengths to excite them to a maximum fluorescence, so it is, therefore, obviously desirable that the ultra-violet radiation used for producing fluorescence should include as much as possible of the invisible spectrum. In other words, if we could speak of it as visible light we might say that it should be polychromatic.



Front and Back Views of Ultra-Violet Radiation Generator

The high tension disruptive electric spark between iron terminals is very rich in ultra-violet radiation covering about 80 per cent of that part of the spectrum which is useful for producing fluorescent effects. A number of metals other than iron have been used for electrodes, such as zinc, cadmium, magnesium, nickel, cobalt, etc., but, while some of these produce more intense radiation than iron in certain regions of the ultra-violet spectrum, they fail to produce any rays of useful power in other regions, whereas iron shows a more uniform distribution throughout the entire range.

Iron electrodes have therefore been adopted for use in an outfit recently designed especially for the production of fluorescent effects, but these electrodes can be readily exchanged for others of a different metal that may be desired for some special purpose.

This outfit comprises:

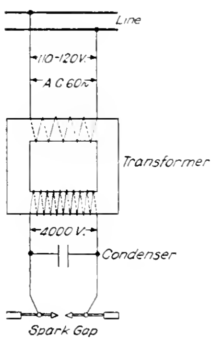
1. A small transformer that steps up 60-cycle, 110-120-volt alternating current to about 4000 volts.

2. A suitable condenser.

3. An adjustable spark gap with removable iron terminals, the whole being protected in a chamber of insulating material

4. Sundry fittings with connecting cords and plugs, etc.

All of the above parts are fitted into a neat mahogany box for convenient transportation, and it is only a few minutes work to take out



Connections of Apparatus

the spark gap, fit it in position and connect the apparatus to any suitable current outlet. As this outfit only uses about 250 to 300 watts it can be safely connected to any alternating current lighting circuit.

The iron electrodes are enclosed in a small cylindrical chamber of insulating material, open at one end only, and having the insulated heads of adjusting screws projecting outside, by which the operator is able to regulate the frequency of the spark from 120 per second (with 60-cycle current) up to ten or twenty times that value.

This small outfit produces an abundance of ultra-violet radiation with which a number of very interesting fluorescent effects may be produced.

The following is a list of a few fluorescent substances most of which are readily obtainable and which appear white or nearly so under visible light but which assume bright colors under the invisible ultra-violet rays:

Natural calcite from Franklin Forge, N. J., and other localities	Red
Barium sulphide, all tints of	Orange
Cadmium compounds	Yellow
Willemite, natural and artificial	Green
All salts of salicylic acid, such as soda salicylate, etc.	Blue
Some compounds of calcium	Violet

Many other compounds that show beautiful fluorescent colors might be mentioned, but the above suffice to include all the principal colors.

It is a remarkable fact that, broadly speaking, many substances that are quite transparent to visible light are entirely opaque to ultra-violet radiation, while other substances are equally transparent to both. Thus glass, mica, gelatin and celluloid even in very thin sheets are quite opaque to ultra violet rays, but clear rock-crystal or quartz, fluorite and selenite are all about equally transparent to visible light and invisible ultra violet rays.

These curious properties may be readily demonstrated thus:

If the light from the iron spark is directed on a lump of willemite for example, the latter will glow with a beautiful green fluorescence. If a thin plate of glass or clear mica is now placed between the iron spark and the willemite, the green fluorescence of the latter will instantly vanish, and it will appear in its natural color as seen by daylight or any ordinary artificial light. If now a plate of clear quartz or selenite is substituted for the glass or mica, the willemite will continue to glow with its characteristic green fluorescence. It is thus made evident that the glass and mica are opaque to the ultra-violet rays which produce fluorescence, while the quartz and selenite are transparent to them. This experiment may be tried with any fluorescent substance other than willemite with similar results.

Lenses made of rock crystal (clear natural quartz) may be used to concentrate the ultra-violet rays from the iron spark and thus enhance their fluorescent effect.

Some substances, such as barium sulphide, continue to glow for a time after the exciting ultra violet rays have been cut off, thus illustrating the phenomenon of *phosphorescence* which is simply a persistence of fluorescence.

The rays that are produced by the iron spark as above described naturally contain a large proportion of visible light, and in certain cases, when a substance may show only a weak degree of fluorescence, the color of the latter may be masked or overpowered to some extent by the visible light component. There are means by which the visible and invisible components may be entirely separated from each other, but the apparatus required for this is somewhat costly, and for ordinary purposes of illustration the visible light of the spark is not detrimental.

The spark between iron terminals should not be looked at by the unprotected eye on account of the danger of injury to sight from the ultra-violet rays. Ordinary spectacles or eye-glasses, however, provide complete protection if the lenses are *not* made of rock crystal. They can be tested in a moment by holding the lens between the iron spark and the fluorescent substance (preferably a piece of Willemite). If the fluorescence is cut off by the lens it is made of glass, in which case the wearer may safely look at the iron spark, but if the green fluorescence of the willemite is not obscured by the lens it is made of rock crystal and will therefore afford no protection to the eye.

The illustrations show the above described apparatus set up for operation and also closed for transportation. A diagram showing the various parts and electrical connections is also shown.

This outfit should be found especially valuable in physical and chemical laboratories and in many branches of research. As far as the writer is aware there is at present no other apparatus on the market that will produce equivalent effects.

ELECTRICAL EQUIPMENT OF THE ALABAMA MARBLE COMPANY

By R. T. Brooke

Birmingham Office, General Electric Company

While the employment of electric power for quarrying marble is not an innovation, the following article descriptive of a partly electrified quarry possesses rather unusual interest. It narrates how the change-over from steam to electricity is being made step by step, which method permits a comparison being made of the simultaneous operation of the steam-driven and the electric-driven equipment. The author points out that this comparison has resulted in the establishing of two significant facts; electric drive is superior to steam drive, and the squirrel-cage type of induction motor is adaptable to this service.—Editor.

The Alabama Marble Company, "Gantt's Quarry," gives Alabama a high rank as a marble producing state. This quarry is located some four miles from Sylacauga, in Talladega County, and is fifty-seven miles from Birmingham. It was operated in a small way with primitive methods as early as 1845 and was known as the Alabama White Marble Co. The active history of the quarry dates from the reorganization of the Alabama White Marble Co. as the Alabama Marble Co. in 1906. At that time the capitalization was increased, the operations extended, and more modern methods installed.

The company's property consists of 700 acres through which the marble vein is approximately 1½ miles long and 600 to 700 feet thick. The deposit dips at an angle of approximately 35 deg. and the layers vary from 2 to 7 feet in thickness. Bore holes sunk at different parts of the vein have failed to find its bottom.

Figs. 1*, 2 and 3 show the present quarry development. The tunnel shown is No. 1 and has already been worked to a considerable depth. Tunnels No. 2 and No. 3 are now being opened and, when workable, will present an almost unlimited supply of perfect stock without the necessity of removing the overburden, which will result in a handsome saving in the cost of production.

At the time of reorganization the power plant consisted of boilers that furnished steam to channelers, derricks, etc., in the quarry and of a 500-h.p. Corliss engine belted to a continuous line shaft that drove the saw mill and finishing shop. This shop, being somewhat out of date and inadequate to accommodate the increasing demand, was remodeled, enlarged, and equipped with motor drive.

The original electrical equipment consisted of the motors for the finishing shop and a 220-volt three-phase 60-cycle belted generator of sufficient capacity for the finishing shop and village lights. This apparatus operated very satisfactorily but, in 1910, the entire plant was destroyed by fire. Plans were at once prepared for a new plant of increased capacity and of the most modern and up-to-date construction throughout.

* Frontispiece.

The partial electrification of the old plant had proved so satisfactory in operation and in reducing the cost of the output that it was unanimously decided to completely electrify the new plant. The following power-house equipment was consequently installed: four

Fig. 2. Mouth of Tunnel

Fig. 3. Tunnel with Steam Channelers on Left

300-h.p. vertical return tubular boilers to furnish steam at 160 lb. gauge, 125 deg. superheat; one 500-kw. 3600-r.p.m. three-phase 60-cycle Curtis steam turbine-generator with direct-connected exciter; and a barometric condenser of the "Beyer Type." Fig. 4 is a photograph of the turbine and generator. A fully equipped switchboard. Fig. 5, with panels of Alabama Marble, completes the power-house electrical installation.

Power is generated and distributed at 440 volts for all purposes except for cranes, derricks, channelers and lights, which are served through transformers at 220 volts.

In the quarry both steam and electric derricks and hoists are in use; the old steam ones, however, are being replaced as rapidly as possible by others that are motor-driven. At present, two electric channelers are in use and others which are on order will completely electrify this feature of the operation. Accurate records over a considerable period of time show an increased time-efficiency for these machines over both the steam and air channelers. The records also show that the output of the electrical machine is about 10 per cent greater than that of machines of the other two types. The electric channeler is easier to operate, requires less adjustment, and being balanced will cut on both the up-hill and down-hill sides of a sloping track; also, the hammer blow can be more delicately adjusted. Its maintenance cost is about equal to that of the steam or the air channeler, but the electric type of machine requires only approximately 20-h.p. at the boilers against about 60-h.p. for the others.

The marble blocks, on being cut to proper size, are raised from the quarry by hoists and derricks and then taken over the company's tracks to the rough stock yard or the saw mill; a locomotive crane, a standard locomotive, and flat cars serve as the means of transportation. A 30-ton electric traveling crane, Fig. 6, is installed between the saw mill and the finishing shop for handling both raw and finished material.

All the motors except the cram motors are of the three-phase squirrel-cage type;

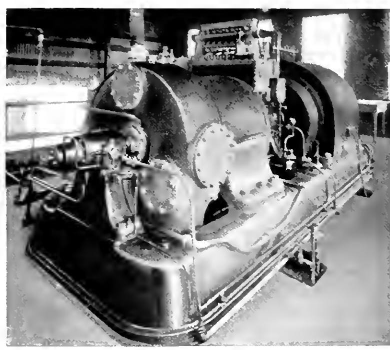


Fig. 4. 500-kw. Curtis Steam Turbine Operating Plant of the Alabama Marble Company

and individual drive is used for all purposes in the mill and the shop, except for gang saws and rubbing beds, for which group drive is more desirable. The increased power demanded by these machines under certain conditions of operation makes a large reserve necessary. However, since

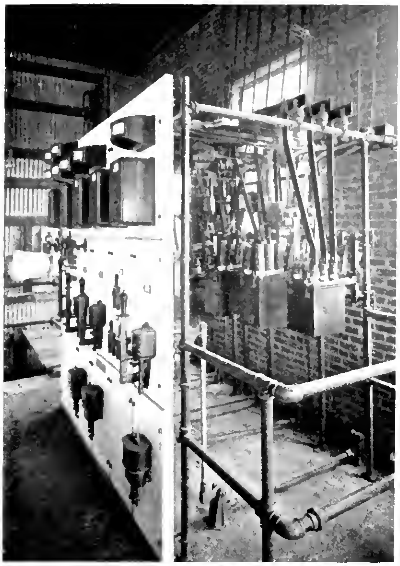


Fig. 5. Switchboard and Oil Switches. (Switchboard Panels of Alabama White Marble)

Fig. 7. Hurst Saw Frames

Fig. 6. 30-ton Crane Operated by A C Motors

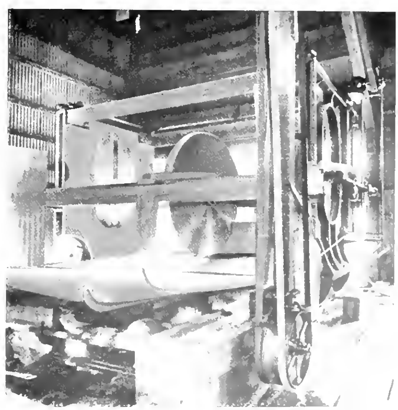


Fig. 8 72-in. Diamond Saw Belt Driven by a 440-volt, 3-phase, 100-h p., 60-cycle, 154-r p.m Induction Motor it is probable that some one machine in any particular group will be idle much of the time, its proportion of the total horse power will be available for the other machines.

In the saw mill there are five groups of standard Hurst saw frames, Fig. 7. Group No. 1 is composed of one 10-ft., one 14-ft., and one 16-ft. frame. Groups No. 2, 3, and 4 are made up of four 12-ft. frames. These four groups are each belt-driven from a line shaft, which in turn is belted from a three-phase squirrel-cage 75-h.p. 514-r.p.m. induction motor. In group No. 5 there are four 12-ft. frames and one 72-in. diamond saw which latter is shown in Fig. 8. This group is driven by a three-phase squirrel-cage 100-h p. 514-r.p.m. motor through belting and shafting similar to that used in the other groups. It is of interest to note that with diamonds costing $10,000 per pound this saw will make a single cut cheaper than an ordinary saw with sand at $1.00 per ton.

In the finishing shop a 400 cu. ft. per minute air compressor is belt-driven from a 75-h.p. 514-r.p.m. motor having an automatic control for maintaining constant pressure. This compressor exhausts into a large receiver from which air is supplied at approximately 100 lb. pressure to hammers, chisels, etc.

One carborundum machine in combination with a circular planer and carborundum machine is belt-driven as a group from a 75-h.p. 900-r.p.m. motor. The latter machine is equipped to use steel tools or a motor head driven through oil immersed gearing by a 25-h.p. 1800-r.p.m. motor (Fig. 9).

There are six 14-ft. and two 12-ft. rubbing beds arranged in groups of two for belt drive from three-phase squirrel-cage 50-h.p. 900-r.p.m. motors. Three large polishing machines for buffing are belt-driven with quarter-turn belts from three-phase squirrel-cage 20-h.p 1200-r.p.m. motors; also eight smaller machines for gritting and honing are similarly driven from 10-h.p. 1200-r.p.m. motors.

The installation is completed by a 75-h.p. 900-r.p.m. motor group drive of a small carborundum machine, several small buffing machines, and a 16-ft. lathe equipped to use either steel tools or a direct-driven motor head.

Fig. 9. 440-volt, 3-phase, 60-cycle Induction Motor geared to a Carborundum Attachment on a Single Circular Planer

An ingenious and very effective manner of cooling the circulating water is employed. From the hot well it flows to the saw mill and the finishing shop where it is used on saws, rubbing beds, etc. From there it gravitates over rocks and pebbles for a distance of about 1000 ft. to a large spring, from which point it is again pumped to the condenser. An average vacuum of 26.5 in. is maintained and 29 in. is not unusual in the winter months.

The complete electrical equipment for this plant was furnished and installed during August, 1911; and since that time it has given a remarkable performance by its continued operation day and night (Sundays excepted), without serious delay in production or shut down due to failure.

CANDLE-POWER MEASUREMENTS OF SERIES GAS-FILLED INCANDESCENT LAMPS

By Ralph C. Robinson

Research Laboratory, General Electric Company

The advent of the gas-filled lamp for various reasons made the method of rating incandescent lamps in terms of mean horizontal candle-power unsatisfactory. The more modern method is to rate incandescent lamps in spherical candle-power—or lumens. The author gives the reasons for making this change in the method of rating and describes the procedure as well as the apparatus used.—Editor.

The basis of this article is a paper presented before the Illuminating Engineering Society in New York, February 11, 1916.

It has been customary to rate the candle-power of incandescent lamps as the mean horizontal candle-power. With the advent of the gas-filled lamp this is not satisfactory, so we are gradually changing our ratings to spherical candle-power, or lumens. As the art of making spherical candle-power measurements is not on as firm a foundation as is that of making horizontal candle-power measurements, it was first necessary to determine once for all the reduction factor for all types of lamps in order to ascertain the spherical candle-power. Then all that was necessary to find the spherical candle-power was to measure the mean horizontal candle-power and multiply the value by the reduction factor. Small differences in the arrangement of the filament, however, make the reduction factor method of determining spherical candle-power unreliable and inaccurate. The examples cited below show how greatly the reduction factors may be made to vary in one size of lamp by changing the direction of mounting the filament.

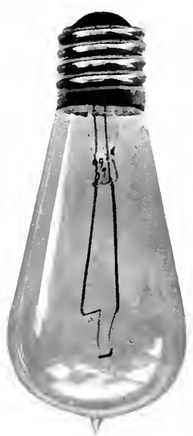


Fig. 1. Typical Series Type Gas-Filled Mazda Lamp

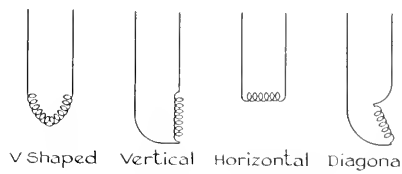


Fig. 2. Methods of Mounting Filaments for Test

Several Mazda C lamps of the well known series type, see Fig. 1, were used for this experiment. They were 6.6-ampere lamps, of 80-candle-power rating. The filaments were spiralled in the form customary in these lamps, all having as nearly as possible the same number of turns, the same spacing between turns, the same diameter and the same size leads, etc. They were mounted in four different styles, as shown in Fig. 2. In order to make all the measurements comparable the lamps in every instance were run with their filaments at the same average temperature, 2825 deg. K. The life of lamps is more uniform when they are placed on test at a definite filament temperature, than when they are set up by any other method of rating. The current at which a lamp will run in order to raise the temperature to 2825 deg. K. is ascertained by the color matching method described by Langmuir and Orange (Trans. A.I.E.E. 32, 1935, (1913). When tungsten filaments match in color they are of equal temperature. This color matching is carried out on a standard photometer, see Fig. 3, the actual matching being accomplished with a Lummer-Brodhun photometer. The operation consists in changing the voltage or current of the lamp being measured until its color as seen in one side of the photometer field is the same as the color of a standard lamp which shines on the other half of the field. By this method temperatures can be checked to within 5 deg.

As the standard lamp would have a comparatively short life, or would deteriorate rapidly, if run at high temperatures, it must be run only at low temperatures. To make it burn apparently at high temperatures a specially selected blue glass screen is inserted between it and the photometer. This cuts out the red rays and causes the filament to look much hotter than it really is. By either changing the actual temperature of the filament, or by varying the density of the blue glass screen, any temperature desired can be approximated.

The actual temperature of filaments is calculated from the equation derived by Langmuir. (Phys. Rev 6 140 (1915)—

$$T=\frac{11230}{7.029}-\log H,$$ where T is the absolute temperature and H is the intrinsic brilliancy of the filament in candle-power per sq. cm of projected area.

Burning all the lamps at the same temperature necessitated a slightly different current for individual lamps. This current was ascertained for every lamp, and all the photometer measurements were made at that current.

The mean horizontal candle-power of gas-filled lamps (Mazda C) cannot be determined by the usual method of rotating the lamp around its vertical axis, unless it is done with the aid of a system of mirrors (Sharp, C. H., Elec. World 64, 992; Trans. Ill. Eng. Soc. 9, 1021), or similar contrivance. Consequently the candle-power was measured every 10 deg. around the lamp in a horizontal plane. These values were plotted, typical curves of which are shown in Figs. 4, 5, 6 and 7.

The large indentations in these curves, noticeable especially in Fig. 6, are caused by the lead wires hiding portions of the filament so that but very little light comes from the ends of the filament. The smaller irregularities, see Fig. 7, are due to slight twists in the filament, to opening up of the spirals and to reflections from the bulb, etc.

Fig. 3. Standard Photometer

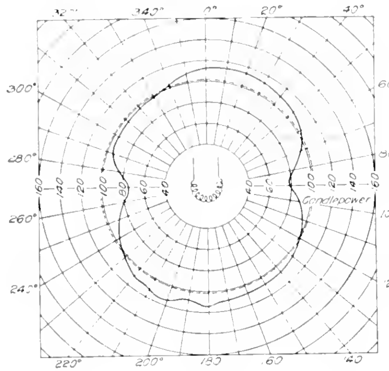


Fig. 4

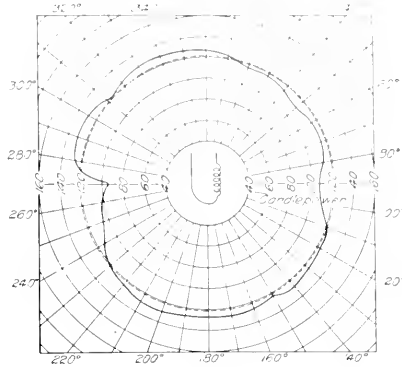


Fig. 5

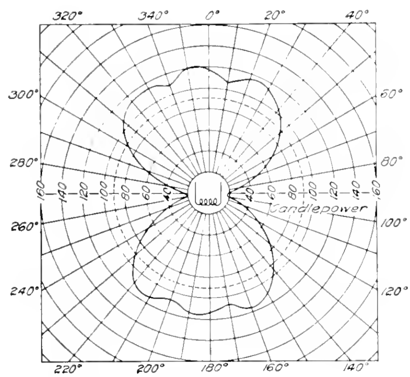


Fig. 6

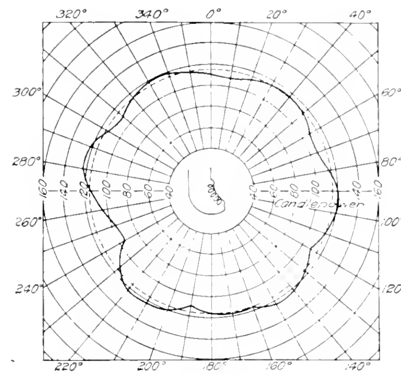
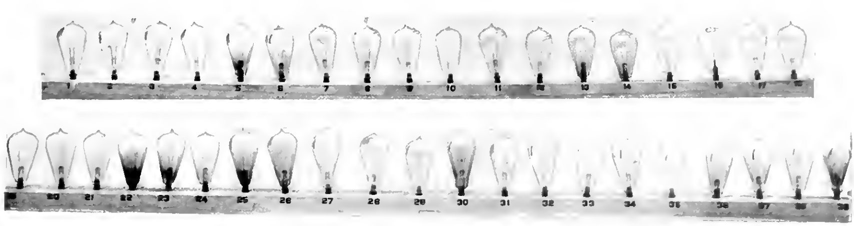


Fig. 7



The mean horizontal candle-power of each lamp was determined from the curves by obtaining with a planimeter the area enclosed within the curve, and then calculating the radius of the circle which would have the same area. This radius, when laid out on the plotting paper, gives the mean horizontal candle-power reading.

When making the spherical candle-power readings the same blue glass screens had to be used in front of the standard photometer as was used in the color matching of the lamp, so that it would not have to be run at as high a temperature as is the lamp being measured.

If one does not have approximately the same color of lamps to measure when using Lummer-Brodhun photometers, the results cannot be relied upon. As a Lummer-Brodhun photometer is very easy to read, and as it is extremely accurate when lamps of similar color are being measured, it is universally used when possible.

As a blue screen was employed in this work its candle-power absorption had to be determined. This necessitated measuring the candle-power of some lamp without the screen, and then with it. As the color in these two instances is so different, a Lummer-Brodhun photometer is not satisfactory. The best photometer to use in this case is a Flicker, as readings with it are unaffected by differences in color.

The Ulbricht sphere is now accepted as the best apparatus with which to determine the mean spherical candle-power. Fig. 8* shows the one in use in the Research Laboratory. It is a 50-inch (127 cm.) hollow globe painted white inside. The lamp to be measured is placed inside the sphere. As the walls are practically totally reflecting, they are uniformly lighted by the lamp. Consequently, all that has to be done is to measure the candle-power of a small diffusing glass window inserted in the wall of the sphere. This candle-power represents the mean spherical candle-power of the lamp. A Weber (Lummer-Brodhun principle) photometer was used for measuring the candle-power of the lamp. As with the horizontal measurements, blue glass screens have to be used in front of the standard lamp so as to obviate color differences.

The results tabulated below are the average of a number of different lamps of each type.

Filament mounting	Volts	Amp.	Watts	Mean Horizontal		Spherical		Reduction Factor
				Candle-power	Watts per Candle	Candle-power	Watts per Candle	
V-shaped	9.5	6.97	66.2	100.7	0.66	82.5	0.805	0.82
Vertical	10.76	7.02	75.5	126.8	0.595	93.7	0.805	0.74
Horizontal	10.73	7.07	75.9	93.5	0.82	95.2	0.800	1.01
Diagonal	11.2	6.93	77.5	122.0	0.635	95.2	0.815	0.78

As will be noted in this table the watts per mean horizontal candle-power are very different for the various filament mountings, while the watts per spherical candle-power are nearly the same in all cases. The reduction factors consequently are also very different.

In commercial practice one will not meet in lamps of the same class such different mountings as those used in this test. However, even in spite of the careful methods used in the manufacture of these lamps, slight variations in the shape of the filament, in its position, or direction, are liable to occur. These will have such an effect on the horizontal candle-power and the reduction factor that measurements of these are very misleading. As the watts per spherical candle-power, or the watts per lumen of individual lamps at the same filament temperature agree much more closely than the watts per horizontal candle-power, it is better to rate Mazda C lamps the first way.

In conclusion the author wishes to express his appreciation for the assistance of Mr. Edward Guyon, who made the measurements recorded in this paper.

* Cover illustration.

PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

PART XVII (NOS. 71 AND 72)

BY E. C. PARHAM

CONSTRUCTION DEPARTMENT, GENERAL ELECTRIC COMPANY

(71) MOTOR NAME PLATES EXCHANGED

A new motor that had been just received from one of the large manufacturing companies was made the subject of a complaint because it had so little "turning power." The motor would revolve, but it heated excessively and would carry no load. A visit by an inspector revealed the following situation: The operator had another motor, the name plate of which had the same rating as that of the new motor. In fact, when ordering the new motor he had taken the name plate rating of the older motor because he wished that motor to be duplicated. The new motor, however, had only three leads; the older motor had four leads. Aside from this difference in external appearance, the two motors seemed to be the same; a checking of their windings, after the machines had been unassembled, disclosed the facts that the new motor was wound for three-phase service and the old motor for quarter-phase service, *although it had a three-phase name plate.* Both stators had the same number of slots and the same number of poles, but in the quarter-phase motor the coils were grouped three in series while in the three-phase machine the coils were grouped two in series. Under this condition the stator could not well be reconnected without removing the coils, because any such reconnection would bring the group insulation in the wrong places. The original cause of the confusion could not be determined with certainty because the old motor had been in service for several years. However, the probabilities are that at some previous time it had been sent to a repair shop at the same time as another motor of the same rating but a different number of phases. Furthermore, as the stators were probably exactly alike it was an easy matter to get them confused. The repairman knew that the motor was a quarter-phase machine, that it was going to operate on a quarter-phase circuit, and that his own man was to install it; therefore even had he noticed the discrepancy in the name plate, probably he would have attached no importance to it.

(72) VOLTAGE VARIED

Ordinarily a voltmeter, that is used without a multiplier, indicates the value of the voltage that is applied to its terminals. When a multiplying resistance is used in series with the voltmeter, to increase the range of the instrument, the voltmeter scale may be so marked that the needle indicates the value of the voltage that is applied across the voltmeter and the multiplying resistance combined; this is the case with the switchboard type of meter that has a resistance permanently in series with it. When a multiplier is used for increasing the range of a meter, the scale of which is not marked in terms of the total voltage impressed, it is necessary to use a multiplying constant for deriving the value of the total impressed voltage from the indication of the meter; this is the case with portable meters which often must be used for measuring voltages that exceed their range. In either case, the voltage that is effective in producing the deflection is that across the voltmeter terminals; and, if an irregularity of any kind changes the value of this voltage drop, the indications of the instrument will be in error.

An operator complained that his generator voltage regulator was not maintaining the generator voltage constant. A regulator expert investigated the complaint, and he found that the regulator was in perfect condition and was functioning in an entirely normal manner. Also, he learned that the operator had no fault to find with the regulation so far as constant brilliancy of the lamps was concerned. The operator had drawn his conclusions as to unsatisfactory regulation from the record of a recording voltmeter that was installed in his office. When the inspector's observation was directed toward the meter, he noted that the needle acted as if uncertain where to indicate. An inspection of the sectionalized multiplier, by means of which the meter could be adapted to measure any of several maximum voltages, disclosed an odor of burnt metal and insulation and at times a slight smoking could be detected.

The trouble evidently had been due to a variation of the multiplier resistance incident to an internal fault.

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.

A-C. GENERATOR: HIGH INDUCED POTENTIAL WHEN STARTING FOR USE AS A SYNCHRONOUS MOTOR

(164) Trouble is experienced when starting a certain 150-kw., 2400-volt, three-phase, 8-pole generator, which is being used as a synchronous motor. The starting equipment consists of two water barrel rheostats, one in each of two of the lines to the machine. By means of these barrels, increasing values of voltage are applied to the machine during the starting period, at the termination of which they are short-circuited.

Oftentimes, breakdowns occur from field to ground at starting because of a high induced voltage in the field windings. (A measurement of the maximum voltage between slip rings showed 3000 volts induced in the field.)

Is there no way of overcoming this high induced voltage other than by installing the ordinary synchronous-motor squirrel-cage winding in the generator pole faces? (The conditions peculiar to this installation render impossible the use of a separate driving motor for starting purposes.)

When an ordinary generator is being utilized as a synchronous motor, the high voltage that is induced in the field winding at starting can be reduced in either one of the following ways.

(a) When the machine is at rest, apply only the minimum voltage that will break its static friction (start rotation). As the ratio of the machine's transformer action is greatest while the unit is at rest, it is vitally important that the stator (primary) voltage applied should not be greater than absolutely necessary to start rotation. After the rotor is underway, the danger of producing excessive induced potentials in the field lessens; but it would nevertheless be advisable to bring the impressed voltage to normal at a slow rate. Forcing the acceleration might result in undue insulation strain.

(b) With the starting equipment used it may be difficult to lower the initial impressed voltage below that value which would result in a dangerously high induced voltage in the field winding. If such is the case, or a maximum precaution is to be secured, the following change should be made in the method of starting. From the time the start is to be made to the time the machine reaches at least approximately synchronous speed, the field should be short-circuited by a resistance; then the resistance can be disconnected and the exciting current applied. This connection should be non-inductive, should have a current-carrying capacity of about the no-load full-voltage excitation current of the machine, and generally will be satisfactory if of a resistance at least 15 times that of the field winding. Other conditions being the same, the lower the value of resistance, the less the voltage induced in the field and the greater the likelihood of the rotor sticking at half speed (i.e., not accelerating above half speed), and vice versa. Should either of these objectionable effects prove to be troublesome when a 15-times resistance is used, a new value can be chosen which will compromise the effects.

R.E.D.

INDUCTION MOTOR: SPEED, TORQUE, AND ROTOR RESISTANCE

(165) What is the physical explanation and principle underlying the speed-torque relation of a phase-wound induction motor when resistance is inserted in the rotor circuit?

An induction motor furnishes torque as the result of the following sequence of events:

(1) The rotor runs at less than synchronous speed, the difference being the "slip."

(2) The conductors of the rotor are constantly cutting the stator field (for this field rotates at synchronous speed). An e.m.f. is therefore generated in the rotor conductors.

(3) This e.m.f. causes a current flow in the rotor.

(4) The rotor current sets up a field around the rotor which revolves with the rotor.

(5) The torque is the result of the mutual attraction and repulsion between these two fields, viz., the rotor field and the stator field.

Since the speed of rotation of the stator field is constant, there is practically a direct relation between the rotor current and the torque.

Now assume that additional resistance is inserted in the rotor. To deliver the same torque as before, the rotor current must be the same as before which requires that a greater e.m.f. be induced in the rotor circuit in order to produce that current flow through the higher rotor resistance. Since the value of the e.m.f. generated in the rotor depends directly upon the difference in speed between the rotor conductors and the stator magnetism (or synchronous speed), the necessarily increased e.m.f. can only be obtained by the rotor running at a lower speed, which it does automatically.

Summarizing, the speed of a phase-wound induction motor decreases with each increase of rotor resistance when the motor is called upon to deliver a constant torque.

E.C.S.

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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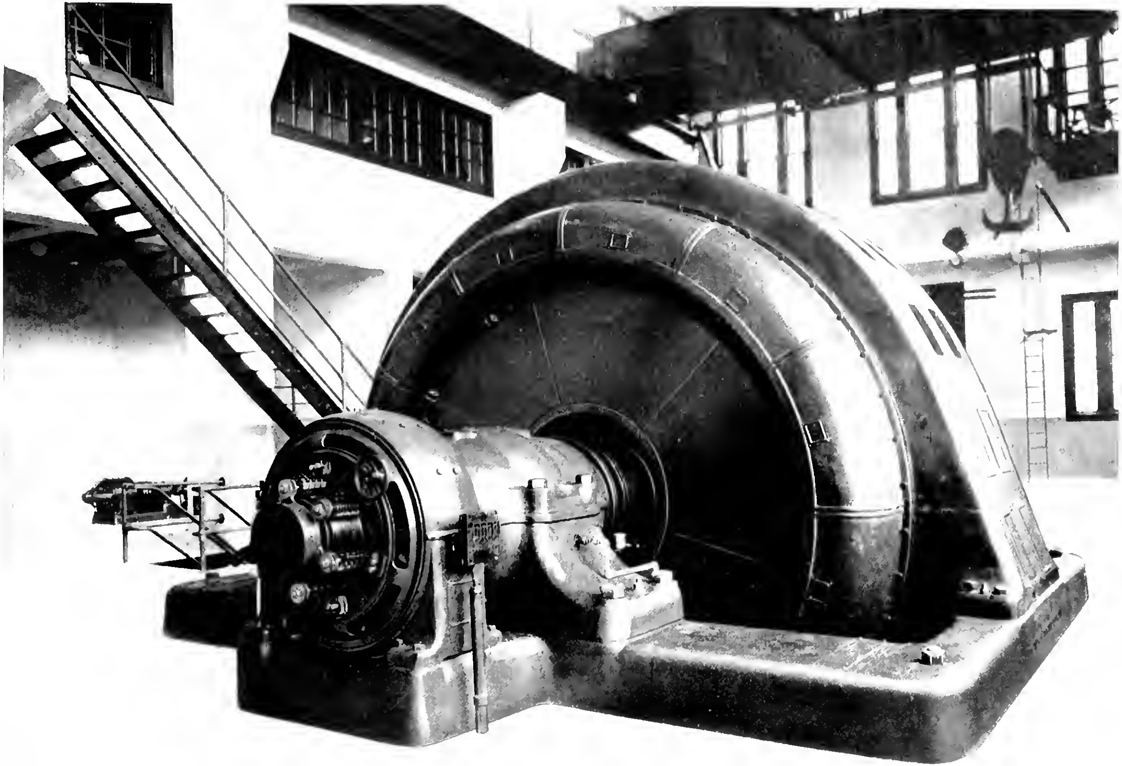

A 15,000-KV-A. SYNCHRONOUS CONDENSER VENTILATED BY AIR FROM OUTSIDE THE BUILDING

The air, which enters through a duct, is drawn into and forced through the machine by fans on the rotor, and discharged into the room.

(See page 406)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

Two important articles on magnetism are published in this issue, the one by Mr. J. D. Ball, covering "Investigations of Magnetic Laws for Steel and Other Materials," and the other by Dr. Saul Dushman, on "Theories of Magnetism." In connection with these two articles we wish to call the attention of our readers to the importance of the study of magnetic laws to the electrical industry. In spite of the important and inseparable relationship existing between electricity and magnetism there seems to be a great lack of any comprehensive theory of magnetic phenomena. While it is true that much useful work has been done in the investigation of magnetic laws in recent years, we know of no comprehensive treatise bringing together our fragmentary knowledge since Ewing published his famous book "Magnetic Induction in Iron and Other Materials" over twenty years ago. A collection of the work that has been done during this long period of intense industrial activity would be of very material value to the electrical industry.

It is strange that, although the study of magnetism is perhaps the oldest scientific study of which we have any record, in many respects this science has been one of the most baffling, and very strangely long periods are to be found between important discoveries. Up to the end of the fifteenth century only two facts about magnetism were known over and above that of the power of attraction, namely the property of the magnet that causes it to point to the north, and magnetic induction which causes a piece of iron in contact with a magnet to itself become magnetic. While it is claimed that the principle of the mariner's compass was known to the Chinese as early as 1100 B. C., there is no record of this knowledge having reached Europe until 2000 years later. Again it was not until the year 1600 that Gilbert discovered that the earth itself was a magnet. It was in 1600 that Gilbert published his famous book "de Magnet" which was for that period an astonishingly complete collection of our knowledge of magnetism up-to-date. There is a long period between this and the early part of the 19th century when Faraday made his epoch-making discovery of electro-magnetic induction, thus laying the corner stone on which our modern electrical industry has been built.

The study of the relationship between magnetism and light does not seem to have made the progress that was at one time expected, but even such knowledge as has been accumulated in recent years does not seem to have found its way into the modern text book. The study of the sun as a magnet has received considerable attention, especially at the hands of Dr. Hale of the Mount Wilson Observatory.

We hope that the series of articles that Dr. Dushman is preparing for the Review will, at least in a measure, give us a valuable collection of material covering the work done in recent years in the science of magnetism and inform us to what extent modern scientific advances in other directions have led to a more thorough understanding of magnetic phenomena.

An attempt to explain magnetic phenomena on the basis of the electron theory of conduction, and also the relationship between magnetic and other properties of the atom as determined by different conceptions of the structure of the atom itself should prove most instructive, and an account of such speculations should prove both interesting and stimulating.

We wish to call attention to the fact that the first installment of this series should be regarded as the ground work, giving the working data upon which subsequent contributions will be built up.

THE WORK OF THOMAS ALVA EDISON IN THE FIELD OF ILLUMINATION WITH RELATION TO THE CONTEMPORARY STATE OF THE ART

By John W. Lieb,

Vice-President New York Edison Company

It is through the courtesy of the Illuminating Engineering Society that we publish this address, which was delivered at the Biltmore Hotel, New York, on February 10, 1916, on the occasion of the presentation to Mr. Edison of the honorary membership of the Society. This address is rich in historical interest and its value is greatly increased from the fact that the author was for so many years a collaborator with Mr. Edison.—Editor.

The forward march of civilization through the ages is indicated in no more striking manner than in the desire of the human race for more and more light. Starting with the smoky pine knot and resinous strips of the cave man, followed by the shallow clay basins and dingy oil lamps of Egypt, Greece and the Far East, by progressive steps we reach the beautiful and effective lamps and candelabra so strikingly evidenced in the buried treasures of Pompeii and Herculaneum.

Coming to a later date we are struck by the fact that there is a substantial historical basis for the view that the characteristic phrase, the Dark Ages, used to designate an epoch in history, indicates not merely a period during which the steady advance in civilization of the human race was temporarily checked, but literally also an age of gloom, for the luxury and brilliancy of Greece and Imperial Rome, bringing with it evidences of a desire for adequate illumination, was followed in the so-called Dark Ages by a retrogression to crude and ineffective means for supplying artificial light.

The Renaissance, with the gorgeousness and sumptuousness of its regal and ducal courts, brought with it also an increased demand for more light, confined largely, at first, to display at brilliant festivals and princely celebrations. About this time the candle first made its appearance, and by its flickering gleams and clustered groupings added mystery and pomp to religious and state ceremonials.

We have ample evidence in the works of that master mind and extraordinary genius, Leonardo da Vinci, of the attention that was being paid during this time to the providing of bizarre illuminating effects for gorgeous pageants and in the improvement for general interior illumination of the crude lamps, by the addition of chimneys, reflectors and even bull's-eye lenses. In the centuries immediately following important advances were made in the application of improved burners for oil lamps using animal and vegetable oils, in which connection we recall the familiar names of Argand, Carcel and Hinks. Improved means of feeding the oil to the wick appeared in various forms of pump and clock lamps, of which the moderateur type survives in the still popular so-called student lamp.

In the early part of the last century, notable progress was made in the field of lighting by oil lamps, due to the impetus given by the discovery of mineral oil, first used as an illuminant in 1853, and giving rise in later years to steady, efficient and powerful oil lamps. The candle industry had also in the meantime been making progress, resulting in the displacement of the old tallow dip and wax candles with the improved stearic acid and paraffine candles, which are still popular for special uses and which have given us our unit value of illuminating effect, the parliamentary standard candle.

In the latter part of the 18th and early part of the 19th century, the manufacture of illuminating gas had progressed to such a stage that William Murdock in 1802 was able to light the famous Soho Foundry of Bolton & Watt, at Manchester, and there was exhibited in 1807 on Pall Mall, London, a complete system of street lighting by gas. Contented at first with the simple but inefficient fish-tail and bat wing burners, the gas industry soon appropriated to its uses the Argand and Bunsen principles, also preheating the gas, and perfected intensive and regenerative gas burners came into general use during the years 1878 and 1880, the period in which we are particularly interested this evening.

A new and radically advanced type of illuminant had its birth, however, when Sir Humphrey Davy in 1809 produced a brilliant electric spark from the batteries of the Royal Society; then followed a period of experimentation and research with the electric arc, applying first the carbon from gas retorts to the current produced by grouping battery cells, to which an immense impulse was given by the advent of that cheap and powerful source of current, the dynamo-electric machine. We have but little time to consider the historical progress of this new illuminant, with which the names of Carré, Foucault and Dubosq are associated, and which had reached an advanced stage of development about 1878-1879, as exemplified in the Serrin, Lontin, Farmer, Heffner von Alteneck, Crompton, Gulcher and other lamps and the lighting systems of Siemens, Brush, Thomson-Houston, Weston, Schuyler, etc. The open arc lamp by this time having attained its full efficiency, there remained for improvement only the details of functional machinery, and lamp mechanism. Paralleling this development, there was much done, also, in the direction of experimentation and application of inventive ingenuity in the study of so-called semi-incandescent lamps, of which the Soleil and Werdermann lamps and the Jamin and Jablochkoff electric candles were typical, the latter even attaining a certain degree of commercial application.

Very soon after the voltaic battery became available, it appeared that a heavy current would heat and bring to brilliant incandescence metals in the shape of thin strips or wires, and platinum from its high fusing point became the material on which early inventors based their hopes for a new illuminant. Carbon also, from its elevated fusing point and high resistance, was among the promising materials, and experiments were made with carbon, in rods, plates and also pencils in almost wirelike attenuation, but never reaching the extreme tenuity of a "filament;" also platinum wire—often alloyed with iridium—rendered incandescent in the open air and in glass globes, sometimes evacuated of air and sometimes filled with neutral gases, was the subject of endless researches and investigations. We have time only in this connection to mention the names of such pioneer workers in this field as Jobard, Depretz, de Changy, Starr, Roberts, Lodyguine, Konn, Kosloff and De Khotinsky.

These experiments conducted by a number of enthusiastic and tireless workers held much of promise and, could they have had from the beginning the convenient and potent source of electrical energy which the dynamo made available, the goal would probably have been reached much sooner.

It has been necessary to sketch briefly—altogether too superficially to be historically satisfactory—the situation as regards artificial illumination—the "state of the art," as it were—for without such a statement it would be impossible to correctly assign a proper place, historically, to the man to whose genius we are paying homage this evening. Although we are not here to consider the work of Mr. Edison along all of the many paths of research and invention in which he has produced so much and of such great value, we cannot obtain a just appreciation of his work in the field of illumination, with which we are primarily concerned at this time, without giving some consideration, superficial as it must be, to his work in related fields, which served as a preparation for his work in the special sphere which interests us this evening.

In the little village of Milan, Ohio—it will be exactly *69 years ago to-morrow*, February 11, 1916—there was born our honored guest of this evening, Thomas Alva Edison. Time presses upon us so that we must regretfully omit a sketch of his early life as a schoolboy, newsboy and embryonic journalist and newspaper editor developing into the dabbler in chemical and physical experimentation, and finally the expert telegrapher, until he reaches the Patent Office with his first patent—the electro-graphic vote recorder—taken out October 13, 1868. Then followed a long series of inventions and improvements by him in telegraph systems and apparatus, including the stock printer, district telegraph and chemical telegraph, and culminating in the wonderful duplex, and finally his crowning telegraphic achievement, the brilliant quadruplex system of telegraphy.

Late in 1877 appeared his carbon button transmitter, that most necessary and invaluable auxiliary of Alexander Graham Bell's epoch-making invention. A short time after appeared that scientific marvel which has in later years, through its commercial development, made available to every home the works of the musical geniuses of the world and their interpretation by instrumental virtuosi and song birds that most genial perhaps of all of Edison's inventions, the phonograph.

On October 14, 1878, there appeared Mr. Edison's first invention in the field of electric lighting—a thermo-static regulator—for use in combination with a platinum-iridium lamp to keep the current to a safe value by the insertion of a shunt resistance operated by the mechanical expansion of the incandescent conductor.

Because Mr. Edison did not always choose to follow the paths beaten by his predecessors, because he often sought out lines of investigation and experiment which were original and untried, because he looked for the solution of the problems before him in the unobvious, the unexpected, he has been considered by many as a purely empirical worker, a lucky experimenter, the embodiment of the cut-and-try, haphazard method of research and investigation. Nothing could be farther from the truth, as witness the stern logic with which he pursued relentlessly and industriously his fundamental idea of finding the complete electrical analogue of the gas lighting system.

In launching into this field Edison did not proceed as others, who were at this time investigating and experimenting, to find a practical solution of that *ignis fatuus* of the time—the subdivision of the electric light—one group of investigators working at details of the lamp, another group at the development of the dynamo-electric machine, still another at regulating and controlling devices, etc. He started out with the broad conception of developing a complete system in its every detail, based on the solid and broad foundation of precedent established by the intensely practical and successful gas industry. Right from the very beginning he had ever before him this broad conception—and in carrying out this idea he planned a complete system from the electric generators, giving consideration even to special types of boilers and engines adapted to drive them, down to the lamp and other utilization devices, not omitting any of the innumerable details inside the station, such as ammeters, voltmeters, regulators and switching gear, and outside of the central station underground conductors, feeders, mains, junction and coupling boxes, service switches and cutouts, safety fuses, meters, wiring and wiring devices such as safety plugs, circuit switches, chandeliers, brackets, sockets, lamps, etc.—the number of devices he developed is legion.

Let us now avail ourselves of Mr. Edison's own words—which he used some years ago to describe the problem which he, in 1878, set out to solve:

"We soon saw that the subdivision (of the electric light) never could be accomplished unless each light was independent of every other. Now it was plain enough that they could not burn in series. Hence they must burn in multiple arc. It was with this conviction that I started I was fired with the idea of the incandescent lamp as opposed to the arc lamp, so I went to work and got some very fine platinum wire drawn Experiment with this, however, resulted in failure, and then we tried mixing in with the platinum about 10 per cent of iridium, but we could not force that high enough without melting it. After that came a lot of experimenting—covering the wire with oxide of cerium and a number of other things.

"I then took a cylinder of zirconia and wound about a hundred feet of the fine platinum wire on it coated with magnesia. What I was after was getting a high resistance lamp, and I made one that way that worked up to 40 ohms. But the oxide developed the phenomena now familiar to electricians, and the lamp short-circuited itself. After that we went fishing around and trying all sorts of shapes and things to make a filament that would stand. We tried silicon and boron, and a lot of things that I have forgotten now. I never thought in those days that a carbon filament would answer, because a fine hair of carbon was so sensitive to oxidation. Finally, I thought I would try it because we had got very high vacua and good conditions for it.

"We sent out and bought some cotton thread, carbonized it, and made the first filament. We had already managed to get pretty high vacua and we thought, maybe, the filament would be stable. We built the lamp and turned on the current. It lit up, and in the first few breathless minutes we measured its resistance quickly and found it was 275 ohms—all we wanted. Then we sat down and looked at that lamp. We wanted to see how long it would burn. The problem was solved—*if* the filament would last. The day was—let me see—*October 21, 1879*. We sat and looked, and the lamp continued to burn, and the longer it burned the more fascinated we were. None of us could go to bed, and there was no sleep for any of us for forty hours. We sat and just watched it with anxiety growing into elation. It lasted about forty-five hours, and then I said, 'If it will burn that number of hours now, I know I can make if burn a hundred.' We saw that carbon was what we wanted, and the next question was what kind of carbon. I began to try various things, and finally I carbonized a strip of bamboo from a Japanese fan, and saw that I was on the right track."

Let us complete the picture by quoting from Mr. Edison's patent specification, which was the outgrowth of this successful experiment of October 21, 1879, the date universally recognized as the birthday of the commercial incandescent lamp, because this specification is couched in Mr. Edison's own language.

"The object of this invention is to produce electric lamps giving light by incandescence, which lamps shall have high resistance, so as to allow of the practical subdivision of the electric light. The invention consists in a light-giving body of carbon wire coiled or arranged in such a manner as to offer great resistance to the passage of the electric current and, at the same time, present but a slight surface from which radiation can take place. The invention further consists in placing such burner of great resistance in a nearly perfect vacuum to prevent oxidation and injury to the conductor by the atmosphere. The current so conducted into the vacuum bulb through platina wires sealed into the glass. The invention further consists in the method of manufacturing carbon conductors of high resistance, so as to be suitable for giving light by incandescence.

"Heretofore, light by incandescence has been obtained from rods of carbon of 1 to 4 ohms resistance and placed in closed vessels, in which the atmospheric air has been replaced by gases that do not combine chemically. The leading-in wires have always been large, so that their resistance shall be many times less than the burner, and, in general the attempts of previous workers have been to reduce the resistance of the carbon rod. The disadvantages of following this practice are that a lamp having but 1 to 4 ohms resistance cannot be worked in great numbers in multiple arc without the employment of main conductors of enormous dimensions; that owing to the low resistance of the lamp, the leading in wires must be of large dimensions and good conductors, and a glass globe cannot be kept tight at the place where the wires pass in and are cemented; hence the carbon is consumed, because there must always be a perfect vacuum to render the carbon stable, especially when such carbon is small in mass and high in electrical resistance.

"The use of gas in the receiver at the atmospheric pressure, although not attacking the carbon, serves to destroy it in time by "air-washing" or the attrition produced by the rapid passage of the gas over the slightly coherent, highly heated surface of the carbon I have reversed this practice I have discovered that even a cotton thread properly carbonized and placed in a sealed glass bulb exhausted to one millionth of an atmosphere, offers from one hundred to five hundred ohms resistance to the passage of the current, and that it is absolutely stable at very high temperatures; that if the thread be coiled as a spiral and carbonized, or if any fibrous vegetable substance which will have a carbon residue after heating in a closed chamber, be so coiled, as much as 2,000 ohms resistance can be obtained without presenting a radiating surface greater than three-sixteenths of an inch. I have carbonized and used cotton and linen thread, wood-splints, paper coiled in various ways, also lampblack, plumbago, and carbon in various forms mixed with tar and rolled out into wires of various lengths and diameters."

Let us now consider for a moment what had been accomplished at this time up to, say, 1878-1880 in the search for a practical incandescent lamp as the most important element in the solution of the problem of the subdivision of the electric light and the opinions of leading scientific authorities as to the probability of its successful solution.

As illustrative of the views held at this time by prominent scientific men abroad we may quote an abstract from a report by Mr. John T. Sprague of London, a well known electrician of the time and writer of an authoritative electrical textbook, to the following effect:

"Neither Mr. Edison nor anyone else can override the well known laws of Nature and when he is made to say that the same wire which brings you light will also bring you power and heat, there is no difficulty in seeing that more is promised than can possibly be performed. To talk about cooking food by heat derived from electricity is absurd."

Mr. (later Sir) William H. Preece in a lecture on February 17, 1879, after discussing the problem of the subdivision of the electric current, mathematically, said: "Hence the subdivision of the light is an *ignis fatuus*." Incidentally, it may be mentioned, Mr. Preece a year or so later became one of Mr Edison's most enthusiastic supporters.

Dr. Paget Higgs in a book published in London in 1879 stated "Much nonsense has been talked in relation to this subject. Some inventors have claimed the power to 'infinitely divide' the electric current, not knowing, or forgetting, that such a statement is incompatible with the well proven law of conservation of energy."

The eminent scientist John Tyndall in a lecture on the electric light delivered before the Royal Institution in January, 1879, and speaking of Mr. Edison in connection with the contemporary state of the art, said: "Knowing something of the intricacy of the practical problem, I should certainly prefer having it in Mr. Edison's hands to having it in mine."

A short time before, Professor Sylvanus P. Thompson, now one of England's most distinguished authorities in electrical science, in a lecture had stated: "This I can tell you, as the result of all experience, that any system of electric lighting depending on incandescence will utterly fail from an economic point of view, and will be the more uneconomic the more the light is subdivided."

The eminent scientist Fontaine in France about this time demonstrated to the satisfaction of the scientific world that the subdivision of the electric light was impossible of attainment and that the disintegration of carbon when made incandescent ruled it out of consideration for small burners.

Among the contemporary workers with Edison in developing the incandescent lamp may be mentioned William E. Sawyer and Albon Man, who took out their first patent June 18, 1878, for a lamp consisting of a two-part enclosing globe containing a low resistance pencil of carbon with a mechanism for feeding it as it was consumed and large spiral radiating conductors made hollow to permit of exhaustion of the air and the introduction of nitrogen gas. In a subsequent modification the carbon rod was shortened, the feed pressure being exerted from below instead of from above, and a later patent of January 7, 1879, referred to depositing dense carbon by the "flashing" process, and finally they formed carbons solely in this way.

Previous patents indicate that the lamps referred to had a resistance as low as 0.6 ohm and were therefore to be used for series and multiple series lighting and not for use in parallel, Mr. Edison's lamps for the latter purpose having a resistance, hot, of over 140 ohms.

Judge Bradley in a court opinion referring to the work of these two pioneers stated: "It seems to us that Sawyer and Man were following the wrong principle—the principle of small resistance in an incandescing conductor and a strong current of electricity and that the great discovery in the art was that of adopting high resistance in the conductor with a small illuminating surface, and a corresponding diminution in the strength of the current. This was accomplished by Edison in his filamental thread-like conductors, rendered practicable by the perfection of the vacuum in the globe of the lamp."

Hiram S. Maxim, another distinguished pioneer in this field, in 1877 constructed a platinum lamp with thermostatic regulator, which he operated from batteries and later by a dynamo, and in 1880-1881, he took out patents for a low resistance series lamp of the "stopper" or separable two-part globe type with carbons formed from paper, wood, or carbonaceous materials in a hydro-carbon vapor, and he stated "lamps of high resistance cannot well be used in any considerable number in series on account of the immense electromotive force required for passing a current through their combined resistance, and it is one of the objects of this invention to provide an incandescent lamp adapted to be used in *series* and capable of giving a large amount of light."

Mr. (later Sir) Joseph W. Swan, in England, has been credited with having had a more correct idea of the path along which the successful solution of this problem of the subdivision of electric light would lie, than any other investigator save Mr. Edison. One of his first exhibits of an incandescent lamp was made before the Chemical Society at Newcastle on December 16, 1878. It consisted of a slender rod or pencil of carbon suspended between platinum leading-in wires in an exhausted glass globe, but as was stated later by Lord Justice Fry: "The burner was not so slender that it could be described as a 'filament' and it burned but a short time, the carbon rod bending from the excessive current."

A second lamp exhibited on February 3, 1879, lasted for some twenty minutes and in some lamps shown as late as October 20, 1880—some nine months after the publication of Edison's filament patent—he still utilized a short and thick low resistance carbon only suitable for series lighting, and he states that he understands Mr. Edison's lamp to have a high resistance much higher than he (Swan) believed safe in an incandescent burner. In a further statement made at this time, referring to the grouping of his lamps in series of ten to fifty or more, he stated: "There is no escape that I know of from this dilemma, viz.: that if we must make our unit of light larger than necessary for a great many purposes and so give us the idea of extensive division and extensive distribution in order to gain these points, we must group the lamps in the manner I have proposed" (i. e., in series).

Another English experimenter at this time (1878-1880), St. George Lane-Fox, seemed to have a more definite conception of the importance of using a filament of high resistance and small radiating surface, but while the specifications in his patent indicate a grasp of the theory, his platinum-iridium wire conductor in nitrogen gas, wires coated with finely divided asbestos fire clay and also his luminous bridge of combined conducting and non-conducting substances, were all of insufficiently high resistance for multiple arc distribution.

In 1881 Mr. Lane-Fox in discussing the problem made the following important statement: "I think great credit is due Mr. Edison for having stated from the first that it was possible to introduce a system of electric light that could be so distributed and divided as to be available for household purposes. I think Mr. Edison was the first, and not Mr. Swan, to produce a practically useful lamp on the incandescent principle with a filament of carbon in a vacuum. Mr. Edison's researches, too, in respect to the presence of occluded gases in metal and other substances, are exceedingly interesting and very sound and scientific in the manner he has carried them out. I think he rendered very great service not only to the future of electric lighting, but also to science by his investigations, and for this proper credit should be given him, more especially as in the future he will be able to show, and I have no doubt will show, that he was the first to succeed and I think it is as well to recognize it at once. I say this entirely disinterestedly, because it is very much to my disadvantage that Mr. Edison should be first, as I also have claims in this direction."

So much for the opinions of contemporary workers and what had been accomplished when Mr. Edison announced the birth of the commercially successful lamp on October 21, 1879.

Again we must call attention to the fact that what Mr. Edison presented at the time in the terse language of Judge Lacombe was "a burner of carbon, so small in cross-section that, by the ordinary usage of common speech, it may be fairly called a *filament;* the receiver which contains the burner is made *entirely* of glass; the conductors which connect with the burner pass through the glass; and from the receiver the air is exhausted."

He stated further in a famous court opinion: "Prior to 1879 experimenters seemed to have reached the conclusion that success was to be attained, if at all, by modifications of the arc lamp, but up to that time no lamp, arc or incandescent, had been given to the public which, with the means then existing for generating and distributing the electric current, accomplished the result. After the date of the patent electric lighting by lights of moderate intensity became a commercial success. Subsequent improvements in the lamps and in other parts of the system have undoubtedly contributed materially to its development, but the record abundantly shows that, with lamps such as the patent described, constructed with the skill known to the art and operated under the conditions admitted by the generating and conducting apparatus then existing, it became practical for one generator to operate a considerable number of lamps, located at reasonable distances from it, and which at the same time were economical, durable and cheap enough to be commercially useful and so simple and reliable that they could be manipulated by the public. In view of the utter failure of the prior art to produce any such dubdivision of the electric light, a lamp of this kind, which was capable of economical use in factories, large buildings and in smaller buildings should be considered commercially successful, though further development were needed to enable it to compete with gas for domestic lighting on even approximately equal terms."

It should be noted that in Mr. Edison's patent description he used the word "filament"—the first appearance of that useful term in the art. It would be interesting to present here some evidence to show that the filament of Mr. Edison was a structure more thread-like than any of his predecessors—a diameter of about $\frac{1}{64}$ in.—whereas the prior art showed structures many times that size. So also the resistance of Mr. Edison's filament was many times the resistance common to the prior art.

These factors so clearly defined by the learned Judge—a carbon filament of high resistance in an all-glass globe; conductors sealed into the glass, all enclosed in an exhausted glass globe, made a combination which spelled success, "long desired, sometimes sought, and never before attained" and this combination in the opinion of the court constituted a patentable invention.

Judge Wallace in a court decision rendered July 14, 1891, stated "It is impossible to resist the conclusion that the invention of the slender thread of carbon as a substitute for the burner previously employed, opened the path to the practical subdivision of the electric light."

Again, Judges Lacombe and Shipman stated in an opinion rendered October 4, 1892, "Edison's invention was practically made when he ascertained the theretofore unknown fact that carbon would stand a high temperature, even when very attenuated, if operated in a high vacuum, without the phenomenon of disintegration. This fact he utilized by the means he has described, a lamp having a filamentary carbon burner in a nearly perfect vacuum."

And, finally, Judge Colt on January 11, 1894, stated "Edison made an important invention, he produced the first *practical* incandescent electric lamp, the patent is a pioneer in the sense of the patent law, it may be said that this invention created the art of incandescent electric lighting."

These quotations from court opinions are presented not in the desire to emphasize the legal aspects of Mr. Edison's claims to priority of invention, but because their language is so direct and explicit that it would be difficult to convey the ideas expressed in them in clearer language.

An interesting story could be told of the search, covering every part of the globe, made to find the special type of bamboo, of the most uniform grade and containing a minimum of silicious matter, in order to furnish material for the bamboo filament which for a number of years was such a prominent feature of the Edison lamp and contributed in no small measure to its early success. The extraordinary uniformity and exactitude with which filaments in great numbers and of a given size could be produced from the bamboo fiber, both before and after carbonization, made it practicable, by assignment of different voltages to various central stations, to dispose of the entire factory product without recourse to the "flashing" process. The latter, an early development in the art, was applied only in the later years of the bamboo filament, and became of great importance only with the advent of the so-called "squirted" cellulose filament.

The extent to which auxiliary apparatus developed or improved by Mr. Edison was contributory to the successful solution of the problem, is illustrated by the notable improvements which he made in the apparatus for producing very high vacua, first improvements in the means of obtaining the Torricellian vacuum, then by modification of the Geissler and Sprengel pumps, to which notable additions were applied, making it possible to obtain the highest vacua on the commercial scale that was necessary for exhausting incandescent lamp globes.

Such then was the Edison lamp—the keystone of the complete electric lighting system devised by him and worked out and developed along such permanently practical lines, forming the foundation of one of the most wonderful industrial developments the world has ever seen.

So much for the initial idea of the incandescent lamp itself. Let us again, quoting Mr. Edison, follow out in detail the development of his idea of a complete electric lighting 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 network of conductors must be capable of being fed from many different points. A commercially sound network 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 receive 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; 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. of salable energy.

"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 matter of reducing the cost of copper and the difficulties we had in making filaments stable at high voltages. I thought that 110 volts would be sufficient to insure the commercial introduction of the system, and 110 volts is still the standard."

To have conceived and reduced to practical operative form the innumerable elements which constituted such a broadly conceived plan was indeed a colossal undertaking. From the time that Mr. Edison announced the consummation of his indefatigable labors, by the demonstration of a practical and commercially successful incandescent lamp, to the putting into operation of the Pearl Street Station in New York City September 4, 1882, the public clamored for some tangible evidence of the arrival of the much heralded rival of gas, although hardly three years had elapsed—an absurdly short time for the carrying out of such a stupendous programme.

The intensity of application, indomitable perseverance, inventive and constructive resourcefulness, and joy in accomplishment, that were necessary to achieve such a result, it is difficult now to appreciate. It was indeed a severe tax on the endurance of the human machine.

The old Pearl Street Station, the prototype of the modern central station for the generation and distribution of electricity for light and power purposes, started off with a load of 400 lamps supplying some 85 buildings wired for 2300 lamps, and it served them through a complete underground system having a total length of 18 miles of feeders and mains, distributing the current over an area of a square mile.

The Edison Central Station system was a practical working success at the very outset. Difficulties were encountered, of course, unexpected, patience-trying contingencies and emergencies had to be met, but the system worked, it delivered satisfactory service and presently it showed also the beginnings of a sound commercial and financial success.

The inquiry has often been made as to what single element out of all this splendid aggregation of units, called the Edison System, can be considered to have been primarily the factor to which its success is attributable.

The keystone of it all can be said to be in the very early recognition by Mr. Edison of the practical importance of the "multiple arc principle." This fundamental idea is so important and its engineering application so broad, that a word or two of definition seems essential to a proper comprehension of Mr. Edison's scheme. The earlier conceptions of electric lamps, as exemplified in all the existing arc light systems and also in the experimental demonstrations, was that their mode of circuit connection, almost without exception, involved the use of the "series" system, the lamps being connected one after another—in series, as we say—like beads on a string and, therefore, not independent of one another, but all dependent on the integrity and continuity of the circuit or string.

At the very outset Mr. Edison proceeded on different lines—based on the important principle of his lamp, a filament of high resistance—providing for absolute independence not only of the individual lamp, but almost every other element of the system, from the boiler in the station to the interior wiring on the consumer's premises—and where the apparatus was mechanical, protecting it by stop valves, by-passes, or apparatus in duplicate, and where electrical, by providing alternate paths and parallel supply circuits, all constructively connected like the rungs of a ladder. In other words, the system was not dependent on any single one of its elements, every feature was practically in duplicate, and means were provided so that any defective section could be instantly segregated and eliminated, where practicable, automatically.

This principle of operating everything in "multiple arc," an efficient method of duplicating everything, is the principal essential to regularity and continuity of electric service of the highest standard and this has always been a conspicuous outstanding feature of the Edison system where it has been properly installed and operated.

This principle was not essentially new, as it is also one of the characteristic features of the modern system for the manufacture and distribution of illuminating gas, and Mr. Edison in adopting it for the electrical analogue showed a keen appreciation of its practical utility and of its demonstrated value

Many of the important elements of the system might warrant a more detailed reference, such as the beautiful—for it is more than merely ingenious—conception underlying the feeder and main system and its inter-connections, the interesting types of switches that were developed to meet new needs as they arose, from the giant instantaneous knife switches of the Jumbo machines to the lamp socket switches, wiring and distributing devices, and many other constituents of the system, all of which served as prototypes for the best modern devices in use to-day.

It would lead us too far afield to review the numberless inventions which followed the Edison lamp in such rapid succession and which, as an official said, "kept hot the path to the Patent Office," but it may be interesting to note the immense number of these with which Mr. Edison is credited—over 100 patents covering phonographs, 20 on storage batteries, 20 on meters, 147 on the telegraph, 32 on the telephone, 169 on electric lights, and 53 on ore milling machinery.

Did time and the occasion permit, it would be interesting to consider in detail Mr. Edison's work in the development of the dynamo-electric machine, the electric meter, the underground distributing system, and the numberless devices designed for use in conjunction therewith. The latest patent relating to this line of work, showing how constantly it has occupied Mr. Edison's interest, even in the midst of the press in later years of pioneer work in divergent fields, is indicated by the fact that his latest patent covering a filament for incandescent lamps, bears the date of March 29,1898.

I desire to say a word here in regard to Mr. Edison's work in another field, that of chemistry, involving, if I may be permitted to refer to it, a personal reminiscence. Some years ago I had the great honor of accompanying Lord and Lady Kelvin, both ardent admirers of Mr. and Mrs. Edison, on a visit to their laboratory and home at Orange, N. J. Lord Kelvin will be remembered not only as a warm friend of Mr. Edison but as one of his most enthusiastic supporters. Mr. Edison after explaining to Lord Kelvin some details of his nickel-iron storage battery, entered into a very warm discussion with him as to the stability of some of the higher oxides of nickel, a field in which Lord Kelvin had done much research work. Later at Mr. Edison's home the visitors were shown an elaborate investigation that was being conducted there, Mrs. Edison being an interested participator and *keeper of the records*, covering the crystallization of metallic salts under the influence of a magnetic field.

In the train on the return to New York, Lord Kelvin expressed the view that the visit had revealed an entirely new, and to him hitherto unappreciated side of Mr. Edison's genius—his intimate knowledge of theoretical and applied chemistry, justifying him in expressing the opinion that he considered Mr. Edison to be one of the great industrial chemists of the time.

The personality of Mr. Edison has many points in common with that master mind of the Middle Ages and of all times, Leonardo da Vinci. They are strikingly similar in their keenness of observation, inventive capacity, mechanical genius and thirst for knowledge—amounting almost to an obsession—a desire to investigate and wrest from nature her secrets by experimental processes. As Leonardo says in his famous note-books:

"Before deducing a general rule from the specific case, try the experiment two or three times and observe if the experiments always give the same results."

"If you want to make simple castings quickly, make them in a box of river sand, wetted with vinegar."

"Try if the *hot* iron will attract iron filings."

"To-morrow I will have a new type of whip made and will try it."

"The thickness of the muzzle of small guns should be from ½ to ⅓ of the diameter of the ball and the length from 30 to 36 balls."

Let us compare this with a few characteristic excerpts from Mr. Edison's so-called "Notion Books."

"Experiment with the instantaneous formation of metallic tin-flake by chemical composition in glass and on paper to form metallic dots and dashes in paper for repeating."

"Chloroform is a test for iodine."

"Experiment on the speed, strength of current and form of coil which is best to work by induction. It may be a primary of 20,000 ohms resistance and a secondary of 10,000 ohms will work with very delicate current."

"This is a great discovery for electric light in the way of economy."

But here the comparison ends, as Leonardo was also an accomplished courtier, a musician, a poet and an artist in the broad Renaissance sense of the term, a carver, sculptor and painter.

It is the common belief that Mr. Edison is altogether empirical in his methods, a despiser of precedent along paths previously followed and a lucky though haphazard experimenter in opening new ones, but this altogether needs qualification if not restatement.

Before launching into a new line of investigation he carefully considers what may be learned from past experience and what others have done along similar lines, although he does not then blindly follow their lead, but with original thought and untrammeled by precedent he seeks to open up new possibilities by research and he does not shrink from exploring the most unpromising paths and put to test the most paradoxical alternatives. His splendid library compassing the best there is in the scientific literature of all languages is put under tribute and the assistance of men with scientific training and experience in research is enlisted and consulted.

While we are conveying this tribute to our honored guest I am sure he would feel displeased if we failed to mention the important part, in achieving his wonderful success, played by the zealous and enthusiastic galaxy of personal associates and assistants whose loyal co-operation Mr. Edison enjoyed and the support he received from the host of expert specialists and skilled mechanics who constituted the working forces which knew so well how to put his ideas into practical commercial form.

And here let us refer in passing to a foible which is largely responsible for a misconception in regard to Mr. Edison assigning to him an excessive desire for newspaper notoriety. As a matter of fact the extreme good nature of our subject, his desire to help the "boys" of the press, and his readiness to be interviewed by them, often results in "copy," which is afterwards colored by their own perfervid imagination and in which scientific accuracy of statement is not conspicuous. Let me read the text of a letter from Mr Edison written to a New York paper on this subject in 1898:

"Sir: I wish to protest through *The Sun* against the many articles appearing in the sensational papers of New York from time to time, purporting to be interviews with me about wonderful inventions and discoveries made or to be made by myself. Scarcely a single one is authentic, and the statements purporting to be made by me are the inventions of the reporter. The public are led from these articles to draw conclusions just the opposite of the facts. I have never made it a practice to work on any line not purely practical and useful, and I especially desire it to be known, if you will permit me, that I have nothing to do with an article advertised to appear in one of the papers about Mars" T. A. EDISON.

Mr. Edison is an indefatigable worker, with the imagination of a poet, preaching the gospel of the joy of work, a man of the simplest tastes, an untiring searcher after truth; an altogether charming personality, patient, affable, always optimistic.

We are, therefore, delighted to honor Thomas Alva Edison to-night, not only as a great scientist and one of the greatest inventive geniuses of all time, but as a modest, unspoiled and unassuming man, with broad sympathies for all sorts and conditions of men; the greatest living American, a great benefactor of the human race!

Mr. President, I have the distinguished honor of presenting Mr. Thomas Alva Edison, Doctor of Science Princeton University, honored by many foreign sovereigns and governments with their highest civil decorations, distinguished by numerous national and foreign scientific societies and academies with their honorary memberships and medals. And now on behalf of the Illuminating Engineering Society I ask that you bestow upon him its honorary membership.

TRANSFORMER CONNECTIONS

PART II

BY ERIC A. LOF
POWER AND MINING ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY
AND LOUIS F. BLUME
TRANSFORMER ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY

In the first installment of this article the connections of transformers for single-phase, two-phase and three-phase operation were discussed, as were also with the connections for obtaining phase transformations, such as three-phase and two-phase to single-phase, and three-phase to two-phase, etc. The present installment has to do with the very important subject of parallel operation of transformers, in which are discussed the influences of polarity, impedance and ratio, and in the case of three-phase groups the necessity for using only those connections that will give the same phase relations in all groups. The article is concluded with a table of the transformer voltages and connections of some of the larger transmission systems, and a valuable bibliography.—EDITOR.

PARALLEL OPERATION

In order that two or more transformers or groups of transformers shall operate successfully in parallel, it is necessary that they be connected so that their polarity is the same, that their voltages and voltage ratios be identical, and that their impedances in ohms be inversely proportional to the ratings.

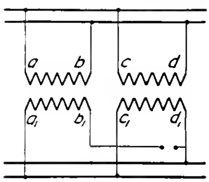

Fig. 37

The polarity expresses the phase relation between the high and low voltages as measured at the terminals. When the transformers are by the same manufacturer, they usually have the same polarity, while if of different makes some may have the high and low-voltage windings in phase and others 180 degrees apart.

Effect of Polarity on Parallel Operation

It is easy to determine the right polarity of two single-phase transformers which are to operate in parallel. Fig. 37 represents such a case in which all connections are made except b_1. If now the voltage between b_1 and d_1 is zero it indicates that the two transformers have the same polarity, while if the polarities were opposite the voltage from b_1 to d_1 would be the sum of that of the two transformers, and joining the two leads would cause a short-circuit. When testing for polarity the two terminals should therefore be joined through a fuse or automatic switch. If the fuse does not blow, the connections may be made permanent, while if the fuse blows the two leads of one transformer must be reversed.

With three-phase transformer banks operating in parallel it is also necessary that the phase relation of the voltages in the two banks be the same, both as to direction and position. It is therefore not possible to parallel a group of transformers which is connected in delta on both high and low-voltage sides with a group connected in delta on the high-voltage side and Y on the low-voltage side, or vice versa. On the other hand, it is possible to parallel a delta—delta connection with a Y—Y connection, and also a delta—Y connection with a Y—delta connection.

Three-phase transformer banks divide themselves into three-groups, depending upon the angular displacement between high-voltage and low-voltage windings. These

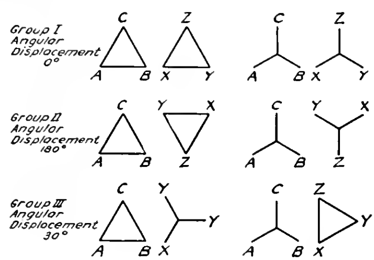

Fig. 38

groups are given in Fig. 38, which shows that the delta—delta connection and the Y—Y connection are similar, both capable of being connected so as to give an angular displacement of zero degrees between high-voltage and low voltage, or an angular displacement of 180 degrees between high and low-voltages. Group 3 consists of the delta-Y or Y-delta bank, in which the angular displacement is 30 degrees.

Three-phase transformer banks will not operate in parallel unless the angular displacements between high and low voltages are equal.

There are four other combinations possible for these two banks of transformers, but these combinations will not operate in parallel. They are as follows:

For example, consider case No. 2—low-voltage sides in delta and high-voltage sides in Y and delta respectively. Then assuming the low-voltage sides already paralleled and high-voltage sides open, the phase diagrams are as follows where A, B, C, a, b, c represent one bank and X, Y, Z, x, y, z the second bank. (See Fig. 39.)

Then if b and y are joined on the low-voltage side, serious displacement voltages occur between a and x and c and z (see Fig. 40), and if these terminals are connected, these displacement voltages will cause heavy short-circuit currents and destroy the transformers.

The reversal of two leads of either the high or low-voltage windings will reverse the polarity, this being identical with reversing one winding. Reversing the line leads of a delta or T-connected combination will, however, not reverse the polarity, since the transformer leads themselves must be changed in order to make the change in polarity.

With delta—delta connection, the reversal of one or two high-voltage windings will immediately produce a short-circuit when the low-voltage delta is closed, and the maximum voltage difference will be double line voltage.

For delta—Y connection, such a reversal will not produce a short-circuit when the Y is closed, but the voltages and phase relations

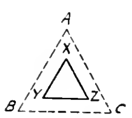

Fig. 39
High Voltage Side

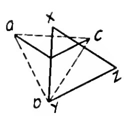

Fig. 40
Low Voltage Side

will be unequal. The maximum potential difference will equal the line voltage.

A reversal of one or two high-voltage windings with a Y—delta connection will immediately produce a short circuit when the delta is closed, and the maximum potential difference will be double line voltage.

With Y—Y connection the result of reversing a high-voltage coil will be the same as for the delta—Y connection.

Effect of Ratio on Parallel Operation

For successful parallel operation, correct ratios between the high and low-voltage windings of the different banks is, as previously mentioned, also essential, otherwise a cross-current will be established, even if the ratios are only slightly different. This current is then due to the difference of the two voltages divided by the sum of the impedances of the two transformers, and its effect is to balance the voltages of the two transformers with a resultant equilibrium of the two transformers.

To determine this current, assume that e_1 and z_1 are the voltage and impedance in low-voltage terms of one transformer and e_2 and z_2 are corresponding terms of the second transformer, connected in parallel with the other. The circulating current would then be

$$i = \frac{e_1 - e_2}{z_1 + z_2}$$

where z_1 and z_2 are expressed in ohms; or expressed in percentage of normal current by the following formula:

$$\%\ I = \frac{\text{per cent voltage difference}}{\text{sum of per cent impedance}} \times 100.$$

For example, suppose that the voltage ratios of two transformers are such as to cause a voltage difference of 2 per cent. If each transformer has a 2 per cent impedance, the circulating current is equal to

$$\%\ I = \frac{2}{2+2} = 50 \text{ per cent}$$

which means that a current equal to 50 per cent of normal circulates between the transformers in both high and low-voltage windings. It adds to the load current in the transformer having the higher induced voltage and subtracts in the other, causing the former to carry the greater load.

The impedance Z_1 can be found for the first transformer by impressing a voltage on the low-voltage winding with the high-voltage winding short-circuited. The current is then read, and if I is the current and E the voltage, then $z_1 = \frac{E}{I}$. In the same manner z_2 is determined.

With three-phase delta—delta-connected transformers different voltage ratios will cause unbalanced voltages and set up a circulating current in the delta in both the high and low-voltage windings. Unbalanced voltages outside the delta, however, can not produce any circulating currents within the delta, and unbalanced voltages applied to a delta-connected transformer bank cannot be equalized on the secondary side by the introduction of additional voltage in the delta.

As with single-phase transformers the value of the circulating current is obtained by dividing the voltage difference by the total impedance of the transformer bank. For example, if three transformers having impedances of 4 per cent are connected delta—delta, and one has a ratio one per cent greater than the other two, the resulting circulating current will be

$$\% \; I = \frac{1}{3 \times 4} = 8.33 \text{ per cent.}$$

When the load is taken from such a bank, the load currents and circulating currents are superimposed, and the transformer having the highest secondary voltage will carry the greatest load, as before.

With delta—Y connected transformers a slight difference in the ratios has a very small effect compared with a delta—delta connected bank. This is due to the shifting of the neutral point, causing an equalization of the voltages.

Effect of Impedance on Parallel Operation

In addition to identical polarities and voltage ratios, successful parallel operation of transformers requires that their impedances be in inverse proportion to the load which they are to carry, so that the voltage drop from no load to full load will be the same in all the units, both in magnitude and phase.

The impedance of a transformer is generally expressed as the voltage drop at normal load in percentage of normal voltage. It is the resultant of two components, the resistance drop, which depends only on the ohmic resistance of the windings and is in phase with the current, and the reactance drop, which depends on the magnetic leakage between the high and low-tension windings and is 90 degrees out of phase with the current.

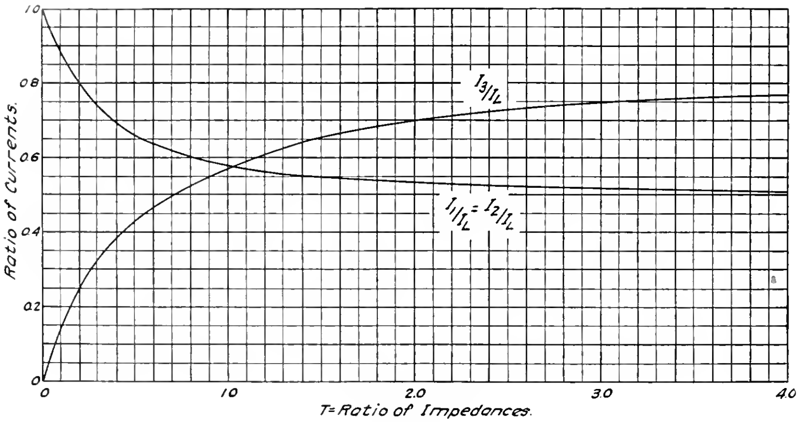

Fig. 41

Thus $\% \; IZ = \sqrt{(\% \; IR)^2 + (\% \; IX)}$

Where

IZ = Total impedance drop.

IR = Resistance drop of high and low-voltage windings.

IX = Reactance drop of high and low-voltage windings.

The value of $\% \; IZ$ is easly obtained by short-circuiting one winding and measuring the e.m.f. which must be applied at the terminals of the other winding to force full-load current through the winding at normal frequency. The impedance may therefore be measured directly.

The resistance e.m.f. is equal to the high-voltage current multiplied by the equivalent resistance of the transformer, which may be obtained by measuring the resistance of both the high and low-voltage windings, and adding to the resistance of the high-voltage winding that of the low-voltage winding multiplied by the square of the ratio of transformation.

The reactance e.m.f. may be calculated from the known values for the impedance e.m.f. and resistance e.m.f. Thus

$$IX = \sqrt{(IZ)^2 - (IR)^2}$$

In the majority of power transformers, the total resistance drop is small compared to the reactance drop, in which case the per cent impedance drop ($\%IZ$) can be taken as approximately equal to the per cent reactance drop ($\%IX$). In many lighting transformers, however, where the reactance is made as small as possible, this cannot be done without introducing considerable error.

The following formulæ may be used for finding the division of load between any number of transformer banks operating in parallel on single-phase circuits.

$$I_1 = \frac{\left(\frac{kv\text{-}a.}{\%\,IZ}\right)_1}{\left(\frac{kv\text{-}a.}{\%\,IZ}\right)_1 + \left(\frac{kv\text{-}a.}{\%\,IZ}\right)_2 + \ldots} \times I_L$$

$$I_2 = \frac{\left(\frac{kv\text{-}a.}{\%\,IZ}\right)_2}{\left(\frac{kv\text{-}a.}{\%\,IZ}\right)_1 + \left(\frac{kv\text{-}a.}{\%\,IZ}\right)_2 + \ldots} \times I_L$$

where

I_1 = load current in transformer bank No. 1.
I_2 = load current in transformer bank No. 2.
I_L = line current for any given load.
$\left(\frac{\text{kv-a.}}{\%IZ}\right)_1$ = capacity rating of bank No. 1, divided by its per cent impedance
$\left(\frac{\text{kv-a.}}{\%IZ}\right)_2$ = capacity rating of bank No. 2, divided by its per cent inpedance.

The above formulæ are, however, only correct when the ratio between the resistance and reactance of each of the transformers is equal. If not, the sum of the individual load currents will be greater than the current in the line, due to a phase difference between the currents in the different transformers. The error introduced by the inequalities in the values of this ratio is generally so small that it can be safely neglected.

For delta—delta connected transformers the effect of different impedances is also an unequal division of load among the three transformers. *The curves of Fig. 41 show the relation of current in the three legs of the delta, assuming two legs always to be alike in percentage impedance and capacity, and also assuming that the ratio between the resistance and reactance of all the transformers is equal. The abscissæ represent ratio of impedances of like legs to the odd leg.

$$r = \frac{Z_1}{Z_3} = \frac{Z_2}{Z_3}$$

where Z_1, Z_2 and Z_3 are the impedances of the different legs. But since Z is proportional to $\frac{\%IZ}{kv\text{-}a.}$ we can write

$$r = \frac{\left(\frac{\%\,IZ}{kv\text{-}a.}\right)_1}{\left(\frac{\%\,IZ}{kv\text{-}a.}\right)_3} = \frac{\left(\frac{\%\,IZ}{kv\text{-}a.}\right)_2}{\left(\frac{\%\,IZ}{kv\text{-}a.}\right)_3}$$

If I_L = line current for any given balanced load, and I_1, I_2 and I_3 are the leg currents, with the same load, the ordinates of the curve represent the ratio of leg current to line current $\frac{I_1}{I_L} = \frac{I_2}{I_L}$ and $\frac{I_3}{I_L}$ respectively.

If, for example, we have three transformers connected in delta—delta, with capacities and impedances as follows

Kv-a.$_1$ = 100 $\quad \%IZ = 2$
Kv-a.$_2$ = 100 $\quad \%IZ_2 = 2$
Kv-a.$_3$ = 50 $\quad \%IZ_3 = 2.3$
Line voltage = 1000.

we find that $r = \frac{2 \div 100}{2.3 \div 50} = 0.435$

and $\frac{I_1}{I_L} = \frac{I_2}{I_L} = 0.68$

also $\frac{I_3}{I_L} = 0.40$

If $I_1 = 100$ amp., the normal current for that transformer, $I_L = \frac{100}{0.68} = 147$ amp.

I_3 would then be equal to $147 \times 0.40 = 59$ amp. or 18 per cent overload on leg 3.

Again, if we assume that $I_3 = 50$ so as not to overload leg 3, $I_1 = 125$ and $I_1 = 85$, legs 1 and 2 are, therefore, carrying only 85 per cent of their rated capacity. This means that without any overload on any of the three transformers, the system can carry only 125 amp. line current or 87 per cent of the rated capacity of the three transformers.

* For a complete explanation see article by W. W. Lewis, GENERAL ELECTRIC REVIEW, January, 1912.

TABLE I

TRANSFORMER VOLTAGES AND CONNECTIONS OF SOME LARGE TRANSMISSION SYSTEMS*

Name of System	Frequency	Length of Transmission in Miles	Step-up Transformers: Low-tension Volts	Low-tension Conn.	High-tension Volts	High-tension Conn.	Y Grd. Dir. or with Res	Step-down Transformers: Low-tension Volts	Low-tension Conn.	High-tension Volts	High-tension Conn.
Pacific Lt. & Pwr. Co.	50	241	6,600	△	150,000	Y	D.	72,000 18,000	△	150,000	△
Au Sable Elec. Co.	60	245	2,500	△	140,000	△	No	5,500 22,000 44,000	△	140,000	△
Southern Sierras Pwr. Co.	60	239	2,200	△	140,000	Y	R.	33,000 to 4,000	△	138,500 140,000	Y
Utah Pwr. & Lt. Co.	60	135	6,600	△	130,000	△	No	44,000	△	120,000	△
Pacific Gas & Elec. Co.	60	110	6,600	△	125,000 to 110,000	Y	D.	60,000	Y	100,000	Y
West Penn. Tract. & Wtr. Pwr. Co.	60	106	6,600	△	125,000	△	No	22,000 6,600	△	120,000	△
Tennessee Pwr. Co.	60	140	6,600	△	120,000	△	No	13,200	△	120,000 to 95,000	△
Connecticut River Trans. Co.	60	60	2,300	△	120,000	Y	D.	13,200	△	110,000	△ & Y
Inawashiro Hydroelec. Pwr. Co.	50	144	6,600	△	115,000	△	No	11,000	△	100,000	△
Hydro Elec. Pwr. Com. of Ontario	25	135 90	12,000	△	110,000	Y	R.	26,400 13,200 6,600	△	110,000	Y
Lauchhammer, A. G.	50	35	5,000 5,000	Y	110,000	Y	No	60,000 15,000	Y	110,000	Y
Georgia Ry. & Pwr. Co.	60	210	6,600	△	110,000	Y	R.	22,000 11,000	△	110,000	△
Alabama Pwr. Co.	60	150	6,600	△	110,000	Y	R.	22,000	△	110,000	△ & Y
Mississippi River Pwr. Co.	25	144	11,000	△	110,000	Y	D.	66,000 33,000 13,200	△	95,000	△
Lehigh Nav. Elec. Co.	25	24	11,000	△	110,000	Y	R.	22,000	△	110,000	△
Cedar Rapids Mfg. & Pwr. Co.	60	60	6,600	△	110,000	△	No	6,600	△	110,000	△
Mex. Northern Pwr. Co.	60	157	4,000	△	110,000	Y	R.	13,200	△	110,000	Y
Ebro Irrigation & Pwr. Co., Ltd.	50	105	6,600	△	110,000	△	No	25,000 6,000	Y	110,000	△
Chile Exploration Co.	50	86	5,000	Y	110,000	Y	No	5,000	Y	Ca. 100,000	Y
Sierra & San Francisco Pwr. Co.	60	138	4,000	△	104,000	Y	D.	11,000	△	104,000	Y
Great Falls Pwr. Co.	60	150	6,600	△	102,000	△	No	2,500	△	91,800	△
Yadkin River Pwr. Co.	60	96	4,000	△	100,000	Y	D.	60,000	△	100,000	△
Colorado Pwr. Co.	60	152	4,000	△	100,000	△	No	6,600	△	90,000	△
Great Western Pwr. Co.	60	154	11,500 11,000	△	100,000	△	No	11,000	△	90,000	△

(*) Compiled from "Details of Transmission Systems" in *Electrical World* for April 25, 1914.

TABLE 1—(Continued)

Name of System	Frequency	Length of Transmission in Miles	Step-up Transformers Low-tension Volts	Conn.	Step-up Transformers High-tension Volts	Conn.	Y Grd. Dir. or with Res.	Step-down Transformers Low-tension Volts	Conn.	Step-down Transformers High-tension Volts	Conn.
Southern Pwr. Co...	60	210	2,400	△	100,000	Y	R.	44,000 13,000 2,400	△	100,000	△
Shawinigan Wtr. & Pwr. Co..................	60	87	6,600	△	100,000	Y	R	12,800	△	85,000	△
Los Angeles Aqueduct..	50	47	6,600	△	100,000	△	D.	33,000 16,500	△	....	Y
Tata Hydroelec. Co....	50	43	5,000	△	100,000	△	No	6,600	△	85,800	△
Società taliana di Elettrochimica...........	42	124	6,600	△	88,000	Y	No	9,600	Y	72,000	Y
Appalachian Pwr. Co...	60	75	13,200	△	88,000	△	No	13,200	△	88,000	△
Rio Janerio Tram., Lt. & Pwr. Co...........	50	51	6.300	△	88,000	△	No	6,000	△	80,000	△
São Paulo Elec. Co.....	60	56	6,300	△	88,000	△	No	25,000	Y	80,000	△
Mex. Ot. & Pwr. Co....	50	169	4,000	△	85,000	Y	D.	3,000 210	△	81,000	Y
Toronto Pwr. Co......	25	80	12,000	△	85,000	△ Y	No	12,000	△	81,000	Y
Victoria Falls & Transvaal Pwr. Co.........	50	30	5,000	△	84,000	Y	R.	20,000	Y	Ca. 80,000	△
Katsura-Gawa Denryoku Kabushiki Kaisha.	50	48	11,000	△	77,000	Y	R.	11,000	△	70,000	Y
Southern Cal. Edison Co.	50	117	2,300	△	75,000	Y	D.	30,000 15,000 2,300	Y Y △	64,000	Y
Grand Rapids Muskegon	30	66	6,600	△	72,000	△	No	6,600	△	66,000	△
City of Milan.........	42	93	10,000	△	72,000	Y	R.	8,650	△	65,000	Y
Società Generale Elettrica dell' Adamello..	42	72	13,000 12,000	△	72,000	△	No	13,000	Y	60,000	Y
Montana Co...........	60	100	550 2,400	△	70,000	△	No	2,400	△	60,000	△
Hidroelectrica Española Molinar...........	50	158	7,000	Y	70,000	Y	No	6,000	Y	60,000	Y
Penn. Wtr. & Pwr. Co..	25	40	11,000	△	70,000	Y	R.	13,000	Y	60,000	△
Guadalajara, Mexico...	50	180	10,000	Y	70,000	Y	No	20,000 3,000	Y	67,500	Y
City of Winnipeg.......	60	77	6,600	△	66,000 to 72,000	△	..	12,000	△	60,000	△

At the point where $r=0$, we have the current in legs 1 and 2 equal to the line current, giving the condition of open delta. By decreasing the capacity of leg 3 to zero, which is the same as increasing its impedance to infinity, we have but two legs on which to carry the three-phase load.

With delta—Y connected transformer banks a small difference in the per cent impedance has, as for the voltage ratios, a negligible effect. For example, if two transformers having impedances of 6 per cent are connected in delta—Y with another transformer having an impedance of 3 per cent, the potential of the neutral will be shifted at full load by an amount approximately equal to one-third of (6%–3%) or 1 per cent of the normal voltage of the transformer.

TRANSFORMER TAPS

It is customary to provide the high voltage transformer windings with taps for four $2\frac{1}{2}$

per cent steps below the normal operating voltage so as to compensate for voltage drop in the line. Fig. 42 illustrates this point, the diagram representing a single-phase system for the sake of simplicity.

For the step-up transformers in the generating station it is obvious that taps are not required, but they are sometimes provided for the sake of uniformity with the step-down transformers. Thus with a 10 per cent voltage drop in the line, the conductors can be connected to the 10 per cent tap, thereby compensating for the line drop. As this tap is used when the load is greatest it follows that, theoretically, the taps should be of full capacity; i.e., the current-carrying capacity of the high-voltage winding should correspond to the lower voltage value. Often, however, reduced capacity taps are specified, and reliance is placed on the ability of the transformer to carry the increased current safely. On account of the low-voltage winding the capacity of the transformer is, however, based on the full rated voltage.

Sometimes large power transformers have their high-voltage windings so arranged that the two halves can be connected either in parallel or series. The former connection corresponds to only half the voltage of the latter and is for use during the first period of operation of a system when the load is light and when the lower operating voltage is sufficient. When the load has increased so as to necessitate a higher voltage, the two windings are connected in series, thereby doubling the transmission voltage.

Transformers are sometimes arranged for supplying simultaneously two loads, one at full voltage and the other at half voltage. The question then often arises as to how much each side may be loaded without causing overheating of the transformers. This can readily be ascertained from the curves in Fig. 43. For example, with a full voltage load of 75 per cent it is possible to load the half voltage circuit for 40 per cent current, which is equal to 20 per cent the capacity.

Where taps are not essential for the satisfactory operation of a system, they should be avoided as much as possible, expecially in very high voltage transformers, and standard practice does not contemplate any taps for voltages below 6600, nor above 66,000. It is evident that taps are difficult to insulate and bring out to the connection board and that they therefore introduce additional weaknesses in the design of a transformer and thus decrease the reliability of operation.

Fig 42

Induction motors, synchronous motors and synchronous converters started from the a-c. side frequently require transformers with taps for reducing the potential at starting in order to prevent a heavy rush of current.

Fig. 44 shows the arrangement of taps for starting three-phase converters, leads 1, 2 and 3 being the operating terminals, and leads 1, 4 and 5 those for starting at half voltage. Lead 6 is merely for the purpose of making the three transformers duplicates. With some converters it has been found advantageous to insert resistances in the starting connections so as to still further lower the applied voltage.

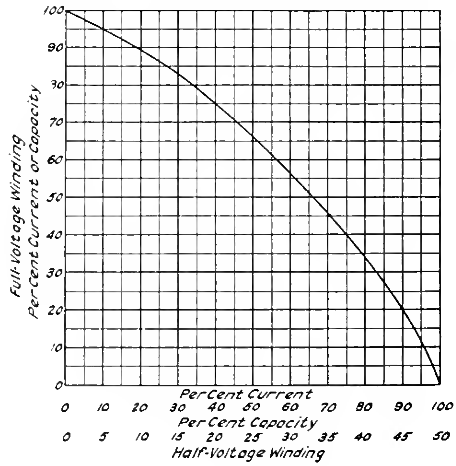

Fig. 43

Large converters are usually connected six-phase diametrical, and when started from the alternating current side it is desirable to provide taps on the transformers for one-third and two-thirds voltage as shown in Fig. 45. Leads 1 to 6, inclusive, are the operating terminals; leads 1, 3, 5, 7, 8 and 9 are for the first step, and leads 1, 3, 5, 10, 11 and 12 for the second step. Leads 2, 4 and 6 are for the final or full voltage step. Leads 1, 3 and 5 are connected directly to the converter and the starting is done by two triple-pole double-throw switches as shown.

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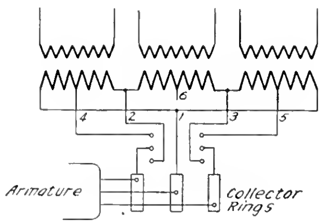

Fig. 44

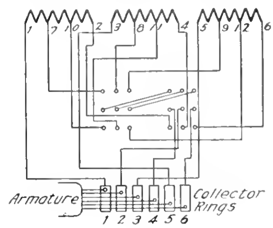

Fig. 45

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THEORIES OF MAGNETISM

Part I

By Saul Dushman

Research Laboratory, General Electric Company

This is the first installment of a series of articles the author is preparing for the Review on "Theories of Magnetism." We call special attention to the importance of this subject in our editorial this month. This installment contains simply the introduction, and the definitions and classifications of magnetic phenomena which the author will use as a basis for developing the subsequent articles. The first part of the discussion dealing with the relationship between susceptibility and field strength is also given.—Editor.

INTRODUCTION

From earliest times the phenomenon of magnetism has attracted a great deal of attention. The honor of having made the first observation in terrestrial magnetism is claimed by the fabulous shepherd of Asia Minor and the equally legendary Chinese navigator.

The Roman poet, Lucretius, mentions in his "De Rerum Natura" that the lodestone can support a chain of little rings, each adhering to the one above it.(1) Evidently the ancients had also observed the phenomenon of magnetism by induction. During the middle ages, we find the Cagliostos and Theophrastus's of those times ascribing to the lodestone numerous properties of which we are at present ignorant, such as that "if a lodestone be anointed with garlic, or if a diamond be near it, it does not attract iron," and that "if pickled in the salt of a sucking fish, there is power to pick up gold which has fallen into the deepest wells!"(2) Thus does the humble lodestone become associated with the Philosopher's stone and the Elixir of life.

The scientific study of magnetic phenomena may be said, however, to have begun with the publication in the year 1600 of Gilbert's "De Magnete," in which for the first time the facts are sorted out from the conglomerate of legends, conjectures, and falsehoods, and precise rules are laid down along which future investigations ought to follow. In 1785, Coulomb established his well-known law of magnetic attraction and repulsion, thus furnishing a foundation upon which the physicists could build the mathematical theory of magnetism; while in 1820, Oersted made his famous discovery of the relation between magnetism and electricity and thus provided the basic fact upon which not only the speculations of Faraday and Maxwell, but also all our progress in electrical industry in the past century is founded.

The subject of magnetism is thus of interest, not only from the point of view of the theoretical physicist, but also from that of the electrical engineer, and it is therefore not surprising that the literature on the subject is immense. Yet, there is hardly any other branch of science in which a comprehensive theory has been so conspicuously lacking as in that of magnetism. It would seem as if the very complexity of the observations that have been made, has been a barrier to the establishment of a successful theory. In view of these facts, it would seem like "bringing coals to Newcastle" to attempt to write on the subject of this paper. On the other hand, an account of the most recent theories of magnetism with a more or less brief survey of the facts which they seek to correlate may not prove uninteresting.

In the following series of articles, the writer intends therefore to first outline briefly the different magnetic phenomena which have been observed, and having pointed out the essential complexity of these to pass on to a more detailed discussion of the recent speculations of Langevin, Weiss, Kunz and others.

The following section on "Definitions" is, to a large extent, a review of concepts that are very familiar to the electrical engineer. The two reasons, however, for introducing such a discussion in this connection are, firstly, in order to make the series of articles fairly self-contained, so that the reader may have precise definitions at hand, of the different terms as used in this paper, and secondly, because in dealing with magnetism as a molecular and atomic property, it is necessary to introduce some terms that are not commonly used in engineering literature.

(1) Encycl. Brit. 11th Ed. Art. Magnetism.
(2) Loc. cit.; quoted from Gilbert's "De Magnete."

DEFINITIONS

Coulomb's Law

Two magnet poles attract or repel each other with a force varying *directly as the strengths of* the poles and *inversely as the square of the distance* between them.

Denoting the force by F; pole-strengths by M and M', and the distance between them by d, the law states that

$$F = \frac{kMM'}{d^2} \qquad (1)$$

The value of the constant, k, depends not only upon the units chosen for F, M, and d, but also upon the medium between the poles. Assuming the latter to be a vacuum (or air, for which the value of k is practically the same), we can so choose the units that $k=1$.

The *unit pole-strength* is defined to be that quantity of magnetism which repels another unit pole of the same polarity at a distance of 1 centimeter with a force of 1 dyne. Since it is of course impossible to have a north-seeking pole without an accompanying south-seeking pole, it is assumed in the above definition that the magnet is long enough to make the attractive effect of the other pole negligible.

Magnetic Field—Field Strength

It is a matter of common observation that a magnet cannot only act upon another magnet, but can also induce magnetism in a piece of iron placed near it. One of the simplest experiments in magnetism consists in sprinkling a piece of cardboard, lying on top of a magnet, with iron filings and observing the lines along which the filings set themselves. Experiments of this sort suggested to Faraday the conception of "lines of magnetic force," and "magnetic field." The lines are crowded near the poles and diverge more and more as they travel outwards. A very small unit magnet (having unit north and south poles) if taken around the magnet in different positions will be found to set itself always in such a manner that its axis (that is the line joining the poles) is in a direction which is tangential to that of the curve (as indicated by the iron filings) which passes through the same point. Thus we are led to the conception that from every magnet pole there radiate *lines of force*, which by their *density* (that is number of lines crossing unit area in a normal direction) at any point measure the *strength of the magnetic field* at that point. A line of force is regarded as proceeding from the north pole towards the south pole of the magnet, its direction being that in which an isolated north pole would be urged along it. Inside the magnet the lines pass from the south to the north pole.

Assuming that we indicate *unit field strength at any point by one line per square centimeter*, it follows from the above considerations that a unit pole has 4π lines radiating from it. Thus a pole of strength M has $4\pi M$ lines of force radiating from it. At a point distant r cms., the number of lines crossing unit area in a direction at right angles to the area is $H = \frac{4\pi M}{4\pi r^2} = \frac{M}{r^2}$, which according to Coulomb's law is the force in dynes exerted on unit pole at that distance. The field strength at any point is thus denoted by the letter H, giving the number of lines crossing unit area in a normal direction. The unit of H is known as the *gauss*, and is defined to be one line per unit area.

Magnetic Moment

If a magnet having poles of strength M is placed with its axis at right angles to the direction of the lines of magnetic force, it will tend to turn so as to set itself along the direction of the line of force passing through its center. If the length between poles is l, the torque exerted on the magnet by the field of strength H will be HMl. The greater the product Ml, the greater the couple tending to turn the magnet. The product Ml is termed the *magnetic moment*, and is denoted by $\mathbf{M}$. The greater $\mathbf{M}$, the more "powerful" the magnet.

Intensity of Magnetization

As we divide a magnet up into smaller lengths, we find that each shorter length has north and south poles and that these are of approximately the same strength as those of the original magnet. We may also slice up a magnet into thinner bars parallel to the magnetic aixs and thus obtain magnets having the same length, but possessing smaller quantities of magnetisms at the pole, that is smaller pole-strengths. We can thus consider any magnet as made up of a number of elementary magnets having unit length and unit area of pole-face and determine the moment of each of these elementary magnets.

Denoting the cross section of the magnet which we will suppose to be a uniformly magnetized bar of iron, by A and the length by l, it follows that the magnetic moment of each of these elementary magnets will be $\frac{\mathbf{M}}{Al}=\frac{\mathbf{M}}{V}$ where V denotes the volume of the bar and $\mathbf{M}$ its magnetic moment. Since $\mathbf{M}=Ml$, and therefore,

$$\frac{\mathbf{M}}{V}=\frac{Ml}{Al}=\frac{M}{A} \qquad (2)$$

it is evident that the quotient $\frac{\mathbf{M}}{V}$ is the same as the *pole-strength per unit sectional area* of the pole.

The magnetic moment per unit volume is thus a measure of the *intensity of magnetization* in the metal. It is, for instance, conceivable that we could have two magnets with the same value of $\mathbf{M}$, but different *intensities of magnetization*. The intensity of magnetization is ordinarily denoted by I. From the relation

$$I=\frac{\mathbf{M}}{V}=\frac{M}{A} \qquad (3)$$

it follows that the *number of lines of force leaving unit area of the pole* is $\frac{4\pi M}{A}=4\pi I$.

If instead of referring to unit volume, we choose *unit mass*, we have

$$J=\frac{\mathbf{M}}{V\rho}=\frac{I}{\rho} \qquad (4)$$

where J denotes the so-called *specific intensity of magnetization* and ρ denotes the density (grms. per cm.^{3}).

In comparing different substances, it is customary to use the gram-atomic or gram-molecular weights as standards of mass. We shall denote the atomic or molecular intensity by

$$\left.\begin{aligned} J_M &= J\times(\text{molecular weight}) \\ J_A &= J\times(\text{atomic weight}) \end{aligned}\right\} \qquad (5)$$

Magnetic Flux—Flux Density

If we place a uniformly magnetized iron bar in a *uniform magnetic field** of strength H, so that the axis of the magnet coincides with that of the field, then the field strength near the magnet will be the resultant of the original field of strength H and that due to the magnet. If the pole-strength of the latter be M, and sectional area A, then the total magnetic flux passing through the bar is equal to

$$\phi=4\pi M+H A$$

and the *flux density* or *magnetic flux* per unit area (in gausses),

$$B=\frac{\phi}{A}=4\pi I+H \qquad (6)$$

The flux density is also known as the *magnetic induction* or *induction*.

Magnetic Permeability

A long coil of wire carrying a current (solenoid) produces a magnetic field similar to that of a permanent magnet. The direction and strength of the field at any point in the interior of the coil (air-filled) depends upon the direction of the current in the wire and the number of ampere-turns per unit length. Taking the unit of current strength as the ampere, then the field-strength (in *gauss*) at any point in the interior of the solenoid is given by

$$H=\frac{4\pi}{10}\cdot ni \qquad (7)$$

where

n = number of turns per cm. length
i = current in amperes.

If now, the inside of the coil is filled with iron, the induction is increased considerably, that is, the number of lines of force per unit area, B, passing through the coil is much greater than H; in other words, the iron core multiplies the magnetic moment of the coil considered as a magnet.

The ratio

$$\mu=\frac{B}{H} \qquad (8)$$

is known as the *permeability*.

Susceptibility

So far we have considered the effect of the iron core on the magnetic field strength produced by a long coil of wire. Let us, however, consider the effect on the iron core itself. The latter which was presumably unmagnetized before being inserted in the coil has by means of the electric current circulating in the latter, become a magnet with poles of strength M and intensity of magnetization I.

The ratio

$$\kappa=\frac{I}{H} \qquad (9)$$

is known as the *magnetic susceptibility per unit volume*. The value of κ is, as it were, a measure of the magnetizing effect of a magnetic field on the material placed in this field. If, therefore, *we are comparing the magnetic properties of different substances we will be much more interested in the susceptibility than in the permeability.*

* A uniform magnetic field is one in which the lines of force are parallel to each other, so that the field strength remains constant over a definite distance.

Writing equation (8) in the form

$$\mu = \frac{4\pi I + H}{H}$$

it is seen by comparing this with equation (9) that

$$\mu = 4\pi \kappa + 1 \qquad (10)$$

Ferro-, Para- and Diamagnetism

There are a few substances which like iron are distinguished by large values of κ and μ, that is, they possess the property of being readily magnetized, to a very high degree. Such substances are known as *ferromagnetic*. Besides iron, the metals nickel and cobalt, Heusler's alloy, magnetite (Fe_3O_4) and a few exceptional compounds of manganese are ferro-magnetic. The values of κ vary from around 350 for sheet steel and even as high as 5300 for silicon steel,* to 1 or less for the antimonide and phosphide of manganese.

These last named substances represent a gradation from the weakly ferro-magnetic substances to the very weakly magnetic substances for which κ is considerably less than unity, but *positive*. These are known as *paramagnetic*. The values of κ vary from 10^{-3} to 10^{-6}; the paramagnetic substances can, therefore be magnetized to only one-thousandth or one-millionth of the intensity which can be imparted to the ferromagnetic substances. Illustrations of paramagnetic substances are oxygen, especially at extremely low temperatures, some of the salts of iron, nickel, manganese, and a large number of the metallic elements.

There is still another class of substances for which κ is *negative*. These are known as *diamagnetic*. They possess the property of being repelled in a magnetic field, the flux density in these substances is much less than in the surrounding magnetic field. The most diamagnetic substance known is bismuth, for which κ is approximately 14×10^{-6}.

The distinction between paramagnetic and diamagnetic bodies may also be considered from the point of view of the effect on the force between two magnet poles. It can readily be shown from the definition of μ given above that the force between two poles M, M', d cms. apart in a medium of permeability, μ, is equal to

$$F = \frac{1}{\mu} \cdot \frac{MM'}{d^2} \qquad (1a)$$

It follows from this that the greater the value of μ for the medium interposed between two magnet poles the smaller the force between them. This is illustrated by the well known observation that a magnetic needle placed inside a hollow iron sphere

* According to J. D. Ball, General Electric Review, January, 1915, Fig. 1, μ max. =4550 approx. for sheet steel. T. D. Yensen (Bull. 83, Univ. Ill. Exp. Station) gives μ max. for silicon iron as 66,500.

TABLE I

DEFINITIONS OF MAGNETIC TERMS

Symbol	Definition
M	Number of unit magnetic poles, or quantity of magnetism. Force between two poles M, M', d cms. (in vacuum) apart is $\frac{M\,M'}{d^2}$ dynes.
$\mathbf{M} = M\,l$	Magnetic moment. l = distance between poles.
$I = \frac{M\,l}{V} = \frac{M}{A}$	Intensity of magnetization or pole-strength per unit sectional area. V = volume of magnet, A = cross-section of pole face.
$J = \frac{I}{\rho}$	Specific intensity of magnetization. ρ = density.
H	Field strength. Force exerted on unit pole. Number of lines per unit sectional area.
B	Magnetic induction. Flux density.
$\mu = B/H$	Permeability.
$B = 4\pi I + H$	Flux density or induction.
$\kappa = \frac{I}{H} = \frac{\mu - 1}{4\pi}$	Susceptibility.
$\chi = \frac{\kappa}{\rho} = \frac{J}{H} = \frac{B - H}{4\pi H \rho}$	Specific susceptibility (per unit mass).
$\chi_A = \chi \times$ (atomic weight)	Atomic susceptibility.
$J_A = J \times$ (atomic weight)	Atomic intensity of magnetization.
χ_M, J_M	Refer to molecular weights.

Ferromagnetic	—	μ very large	—	κ very large.
Paramagnetic	—	$\mu > 1$	—	κ very small, positive.
Diamagnetic	—	$\mu < 1$	—	κ negative.

is protected from the action of external magnets.

Now in all paramagnetic media μ is greater than unity, that is the force between two magnet poles assumed capable of free motion in these media is less than in vacuum (or in air, for which μ is practically equal to unity). On the other hand, in diamagnetic media, the force is greater than in vacuum, that is, μ is less than 1.

Susceptibility per Unit Mass—Atomic and Molecular Susceptibility

Instead of using the susceptibility per unit volume, κ, it is more convenient in comparing different materials, to refer to the specific susceptibility or *susceptibility per unit mass.* It is evident from equation (4) above, that

$$\chi = \frac{J}{H} = \frac{I}{H\rho} = \frac{\kappa}{\rho} \qquad (11)$$

where ρ = density in gms. per cm.^{3}.

The atomic susceptibility

$$\left.\begin{array}{l} \chi_A = \chi \times (\text{atomic weight}) \\ \text{and the molecular susceptibility} \\ \chi_M = \chi \times (\text{molecular weight}) \end{array}\right\} \qquad (12)$$

This concludes our definitions.* Table I gives a summary of these for the purpose of ready reference.

MAGNETIC PHENOMENA

As a preliminary to any intelligent discussion of the recent theories of magnetism, it is necessary to take a sort of "bird's eye-view" of the immense number of observations which have been made in the course of investigations on the effects of magnetic fields. The relations between the magnetic properties of substances and such factors as chemical composition, and molecular structure; the effects of mechanical strains and of change of temperature; the so-called magneto-strictive and magneto-optical effects; the phenomena of hysteresis, coercive force and retentivity—all of these observations must be capable of explanation by any theory that seeks to explain the true nature of magnetism.

In discussing these different magnetic phenomena, it will be found convenient to follow more or less closely a system of classification which has been given in a recent paper by S. R. Williams†, and which is reproduced with slight modifications in Table II.

TABLE II

CLASSIFICATION OF MAGNETIC PHENOMENA

I. Induction Effects

1. Relation between field strength and magnetic induction. Permeability, susceptibility, coercive force, retentivity, hysteresis.
2. Para, Dia, and Ferromagnetism.
3. Terrestrial Magnetism.
4. Alternating currents.
5. Inductive effects as influenced by temperature, mechanical strains, aging, etc.
6. Villari effect.

II. Mechanical Effects

(a) *Reaction Effects Between Magnetic Fields.*
1. Attraction and Repulsion of Magnetic Poles.
2. Motion of Electric Conductors or of Currents, whether in a solid, liquid, or gaseous condition, when placed in a magnetic field.
3. Hall effect and its Reciprocal Relations.
4. Change in Resistance due to a Magnetic Field.
5. Effect on Thermo-electric Phenomena.

(*b*) *Magneto-strictive Effects.*
1. Joule Effect. Its Reciprocal Relations.
2. Wiedemann Effect. Its Reciprocal Relations.
3. Volume Change. Its Reciprocal Relations.
4. Production of Sound.
5. Piezo- and Pyro-magnetism.
6. Magne Crystallic Action.

III. Magneto-optical Effects

1. Faraday Effect.
2. Kerr Effect.
3. Zeeman Effect.
4. Magnetic Double Refraction.

It is, of course, impossible to discuss all of these phenomena, even superficially, in the limits of an article such as the present. Also, in view of the object of the present article, this is not at all essential. We shall, therefore, omit any discussion of terrestrial magnetism or alternating currents, and touch only briefly upon such topics as coercive force and retentivity, or the motion of electric conductors when placed in magnetic fields. On the other hand, the discussion of the relations between susceptibility and temperature; of the magneto-strictive effects, and magneto-optical phenomena leads to important conclusions on the problem which interests us in the present connection. A subject not taken care of in the above classification (or only indirectly so) is the relation between susceptibility and chemical composition. Yet the discussion of these relations forms one of the most interesting topics from the point of view of theories of magnetism.

* For methods of measuring *magnetic moment* and *permeability*, or *susceptibility*, etc., the reader may refer to standard text-books on electricity and magnetism and also to the following:
Ewing, Magnetic Induction in Iron and Other Metals, Chapters II and III.
S. Bidwell, Encycl. Brit., 11th Ed., Vol. 17, pp. 328-330.
C. W. Burrows, Bull. Bur. Stand. *6*, 31-38 (1909). Describes a method of making precision magnetic measurements, which has been used by a number of investigators in the past few years.

† School, Science, and Mathematics, Vol. 5, 474 (1915).

RELATION BETWEEN SUSCEPTIBILITY AND FIELD STRENGTH

(a) Ferromagnetic Substances

It is a matter of common knowledge that the permeability of iron and other ferromagnetic substances varies with the intensity of magnetization. The intensity increases at first slowly with increase in field strength,

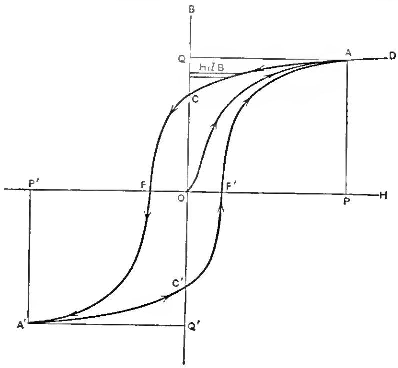

Fig. 1

then rapidly, and finally reaches a stage in which a very large increase in H leads to little or no change in I, that is, the material is said to be magnetically saturated. It follows that the susceptibility, κ, increases from a relatively small value to a maximum and then decreases again as the saturation intensity is attained. If, now, the field strength is gradually decreased again, the values of I are found to be larger for the same values of H than they were on the previous curve, that is, the demagnetization curve *lags* behind that for magnetization. This constitutes the well known phenomenon of *hysteresis*. As a result of this effect, the intensity of magnetization does not decrease to zero when the magnetizing force becomes zero, but remains as a more or less permanent residual magnetism. The *retentivity* is a measure of the intensity of this residual effect. Reversing the original direction of the magnetizing field, so as to demagnetize the material still more, finally reduces this residual magnetism to zero. The reverse field strength which is sufficient to accomplish this effect is known as the *coercive force*.

Fig. 1 taken from Karapetoff's book on the "Magnetic Circuit" shows the curve of magnetization observed in iron. The order of magnetization and demagnetization is indicated by the arrows. The ordinate OC corresponds to the retentivity, while the negative abscissa OF measures the coercive force.

It is evident that when a piece of iron is magnetized energy is stored up in it in the form of potential energy of the elementary magnets. On demagnetizing the iron, only a fraction of this energy is restored to the magnetizing source. The amount of energy in ergs used up in establishing a flux density B_1 (corresponding to the ordinate OQ in Fig. 1) is given by the area contained between the H-B curve, the axis of B, and the horizontal line (AQ) corresponding to B_1, and it can readily be shown that this energy input in ergs per cubic centimeter

$$E = \frac{1}{4\pi}\int_0^{B_1} HdB \qquad (13)$$

During a complete cycle, such as that shown in Fig. 1, and known as a *hysteresis loop*, the area contained in the loop corresponds to the total energy dissipated per cubic centimeter during the cycle, and is thus a measure of the value of the iron for alternating current apparatus.*

Dr. C. P. Steinmetz has deduced the empirical relation that in the case of iron or steel the *hysteresis loss*,

$$E = \eta\, B^{1.6}$$

where η is a constant for any given material.* It is rather curious that the same law holds approximately for nickel and cobalt as well as iron.†

Table III taken from a recent paper by T. D. Yensen‡ shows the progress which has been made in recent years in producing iron of very high maximum permeability, and low hysteresis loss. A column containing values of the maximum susceptibility calculated from those given for the maximum permeability has been added for the purpose of subsequent reference.

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* The literature on hysteresis is so extensive that any further discussion in this connection would be out of place. For methods of measuring hysteresis loss and general remarks on this topic, the reader will find valuable information in the following references:

S. Bidwell, Encycl. Brit., 11th Ed., Vol. 17, pp. 331-333. The relation between hysteresis loss and chemical composition will be discussed in a subsequent section.

Ewing, Magnetic Induction in Iron, Chapter V, Magnetic Hysteresis.

L. T. Robinson, Commercial Testing of Sheet Iron for Hysteresis Loss, A.I.E.E., Trans. *30*, 741-760 (1911). Also Discussion, pp. 776-802.

J. D. Ball, page 369, this number of the G. E. REVIEW.

† Kaye and Laby Physical and Chemical Constants, p. 91, contains values of η for different materials.

‡ Bull. 83, Univ. Ill. Exp. Station, November, 1915. See also Trans. A.I.E.E. *33*, 451, 1914.

The large increase in permeability accompanied by the gradual decrease in hysteresis loss is a striking feature of these data. It ought to be observed that ordinary sheet steel, such as used in a great deal of our electrical apparatus at present has a maximum permeability of about 4500, while its hysteresis loss varies around 5000. It is evident from the above table that the magnetic properties of iron are profoundly affected by slight changes in composition and mode of treatment. This is quite characteristic of all ferromagnetic substances.

TABLE IV

Values of I_m ($t = 20°$ C.)

Commercial steel (Williams)	1751
Swedish wrought iron (Ewing)	1690
Bessemer steel, 0.4 per cent C.	1770
Electrolytic iron melted in vacuum furnace (Williams)	1798
Cobalt, 1.66 per cent *Fe* (Ewing)	1310
Cobalt, pure (Stifler)	1421
Cobalt, melted in vacuum furnace (Williams)	1504
Fe_2Co, melted in vacuum furnace (Williams)	1791
Fe_2Co, forged with steam hammer (Williams)	1977
Fe_2Co, melted in vacuum furnace and forged with steam hammer (Williams)	2056

As already stated above, the ferromagnetic substances are also characterized by the fact that I tends to attain a constant maximum value as H is increased.* This limiting value of the intensity of magnetization we shall denote by I_m, or J_m (when dealing with specific intensity of magnetization). Table IV, abstracted from a recent paper by E. H. Williams†, gives values of I_m obtained for different metals by various investigators.

According to Du Bois‡, the values of I_m, J_m, and atomic (or molecular) magnetization, $J_m \times$ atomic weight (or $J_m \times$ molecular weight) for different ferromagnetic substances are those given in Table V. These results were obtained at room temperature ($t = 18$ deg. C.) and in very strong magnetic fields ($H > 10{,}000$).

TABLE V

Values of I_m, J_m, etc., According to Du Bois

Material	Atomic or Molecular Weight	Density (ρ)	I_m	J_m	Molecular or Atomic Magnetization
Mn	55.0	7.2	110	15	800
Fe (pure)	56.0	7.86	1850	236 §	13200
Co	59.0	8.7	1370	158	9300
Ni	58.7	8.93	580	65	3800
Magnetite	232	5.1	435	85	19800
Fe_7S_8	648	4.6	70	15	9800

* The values of H at which these limiting values are attained range from 10,000 to over 50,000. P. Weiss has constructed very powerful electromagnets by which he has been able to produce magnetic fields of over 65,000 gauss (Compt. Rend. *156*, 1970 (1913). He uses pole pieces of an alloy of iron and cobalt in the proportion Fe_2Co which at ordinary temperature has about 10 per cent higher saturation than iron (see Table IV).

† Phys. Rev., Vol. 6, 404 (1915).

‡ *Rapports du Congres International de Physique* (1900), Vol. 2, p. 460. This is an excellent summary dealing with "the magnetic properties of matter" as investigated up to that time. It contains an extensive bibliography of papers on the whole subject of magnetism, and next to Ewing's classical work is the most important article for reference on this subject.

§ According to Honda and Owen (Aun. Phys. *32*, 1027, 1910, and ib. *37*, 657, 1911) the specific magnetization for pure iron as deduced by Weiss is 217.

TABLE III

MAGNETIC PROPERTIES OF IRON AND IRON-SILICON ALLOYS‖

Year	Investigator	Kind of Material	Max. Permeability	Max. Susceptibility	Coercive Force in Terms of H ¶ $B_m = 1000$	Coercive Force in Terms of H $B_m = 15000$	Hystersis Loss Ergs per cc per Cycle $B_m = 10000$	Hystersis Loss Ergs per cc per Cycle $B_m = 15000$
1900	Hadfield	S. W. charcoal iron	4000	318	0.920	1.00	About 2700	About 5500
1900	Hadfield	2.5 per cent Si iron	5100	406	0.72	0.79	About 2900	About 4700
1901	Gumlich & Schmidt	Wrought iron	8350	664		0.60		
1903	Baker	4.9 per cent Si iron				1.20		About 6200
1910	Terry	Electrolytic iron	11000	875				
1912	Gumlich & Georens	0.4 per cent Si sheets	11600	923		0.54		
1912	Gumlich & Georens	4.0 per cent Si sheets	9400	748				
1912	Paglianti	1.75 per cent Si iron			0.60	0.75	1650	3500
1914	Yensen	Pure vacuum iron	19000	1512		0.29	813	1640
1915	Yensen	0.15 per cent Si vacuum iron	66500	5290	0.09	0.16	286	916
1915	Yensen	3.4 per cent Si vacuum iron	63300	5039	0.08	0.15	280	1025

‖ For the same properties of other ferromagnetic substances, see Kaye and Laby, Physical and Chemical Constants, p. 89.

¶ B_m denotes the maximum value of B attained on magnetization.

(b) Paramagnetic and Diamagnetic Substances

Both K. Honda and M. Owen*, draw the conclusions that the specific susceptibility, χ, for both para. and diamagnetic substances when these are obtained free from iron or other ferromagnetic impurities, is *independent of field strength*. When it is considered that even in the strongest magnetic fields obtained, the value of J does not exceed much over 0.01 (χ varies between 10^{-5} and 10^{-6}), it is evident that it requires the presence of only a slight trace of iron ($J_m = 217$)* to mask completely the magnetic properties of the material under investigation.

According to Du Bois† even 1/500 per cent of iron is sufficient for this purpose. Whenever iron is present, χ tends to decrease to a constant minimum value with increase in H. Owen has pointed out in what manner this result may be used to calculate the true susceptibility of the pure substance.

As pointed out by Wedekind‡, it is rather difficult to distinguish weakly ferromagnetic from strongly paramagnetic substances. It is, in fact, possible with alloys of two such metals as iron and manganese to obtain all gradations between a metal of very high permeability to one of exceptionally low permeability. However, it may be taken as a distinguishing property of paramagnetic substances that they show no *retentivity or hysteresis effect* and that their susceptibility is independent of field strength.§ A better criterion, by which to distinguish ferromagnetic from paramagnetic substances will be pointed out in a subsequent section when discussing susceptibility in relation to temperature.

In the next article of the series, we shall discuss this relation as well as that between susceptibility, and chemical composition or molecular structure.

* Loc. cit. above.
† Rapports, p. 483.
‡ E. Wedekind, Magnetochemie, p. 67-68, footnote.
§ This is, of course, also true for diamagnetic substances.

ELECTRIC CONDUCTORS

Part I

By Charles Proteus Steinmetz

Chief Consulting Engineer, General Electric Company

The author gives a very interesting presentation of the properties of the different kinds of electric conductors, which he has grouped, according to their characteristics, into metallic, electrolytic, and pyroelectric conductors; and these, together with carbon, which possesses some properties peculiar to itself, constitute the subject matter of this installment. In the second and concluding installment, conduction through insulators, and through gas, vapor and vacuum, and arc conduction, are discussed.—Editor.

1. When electric power flows through a circuit, we find phenomena taking place outside of the conductor which directs the flow of power, and also inside. The phenomena outside the conductor are conditions of stress in space which are called the electric field; the two main components of the electric field being the electromagnetic component, characterized by the circuit constant inductance L, and the electrostatic component, characterized by the electric circuit constant capacity C. Inside of the conductor we find a conversion of energy into heat; that is, electric power is consumed in the conductor by what may be considered as a kind of resistance of the conductor to the flow of electric power, and so we speak of resistance of the conductor as an electric quantity, representing the power consumption in the conductor.

Electric conductors have been classified and divided into distinct groups. We must realize, however, that there are no distinct lines of demarkation between the classes in nature, but a gradual transition from type to type.

Metallic Conductors

2. The first class of conductors are the metallic conductors. They can best be characterized by a negative statement, which is, that metallic conductors are those conductors in which the conduction of the electric current converts energy into no other form but heat; that is, a consumption of power takes place in the metallic conductors by conversion into heat, and into heat only. Indirectly, we may get light if the heat produced raises the temperature high enough to get visible radiation as in the incandescent lamp filament; but this radiation is produced from heat, and directly the conversion of electric energy takes place into heat. Most of the metallic conductors cover, as regards their specific resistance, a rather narrow range, extending between about 1.6 microhm-

centimeters (1.6×10^{-6}) for copper, to about 100 microhm-centimeters for cast iron, mercury, high-resistance alloys, etc. They therefore cover a range of less than 1 to 100.

A characteristic of metallic conductors is that the resistance is approximately constant, varying only slightly with the temperature, and this variation is a rise of resistance with increase of temperature; that is, they have a positive temperature coefficient. In the pure metals, the resistance apparently is approximately proportional to the absolute temperature; that is, the temperature coefficient of resistance is constant, and such that the resistance plotted as a function of the temperature is a straight line which points towards the absolute zero of temperature, or, in other words, which prolonged backwards towards falling temperature would reach zero at 273 deg. C., as illustrated by curves I on Fig. 1. Thus, the resistance may be expressed by:

$$r = r_o T \qquad (1)$$

where T is the absolute temperature.

In alloys of metals we generally find a much lower temperature coefficient, and find that the resistance curve is no longer a straight line, but is curved more or less, as illustrated by curves II, Fig. 1, and therefore ranges of zero temperature coefficient, as at A in curve II, and even ranges of negative temperature coefficient, as at B in curve II, Fig. 1, may be found in metallic conductors which are alloys; but the general trend is upward. That is, if we extend the investigation over a very wide range of temperature, we find that even in those alloys which have a negative temperature coefficient for a limited temperature range, the average temperature coefficient is positive for a very wide range of temperature—the resistance is higher at very high and lower at very low temperature, and the zero or negative coefficient occurs at a local flexure in the resistance curve.

3. The metallic conductors are the most important ones in industrial electrical engineering; so much so that when speaking of a "conductor," practically always a metallic conductor is understood. The foremost reason is, that the resistivity or specific resistance of all other classes of conductors is so very much higher than that of metallic conductors that for directing the flow of current only metallic conductors can usually come into consideration.

As even with pure metals the change of resistance of metallic conductors with change of temperature is small (about one-third per cent per degree centigrade), and the temperature of most apparatus during its use does not vary over a wide range of temperature, the resistance of metallic conductors, r, is usually assumed as constant, and of a

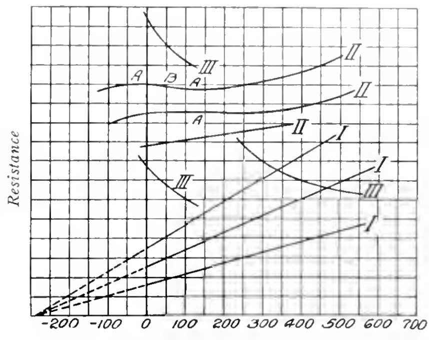


Fig. 1. Resistance-Temperature Characteristic
I Pure Metals
II Alloys
III Electrolytes

value corresponding to the operating temperature chosen. However, for measuring temperature rise of electric circuits, the increase of the conductor resistance is frequently employed.

Where the temperature range is very large, as between room temperature and operating temperature of the lamp filament, the change of resistance is very considerable. The resistance of the tungsten filament at its operating temperature is about nine time its cold resistance in the vacuum lamp, and twelve times in the gas filled lamp.

Thus the metallic conductors are the most important. They require little discussion, due to their constancy and absence of secondary energy transformation.

Iron is an exception among the pure metals, in that it has an abnormally high temperature coefficient, about 30 per cent higher than other pure metals, and at red heat, when approaching the temperature where the iron ceases to be magnetizable, the temperature coefficient becomes still higher, until the temperature is reached where the iron ceases to be magnetic. At this point its temperature coefficient becomes that of other pure metals. Iron wire—usually mounted in hydrogen to keep it from oxidizing—thus finds a use as series resistance for current limitations in vacuum arc circuits, etc.

Electrolytic Conductors

4. The conductors of the second class are the electrolytic conductors. Their characteristic is that the conduction is accompanied by chemical action. The specific resistance of electrolytic conductors in general is about 1,000,000 times higher than that of the metallic conductors. They are either fused compounds, or solutions of compounds in solvents, ranging in resistivity from 1.3 ohm centimeters in 30 per cent nitric acid (and still lower in fused salts), to about 10,000 ohm centimeters in pure river water, and from there up to infinity (distilled water, alcohol, oils etc.). They are all liquids, and when frozen become insulators.

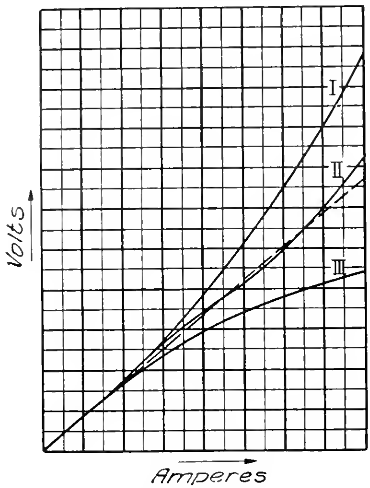


Fig. 2. Volt-ampere Characteristic
I Pure Metals
II Alloys
III Electrolytes

Characteristic of the electrolytic conductors is the negative temperature coefficient of resistance; the resistance decreasing with increasing temperature, not in a straight line, but in a curve, as illustrated by curves III in Fig. 1.

When dealing with electrical resistances, it is in many cases more convenient (and at the same time a better insight into the character of the conductor) not to consider the resistance as a function of the temperature, but rather the voltage consumed by the conductor as a function of the current under stationary conditions. In this case, with increasing current, and therefore increasing power consumption, the temperature also rises, and the curve of voltage for increasing current therefore illustrates the electrical effect of increasing temperature. The advantage of this method is that in many cases we get a better view of the action of the conductor in an electric circuit by eliminating the temperature, and relating only electrical quantities with each other. Such volt-ampere characteristics of electric conductors can easily and very accurately be determined and, if desired, from the radiation law, approximate values of the temperature be derived, and from these the temperature-resistance curve calculated; while a direct measurement of the resistance over a very wide range of temperature is extremely difficult, and often no more accurate.

In Fig. 2 are shown such volt-ampere characteristics of conductors. The dotted straight line is the curve of absolutely constant resistance, which does not exist. Curves I and II show characteristics of metallic conductors, and curve III of electrolytic conductors. As seen, for higher currents I and II rise faster, and III slower than for low currents.

It must be realized, however, that the volt-ampere characteristic depends not only on the material of the conductor, but also on the size and shape of the conductor and its surroundings. For a long and thin conductor in horizontal position in air it would be materially different numerically from that of a short and thick conductor in different positions at different surrounding temperatures. However, qualitatively it would have the same characteristic, the same characteristic deviation from straight line, etc., but merely shifted in numerical values. Thus it characterizes the generator nature of the conductor; but where comparison between different conductor materials is required, either they have to be used in the same shape and position, when determining their volt-ampere characteristics, or the volt-ampere characteristics have to be reduced to the resistivity temperature characteristics. The volt-ampere characteristics become of special importance with those conductors to which the term resistivity is not physically applicable, and therefore the "effective resistivity" is of little meaning, as in gas and vapor conduction, such as arcs, etc.

5. The electric conductor is characterized by chemical action accompanying the conduction. This chemical action follows Faraday's law: "The amount of chemical action is proportional to the current and to the chemical equivalent of the reaction."

The product of the reaction appears at the terminals or "electrodes," between the electrolytic conductor or "electrolyte," and the metallic conductors. Approximately, 0.01 milligram of hydrogen is produced per coulomb, or ampere-second. From this electrochemical equivalent of hydrogen, all other chemical reaction can easily be calculated from atomic weight and valency. For instance, copper, with atomic weight 63 and valency 2, has the equivalent $63/2=31.5$, and copper therefore is deposited at the negative terminal or "cathode," or dissolved at the positive terminal or "anode," at the rate of 0.315 milligram per ampere second; aluminum, atomic weight 28 and valency 3, at the rate of 0.093 milligram per ampere second, etc.

The chemical reaction at the electrodes represents an energy transformation between electrical and chemical energy, and as the rate of electrical energy supply is expressed by current times voltage it follows that a voltage drop or potential difference occurs at the electrodes in the electrolytes. This is in opposition to the current, or a counter e.m.f., the "counter e.m.f. of electrochemical polarization." It thus consumes energy, if the chemical reaction requires energy such as the deposition of copper from a solution of a copper salt. It is in the same direction as the current, thus producing electric energy, if the chemical reaction produces energy, such as the dissolution of copper from the anode.

As the chemical reaction, and therefore the energy required for it, is proportional to the current, the potential drop at the electrodes is independent of the current density, and is constant for the same chemical reaction and temperature, except insofar as secondary reaction interferes. It can be calculated from the chemical energy of the reaction, and the amount of chemical reaction as given by Faraday's law. For instance, one ampere second deposits 0.315 milligram of copper. The voltage drop e, or polarization voltage, must therefore be such that e volts times one ampere-second, or e watt-seconds, or joules, equal the chemical reaction energy of 0.315 milligram of copper in combining with the compound from which it is deposited in the electrolyte.

If the two electrodes are the same and in the same electrolyte at the same temperature, and no secondary reaction occurs, the reactions are the same but in opposite direction at the two electrodes, such as deposition of copper from a copper sulphate solution at the cathode, and solution of copper at the anode. In this case the two potential differences are equal and opposite, their resultant is thus zero, and it is said that no polarization occurs.

If the two reactions at the anode and cathode are different, such as the dissolution of zinc at the anode the deposition of copper at the cathode, or the production of oxygen at the (carbon) anode and the deposition of zinc at the cathode, then the two potential differences are unequal and a resultant remains. This may be in the same direction as the current, producing electric energy, or in the opposite direction, consuming electric energy. In the first case, copper deposition and zinc dissolution, the chemical energy set free by the dissolution of the zinc and the voltage produced by it are greater than the chemical energy consumed by the deposition of the copper and the voltage consumed by it, and the resultant of the two potential differences at the electrodes thus is in the same direction as the current, and therefore may produce this current. Such a device then transforms chemical energy into electrical energy, and is called a *battery*. In the second case, zinc deposition at the cathode and oxygen production at the anode, the resultant of the two potential differences at the electrodes is in opposition to the current, that is, the device consumes electric energy and converts it into chemical energy, as in the *electrolytic cell*.

Both arrangements are extensively used: the battery for producing electric power, expecially in small amounts, as for hand lamps, the operation of house bells etc., while the electrolytic cell is used extensively in the industries for the production of metals, including aluminum, magnesium, calcium, etc., and for the refining of metals such as copper, and constitutes one of the most important industrial applications of electric power.

A device which can efficiently be used alternately as battery and as electrolytic cell is the storage battery. Thus in the lead storage battery, when discharging, the chemical reaction at the anode is the conversion of lead peroxide into lead oxide, and at the cathode the conversion of lead into lead oxide. In charging, the reverse reaction occurs.

6. Specifically, by "polarization cell" is understood a combination of an electrolytic conductor with two electrodes, of such character that no permanent change occurs during the passage of the current. Such an arrangement consists, for instance of two platinum electrodes in diluted sulphuric acid. During the passage of the current, hydrogen is given off at the cathode and oxygen at the anode, but terminals and electrolyte remain the same (assuming that the small amount of dissociated water is replaced).

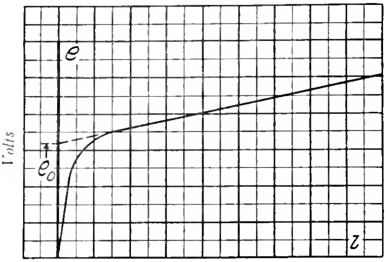


Fig. 3. Electrolytic Conduction of Polarization Cell at Low-voltage

In such a polarization cell, if e_0 = counter e.m.f. of polarization (corresponding to the chemical energy of dissociation of water, and approximately 1.6 volts) at constant temperature, and thus constant resistance of the electrolyte, the current i is proportional to the voltage e minus the counter e.m.f. of polarization e_0.

$$i = \frac{e - e_0}{r} \qquad (2)$$

In such a case the curve III of Fig. 2 would not go down to zero volts with decreasing current, but would reach zero amperes at a voltage $e = e_0$, and its lower part would have the shape shown in Fig. 3. That is, the current begins at voltage e_0, and below this voltage only a very small "diffusion" current flows.

When dealing with electrolytic conductors, as when measuring their resistance, the counter e.m.f. of polarization thus must be considered, and with an impressed voltage less than the polarization voltage, no permanent current flows through the electrolyte, or rather only a very small "leakage" current or "diffusion" current, as shown in Fig. 3. When closing the circuit, however, a transient current flows. At the moment of circuit closing, no counter e.m.f. exists and current flows under the full impressed voltage. This current, however, electrolytically produces a hydrogen and an oxygen film at the electrodes, and with their gradual formation the counter e.m.f. of polarization increases, which acts to decrease the current, until it is finally stopped. The duration of this transient depends on the resistance of the electrolyte and the surface of the electrodes, but it is usually fairly short.

7. This transient becomes permanent with alternating impressed voltage. Thus, when an alternating voltage of a maximum value lower than the polarization voltage is impressed upon an electrolytic cell, an alternating current flows through the cell which produces hydrogen and oxygen films which hold back the current flow by their counter e.m.f. The current thus flows ahead of the voltage (counter e.m.f.) which it produces, as a leading current, and the polarization cell thus acts like a condenser and is called an "electrolytic condenser." It has an enormous electrostatic capacity, or "effective capacity," but can stand low voltage only—one volt or less—and therefore is of limited industrial value. As chemical action requires appreciable time, such electrolytic condensers at commercial frequencies show high losses of power and therefore low efficiencies, by what may be called "chemical hysteresis;" but they become very efficient at very low frequencies. For this reason they have been used in the secondaries of induction motors for power factor compensation. Iron plates in alkaline solution, such as sodium carbonate, are often used for this purpose.*

Pyroelectric Conductors

8. A third class of conductors are the *pyroelectric conductors* or *pyroelectrolytes.* In some features they are intermediate between the metallic conductors and the electrolytes, but in their essential characteristics they are outside the range of either.

* NOTE: The aluminum cell, consisting of two aluminum plates with an electrolyte which does not attack aluminum, is often called an electrolytic condenser, because its current is leading, that is, it acts as capacity. It is, however, not an electrolytic condenser, and the counter e.m.f., which gives the capacity effect, is not electrolytic polarization. The aluminum cell is a true electrostatic condenser, in which the film of aluminum, formed on the positive aluminum plates, is the dielectric. Its characteristic is, that the condenser is self healing, that is, a puncture of the aluminum film causes a current to flow which electrolytically produces alumina at the puncture hole, and so closes it. The capacity is very high, due to the great thinness of the film, but the energy losses are considerable, owing to the continual puncture and repair of the dielectric film.

The metallic conductors, as do the electrolytic conductors, give a volt-ampere characteristic in which, with increase of current, the voltage rises faster than the current in the metallic conductors, due to their positive temperature coefficient, and slower than the current in the electrolytes, due to their negative temperature coefficient.

The characteristic of the pyroelectric conductors, however, has such a very high negative temperature coefficient of resistance, that is, such rapid decrease of resistance with increase of temperature, that over a wide range of current the voltage decreases with increase of current. Their volt-ampere characteristic therefore has a shape as shown diagrammatically in Fig. 4, though not all such conductors will show the complete curve, or possibly parts of the curve are physically unattainable. For small currents (range 1), the voltage increases approximately proportionally to the current, and some times slightly faster, showing the positive temperature coefficient of metallic conduction. At *a* the temperature coefficient changes from positive to negative, and the voltage begins to increase slower than the current, as in electrolytes (range 2). The negative temperature coefficient rapidly increases and the voltage rise becomes slower, until at point *b* the negative temperature coefficient has become so large that the voltage begins to increase again with increasing current (range 3). The maximum voltage point *b* thus divides the range of rising characteristic, (1) and (2), from that of decreasing characteristic, (3). The negative temperature coefficient reaches a maximum and then decreases again, until at point (*c*) the negative temperature coefficient has fallen so that beyond this minimum voltage point (*c*) the voltage again increases with increasing current (range 4), though the temperature coefficient remains negative, as in electrolytic conductors.

In range 1 the conduction is purely metallic; in range 4 it becomes purely electrolytic, and is usually accompanied by chemical action.

Range 1 and point *a* are often absent, and the conduction begins with a slight negative temperature coefficient.

The complete curve, Fig. 4, can be observed only in few substances, such as magnetite. Minimum voltage point *c* and range 4 are often unattainable owing to melting of the conductor material or to its being otherwise destroyed by heat before this point is reached. This for instance, is the case with cast silicon. The maximum voltage point *b* is often unattainable, and the passage from range 2 to range 3 by increasing the current is therefore not feasible, because the maximum voltage point *b* is so high that disruptive discharge occurs before it is reached. Such, for instance, is the case with glass, the Nernst lamp conductor, etc.

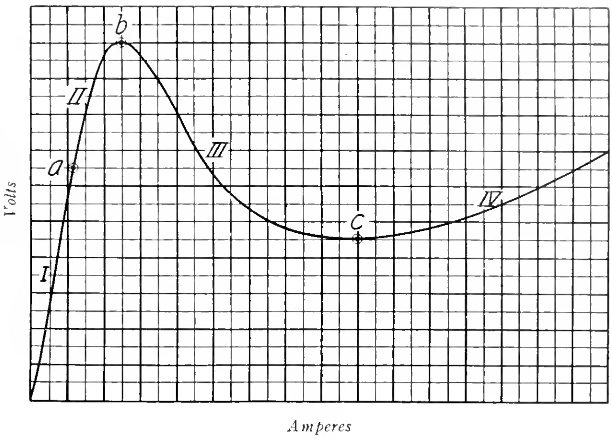


Fig. 4. Pyro-electric Conductor Typical Volt-ampere Characteristic

9. The curve of Fig. 4 is drawn only diagrammatically, and the lower current range is exaggerated to show the characteristics. Usually the current at point (*b*) is very small compared with that at point (*c*)—rarely more than one hundredth of it—and the actual proportions are more nearly represented by Fig. 5. With pyroelectric conductors having a very high value of voltage *b*, the currents in the range 1 and 2 may not exceed one millionth of that at range 3. Therefore such volt-ampere characteristics are often plotted with $\sqrt{i}$ as abscissae, to show the ranges in better proportions.

Pyroelectric conductors are metallic silicon, boron, some forms of carbon as anthracite, many metallic oxides, especially those of the formula $M^{(2)} M_g^{(3)} O_4$, where $M^{(2)}$ is a bivalent.

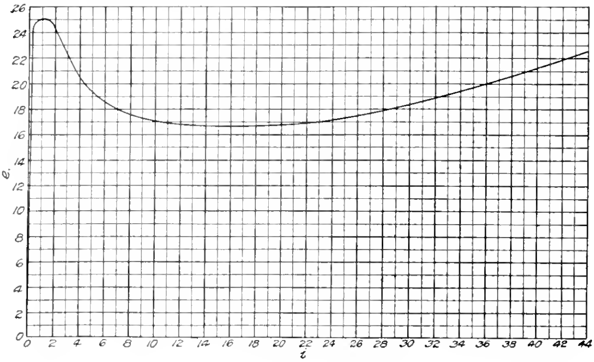


Fig. 5. Volt-ampere Characteristic of Magnetite Rod, 15 cm. Long, 1.9 cm. Diameter

$M^{(3)}$ a trivalent metal (magnetite, chromite), metallic sulphides, silicates such as glass many salts, etc.

Intimate mixtures of conductors, such as graphite, coke, powdered metal, etc. with non-conductors, such as clay, carborundum, and cement, also have pyroelectric conduction. They are used for such purposes as resistance

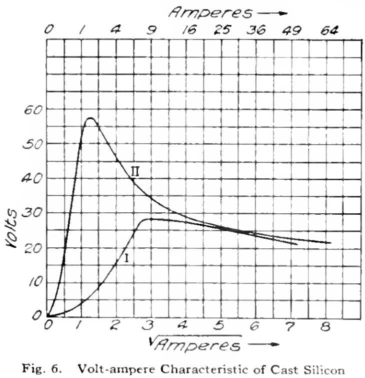


Fig. 6. Volt-ampere Characteristic of Cast Silicon

rods in lightning arresters, and in some rheostats. Many, if not all, so-called insulators probably are in reality pyroelectric conductors, in which the maximum voltage point b is so high that the range 3 of decreasing characteristic can be reached only by the application of external heat, as in the Nernst lamp conductor, or cannot be reached at all because of chemical dissociation beginning below its temperature, as in organic insulators.

Fig. 6 shows the volt-ampere characteristics of two rods of cast silicon, 10 ft. long and 0.22 ft. diameter with $\sqrt{I}$ as abscissae, and Fig. 7 their approximate temperature-resistance characteristics. The curve II of Fig. 7 is replotted in Fig. 8, with log r as ordinates. Where the resistivity varies over a very wide range, it is often preferable to plot the logarithm of the resistivity. It is interesting to note that the range 3 of curve II, between 700 deg. C. and 1400 deg. C., is within the errors of observation represented by the expression:

$$r = 0.01 \epsilon^{-\frac{9080}{T}}$$

where T is the absolute temperature (−273 deg C. as zero point).

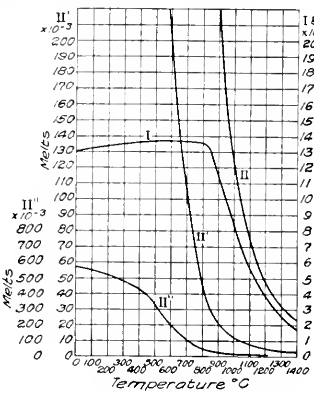


Fig. 7. Resistance-temperature Characteristic of Cast Silicon Resistivity in Ohm-centimeters

The difference between the two silicon rods is, that one contains 1.4 per cent and the other only 0.1 per cent carbon. Besides this, the impurities are less than one per cent. As seen, in these silicon rods the range 4 is not yet reached at the melting point.

Fig. 9 shows the volt-ampere characteristic with $\sqrt{i}$ as abscissae, and Fig. 10 the approximate resistance-temperature characteristic derived therefrom with log r as ordinates, of a magnetite rod 6 in. long and $\frac{3}{4}$ in. diameter, consisting of 90 per cent magnetite (Fe_3O_4), 9 per cent chromite ($Fe\ Cr_2O_4$), and 1 per cent sodium silicate, sintered together.

10. As a result of these volt-ampere characteristics, Figs. 4 to 10, pyroelectric conductors as structural elements of an electric circuit show some very interesting effects, which may be illustrated on the magnetite rod, Fig. 9. The maximum terminal voltage which can exist across this rod in stationary conditions is 25 volts at 1 ampere. With increasing terminal voltage the current gradually increases, until 25 volts is reached, and then without further increase of impressed voltage the current rapidly rises to short-circuit values. Thus such resistance can be used as excess voltage cut out, or, when connected between circuit and ground, as an excess voltage grounding device. Below 24 volts it bipasses a negligible current only; but if the voltage rises above 25 volts it short-circuits the voltage and therefore stops further rise, or operates the circuit breaker or some such device. As the decrease of resistance is the result of temperature rise, it is not instantaneous, and thus the rod does not react on transient voltage rises but only on lasting ones.

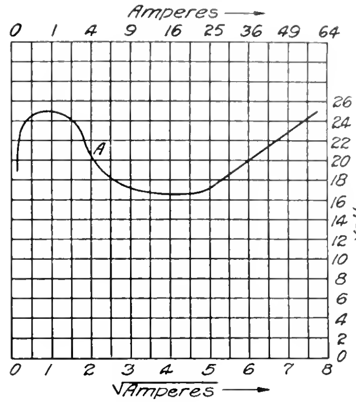


Fig. 9. Volt-ampere Characteristic of Magnetite Resistance

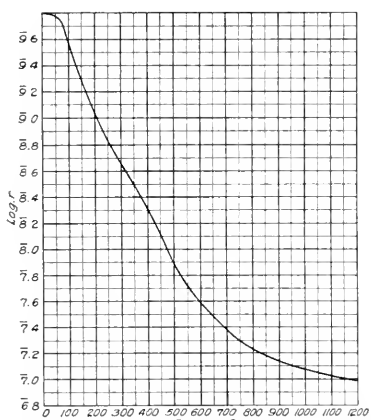


Fig. 8. Resistivity Temperature Characteristic of Cast Silicon Rod 25 cm. Length, 0.56 cm. Diameter. Dotted Curve $r = 0.01\epsilon^{\frac{9080}{T}}$

Within a considerable voltage range—between 16.5 and 25 volts—three values of current exist for the same terminal voltage. Thus at 20 volts between the terminals of the rod, the current may be 0.02 amperes, or 4.1 amperes, or 36 amperes. That is, if placed in series in a constant current circuit

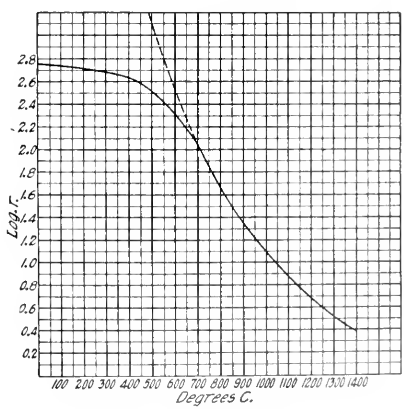


Fig. 10. Resistivity-temperature Characteristic of Magnetite Rod 15 cm. Long, 1.9 cm. Diameter

of 4.1 amperes, this rod would show the same terminal voltage as in a 0.02-ampere or a 36-ampere constant current circuit, viz., 20 volts. On constant potential supply, however, only the ranges 1, 2 and 4 are stable, the range 3 being unstable. Here we have a conductor

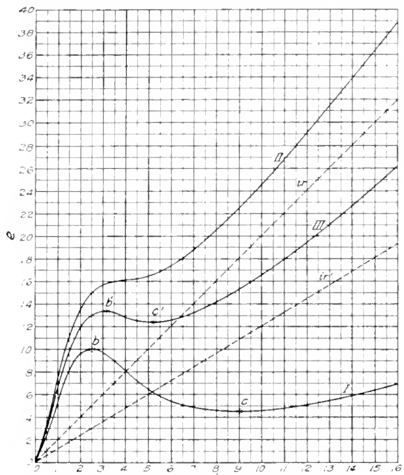


Fig. 11. Stability Curves of Pyro-electric Conductor

that is unstable in a certain range of currents, from point b at 1 ampere to point c at 20 amperes. With 20 volts impressed upon the rod, 0.02-ampere may pass through it, and the conditions are stable That is, a tendency to increase of current would check itself by requiring an increase of voltage beyond that supplied, and a decrease of current would reduce the voltage consumption below that employed, and thus be checked. At the same impressed voltage, 36 amperes may pass through rod, or 1800 times as much as before, and the conditions again are stable. A current of 4.1 amperes also would consume a terminal voltage of 20, but the condition now is unstable. If the current increases ever so little, from a momentary voltage rise, then the voltage consumed by the rod decreases —becomes less than the terminal voltage of 20—and the current thus increases proportionally as the supply voltage exceeds the consumed voltage. This, however, still further decreases the consumed voltage, thereby increasing the current, which rapidly rises until conditions become stable at 36 amperes. Inversely, a momentary decrease of the current below 4.1 amperes increases the voltage required by the rod, and this higher voltage not being available at constant supply voltage the current decreases. This, however, still further increases the required voltage and decreases the current, until conditions become stable at 0.02 amperes.

With the silicon rod II of Fig. 6 on constant potential supply, an increasing voltage produces a gradual increase in current and temperature, until 57.5 volts are reached (at about 450 deg. C.), when without further voltage increase current and temperature rapidly increase until the rod melts.

Thus:

A condition of stability of a conductor on constant voltage supply requires that the volt-ampere characteristic be rising, that is, an increase of current requires an increase of terminal voltage.

A conductor with a falling volt-ampere characteristic, that is, a conductor in which with increase of current the terminal voltage decreases, is unstable on constant potential supply.

11. An important application of pyroelectric conduction has been the glower of the Nernst lamp, which before the development of the tungsten lamp was extensively used for illumination.

Pyroelectrolytes cover the widest range of conductivities. The alloys of silicon with iron and other metals give, depending on their composition, resistivities ranging from those of the pure metals up to the lower resistivities of electrolytes, viz., 1 ohm per cm. cube; borides, carbides, nitrides, oxides etc., give values from 1 ohm per cm. cube or less, up to megohms per cm. cube, and gradually merge into the materials which usually are classed as insulators.

The pyroelectric conductors thus are almost the only ones available in the resistivity range between the metals (0.0001 ohm cm.), and the electrolytes (1 ohm cm.).

Pyroelectric conductors are industrially used to a considerable extent, since they are the only solid conductors which have resistivities much higher than metallic conductors. In most of the industrial uses, however, the dropping volt-ampere characteristic is not of advantage, in fact is often objectionable, and the use is limited to the range 1 and 2 of Fig. 4 It is therefore of importance to consider their pyroelectric characteristics and the effect which they have when over-loaded beyond the maximum voltage point. Thus so-called graphite resistances or carborundum resistances, used in series with lightning arresters to limit the discharge, when exposed to a continual discharge for a sufficient time to reach high temperature practically short-circuit and thereby fail to limit the current.

12. From the dropping volt-ampere characteristic in some pyroelectric conductors, especially those of high resistance, very high negative temperature coefficient, and of considerable cross section, results the tendency to unusual current distribution and the formation of a "luminous streak," at a sudden application of high voltage. Thus, if the current passing through a graphite clay rod of a few hundred ohms resistance is gradually increased, the temperature rises, the voltage first increases and then decreases, while the rod passes from range 2 into range 3 of the volt-ampere characteristic; but the temperature and thus the current density throughout the section of the rod is fairly uniform. If, however, the full voltage is suddenly applied, as by a lightning discharge throwing line voltage on the series resistance of a lightning arrester, the rod heats up very rapidly—too rapid for the temperature to equalize throughout the rod section—and a part of the section passes the maximum voltage point *b* of Fig. 4 into ranges 3 and 4 of low resistance, high current and high temperature, while most of the section is still in the high resistance range 2 and never passes beyond this range, as it is pratically short-circuited. Thus practically all the current passes in an irregular luminous streak through a small section of the rod, while most of the section is relatively cold and practically does not participate in the conduction. Gradually, by heat conduction the temperature and the current density may become more uniform, if before this the rod has not been destroyed by temperature stresses. Thus tests made on such conductors by gradual application of voltage give no information on their behavior under sudden voltage application. The liability to the formation of such luminous streaks naturally increases with decreasing heat conductivity of the material and with increasing resistance and temperature coefficient of resistance, and with conductors of extremely high temperature coefficient, such a silicates, oxide of high resistivity, etc., it is practically impossible to get current to flow through any appreciable conductor section, the conduction being always streak conduction.

Some pyroelectric conductors have the characteristic that their resistance increases permanently, often by many hundred per cent, when the conductor is for some time exposed to high frequency electrostatic discharges.

Coherer action, that is, an abrupt change of conductivity by an electrostatic spark, a

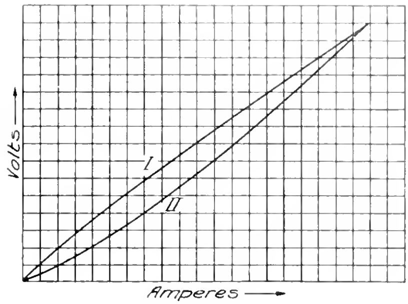


Fig. 12. Volt-ampere Characteristic of Carbon

wireless wave, etc., is also exhibited by some pyroelectric conductors.

13. Operation of pyroelectric conductors on a constant voltage circuit, and in the unstable range 3, is possible by the insertion of a series resistance (or reactance in alternating current circuits) of such value that the resultant volt-ampere characteristic is stable, that is, rises with increase of current. Thus the conductor in Fig. 4, shown as I in Fig. 11, in series with the metallic resistance giving characteristic *A*, gives the resultant characteristic II in Fig. 11, which is stable over the entire range. I in series with a smaller resistance, of characteristic *B*, gives the resultant characteristic III. Here the unstable range has contracted from b^1 to c^1. Further discussion of the instability of such conductors, the effect of resistance in stablizing them, and the resultant stability curve will be given in a later section on Instability of Electric Circuits, under Arcs and Similar Conductors.

14. It is doubtful whether the pyroelectric conductors rarely form one class, or whether by the physical nature of their conduction they should not be divided into at least two classes:

a. True pyroelectric conductors, in which the very high negative temperature coefficient is a characteristic of the material. In this class probably belong silicon and its alloys, boron, magnetite and other metallic oxides, sulphides, carbides, etc.

b. Conductors which are mixtures of materials of high conductivity and of non-conductors, and derive their resistance from the contact resistance between the conducting

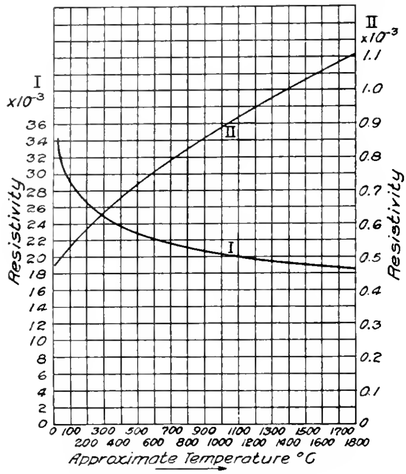


Fig. 13. Resistance-temperature Characteristic of Carbon Resistivity in Ohm-centimeters

particles which are separated by non-conductors. As contact resistance shares with arc conduction the dropping volt-ampere characteristic, such mixtures thereby imitate pyroelectric conduction. In this class probably belong the graphite clay rods used industrially. Powders of metals, graphite and other good conductors also belong in this class.

The very great increase of resistance of some conductors under electrostatic discharges probably is limited to this class, and is the result of the high current density of the condenser discharge burning off the contact points.

Coherer action probably is limited also to these conductors, and is the result of the minute spark at the contact points initiating conduction.

Carbon

15. In some respects ranging outside of the three classes of conductors thus far discussed, and in others intermediate between them, is one of the industrially most important conductors, *carbon*. It exists in a large variety of modifications of different resistance characteristics, all of which are more or less intermediate between three typical forms:

(a) *Metallic Carbon*. This consists of carbon deposited on an incandescent filament from hydrocarbon vapors in a partial vacuum, by exposure to the highest temperatures of the electric furnace. Physically, it has metallic characteristics, i.e., high elasticity, metallic luster, etc., and electrically it has a relatively low resistance approaching that of metallic conduction, and a positive temperature coefficient of resistance of about 0.1 per cent per degree C, that is, of the same magnitude as mercury or cast iron.

The coating of the "Gem" filament incandescent lamp consists of this modification of carbon.

(b) *Amorphous Carbon*. As produced by the carbonization of cellulose. In its purest form, as produced by exposure to the highest temperatures of the electric furnace, it is characterized by a relatively high resistance and a negative temperature coefficient of resistance, its conductivity increasing by about 0.1 per cent per degree C.

(c) *Anthracite*. It has an extremely high resistance, is practically an insulator, but has a very high negative temperature coefficient of resistance and thus becomes a fairly good conductor at high temperature; but its heat conductivity is so low, and the negative temperature coefficient of resistance so high, that the conduction is practically always streak conduction, and at the high temperature of the conducting luminous streak conversion to graphite occurs, with a permanent decrease of resistance.

(a) thus shows the characteristics of metallic conduction; (b) those of electrolytic conduction; and (c) those of pyroelectric conduction.

Fig. 12 shows the volt-ampere characteristics, and Fig. 13 the resistance temperature characteristics of amorphous carbon (curve I) and metallic carbon (curve II)

(*To be Continued*)

INVESTIGATION OF MAGNETIC LAWS FOR STEEL AND OTHER MATERIALS*

By John D. Ball

Consulting Engineering Department, General Electric Company

Many recent investigators have maintained that at high values of inductions, sheet steel does not follow the Steinmetz' 1.6, or hysteresis law. In the present article the author accounts for this deviation by the fact that the steels tested were not homogeneous, containing impurities such as scale, etc. While these impurities themselves follow the Steinmetz' law they have constants differing from the steel. The author gives the results of tests on scale free material, as well as the results of investigations covering the chemical, physical and magnetic properties of the scale itself. The author further demonstrates his theory by tests made on samples of pure iron and pure cobalt tested both together and separately. The article also includes a résumé of the results obtained with unsymmetrical hysteresis loops, that is to say, where the mean induction is other than zero, as in apparatus in rectified circuits and in inductor alternators, etc.—Editor.

From the length of time magnetic phenomena have been observed, we might think that the subject is so old, and the work done by distinguished experts so thorough, that there is little left to be accomplished. As a matter of fact, much has been done and learned since the peculiar properties of the lodestone were first observed, yet today the subject is by no means thoroughly understood. Our formulæ are mostly empirical and the variations in magnetic material under different, and even under apparently the same conditions show so many unaccountable variations from what we consider as correct, that a book on "What we Cannot Account for in Magnetic Behavior" would be easy to write.

That the subject is a live one is witnessed by the number of articles which have been presented before this and other learned societies.

I will not attempt to give you a *résumé* or bibliography of magnetic research in general, but will present to you results of some of our own investigations made during the past two years.

The work has been done with two purposes in view:

Primarily to study magnetic phenomena with a hope of aiding the discovery of their true nature, and secondarily to study the magnetic properties of materials to assist in the economical design of apparatus.

Probably the two most valuable magnetic laws which we have today are the reluctivity equation of Dr. Kennelly, which is a modified form of Fröhlich's equation, and the 1.6 law of Dr. Steinmetz. These two laws give us our best method of attack on magnetic problems. A considerable number of test results has been obtained and much literature written attempting to show apparent inconsistencies in these laws, especially referring to the latter. The fundamental idea of the present investigation was, therefore, to determine the accuracy and cause of these apparent deviations of observed test values from the reluctivity equation of Kennelly and the hysteresis equation of Steinmetz. About three years ago Dr. Steinmetz suggested that these apparent deviations might be due to the fact that the materials tested were not homogeneous. As it was found that the deviations were most noticeable in silicon steel, and as the hysteresis losses in this material are especially interesting from the standpoint of electrical manufacturers, properties of this steel were closely examined. On the theory that heterogeneous materials cause the deviations from magnetic laws, it became necessary to separately determine the properties of steel, free from scale, and the properties of the scale itself. It became also desirable to further investigate the theory by artificially reproducing the characteristics of a heterogeneous material by testing a sample which consisted of two component metals; one of the samples selected was a ring which was practically pure iron, and the other cobalt. The two rings were fastened together and tested as a single sample, after which the properties of each ring were determined separately.

During the process of the investigation we also studied the second hysteresis law of Dr. Steinmetz, or the hysteresis losses in unsymmetrical loops; that is, where the mean introduction of the loop occurs at a density other than zero.

* Presented before the Franklin Institute at a joint meeting of the Electrical Section and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, December 2, 1915. Reprinted by permission of the Franklin Institute.

The present paper is divided into the following divisions:

I. Review of the reluctivity law of Kennelly.
II. The hysteresis law of Steinmetz.
III. The theory of the changes in flux distribution in heterogeneous material to account for apparent deviations in the above laws.
IV. Properties of scale from silicon steel.
V. Application of scale data to show distribution of flux and losses in sheet steel as affected by the presence of steel.
VI. Tests of iron and cobalt separately and together to reproduce effects of steel with scale.
VII. Applications of data in calculating losses.
VIII. Brief *résumé* of investigation to determine losses in unsymmetrical loops.
IX. Appendix: Properties of scale from silicon steel of general interest and value, but not pertinent to the present investigation.

I. The Reluctivity Law of Kennelly

The reluctivity law of Dr. Kennelly as announced is, that for magnetic materials the reluctivity (which is the reciprocal of the permeability), when plotted against the magnetizing force H, gives a curve which, from minimum reluctivity upwards, approximates a straight line over a wide range of values.[1] However, as pointed out by Dr. Kennelly, we find in most cases that the curve is not a straight line, but rather two straight lines joined by a sharp, decided bend. From plotting and examining several hundred curves for many varieties of steel, for nickel, monel metal, "binel" metal, and other metals, we have found that for a given material the bend apparently occurs at a definite value of magnetizing force H, irrespective of the flux density B. Closer examination indicated that above this value of H there are no bends, but below this value there are often evidences of several bends. In any curve there is but one salient deflection, the others being much less pronounced. A variety of these curves are shown in Dr. Kennelly's article.

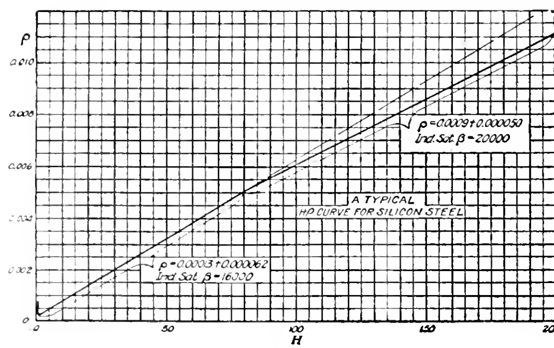


Fig. 1

A curve of the test results of a sample of high silicon steel is shown in Fig. 1, which may be taken as a typical curve. Other curves for silicon steel may be found in another paper.[2]

The reluctivity, ρ, is given by the equation $\rho = \alpha + \sigma H$, wherein:

α is a constant representing the distance from the X axis to the intercept of $\rho - H$ curve if continued along the straight line.

σ is a constant representing the slope of the line. We may consider that α represents the magnetic hardness of the material, as the harder the metal (magnetically) the greater the value of α. The constant σ has been named the coefficient of magnetic saturation because its reciprocal gives the value of absolute saturation of metallic induction.[3] Tests made at very high magnetizations by use of the isthmus method,[4] check ultimate saturation values as found by $\frac{1}{\sigma}$ of the $\rho - H$ curve taken at moderate field strengths.

As $\rho = \frac{H}{B}$ and also $\rho = \alpha + \sigma H$, then the induction,

$$B = \frac{H}{\alpha + \sigma H}\ ^{5}$$

[1] Magnetic Reluctance," A. E. Kennelly, *Trans. A. I. E. E.*, vol. viii, 1891, pp. 485-517.

[2] "Reluctivity of Silicon Steel," J. D. Ball, GENERAL ELECTRIC REVIEW, vol. xvi, 1913, pp. 750-754.

[3] "On the Law of Hysteresis," C. P. Steinmetz, *Trans. A. I. E. E.*, vol. ix, 1892, p. 625 *et seq.*

[4] See "Electrical Properties of Iron and Its Alloys in Intense Fields," Sir Robert Hadfield and Professor B. Hopkinson, *Journ. I. E. E.*, vol. lvi, 1911, pp. 235-306, etc.

[5] There are reasons why the true metallic density $4\pi I$, which is $B - H$, should be used for extrapolation and other applications of this law; this has also been written B_o. In this case the metallic reluctivity $\frac{H}{4\pi I}$ would be represented by $\rho_o = \alpha_o + \sigma H$ and

$$B = \frac{H}{\alpha_o + \sigma_o H} + H$$

This is discussed in a previous paper, "Some Notes on Magnetization Curves," GENERAL ELECTRIC REVIEW, vol. xviii, 1915, pp. 331-335. For the ranges involved in the present discussion, B_o is so nearly identical with B that the difference is negligible and is not taken into account.

Examining the curve Fig. 1, we note that from maximum permeability to about $H=80$, the flux apparently enters a material having an apparent ultimate saturation of $B=17,000$; then later the curve shows a changed condition, as if the flux passed through material whose apparent ultimate saturation is in the neighborhood of $B=20,000$, and whose α shows a harder material. This indicates that the two lines apparently may represent two magnetic materials, one of which takes most of the flux first, and the other carries the additional flux after the first is presumably saturated, or the permeability of the second part begins to increase much more rapidly than in the first.

Before going into detail further concerning the theory of changes in flux paths it is desirable to briefly review the hysteresis law of Steinmetz.

II. The Hysteresis Law of Steinmetz

In the early part of 1892, Dr. Steinmetz presented the well-known classic paper on "The Law of Hysteresis"[6] and gave us the law $h=\eta B^{1.6}$ wherein:

h = the hysteresis loss per cycle in ergs per cm.[3]

B = the maximum induction.

η = a numerical coefficient depending upon the material.

The great value of the discovery has been recognized and requires no comment here. Along in 1910–11, shortly after the German specifications were adopted that the standard test of steel should be made at $B=15,000$ as well as $B=10,000$,[7] a number of experimenters made calculations which gave for the higher ranges of inductions values of the exponent on the order of 3. Some of these values have been published. The calculations were in error, due to certain misconception of taking the percentual slope of the curve *log h − log B* as the exponent where the curve was not a straight line or the original $h-B$ curve was not exactly parabolic. Examination of data, however, does show an apparent increase of the exponent at the higher inductions, the exponent increasing to, say 1.63 at $B=15,000$.

Tests on many samples of $2\frac{1}{2}$ per cent silicon steel and $3\frac{1}{2}$ per cent silicon steel as commercially used show losses at $B=15,000$ to be apparently 30 per cent higher than would be given by the loss at $B=10,000$ and strict application of the law. In other words, the ratio of losses at $B=15,000$ and $B=10,000$ is about 2.5 to 3.5 instead of the value of $\left(\frac{15,000}{10,000}\right)^{1.6}=1.91$.

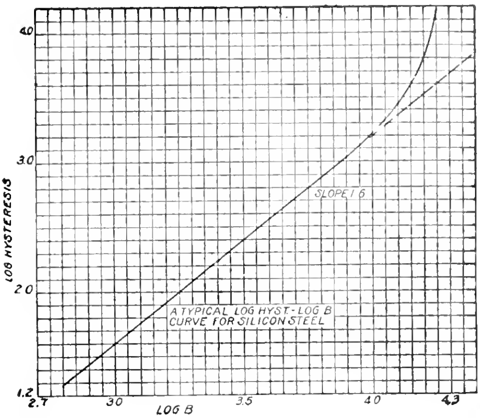


Fig. 2

Plotting a typical *log h − log B*, we find results as given in Fig. 2. The solid curve represents the observed data, and the dotted continuation of the straight line shows what results might be expected if the law were absolutely correct. If we assume that the 1.6 law holds, we see that to about $B=10,000$ the flux enters a material of certain characteristics, but beyond that point the more appreciable amount of the flux is going through some magnetically harder material characterized by greater reluctivity and a higher value of η.

III. The Theory of Changes in Flux Distribution to Account for Apparent Deviations in Magnetic Laws

As pointed out, the bend of the reluctivity curve indicates a non-homogeneous material or a material whose component parts may be divided into two magnetic materials, whose characteristics are different, and in consequence carry different percentages of flux as the magnetizing forces are varied. In such

[6] "On the Law of Hysteresis," C. P. Steinmetz, *Trans. A. I. E. E.*, vol. ix, 1892, pp. 3-51; also vol. ix, 1892, pp. 621-729 vol. xi, 1894, pp. 570-608.

[7] For present standard see V. D. E. Rule's "Normalien für die prufung von Eisenblech."

a case the softer material would carry a correspondingly greater amount of flux until approaching saturation reduces the permeability, after which the additional flux is forced into the harder material whose permeability is then correspondingly higher than before. The percentage of flux in the harder material will then increase very rapidly, due to the fact that the softer material is becoming saturated, and can carry little additional flux. At varying values of magnetizing force the percentage of flux in the two materials constantly varies, due to the fact that the rate of change of their respective permeabilities is constantly varying.

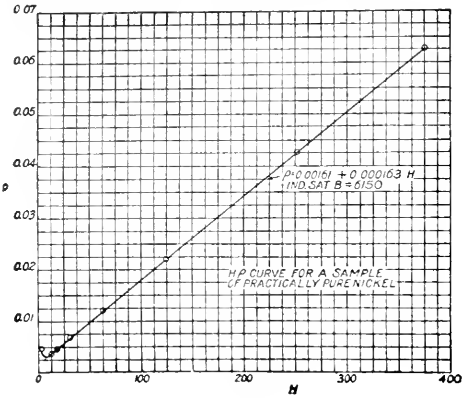


Fig. 3

It would be expected that if pure or homogeneous materials were taken the reluctivity curves would be straight. Tests have been obtained showing this to be true, as, for example, Fig. 3 gives an $H-\rho$ curve for a sample of nearly pure nickel. The chemical analysis showed: Ni 98.91, Cu 0.33, Fe 0.31, Mn 0.21, Si 0.07, Co 0.15. Here we see no evidences of bend, but a straight line from approximately $H=9$ ($B=3000$) to $H=377$ ($B=6350$), the limit of the test. A study of this curve would indicate that in this case the flux is passing through a material whose magnetic characteristics are constant throughout the range of the test.

Referring to the hysteresis law, the deviation from the straight line in the $\log h-\log B$ curve also indicates a heterogeneous material. The most prominent deviations from the reluctivity and hysteresis laws do not occur at the same value of the magnetizing forces, nor would it be expected. The bend of the reluctivity curve would be predicted at a value of H where one material approaches the saturation value. The rapid increase of the hysteresis loss would occur at a point where the permeability of the harder material (which is characterized by the greater value of η) increases at a more rapid rate than the permeability of the softer. This change would be expected at about the value of H, where the softer material reaches maximum permeability, although not necessarily at this point. Beyond this, additional H gives less relative increase of induction, while the relative induction in the second material continues to increase until its permeability is a maximum, which occurs at a much higher value of H.

We know that our sheet steel as commercially used is by no means magnetically homogeneous. The fact that it is especially prominent is because about 10 per cent of the ordinary sheet consists of scale, which scale is naturally less magnetic than iron and at the same induction would have much greater hysteresis loss. In order to further demonstrate this theory, it would be interesting to have a purely theoretical case, where a heterogeneous material forms two or more magnetic paths in multiple, and note the behavior of the combined curves when calculated by assuming the component part thereof to be subjected to the same values of excitation. Unfortunately this is not practical, as it would be necessary to have values of the normal induction curve below maximum permeability for at least one of the components, and we have not as yet been successful in obtaining an equation of the magnetization curve below maximum permeability. A curve representing materials might be drawn at random, but results derived therefrom would necessarily be neither accurate nor convincing. We are therefore forced to investigate our theory with actual data, which, after all, is the correct method of investigating empirical formulæ.

As steel and scale are the salient components of our sheet steel, it becomes desirable to determine the characteristics of scale from silicon steel when removed from the steel itself. We will therefore leave the general investigation of magnetic laws for the time being, to give results of tests on steel scale.

IV. Properties of Scale from Silicon Steel

It is a well-known fact that when steel is heated the exposed surfaces combine chemically with surrounding gases and form a thin scale. Such formations appear when steel is taken from rolling mills, and the thickness thereof is usually greater after materials are subjected to annealing processes. In thin sheets the scale on both sides is usually sufficient to amount to about 10 per cent of the total cross section. In silicon steels this scale is usually in flakes, and sometimes may be easily removed from the sheets. Often large sections may be peeled off, in which manner samples were obtained for this investigation. The samples tested were built of large flakes accumulated from time to time, and therefore are more representative than if a whole sample were taken from one heat or lot only.

The study of steel scales and a knowledge of their properties were required primarily for assistance in determining magnetic laws for materials wherein scale exists, thus rendering test specimens non-homogeneous. Also, it is of interest to be able to determine effect of scale in electrical machines wherein the scale occupies a portion of a section of a magnetic core.

Tests were made on a scale from steel containing 3.5 to 4.3 per cent silicon. One sample of scale was obtained from steel annealed in the ordinary way, which is herein referred to as "mill-annealed." The second variety was obtained from steel annealed at high temperature in a vacuum furnace, which will be herein designated as "vacuum-annealed scale."

For the present discussion the mill-annealed scale is used, but, as the properties of scale from vacuum-annealed steel are of general value, results of these tests are given in the Appendix.

SCALE FROM MILL-ANNEALED STEEL

Physical Appearance and Size of Sample

The scale from mill-annealed silicon steel is dark gray in color, is somewhat pitted, and is fairly rough. The material is reasonably tough, but is, of course, much more brittle than the steel itself. The sample tested was made up of ring punchings 8.89 cm. (3.5 inches) outer diameter, 6.86 cm. (2.9 inches) inner diameter, and weighed 85 grammes (0.187 pounds). The average thickness of the sheets was 0.0064 cm. (0.0025 inch). The scale was obtained from sheets 0.035 cm. (0.014 inch) thick.

Chemical Analysis

The first analysis of this material gave the following results:

Si	7.02
S	0.047
Mn	0.08
C	0.054

Analysis for oxygen gave 1.2 per cent, which was rather surprising, as scale is usually considered as a magnetic oxide, which would, of course, have a larger percentage of oxygen.

A later, and probably more reliable, analysis gave:

Si	5.28	5.52
S	0.047	0.046
P	0.042	0.041
Mn	0.310	0.300
C	0.307	0.300
Total *Fe*	75.84	76.21
Total per cent	81.826	82.417

As before stated, the analysis for oxygen gave only 1.2 per cent., but it is well known that such determinations are often not reliable. In all probability, the 18 per cent missing in the above tabulations is oxygen. We know that all of the silicon and some of the iron exists as oxides. Considering the silicon to appear as SiO_2, and assuming the iron in the oxide form to be in Fe_3O_4, calculated values may be derived from the analysis of the first specimen tabulated above, giving the following possible chemical content:

SiO_2	11.23
S	0.047
P	0.042
Mn	0.310
C	0.307
Fe (free)	43.764
Fe_3O_4	44.3
Total	100.00

The above table of possible values is undoubtedly not entirely correct, as some of the silicon may be in the metallic form, and the iron doubtless appears not only as metallic iron and Fe_3O_4, but there may also be other iron oxides present, making the chemical contents of a more complicated nature.

Resistivity

A sample of mill-annealed scale 0.0050 cm. (0.002 inch) thick was secured for resistivity measurements. The average of the measurements gave a resistivity of 126.6 microhms per cm.[3] at 25 deg. C. The individual values varied from 107 to 157. A test on 0.0064 cm. (0.0025 inch) scale gave 140 microhms per cm.[3], which lies within the results obtained on the thicker scale. Resistivity of silicon sheet steel, such as produced this scale, is usually between 55 and 60 microhms. Ordinary sheet steel gives about 12, and cast iron 80 to 85 microhms.

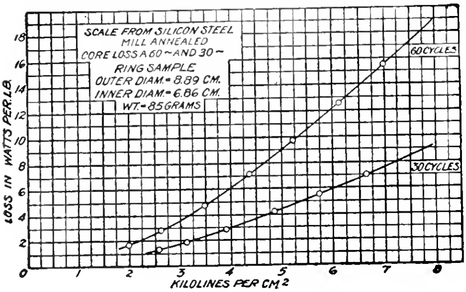


Fig. 4

Specific Gravity

The specific gravity determination of this scale gave 5.54. The gravity of the steel itself is approximately 7.5.

Core Loss

Core loss tests were made on the ring samples, at 60 cycles and 30 cycles, at inductions of from $B=2000$ to $B=7500$. The results of tests are shown on curve, Fig. 4. Data derived from the curves are tabulated with the discussion of the hysteresis loss.

Hysteresis Loss

The hysteresis loss at various densities was first determined from the core loss tests by using the separation method. This was done by taking values from the core loss curves at 60 cycles and 30 cycles and obtaining the loss per cycle, as shown in Table I.

TABLE I

LOSSES IN SCALE FROM SILICON STEEL

(Losses in Watts per Pound)

B	Total Losses		Loss per Cycle		Loss per Cycle at 60 Cycles	
	60 Cycles	30 Cycles	60 Cycles	30 Cycles	Hysteresis	Eddy
7500	17.4	8.5	0.29	0.283	0.276	0.014
6000	12.2	5.95	0.203	0.198	0.193	0.010
5000	9.0	4.4	0.15	0.147	0.144	0.006
4000	6.1	2.95	0.102	0.095	0.094	0.008
3000	3.6	1.70	0.06	0.057	0.054	0.006
2500	2.5	1.2	0.042	0.040	0.038	0.004

From Table I the hysteresis losses in ergs per cm.[3] were calculated, and the logarithms of the losses and of the inductions taken, as shown in Table II.

TABLE II

HYSTERESIS LOSSES IN SCALE FROM SILICON STEEL

B	Hysteresis ergs per cm³	Log B	Log hyst	η ($x=1.6$ assumed)
7500	33,700	3.875	4.528	0.0222
6000	23,570	3.778	4.373	0.0212
5000	17,580	3.699	4.245	0.0212
4000	11,475	3.602	4.060	0.0198
3000	6,595	3.477	3.819	0.0180
2000	4,640	3.398	3.667	0.0170
Average	...		....	0.0199

A plot of the log hysteresis $-$ *log B* is shown in Fig. 5.

In order to find the value of the constants in the Steinmetz equation, $h=\eta\ B^{1.6}$, the slope of the line $\log h - \log B$ was next determined and evaluated by the $\Sigma\ \Delta$ method.[8] Taking all the above points, the slope of the line, which is the value of x in the equation proves to be 1.83. Considering the points lying on the line, we obtain 1.85. As 1.6 is not claimed to be accurate at very low inductions, the most reasonable value is found by taking

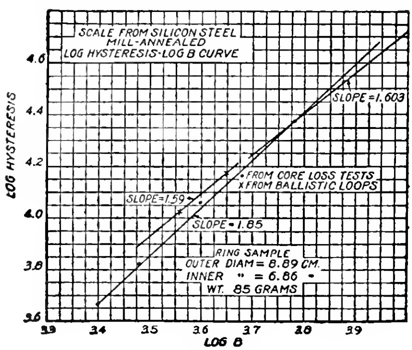


Fig. 5

the three highest points. The slope of a line determined from these points is 1.603, or practically 1.6 as has been found for a variety of magnetic materials.

[8] "Engineering Mathematics," Steinmetz.

In order to evaluate η and to have values comparable with constants for other materials, it is best to assume $x=1.6$. The values of η so obtained are given in the last column of Table II. The average value is 0.0199. The average of the three highest points is 0.0216. From the nature of the tests the above results, especially at low values, are likely to be somewhat in error.

Hysteresis losses were also taken by the usual ballistic galvanometer method. Loops were obtained at $B=4487$ and $B=3639$, and are shown on Fig. 6 and Fig. 7 respectively. The integration of the loops gives values shown in Table III, wherein the logarithms of the values are included.

TABLE III

HYSTERESIS LOSSES IN SCALE

Ballistic Tests

B	Hysteresis ergs per cm.^{3}	Log B	Log Hysteresis	η ($x=1.6$ Assumed)
4480	15,010	3.651	4.176	0.0216
3640	10,975	3.561	4.033	0.0216

Obtaining the slope of the *log h – log B* line, we have 1.59. These points are shown, together with hysteresis points obtained from the core loss curve, on Fig. 5. Assuming $x=1.6$ for the ballistic values, we find $\eta=0.0216$, which agrees with the three upper points before mentioned. We may therefore with reasonable accuracy express the hysteresis loss of this sample as $h=0.0216\ B^{1.6}$

Magnetization, Permeability and Reluctivity

Two tests for magnetization curves were made and found to be within good agreement. The method of test was the common one of

TABLE IV

MAGNETIZATION DATA OF SCALE FROM SILICON STEEL

H	B Test 1	Test 2	Average	$\mu=B/H$	$\rho=H/B$
150	7425	7555	7490	50.0	0.0202
140	7306	7566	7388	52.6	0.0190
130	7187	7332	7260	56.0	0.0179
120	7083	7190	7136	69.4	0.0168
110	6964	7054	7009	63.6	0.0158
100	6890	6920	6905	69.1	0.0145
90	6696	6781	6739	74.9	0.0134
80	6514	6600	6557	82.0	0.0122
70	6290	6380	6335	90.5	0.0110
60	6064	6121	6093	101.5	0.0099
50	5740	5770	5755	115.0	0.00868
40	5266	5283	5275	132.0	0.00766
30	4527	4497	4512	150.5	0.00665
20	2960	2991	2975	148.8	0.00675
10	918	879	899	89.9	0.0111
5	287.7	278	283	55.6	0.0177
3	149.0	144.7	147	49.0	0.0204
2	94.9	81.0	93	46.5	0.0215

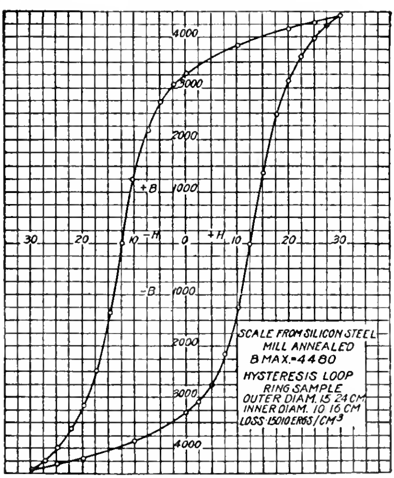


Fig. 6

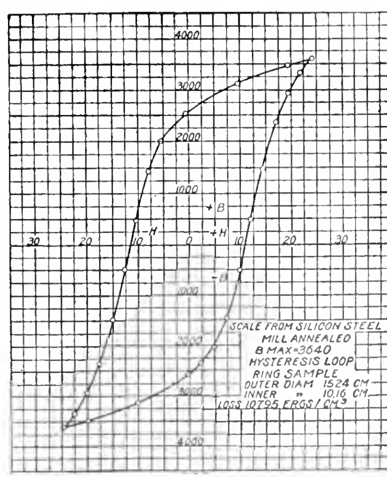


Fig. 7

reversing various currents in a magnetizing winding and noting flux change by means of a ballistic galvanometer. Results of these tests are given in Table IV, and the average of the two tests is plotted on Fig. 8. On this sheet are plotted the $B-H$, $B-\mu$, and reluctivity $H-\rho$ curves. The reluctivity gives

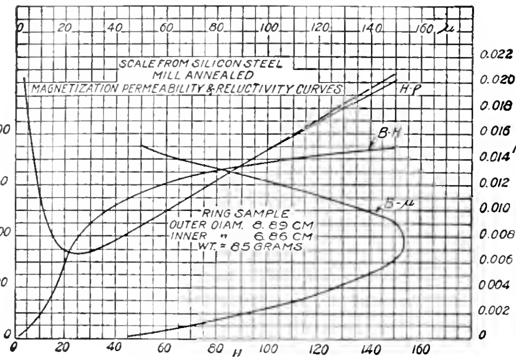


Fig. 8

practically a straight line from $H=40$, which condition, as before stated, has been found for various metals.

Examination of Fig. 8 shows the reluctivity curve to be a straight line from $H=40$ to $H=105$, at which latter value the line bends slightly. From $H=105$ to the end the points also lie on a straight line. Taking the equation of this line as $\rho=\alpha+\sigma H$, evaluating the constants by the $\Sigma\,\Delta$ method, gives

From $H=40$ to $H=105$:

$$\rho=0.00289+0.000117\,H$$

$$\text{Saturation } B=\frac{1}{\sigma}=8550.$$

From $H=105$ on:

$$\rho=0.0033+0.000112\,H$$

Saturation $=8900$.

From these equations we may find the equations of the magnetization curves to be

From $H=40$ to $H=105$

$$B=\frac{H}{0.02289+0.000117\,H}$$

From $H=105$ on:

$$B=\frac{H}{0.0033+0.000112\,H}$$

The maximum permeability of the material is about 154 at an induction $B=3700$.

The results of these tests show two especially interesting features:

1. The loss in the scale itself apparently follows the Steinmetz law.

2. From maximum permeability the reluctivity curve of the scale is practically a straight line.

The slight bend in the reluctivity curve at $H=105$ is accounted for in the same manner as for sheet steel. The scale itself consists of a mixture of iron, silicon, oxides and impurities, and is not magnetically alike throughout.

V. Distribution of Flux and Losses in Steel and Scale Calculated from Test Results on Scale Alone

Having now seen that the scale from steel follows the magnetic laws under discussion, we now desire to determine, by calculations, the nature of its influence on the measured magnetic values and losses of steel upon which scale appears.

If we take a typical magnetization curve representing silicon steel as entirely free from scale and entirely magnetically homogeneous throughout we may expect the following characteristics:

Saturation: $B=20{,}000$.

Maximum Permeability: $\mu=5000$, occurring at $B=5000$.

Then at maximum permeability $H=\frac{5000}{5000}=1$.

In the equation of the magnetization curve,

$$B=\frac{H}{\alpha+\sigma\,H}.$$

σ would then be $\frac{1}{20{,}000}$, or 0.00005.

At $H=1$, $\rho=\frac{1}{5000}=0.0002$.

Also $\rho=\alpha+0.00005\,H$.

From above $\alpha=0.0002-0.00005=0.00015$.

For the typical magnetization curve beyond maximum permeability we then have:

$$B=\frac{H}{0.00015+0.00005\,H}$$

From this equation we obtain values of B corresponding to various values of H as shown in Table V, in which table the values of B corresponding to the same values of H

are given for scale from silicon steel, which values are taken from Fig. 8 and accompanying data in Table IV.

Assuming a total cross section area of steel and scale as 1 cm.², of which 90 per cent is steel and 10 per cent is scale, the flux in the steel and scale are given in Table V, columns 4 and 5 respectively. The total flux, or apparent B, of the mixture is given in column 6.

TABLE V

VALUES OF FLUX IN STEEL AND IN SCALE FOR 10 PER CENT SCALE

H	B In Steel	B In Scale	Flux in 0.9 Cm.² of Steel	Flux in 0.1 Cm.² of Scale	Total Flux or Apparent B of Mixture
2	8,000	93	7,200	9	7,210
3	10,000	147	9,000	15	9,015
4	11,420	200	10,300	20	10,320
6	13,330	400	12,100	40	12,140
10	15,400	900	13,880	90	13,970
20	17,400	2975	15,680	298	15,980
30	18,200	4512	16,400	451	16,850

We have previously found that in the Steinmetz equation for hysteresis an average of certain tests gives a value of $\eta = 0.000675$ for silicon steel. The present investigation shows that for scale η may be taken as 0.0216. Assuming the hysteresis law to hold throughout the range for steel free from impurities, we obtain for the densities of Table V hysteresis losses as given in Table VI. In this table are also given the losses for 0.9 cm.³ of steel and 0.1 cm.³ of scale, which added together, gives the total hysteresis losses per cm.³ of the mixture. The logarithms of the hysteresis

TABLE VI

HYSTERESIS LOSS IN STEEL, SCALE AND MIXTURE WITH 10 PER CENT SCALE

H	Hyst. in Steel per Cm.³	Hyst. in Steel 0.9 Cm.³	Hyst. in Scale per Cm.³	Hyst. in Scale 0.1 Cm.³	Total Hyst. in 1 Cm.³ of Mixture	Log Hyst.	Log of Apparent B
2	1183	1065	29.4	3	1068	3.029	3.858
3	1695	1525	62.0	6	1532	3.185	3.955
4	2090	1880	104	10	1890	3.277	4.013
6	2690	2420	318	32	2452	3.389	4.084
10	3390	3050	1130	113	3163	3.500	4.146
20	4130	3700	7800	780	4480	3.651	4.204
30	4420	3980	14950	1495	5475	3.738	4.226

For steel $\eta = 0.000675$.
For scale $\eta = 0.0216$.

losses and logarithms of apparent densities are also tabulated. Plotting the log hysteresis and *log B*, we find on Fig. 9 that the curve is a straight line to about $B = 12{,}000$ beyond which the increase in hysteresis is greater than if the 1.6 law held for the mixture.

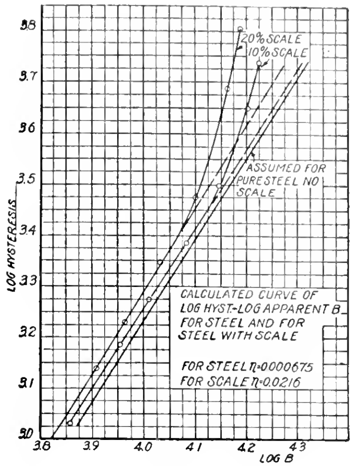


Fig. 9

This agrees with observations made by several authors, and might easily account for the apparent increase of hysteresis in sheet steel at high inductions, concerning which much has been written. For the straight part of the curve the slope is 1.59, or approximately 1.6. Assuming the hysteresis exponent to be 1.6, the higher inductions would show the increases as given in Table VII.

TABLE VII

VALUES OF η WHEN STEEL CONTAINS 10 PER CENT SCALE

B	η of Mixture ($x = 1.6$)	Ratio η to Average η	Average Ratio of Sheet Steel Found from Test Values
7,210	0.000721		1.00
9,015	0.000716		1.01
10,320	0.000716	1.00	1.04
12,140	0.000716		1.13
13,970	0.000737	1.03	1.24
15,980	0.000842	1.17	
16,850	0.000946	1.32	

Average η for first four points = 0.000717.

The increase of η here given is not as great as found by test on sheet steel itself, but shows the same nature and rate of increase. In silicon sheet steel the scale and other impurities in the steel itself might easily be more than 10 per cent of the volume, and the theoretical curve would thereby show greater increase of η and check the test results much closer.

TABLE VIII

VALUES OF FLUX IN STEEL AND IN SCALE FOR 20 PER CENT SCALE

H	B In Steel	B In Scale	Flux in 0.8 Cm.² of Steel	Flux in 0.1 Cm.² of Scale	Total Flux or Apparent B of 1 Cm² of Mixture
2	8,000	93	6,400	18	6,420
3	10,000	147	8,000	20	8,030
4	11,420	200	9,140	40	9,180
6	13,330	400	10,670	80	10,750
10	15,400	900	12,320	180	12,500
20	17,400	2,975	13,920	595	14,500
30	18,200	4,512	14,560	900	15,500

Table VIII gives similar calculations, assuming 20 per cent of the cross section area to be scale, and Table IX gives the hysteresis loss in steel, scale, and the mixture, assuming 20 per cent scale. Table X gives us values of η for the mixture, together with the amount of increase of η with increased induction. Comparing with test values of sheet steel, we find the increase of η with increased induction may be represented by steel and scale taken together, in which case the amount of scale is between 10 per cent and 20 per cent, which we know represents the facts.

TABLE IX

HYSTERESIS LOSS IN STEEL, SCALE AND MIXTURE WITH 20 PER CENT SCALE

H	Hyst. in Steel per Cm.³	Hyst. 0.8 Cm.³ Steel	Hyst. in Scale per Cm.³	Hyst in Scale 0.2 Cm.³	Hyst. in Mixture	Log. Hyst.	Log Apparent B
2	1183	947	29.4	6	953	2.979	3.808
3	1695	1358	62.0	12	1370	3.137	3.905
4	2090	1672	104	21	1690	3.228	3.963
6	2690	2153	318	64	2220	3.346	4.031
10	3390	2715	1130	226	2940	3.468	4.097
20	4130	3310	7800	1560	4870	3.688	4.161
30	4420	3540	14950	2990	6530	3.815	4.190

For steel $\eta = 0.000675$.
For scale $\eta = 0.0216$.

TABLE X

VALUES OF η WHEN STEEL CONTAINS 20 PER CENT SCALE

B	η	Ratio η to Average η
6,420	0.000771	
8,030	0.000771	1.00
9,180	0.000771	
10,750	0.000786	1.02
12,500	0.000818	1.06
14,500	0.00105	1.36
15,500	0.00130	1.68

Average η for first three points = 0.000771.

VI. Tests of Iron and Cobalt Separately and Together to Show Properties of Homogeneous and Heterogeneous Magnetic Materials

In order to show more clearly the behavior of magnetic phenomena on homogeneous and heterogeneous materials, tests were made to determine the properties of as nearly pure materials as could be obtained. A solid ring of iron and a solid ring of cobalt were selected. Solid rings were tested to obtain most satisfactory magnetic flux paths and to eliminate scale as much as possible. The errors due to shape of specimen of the ring sample are not great and are practically the same for both specimens and are therefore negligible. The principal dimensions of the samples are as follows:

	Cobalt Ring	Iron Ring
Outer diameter	3.176 cm. (1.25 inch)	3.178 cm. (1.25 inch)
Inner diameter	2.223 cm. (0.875 inch)	2.223 cm. (0.875 inch)
Mean diameter	2.695 cm. (1.06 inch)	2.7005 cm. (1.06 inch)
Weight	31.15 grammes (0.068 pound)	28.01 grammes (0.062 pound)
Volume	3.534 cm.³ (0.216 cubic inch)	3.562 cm.³ (0.217 cubic inch)
Section	0.4165 cm.² (0.0646 square inch)	0.415 cm.² (0.0644 square inch)
Specific gravity	8.81	7.86

Magnetization and Reluctivity

The test on the iron ring made by the usual ballistic galvanometer method gave results as shown in Table XI.

Results on the cobalt ring are given in Table XII, and in Table XIII we have test results made by taking both rings and testing them together as a single material.

The plotted results are given in Fig. 10. As the inductions at low values of H are required for analyses of hysteresis data, the lower portion of the magnetization curves are given on a larger scale in Fig. 11.

It would naturally be expected that, as the rings are of approximately the same section, the test on the two taken together would give an induction for any value of H which would be the mean of the values for the component parts. This may be shown by Table XIV, wherein test values from the iron, cobalt, and mixture are tabulated with the calculated density in the mixture, assuming the section of the two rings to be the same.

The interesting fact brought out by these tests is shown by plotting the reluctivity curves such as given on Fig. 12. Here we find that there is no indication of the change of slope in the line for the cobalt curve.

TABLE XI

MAGNETIZATION TEST OF IRON RING

H	B	$\mu = B/H$	$\rho = H/B$
212	19,750	93	0.0107
170	19,280	114	0.0088
127	18,680	147	0.0068
84	17,930	213	0.0047
42	16,980	402	0.00247
21	16,130	765	0.00130
15.5	15,560	1,007	0.000995
10.4	15,010	1,450	0.000693
5.2	13,490	2,600	0.000385
4.17	12,670	3,350	0.000330
3.12	11,300	2,630	0.000276
2.09	8,220	3,930	0.000254
1.75	7,040	4,040	0.000248
1.67	5,370	4,040	0.000311
1.46	3,780	2,590	0.000388
1.36	2,920	2,150	0.000465
1.24	2,260	1,810	0.000555
1.10	1,830	1,670	0.000601
0.84	1,000	1,180	0.00084

TABLE XII

MAGNETIZATION TEST OF COBALT RING

H	B	$\mu = B/H$	$\rho = H/B$
179	7,440	41.5	0.0242
135	6,750	50.0	0.0200
91	5,650	62.5	0.0161
36.4	3,160	86.7	0.0115
27.2	2,460	90.5	0.0110
54.3	4,310	79.0	0.0126
45.0	3,732	83.0	0.0121
20.45	1,832	89.6	0.0112
16.28	1,385	83.1	0.0120
12.75	980	76.8	0.0130
9.10	592	65.1	0.0154
5.46	272	49.8	0.0201
3.12	140	45.0	0.0223
2.09	84	40.2	0.0249

TABLE XIII

MAGNETIZATION TEST OF IRON RING AND COBALT RING TAKEN TOGETHER

H	B	$\mu = B/H$	$\rho = H/B$
201	13,680	68	0.0147
186	13,490	73	0.0138
149	13,100	88	0.0114
112	12,450	111	0.0090
74	11,550	156	0.0064
45	10,510	234	0.00428
23.3	9,280	398	0.00252
15.8	8,600	544	0.00184
12.0	8,200	684	0.00147
8.15	7,610	934	0.00107
5.65	7,190	1,270	0.00079
4.52	6,770	1,495	0.00070
3.76	6,390	1,700	0.00059
3.01	5,780	1,920	0.00052
2.25	4,690	2,080	0.00048
1.88	3,650	1,940	0.00052
1.50	2,190	1,460	0.00069

The curve of the iron itself shows a slight bend or change of slope, indicating that the iron ring was very nearly homogeneous magnetically, but not entirely so.

TABLE XIV

COMPARISON OF FLUX DENSITIES IN IRON, COBALT AND MIXTURE

H	B			
	In Iron by Test	In Cobalt by Test	In Both by Test	Calculated Average
150	19,000	7,000	13,000	13,000
100	18,200	5,900	12,200	12,050
50	17,100	4,100	10,700	10,600
20	16,000	1,800	9,000	8,900
10	14,800	700	7,900	7,750
5	13,400	300	6,900	6,850
2	8,000	100	4,000	4,000

Examining the curve for the iron and cobalt tested together, we see that at about $H=55$ there is a sharp and decided bend, such as has been found in so many cases.

This curve, while agreeing with the calculated results, is plotted from test results and is not deducted mathematically by assuming any

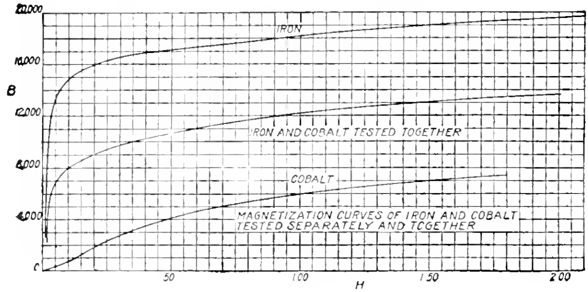


Fig. 10

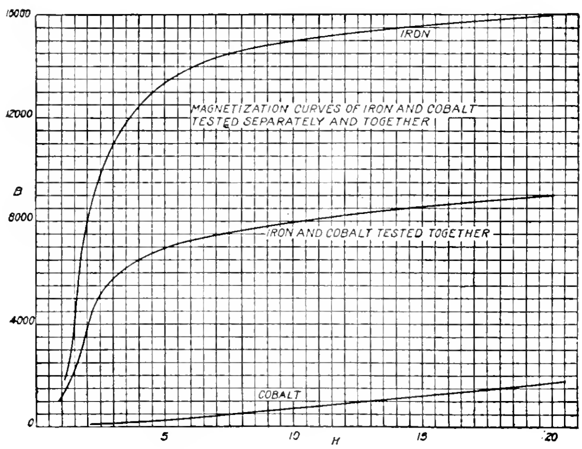


Fig. 11

theory. It is to be noted that the indicated saturation of the lower part of the curve for iron and cobalt together is close to that indicated as the ultimate saturation of the cobalt. It is naturally somewhat higher, due to the effect of the iron.

Hysteresis Losses

Hysteresis tests were made by means of a ballistic galvanometer. The results of the iron ring are given in Table XV.

The *log h – log B* curve is plotted on Fig. 13. The slope of the line, using all points, is 1.65, the upper points give nearer 1.6. The coefficient η is calculated on the basis of 1.6 for purposes of comparison. The results of the cobalt ring are given in Table XVI.

The *log h – log B* curve is shown on Fig. 13: the slope of the line using all points is 1.85. Lack of time prohibited further tests to check these results. It has been shown that the exponent for cobalt is 1.60; and, while this figure would be more satisfactory to quote here, I prefer to give the data as obtained. This high value of the exponent does not interfere with the present demonstration.

The results of hysteresis tests on the iron and cobalt rings together are given in Table XVII.

Here we find that the plotted results on Fig. 13 give a line having a slope of 1.62 (or approximately 1.6) to $B = 6000$, beyond which we again find the indicated abnormal increase of hysteresis loss. The deviation from the straight line is greater for this curve of the two metals than could possibly be considered as a characteristic of either of the metals themselves.

Between the results on the two rings together and the values calculated from the characteristic of the rings taken separately, we find a good agreement. The hysteresis losses are plotted on Figs. 14 and 15. In Table XVIII, column 1 shows the H values of the loops taken on both rings together. Columns 2 and 3 give inductions in iron and cobalt taken from the magnetizing curves on Figs. 10 and 11. The calculated density and the observed density for the loops are given in columns 4 and 5. Columns 6 and 7 give hysteresis results in iron and cobalt at their respective densities, taken from Figs. 14 and 15. Column 8 gives calculated hysteresis losses of the mixture, they being the mean of columns 6 and 7. Column 8 gives the observed hysteresis loss of the mixture from the tests.

VII. Application of Data in Calculating Magnetic Losses

We have shown that the usual deviations from the reluctivity and hysteresis laws may be accounted for by the fact that the materials are not homogeneous. It therefore is evident that to expect the laws to hold for all mixtures is as inconsistent as to take the compressive strength of a brick and use that figure to calculate the strength of a brick wall having, say, 10 per cent mortar.

In the case of sheet steel, for any given magnetization the permeability and hysteresis losses must be calculated for steel and scale separately and combined in correct proportions, especially if accuracy is desired at high inductions.

For purposes of illustration let us assume that it is desired to obtain the ratio of hysteresis losses in silicon steel at inductions of $B=15{,}000$ and $B=10{,}000$.

If the material in question were homogeneous throughout and the hysteresis loss followed the Steinmetz law, between $B=15{,}000$ and $B=10{,}000$ the ratio of hysteresis loss, R_h, would be:

$$R_h=\left(\frac{15{,}000}{10{,}000}\right)^{1.6}=1.91.$$

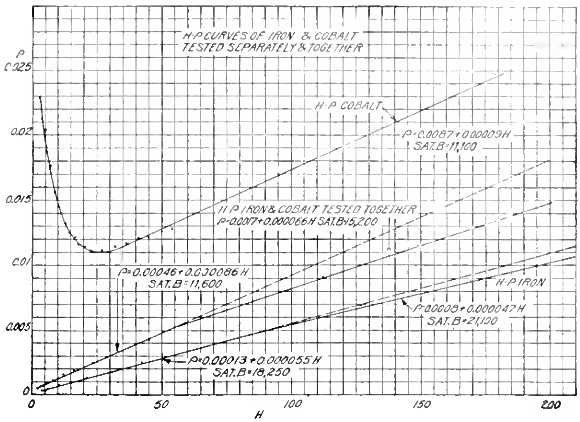


Fig. 12

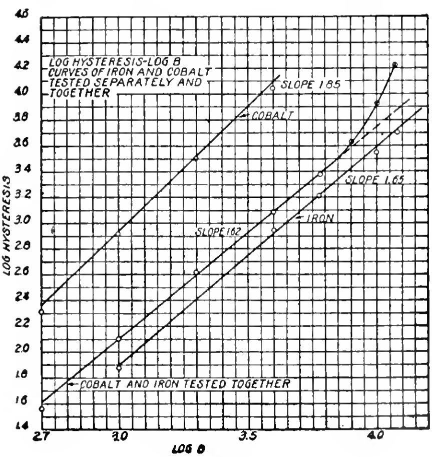


Fig. 13

Assuming 10 per cent scale, the densities in the iron, the scale, and the mixture may be taken for various values of H from Table V.

Plotting a curve, Fig. 16, giving relation of apparent B in the material and the B in scale, and finding therefrom the actual flux density in the steel itself, we obtain values in Table XIX.

TABLE XIX

DISTRIBUTION OF FLUX DENSITIES IN STEEL AND SCALE

B (Apparent)	B in Scale	Flux in 0.1 Cm.² of Scale	Flux in 0.9 Cm.² of Steel	B in Steel
15,000	1500	150	14,850	16,500
10,000	200	20	9,980	11,090

Table XIX shows that when testing at $B=15{,}000$ and $B=10{,}000$ the actual density in the steel is 16,500 and 11,100, and the ratio of densities for the scale is very much greater than the ratio of apparent densities.

TABLE XV

HYSTERESIS LOSSES IN AN IRON RING

(Losses in ergs per cm.³)

B	H	Hyst.	Log B	Log Hyst.	η ($x = 1.6$ Assumed)	
15,000	10.71	7,900	4.176	3.898	0.00164	
12,000	3.58	4,865	4.079	3.687	0.00145	Average 0.00145
10,000	2.455	3,510	4.000	3.545	0.00140	
6,000	1.758	1,614	3.778	3.308	0.00145	
4,000	1.505	873	3.602	2.941	0.00150	
1,000	0.890	73.9	3.000	1.868	0.00117	

TABLE XVI

HYSTERESIS LOSSES IN A COBALT RING

(Losses in ergs per cm.³)

B	Hysteresis	Average Hysteresis	Log B	Log Hysteresis	η ($x = 1.6$ Assumed)	
4,000	11,020 10,950	11,000	3.603	4.041	0.0190	Average 0.0163
2,000	3,210 3,080	3,150	3.301	3.498	0.0168	
1,000	810 848	830	3.000	2.919	0.0131	
500	203	203	2.699	2.308	0.0088	

TABLE XVII

HYSTERESIS LOSSES IN AN IRON AND A COBALT RING TESTED TOGETHER

(Losses in ergs per cm.³)

B	Hyst.	H	Log B	Log Hyst.	η ($B = 1.6$ Assumed)	
12,000	17,470	101.1	4.079	4.242	0.00519	
10,000	8,975	38.6	4.000	3.953	0.00358	
8,000	4,110	11.2	3.903	3.614	0.00234	
6,000	2,360	3.41	3.778	3.373	0.00212	Average 0.0021
4,000	1,228	2.055	3.602	3.089	0.00212	
2,000	409	1.523	3.301	2.612	0.00213	
1,000	126.2	1.191	3.000	2.102	0.00200	
500	35.9	0.885	2.699	1.556	0.00172	

TABLE XVIII

H	B_{Fe}	B_{Co}	B MIXTURE Calculated	B MIXTURE Test	Hysteresis Fe	Hysteresis Co	HYSTERESIS OF MIXTURE Calculated	HYSTERESIS OF MIXTURE Test
101.1	18,200	5,900	12,050	12,000	11,900*	23,100†	17,500	17,470
38.6	16,800	3,300	10,050	10,000	9,770‡	7,750	8,760	8,975
11.2	15,100	800	7,950	8,000	8,000	500	4,250	4,110
3.41	11,700	150	5,925	6,000	4,600	25	2,315	2,360
2.055	8,000	100	4,050	4,000	2,460	10	1,235	1,228
1.52	4,000	50	2,025	2,000	873		435	409
1.191	2,200	.	1,100	1,000	300		150	126.2
0.885	....	..	. .	500	203		100	35.9

* Calculated by extrapolation of $B-\eta$ curve. η taken as 0.0018.

† Calculated by extrapolation of $\eta = 0.021$.

‡ Calculated by extrapolation of $\eta = 0.0017$.

All other results from results Figs. 14 and 15.

Assuming the 1.6 law to hold rigidity for both steel and scale, and taking the values of Table XIX, we should expect, when testing at $B=15,000$ and $B=10,000$, ratios as follows:

Hysteresis ratio for steel:

$$R_h=\left(\frac{16,500}{11,090}\right)^{1.6}=1.89.$$

Hysteresis ratio for scale:

$$R_h=\left(\frac{150}{20}\right)^{1.6}=25.$$

For 90 per cent steel and 10 per cent scale the hysteresis ratio of the mixture would be:

$$R_h=\frac{(90\times1.89)+(10\times25)}{100}=4.20.$$

While our data on scale are limited, and the varying percentages of scale would affect results, yet the figures obtained represent test results reasonably well.

VIII. Investigation to Determine Losses in Unsymmetrical Loops

Shortly after the announcement of the 1.6 law the statement was made that "the energy dissipated by hysteresis depends only upon the difference of the limiting values of magnetic induction, between which the magnetic cycle is performed, but not upon their absolute values, so that the energy dissipated by hysteresis is the same so long as the amplitude of the magnetic cycle is the same."[9] This has been written as

$$h=\left(\frac{B_1-B_2}{2}\right)^{1.6}$$

where B_1 and B_2 are the values between which the magnetism varies. Tests were made which apparently justified and substantiated this statement, and the results were published.

In these tests the range of flux values were comparatively small as compared with the range of values of the mean inductions, and the materials employed were magnetically hard and characterized by high hysteresis loss.

It has recently been observed that when materials are taken through unsymmetrical hysteresis cycles there is, contrary to earlier writers, apparently more energy dissipated than when taken through the symmetrical loop of the same amplitude. By an unsymmetrical loop is meant the hysteresis loop obtained when the magnetism is carried through a cycle in which the limiting values of flux are different in amount, or, in other words, in which the mean value of the flux differs from zero. The recent statements, then, are to the effect that when B_2 is different in amount from B_1 the loss is greater than when $B_2=-B$.

[9] *Trans. A. I. E. E.*, vol. ix, 1892, p. 633.

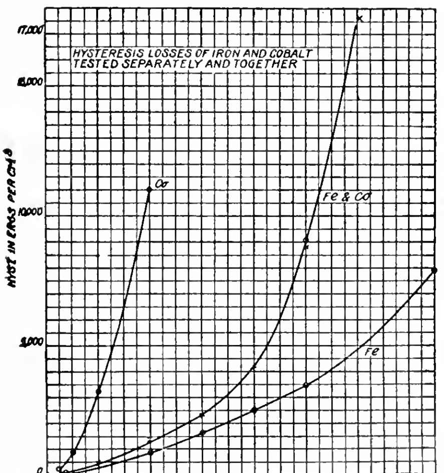


Fig. 14

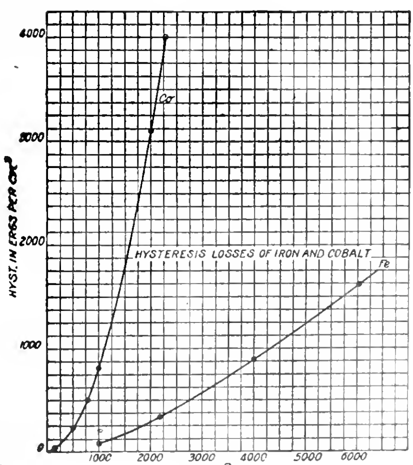


Fig. 15

Some investigations have been made and the results published by Mr. Rosenbaum[10] and Dr. F. Holm.[11] Both investigations led to the conclusion that the hysteresis loss is greater for the unsymmetrical loops than for the symmetrical loops of the same amplitude.

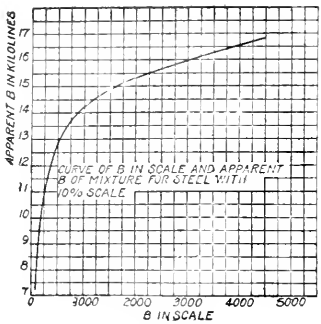


Fig. 16

Such variation of magnetism occurs in many places, such as in an inductor generator, etc. The same phenomena occur in the field cores of machines where the ratio of flux change is so small that the loss is not a consideration. However, in these cases the shapes of the loops are of value in determining the regulation of machines in which the magnetic cycle of the field cores is a determining factor.

The unsymmetrical hysteresis loop is also in evidence in all material magnetized by current from a rectifier, etc.; in short, in all circuits where alternating current and direct current are superimposed. A specified case of interest is the well known fact that core losses of certain machines have been found to exceed calculated values, unless percentages are added. The fact that high-frequency flux ripples in the teeth give a higher hysteresis loss than the same flux change with zero as a mean value of induction would in part account for this additional loss. This is especially noticeable in the case of induction machines.

In the present investigation tests were made which led to these interesting deductions:

1. The hysteresis loss in an unsymmetrical loop is greater than the loss in a symmetrical loop of the same difference of limiting values of flux.[12]

2. Within the limits of the tests, the losses of loops having the same difference of limiting values of flux were found to increase with a definite power of the average or mean flux density.

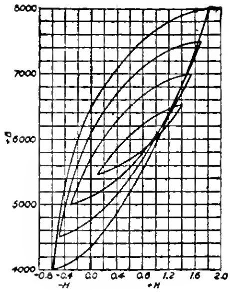


Fig. 17

3. The increased loss as a definite power of the mean flux density was found to be the same for any difference of limiting flux values or range of the loops.

4. With any given value of mean density the increased losses with increased range were found to increase as a definite power of the range, irrespective of the mean value of density.

Fig. 17 shows a group of unsymmetrical loops about a common center, $B_m = 6000$.

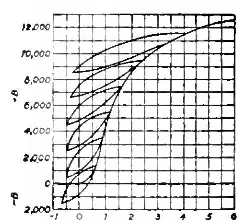


Fig. 18

Fig. 18 shows a group of loops of the same range of flux change, but having different values of mean induction.

[10] *Jour. I. E. E.*, vol. 48, 1912, pp. 534-545.
[11] *Zeit. des ver. deut. Ing.*, vol. 56, 1912, pp. 1746-1751.
[12] This has been again confirmed by a valuable investigation made by Messrs. L. E. Chubb and T. Spooner. See *Proc. A. I. E. E.*, October, 1915, pp. 2321-2342.

We have found that we could write an equation to express the loss in any loop. The general equation is:

$$h = (\eta + \alpha \, B_m^{y}) B^x$$

wherein η and x are the constants of the Steinmetz law, α is a coefficient depending upon the material, and y a power of the mean density. Tests satisfied the equation in the form:

$$h = (\eta + \alpha \, B_m^{1.9}) B^{1.6}$$

The details of this portion of our general investigation have been published elsewhere[13] and need not be reproduced here. It is sufficient to say that with an accumulation of more data the equation for any loop which we give may or may not be verified as a law. However, it seems very definitely shown the loss increases as the mean induction is raised.

CONCLUSIONS

From this investigation we find additional evidences that the hysteresis law as given by Dr. Steinmetz in 1892 is cofirmed, and his equation $h = \eta \; B^{1.6}$ correctly represents the hysteresis loss over a wide range of densities up to the highest recorded for pure or magnetically homogeneous materials. While some results which have been published showing much greater losses at high induction than given by the law are incorrect, due to erroneous calculations, however, most results showing greater losses at high inductions are taken from test data obtained on heterogeneous material whose component parts, if tested separately, would follow the law.

It may be pointed out that if two components of a heterogeneous material followed the 1.6 law, and with increasing H the induction in the two increased at the same rate, the resultant must also show an increased loss following the 1.6 law. The deviations noted are due to the fact that with increasing magnetization the induction in two materials does *not* increase at the same rate throughout. Therefore, as they do not, the measured hysteresis loss could not be expected to follow any law. The difference in materials employed and the difference of their respective volumes may and probably does introduce an infinite variety of possible combinations which prohibits a rational law.

The same reasoning applies to the reluctivity law of Kennelly, which is also confirmed by this investigation.

Test results have been given in considerable detail for the benefit of any who may be interested and may wish to draw conclusions other than those set forth in this paper.

Why the hysteresis loss increases as the 1.6 power of the density has, to our knowledge, never been explained. That it can not hold at very low densities has been shown by Dr. Steinmetz himself. The fact remains, however, that our knowledge has been greatly augmented by the announcement of this useful discovery, and careful research is still showing that the law as stated correctly represents the hysteresis losses in magnetic materials.

In conclusion, the author desires to acknowledge much excellent cooperation. The work was attempted at the instigation of Dr. C. P. Steinmetz, for whose interest and assistance the author is greatly indebted. The writer also desires to thank Mr. L. T. Robinson for helpful suggestions and for placing the facilities of his laboratory at the author's disposal. In this laboratory much of the testing was done by Mr. S. L. Gokhale. The testing of steel scale was done in Mr. A. McK. Gifford's laboratory by Mr. Max. G. Newman.

Acknowledgment is also due to Mr. J. P. Duncombe for much valuable assistance throughout the process of this investigation.

APPENDIX

IX. Additional Properties of Scale from Silicon Steel[14]

While tests described in Section IV of this paper were being made it seemed feasible to take the opportunity to make a further study of the properties of scale as a matter of general interest and also as it has possibilities as a material for certain constructions.

Skin Effect

The fact that scale is thin and has fairly good permeability and high resistivity places it as a desirable material for cores in machines and transformers of high frequency. The resistivity being high and the permeability being lower than that of ordinary steel, deeper penetration as regards skin effect is obtained, which is also an important consideration. Assuming the scale as carrying flux, the effective depth of penetration, l_p in cm., would be, according to the Steinmetz formula:

$$l_p = \frac{3570}{\sqrt{\lambda \mu f}}$$

[13] *Proc. A. I. E. E.*, October, 1915, pp. 2275-2297.

[14] Some results of the investigation of steel scale have been used by the author in connection with a graduate thesis submitted to the University of Illinois and are published here with the permission of that institution.

wherein

λ = electrical conductivity.
μ = magnetic permeability.
f = frequency in cycles per sec.

The permeability varies, of course, with the flux density. We may assume for per-

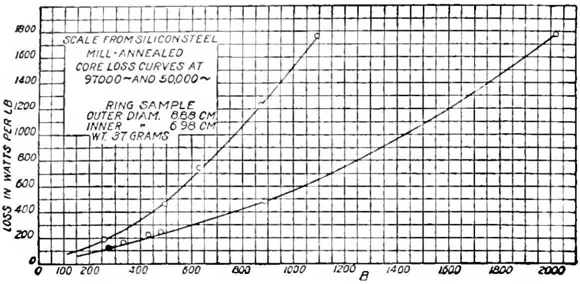


Fig. 19

meability a value $\mu = 60$. The average conductivity is $\frac{1}{126.2} + 10^6 = 7920$. At 10,000 cycles

$$l_p = \frac{3570}{\sqrt{7920 \times 60 \times 10{,}000}} = 0.0518 \text{ cm.}$$

Assuming the thickness of the scale to be 0.0064 cm. l_o, or ½ of the thickness (0.0032). This shows that the penetration l_p is much greater than ½ thickness l_o; therefore there is no appreciable skin effect at 10,000 cycles. The maximum allowable thickness of scale which has no appreciable skin effect at 10,000 cycles would be 0.1036 cm. (0.0408 inch). The maximum frequency at which no appreciable skin effect would be in evidence would be found by letting $l_p = 0.0032$ and solving for f, which gives 2,600,000 cycles.

Properties at High Frequency

Punchings of the same size as described in Section IV, but of less weight, were built up into a test sample for determining the properties at high frequency. A test was made at 10,000 cycles, but the results obtained were not at all consistent. Tests were made at 97,000 cycles and 50,000 cycles, and repeated trials gave close checks with the first tests. The results are given on Fig. 19, from which Table XX was computed.

It will be remembered that the value of η taken from the 60 and 30-cycle core loss curves and the hysteresis loops gave a value of 0.0216.

The results are practically self-explanatory. Values of η, assuming $x = 1.6$, are given, although it would not be expected that the 1.6 law would hold rigidly at these low inductions.

Eddy Current Losses

For the core-loss curves the eddy losses were found to be as shown in Table I. These losses are not consistent, as good results would not be expected by the method of test used and the high hysteresis to be subtracted from the core loss, which is mostly hysteresis. The eddy losses are high, which is probably due to the fact that the sample was taken as a bulk, with no effort to insulate laminations from each other. The eddy loss figures in Table I are therefore not to be considered as reliable, although sufficiently so to be used for hysteresis determinations in the table wherein they were so used.

TABLE XX

LOSSES IN SCALE FROM SILICON STEEL AT HIGH FREQUENCIES

B	Hyst. Loss Watts per Pound		Loss per Cycle		Loss per Cycle 97,000 Cycles	
	97,000 Cycles	50,000 Cycles	97,000 Cycles	50,000 Cycles	Hyst.	Eddy
1000	1540	570	0.0159	0.0114	0.0066	0.0093
900	1290	490	0.0133	0.0098	0.0061	0.0072
800	1060	420	0.0109	0.0084	0.0057	0.0052
700	860	360	0.00887	0.0072	0.00542	0.00345
600	670	300	0.00691	0.0060	0.00503	0.00188
500	500	250	0.00515	0.0050	0.00484	0.0003

B	Hyst. in ergs per Cycle per Cm.³	η ($x = 1.6$ Assumed)
1000	806	0.0128
900	745	0.0142
800	696	0.0155
700	662	0.0182
600	615	0.0223
500	590	0.0283

SCALE FROM VACUUM ANNEALED STEEL

Physcial Appearance and Size of Samples

The scale from vacuum-annealed steel appears to be much smoother than scale from mill-annealed steel. It is apparently tougher and more flexible. It is clean and very much whiter than the usual scale. One side is a dull grayish white, while the other side has a brighter shine and closely resembles silver. Two samples were tested, both of which were made up of ring punchings 0.0056 cm. (0.0022 inch) thick. One sample measured, outer diameter 15.25 cm. (6 inches), inner diameter 10.15 cm. (4 inches); the other sample was, outer diameter 8.89 cm. (3.5 inches), inner diameter 6.86 cm. (2.7 inches).

Specific Gravity

The first determinations gave a specific gravity of 5.54 for both mill-annealed and vacuum-annealed scale. Core-loss and hysteresis tests were calculated on this basis. Subsequent study of the material led to the belief that this figure was low for scale from vacuum-annealed steel, and the analyses were repeated. The figure 5.54 was confirmed for the mill-annealed scale, but the vacuum-annealed product gave a more consistent figure of 6.07 at 15.5 deg. C. The gravity may, therefore, be considered approximately 6.0. The core-loss curves and hysteresis

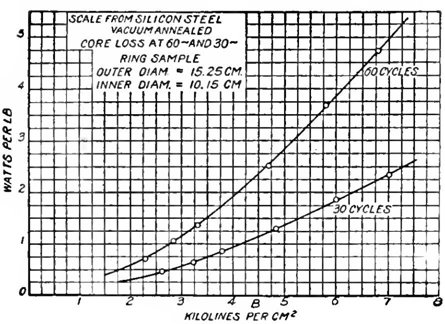


Fig. 20

loops have not been altered, as the results in ergs, upon which analysis of results are based, are the correct figures.

The magnetization curves also include assumptions of specific gravity = 5.54, but the error is much less than the variation in material, and consequently were allowed to stand as originally calculated. The steel from which the scale was taken has a specific gravity of practically 7.5 after vacuum anneal as well as after mill anneal.

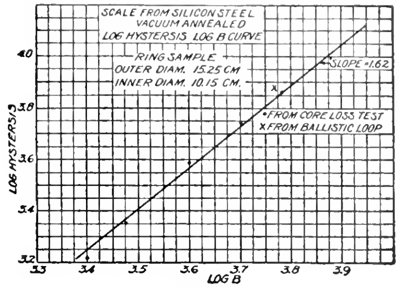


Fig. 21

Chemical Analysis

The first analysis of this material gave the following results:

Si...	7.03
S....	0.148
Mn...	0.43
C....	0.054

An analysis for oxygen gave 0.73 per cent, but this is undoubtedly not correct.

A later and reliable analysis gave:

Si..	5.72	5.48
S...	0.113	0.114
P...	0.019	0.018
Mn..	0.20	0.20
C.	0.180	0.142
Fe..	78.30	78.50
Total...	84,532	84.454

The missing 15 per cent is doubtless oxygen, as most of the silicon and some of the iron are present in the oxide state.

Resistivity

Samples of vacuum-annealed scale were found to have an average resistivity of 53.1 microhms per cm.³ at 25 deg. C. The individual values varied from 30 to 78. Previous tests on this material gave from 60 to 65 microhms, which is within the limits of the tests on the larger number of samples. These values are on the same order as those obtained from the steel itself.

Temperature Coefficient

This material was measured for temperature coefficient. The average figure given was 0.0059.

Core Loss

Core-loss curves were made on the 15.25 cm.×10.15 cm. sample at 60 cycles and 30 cycles from $B=2500$ to $B=7000$. Results are shown in Fig. 20. Data derived from these curves are tabulated with the discussion of the hysteresis loss. A previous core-loss test at 60 cycles was found to agree with the 60-cycle curve in Fig. 20.

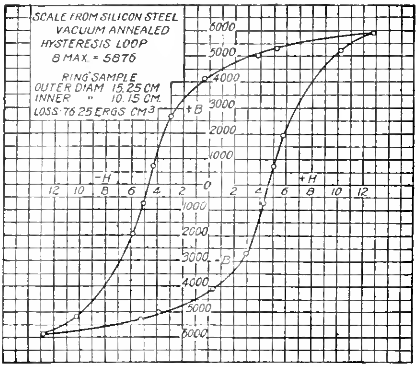


Fig. 22

TABLE XXI

LOSSES IN SCALE FROM VACUUM-ANNEALED SHEET STEEL

B	TOTAL LOSSES		LOSS PER CYCLE		LOSS PER CYCLE AT 60 CYCLES	
	60 Cycles	30 Cycles	60 Cycles	30 Cycles	Hyst.	Eddy
7500	5.52	2.58	0.092	0.0860	0.0800	0.0120
6000	3.82	1.85	0.0636	0.0717	0.0598	0.0038
5000	2.80	1.38	0.0466	0.0460	0.0454	0.0012
4000	1.90	0.95	0.0317	0.0317	0.0317	
3000	1.10	0.56	0.0183	0.0187	0.0185	
2500	0.80	0.40	0.0133	0.0133	0.0133	

TABLE XXII

HYSTERESIS LOSS IN SCALE FROM VACUUM-ANNEALED SHEET STEEL

B	Hyst. ergs per Cm.³	Log B	Log Hyst.	η ($x=1.6$ Assumed)
7500	9770	3.875	3.990	0.00616
6000	7310	3.778	3.864	0.00656
5000	5550	3.699	3.744	0.00670
4000	3870	3.602	3.588	0.00688
3000	2260	3.477	3.354	0.00618
2500	1625	3.398	3.211	0.00595
Average. .	.		. . . .	0.00637

Hysteresis Loss

The hysteresis loss at various densities was determined by the separation method. This was done by taking values from the core-loss curves at 60 cycles and 30 cycles and obtaining the loss per cycle as shown in Table XXI.

A plot of the log hysteresis—*log B* is shown in Fig. 21. Taking the five upper points of the curve, the slope given by the $\Sigma\ \Delta$ method is 1.62. Assuming $x=1.6$, we obtain for η an average of 0.00637. For the five highest points average $\eta=0.00646$. Here again we may note the insistence of the Steinmetz formula.

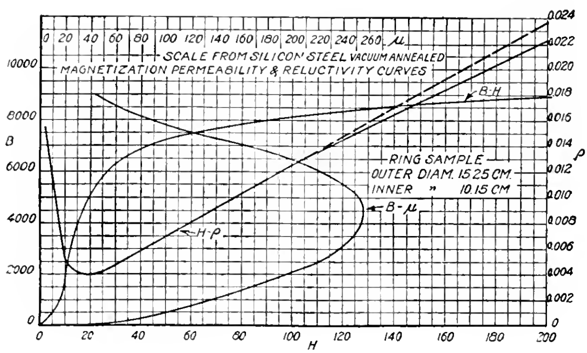


Fig. 23

A loop was taken at B maximum$=5876$, as shown in Fig. 22. The loss was found to be 7625 ergs per cm.³ Assuming $x=1.6$, $\eta=0.00711$. We may, therefore, assume the hysteresis of this material to be approximately $h=0.007\ B^{1.6}$, or about 30 per cent that of scale from mill-annealed material. That the hysteresis loss of silicon sheet steel may be lowered by means of vacuum annealing is a well-known fact.

From Table XXI the hysteresis losses in ergs per cm.³ were calculated and the logarithms of the losses and of the inductions taken as shown in Table XXII.

Eddy Current Losses

Table XXI shows eddy-current losses. These figures are not reliable and apply to a bulk of material rather than insulated sheets, and should not be considered as representing the material with any degree of accuracy.

Magnetization, Permeability and Reluctivity

The two samples previously described were tested for magnetization curves. Results of the tests on the 15.25 cm. × 10.15 cm. ring are given in Table XXIII. The magnetization, permeability, and reluctivity curves are plotted on Fig. 23. The reluctivity curve is a straight line from $H=30$ to $H=90$, and also a straight line from $H=90$ to $H=200$, the limit of the test. The equations of the lines by the $\Sigma\ \Delta$ method are:

From $H=30$ to $H=90$:

$$\rho=0.0014+0.00011\ H$$

Saturation $B=9000$

Form $H=90$ on:

$$\rho=0.0028+0.000097\ H$$

Saturation $B=10,300$

The equations of the magnetization curves are therefore:

From $H=30$ to $H=90$:

$$B=\frac{H}{0.0014+0.00011\ H}$$

From $H=90$ on:

$$B=\frac{H}{0.0028+0.000097\ H}$$

Tests were made on the 8.89 cm. × 6.86 cm. ring which showed better permeability than the previous results. The data are given in Table XXIV, and plotted in Fig. 24.

The equations of the reluctivity and magnetization were found as for the other samples. The results were as follows:

From $H=10$ to $H=70$:

$$\rho=0.00101+0.000121\ H$$

Saturation $B=8300$

$$B=\frac{H}{0.00101+0.000121\ H}$$

From $H=70$ to $H=137$. (Limit of test):

$$\rho=0.00215+0.000103\ H$$

Saturation $B=9700$

$$B=\frac{H}{0.00215+0.000103\ H}$$

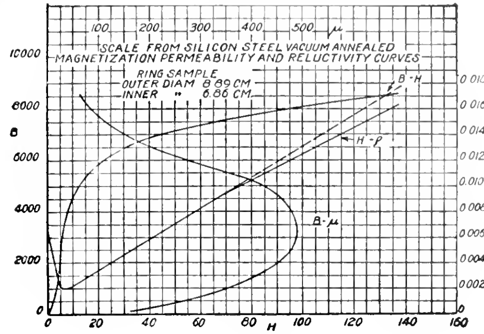


Fig. 24

The maximum permeability of the sample is about 257 at $B=4500$.

TABLE XXIII

MAGNETIZATION DATA OF SCALE FROM VACUUM-ANNEALED SHEET STEEL

H	B	$\mu=B/H$	$\rho=H/B$
200	8980	44	0.0222
150	8640	57	0.0174
140	8530	60	0.0164
130	8430	64	0.0156
120	8375	69	0.0143
110	8250	74	0.0133
100	8170	81	0.0122
90	8010	88	0.0112
80	7920	98	0.0101
70	7708	109	0.0091
60	7499	124	0.0080
50	7245	144	0.0069
40	6876	171	0.0058
30	6337	210	0.0048
20	5060	253	0.0040
10	1919	192	0.0053
5	428	86	0.0116
3	210.2	70	0.0143
2	131.2	65.6	0.0152
1.5	55.3	36.9	0.0272
1.25	49.0	39.1	0.0255
1.0	37.2	37.2	0.0269
0.5	16.7	37.0	0.0269
0.3	10.8	35.9	0.0278

TABLE XXIV

MAGNETIZATION DATA OF SCALE FROM VACUUM-ANNEALED SHEET STEEL SECOND SAMPLE

H	B	$\mu = B/H$	$\rho = H/B$
137	8560	61	0.0160
100	8074	81	0.0124
90	7908	88	0.0114
80	7749	96	0.0103
70	7529	110	0.0093
60	7374	124	0.0081
50	7124	144	0.0070
40	6829	170	0.0059
30	6440	214	0.0047
20	5880	294	0.0034
15	5405	359	0.0028
10	4570	457	0.0022
7.5	3662	487	0.0021
5.0	2385	476	0.0022
2.0	461.9	230	0.0043
1.5	32.5	216	0.0046
1.0	165.8	165	0.0050
0.5	80.7	160	0.0062

The maximum permeability of this sample is about 490 at $B = 3500$.

Skin Effect

The skin effect of this material is more marked than for the mill-annealed product, because of its lower resistivity and high permeability. Considering the permeability $\mu = 200$ and the conductivity 18,800, the penetration l_p at 10,000 cycles would be

$$l_p = \frac{3570}{\sqrt{18,800 \times 200 \times 10,000}} = 0.0194 \text{ cm.}$$

Assuming the thickness of the scales as 0.0056 cm., $l_{.o}$ or ½ of the thickness, is 0.0028. Therefore, there is no appreciable skin effect at 10,000 cycles. The maximum allowable thickness of scale which has no appreciable skin effect at 10,000 cycles would be 0.0388 cm. (0.015 inch). The maximum frequency at which no appreciable skin effect would be in evidence would be found by letting $l_p = 0.0028$ and solving for f, which gives 480,000 cycles.

Considering the magnetization curves, the values of η, and the resistivity, we find scale has these properties in much the same order as found for cast iron. Magnetization curves of silicon steel, cast iron, and the samples of scale are shown in Fig. 25.

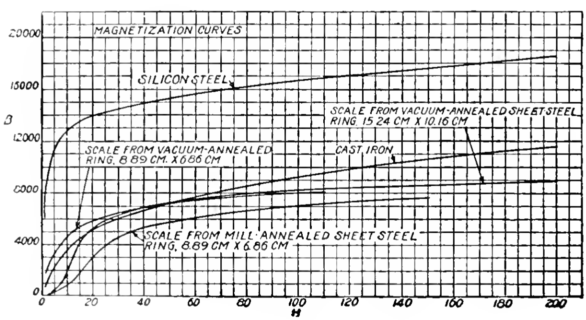


Fig. 25

LAWS AND REGULATIONS REGARDING THE USE OF WATER IN PAN-AMERICAN COUNTRIES

By Rome G. Brown, Minneapolis, Minnesota

The author presents an able treatise on a subject which is of vital importance to all countries, and very specially to the United States. He not only summarizes the laws, but he also notes the ways in which some of these laws are obstacles, and further suggests possible remedies. The sources from which the laws have been derived are dealt with in an interesting and instructive manner. The United States law, both as regard Federal and State legislation, receives considerable attention, and South America is comprehensively dealt with under the following headings: Argentina, Chili, Columbia, Cuba and Porto Rico, Uruguay, Venezuela, Brazil and Mexico. This paper was presented before the Second Pan-American Scientific Congress in Washington, D. C., in February, 1915, and is published in the Review by permission of the author.—Editor.

SCOPE OF THIS DISCUSSION

The proper utilization of the natural resources of the Pan-American countries is of the greatest importance to their internal development, as well as to their industrial and political relations with each other. Of all such natural resources there are none which constitute so valuable a gift of nature, and which are so essentially a potential source of commercial and industrial growth, as the uses of water which are there everywhere available.

Mineral deposits, whether in the form of coal, iron, nitrates, or other minerals, are limited in quantity, comparatively hidden as to their location, and, from their very nature, being not susceptible of renewal, they are, therefore, exhaustible. Timber resources, although renewed by nature, are, nevertheless, in one sense of the word, limited and exhaustible.

Water resources, on the other hand, are the constantly disclosed, ever available, and continuously renewed sources of nature's bounty to man. Whether it be the small creek flowing through an upland farm, barely supplying to the owner, family and stock and to his limited acres of tillage the needs which his own private uses require, or a great continental stream, bearing upon its waters the commerce between inland ports and the sea and fed by its upper mountain reaches wasting their latent energies through unharnessed falls,—the fresh water streams of these countries are ever present, ever renewed, and, therefore, inexhaustible, resources for industrial supremacy.

From the national viewpoint, the three great uses to which such streams are susceptible are those of navigation, irrigation, and water power. It is the latter, the development of water power, with which this article is primarily concerned.

Water power, whether developed or undeveloped, denotes energy. It is, therefore, a part of the many phases of energy which comprise the possible and actual life and success of the country within which it is located. With every fall of water in a natural stream, whether it be the sluggish current in a deep water basin or the cataract from the mountain heights, is constantly exerted the energy which is denoted by the product of the actual weight of the falling water and the number of feet-seconds through which that quantity passes from a higher to a lower elevation. That energy, in other words, is the number of foot-pounds per second of the falling water. We burn a ton of coal for the purpose of developing and utilizing the latent energy stored in the coal, and we find that by such process we obtain from a ton of coal the equivalent of the use of about one horse power of energy for the period of one month. This, again, is equivalent to the use of about one kilowatt of energy for about three weeks. That energy is developed by the mere burning of the coal. If, as so developed, it is utilized, it drives turbines for manufactures, or heats homes and workshops, or helps to turn darkness into light. If it is not utilized, it is forever wasted and becomes a part of the great useless wastes of nature which can never be recouped. The energy of the waterfall, however, is not latent. That energy is a part of the constantly acting force of gravitation. It is ever present and unless utilized, is forever wasted.

Conservation, therefore, of the natural resources of a country demands the greatest and most immediate prevention of this constantly wasting energy from undeveloped water powers and of the quickest and most extensive utilization which can possibly be made consistently with proper protection of the interests of individuals and of the public at large.

Formerly the principal reason for the retardation of this utilization of the wasting energies of water power was the lack of means of transmission for use in localities at a distance from the source of power. But the progress in recent years in electrical science has made commercially feasible the use of immense water-power facilities which theretofore were running to waste. Nevertheless, there is not a country in all America where the commercial demands for water-power development are not to a large extent unfulfilled, and where immense numbers of kilowatts of water-power energy are not wasting.

The cause of this uneconomic waste in all countries is that legislation for the regulation and use of water resources, instead of promoting their use, has become an obstacle to their use. Legislation has not kept pace with the progress in the science of water-power development and use.

It is, therefore, the main scope of this paper to summarize, with reference to the uses of water, and particularly of water powers, the laws and regulations existing under public authority in the Pan-American countries and especially to note certain ways in which such laws are obstacles to that utilization of these resources which would otherwise be made, as well as to suggest possible remedies in such legislation.

GENERAL SOURCES OF THE LAW

In most Pan-American countries, with the exception of the United States, the sources of the law of water rights are, as other phases of their laws, Spanish law. The fundamental principles of the Spanish law, as applied in these countries, was further confirmed or modified by the introduction into their Colonial law of certain principles of the French law. Further modifications have been caused by local and partial recognition and adoption of principles of law which are more peculiarly those of the United States, where the law of waters is generally founded upon that of the English law. But in the United States, wide modifications from the English law have been made to suit the physical conditions peculiar to our country and not characteristic of the mother country to which the English law was adapted.

First then as to these original sources:

Spanish Law:—The groundwork of the Spanish-American legal system was inherited from Spain; and in fact the Spanish law was in force in Spanish America (subject only to such modifications as were introduced by the special laws or decrees promulgated for the Colonies), until the Independence. It continued in force in the various countries until modified by new statutory enactments, which chiefly took the form of Codes, modelled largely on the Napoleonic Codes. A word or two as to the old Spanish law may therefore serve as a fitting introduction.

The *Siete Partidas*, the great medieval Code, whose principles still permeate Spanish or Spanish-American jurisprudence, divide "*things*" into common things (comunes), those belonging to private persons, and those consecrated to the service of God (Partida 3; Title 28, Law 2). There was a curious subdivision of *common* things into (*a*) those common to all living creatures, viz.: the air, rain waters, the sea and its shores (*id.*, Law 3); (*b*) those common to all mankind, viz.: rivers, ports and highways (*id.*, Law 6); and (*c*) the common property of cities and towns to be used only by the inhabitants thereof. This included fountains which played such a prominent part in Spanish life (*id.*, Laws 9 and 10). Law 6 just cited is especially interesting. It provided, following the Roman law, that rivers are common to all men, to strangers as well as to the local inhabitants, and that regardless of the ownership of the adjacent land all mankind can use the banks for mooring, fishing, displaying and selling merchandise and similar uses. It was provided (Law 8) that no mill or structure of any kind could be set up in a navigable river or on its banks, or canal built, for the reason that it might interfere with the common use of mankind; for, says the law, it would not be a meet thing that the common benefit of all mankind should be disturbed for the benefit of one; but ancient structures were not to be torn down so long as they did not disturb the common use.

Other passages, however, in the Partidas are interesting as showing that, in spite of the declaration above cited, rivers and rain water were common either to all living creatures or to all mankind; private rights in waters were recognized, but some rivers were deemed to be the property of the King. Law 18, Title 32, Third Partida, prescribed that one could erect a mill and use the same water as was used by a previously existing mill; that this could be done either (*a*) on one's own land, or (*b*) on the land of a river belonging to the King, under a grant from the King, or (*c*) on town lands, under grant from the town council (concejo):[1] always provided, in all cases, that the earlier mill was not deprived of its customary water. Law 19, Tit. 15, provided that the *ownership*, use and enjoyment of waters which rose and died within the confines of one estate belonged to the owner of the land. This last principle has, I believe, been maintained in nearly all the Spanish-American countries.

The law of the Siete Partidas as to *servitudes* has had an important influence on the

[1] The famous commentator Gregorio Lopez queries whether this be permissible in the case of navigable rivers.

later jurisprudence. They closely followed, in this respect, the Institutes of Justinian. It is sufficient for our present purpose to call attention to the fact that the servitude of *aqueduct* was recognized; that is, the right to conduct water through the servient tenement for the benefit of the dominant tenement for use in mills or for irrigation (Partida 3, Title 31, Law 4). The right could be extended also to cover the original *taking* of water from the servient tenement, in which case the owner of the latter could not grant a similar right to a third party, without the consent of the owner of the dominant tenement, unless the water was abundant enough to suffice for all (*id.*, Law 5). On the other hand, the beneficiary of the servitude, once the water had come on his land, could grant it to neighbors for irrigation (*id.*, Law 12). These servitudes could be gained by prescription (*id.*, Law 15). Other laws of the Partidas prescribe the rights and duties arising by reason of a servitude of aqueduct, and arising out of the use as between upper and lower owners of flowing waters (*id.*, Title 32, Law 15). This servitude of aqueduct appears to have been a voluntary servitude only, that is, created by voluntary act of the parties; but it seems to be the lawful parent of the modern servitude, by operation of the law, in case of necessity, which is such an important and beneficial feature of the modern Spanish-American law.

The laws early prohibited throwing substances into rivers injurious to fish; regulated the methods and prescribed seasons for river fishing, prohibiting, *inter alia*, the diversion of the stream (Year 1435; Laws 9 and 10, Title 8, Book 7, Recopilacion: Laws 8 and 9, Title 30, Book 7, Novisima Recopilacion).

By a law of King Enrique III (Law 2, Title 10, Book 7 of the Recopilacion; Law 7, Title 26, Book 7 of the Novisima Recopilacion) any council or private individual was prohibited from closing canals and rivers to fishing and navigation, or interfering therewith for other uses, even for town uses, except under a special privilege from the King.

This is important to show that the King claimed, and exercised, a paramount right to grant special franchises in connection with navigable rivers and to the detriment of the public or common right of navigation.

At the epoch just prior to the Independence of the Colonies, the public rights were again coming to the front. In a Royal Order of 1795 (Law 16, Title 30, Book 7, Novisima Recopilacion), it was recognized as the existing law that the right to fish in rivers was as free and general as the right of navigation, and consequently that there could be no exclusive private rights to fish therein, *except* by *special Royal privilege*, or an immemorial user which presumed a royal privilege. The existence of these private rights, whatever their origin, was recognized, but it was declared that they could not be used to the disturbance of navigation or of the public right to fish in other places; and hence, weirs crossing rivers were prohibited.

The mining industry was also one of the chief influences in Spain to shape the law of waters, and especially to counteract any undue tendency to the sanctification of private riparian rights. Important *mining ordinances* were promulgated in 1584 by Philip II (incorporated as Law 4, Title 18, Book IX, Novisima Recopilacion). They permitted water to be freely taken for necessary mining purposes, from rivers and *arroyos* as well as other sources, at such places as was most advantageous to the miners (Paragraph 47). If the mining operations could not otherwise be carried on without damage to towns or ranches, the water had to be drawn into reservoirs and not permitted to flow back into the river, and the expense of additional structures, of course, had to be borne by the miners. They could obtain by condemnation the necessary sites.[2]

Colonial Law:—The Colonial Private Law in general followed the Spanish Law, but it must be remembered that the Indies were looked upon largely as the appanage and private property of the Crown. It is stated[3] that the King of Spain always reserved the dominion of rivers in America (Solorzano, Politica Indiana, Chapter 11, Book 6). On the other hand, the laws of the Indies (Recopilacion de Indias, Law 5, Title 17, Book 4) declared that forests, natural pastures and *waters* not granted to private parties are things *common* to *all*. But it was customary for the King to include the rivers in large grants made for him, and private ownership of rivers and other waters was recognized in many royal decrees (*e. g.*, Mining Ordinances of New Spain, Title 19, Art. 9).

The industrial needs of the sparsely populated colonies did not render imperative any clear demarcation of water rights. The confusion that existed in the Colonial law

[2]A translation of the more modern Spanish law as given by Escriche is to be found in *Wiel* on Water Rights (3 Ed.), pages 961-962-963-964.

[3]Velez Sarsfield's notes to Art. 2340 Argentine Civil Code.

on the subject has to a large extent survived, in spite of, or perhaps in several instances because of, the modern Codes. As these were based on the French Codes, new elements of confusion were introduced; and it is only in very recent years that the *law* has made any marked progress towards the solution of the puzzling questions left open by the Codes, in contradistinction to the large arbitrary powers of granting special concessions exercised by dictatorial governments.

These different European sources of our American law of waters should be kept in mind in making any statement of the law of Pan-American countries, and particularly in making any comparison between the laws of these various countries. In the United States there is the greatest actual development, and also the greatest waste, of water resources. There is also in that country the greatest amount of law and legislation with reference to water rights, and at the same time the greatest lack of consistency or sanity in such legislation.

At the outset, then, we shall discuss the situation in the United States.

UNITED STATES LAW

Approximately stated,* the potential water power resources in the United States are 150,000,000 kilowatts. Of this quantity, 20,000,000 kilowatts of water power are so situated as to be reasonably feasible of development, that is, in case only reasonable legislative conditions were imposed upon the investor. Of this latter number of kilowatts only about one-fifth are actually developed and used, and the other four-fifths are running to waste. 75% of this wasting water power energy is located upon navigable streams, and is, therefore, either directly or indirectly subject to Federal legislation. The remaining 25%, or about 4,000,000 kilowatts, is located upon the smaller streams in the several States and is subject directly to State regulation. This immense waste is, therefore, due, primarily, to deficiencies in Federal legislation and, to a great extent also, to defects in State legislation.

In the United States the Federal government is one of express, limited powers. It has only the powers of legislation which are expressly imposed by the Federal Constitution, all other powers of legislation and of control being expressly reserved to the several States. The only power thus given to the Federal government, which even indirectly touches the subject of water rights, including water powers, is that which gives to the Congress the power to "regulate commerce" between the States. It is held that the power to regulate commerce includes the power to regulate the highways of commerce for the protection of navigation; and that, therefore, the Federal control of interstate commerce extends to the regulation and control, for the protection of navigation, of all the navigable streams of the country. It is also held that it is within that power of control to prohibit the construction of dams or other structures across or upon the beds of such navigable streams, except by the consent of Congress and under a permit containing such restrictions, established by the Secretary of War and the Chief of his Engineers, so far as shall be deemed necessary to make the structures reasonably consistent with, or not unreasonably obstructive of, navigation. Regulation statutes have been enacted by the Congress, ostensibly for such purpose of navigation, but so framed that in fact they are unreasonably and unnecessarily preventive of water power development.[4]

Federal Legislation

The present retardation through Federal legislation and its possible remedies involve three classes of Federal control of water powers.

Water Powers on the Public Domain: The "public domain" comprises those various tracts of land, mostly situated in the far western states, owned by the Federal Government under a title which is proprietary in its nature, as distinguished from a purely sovereign right of control or regulation for a particular public interest. Such lands include those which are known as the forest reserves. Connected with this same class are water powers which are neither on, nor a part of, the public domain, but the utilization of which, either for flowage, transmission-lines, or other purposes, requires some use, small or large, of lands which are a part of the public domain.

*Report, U. S. Commissioner of Corporations, March 14, 1912; also Senate Document 274, 62nd Congress, 2nd Session, pp. 11-14, 211, 273; also "Water Power Resources of the U. S." by M. O. Leighton—this Congress.

[4]Act of March 3, 1899, Sec. 9, 30 U. S. Stat. L. 1121; Act of June 21, 1906, 34 U. S. Stat. L. 386; act of June 23, 1910, 36 U. S. Stat. L. 593, (The Dam Acts).

Act of February 26, 1897, 29 U. S. Stat. L., 599; act of June 4, 1897, 30 U. S. Stat. L. 34-36; act of February 15, 1901, 31 U. S. Stat. L. 790; act of February 1, 1905, 33 U. S. Stat. L. 628; act of June 25, 1910, 36 U. S. Stat. L. 847, (Public Domain Acts).

In order to develop water powers which are a part of the public domain, the investor must first obtain a permit from that Department of the Government having jurisdiction of the land in question,—generally either the Department of Agriculture or that of the Interior. The permit must cover the right to construct and maintain and operate the dam, power-plant, and transmission-lines. But such permit is revocable at the will of the Department by which it is granted, and is subject to such conditions as that Department may impose, not only when the permit is granted, but subsequently thereto. Indeed, the permit, under certain circumstances, may be automatically revoked, as by entry by a third person under the homestead or mining laws.[5] This unlimited power to make conditions in the permit and to change the same, allows the head of the Department to exact pecuniary burdens and tributes, the amount of which, from time to time, depends upon the discretion of such official. He has not power to grant a permit for any term which would, for any length of time, give stability to investment, nor the power to make the terms and conditions thereof free from unlimited uncertainties. Private capital has halted before such unbusiness-like conditions. As against over 5,000,000 kilowatts of water power subject to public-domain law which are now capable of commercial development, less than one-tenth of that amount has been developed.

But these prohibitive rules do not alone apply to the water powers which are themselves a part of the public domain. There are many millions of kilowatts of developable water power so located that their development or operation requires some use of some portion of the public domain, either for power-plants, or transmission-lines. Under the present laws such incidental use, however small, of any part of the public domain is subject to permits from government officials, always revocable at will and subject to conditions, and changes in conditions, at the discretion of the official granting the permit. This extends the features of uncertain tenure and of indefinite and changeable conditions to such an extent that the development of this class of water powers has been for years, and still is, at a standstill.

Water Powers on Navigable Streams: Next, are the water powers upon navigable streams outside the public domain. The power of control by the Federal Government over these arises solely from its limited constitutional power to regulate commerce. This is in no sense a proprietary right or interest. It is merely a limited sovereign right of control for the particular purpose specified. Subject only to that limited paramount right, all rights of regulation and proprietary rights to the use and benefit of water powers belong to the States and their citizens, the rule of property rights being fixed by the law of the respective States.

The Act of March 3, 1899, already cited, provides, consistently with the constitutional power of the Congress to regulate commerce, that no obstruction, including water power dams, shall be constructed in the bed of a navigable stream without the consent of the Congress. This prohibition and the reserved power of consent are logically retained for the sole purpose of protecting the present and future uses of streams for navigation. The consent provided had, until 1906, in accordance with the statute of 1899 and previous similar statutes, been granted in each case by a special act of the Congress. Each such statutory consent contained such provisions as might be agreed upon between the Congress and the private investor who was the grantee under the consent. These different special acts vary in the nature of their conditions; but under most of them construction has been made and vested rights thereby acquired. Nevertheless, the legislative tendency to disregard private property rights, and investments made in good faith, is shown by the claim now asserted by many, that the general power of repeal or amendment reserved in those special acts makes such investments lawfully subject to any further burdens or conditions which the Congress shall at any time arbitrarily impose.

This claim originated, not only in the increasing tendency of legislators to disregard the equitable as well as the legal right of investments already made, but also in the growing prevalence of that class of agitators, who falsely pretend to represent the cause of conservation. Disregarding the constitutional limitations of water power legislation, they argue that, as water powers upon navigable streams can be lawfully developed only after consent by the Congress, therefore the Congress may attach to such consent any conditions which it chooses to establish—that it may lawfully impose any burdens upon the investor or reserve any right of tribute or other advantage to the Govern-

[5] Acts of Feb. 26, 1897, June 4, 1897, Feb. 15, 1901, and Feb. 1, 1905.

ment—all as conditions to its consent. What the constitution does not permit directly, indeed that which it prohibits, they would accomplish by indirection. They urge legislation by which the advantages of water power use and the revenues therefrom shall be turned, either from the States in which they were located or from the individuals having property rights therein, to the general government as representing the people at large.

The advocacy of this theory of conservation, and the contest over its application in legislative form, have been, more than anything else, the cause of the lack, in the United States, of proper legislation for water power development. It was intended by the Acts of June 21, 1906, and of June 23, 1910, to establish the statutory conditions for any consent by the Congress so that afterwards the terms of those Acts should become part of any consent granted. It was the fallacious theory of conservation already suggested that made those acts prohibitive, instead of promotive, of private investments. It is also the same pseudo-conservationists who are urging still further legislative restrictions and burdens upon investments, and who are now harassing the legislators and the present administration at Washington in their earnest attempts to enact legislation which shall remove the present legislative obstacles to private investments.

By these Acts, of 1906 and 1910, the term of the consent can not exceed fifty years; and at the end of that time the investor has no rights. More than that, even before the expiration of the fifty years the consent may at any time be arbitrarily revoked without a return to the investor of more than a part of his necessary investment. The investor, therefore, must, in addition to what would otherwise be fair service-charges, make his charges for service to his consumers sufficient, within that period, to pay back to him the entire cost of his investment. No consideration is taken of the fact that the investor might have to wait five or ten years, or more, to build up a market which would consume the products of the full capacity of his plant. By the increased service-charges imposed he cannot in many localities meet the competition with steam power, which, in many places, at the present cost of steam power, is very close. Indeed, in some places the advantage is in favor of steam power. In addition to this, the same Acts reserve to the War Department of the Government the power to impose conditions as a part of the permit to be issued by that Department under the consent given by the Congress, and also to change such conditions, according to discretion. There is no fixed limit to such possible conditions and burdens, thus making the basis of the permit and the conditions to be fulfilled vague and uncertain.

These Acts and the policy therein announced have been so prohibitive of investment that investors, almost without exception, have refused to apply for or to accept any permits under them. Their prohibitive effect upon investment, and therefore upon the development of water powers, has been demonstrated by experience. Reports of the Congress, by those who have investigated the question officially and otherwise, are recognized, by all who really seek a business-like solution of the problem, as proving the insufficiencies of the existing law.[6]

The present Congress is now struggling with this question. Those who appreciate the situation are seeking to remove the present legislative obstacles sufficiently to offer business-like terms and conditions for private investment. They would make the conditions of the Government permit sufficiently broad to admit of the preservation of all present and future navigation interests. They would, however, make all conditions and all burdens upon the investor as specific and definite as possible, in order that the investor may know in advance the extent of his necessary ultimate investment. They would make the term of the permit indeterminate, and revocable only for cause, or renewable at its termination upon reasonable terms, thereby assuring reasonable stability of investment and avoiding the necessity of excessive charges upon consumers. The question of rates to consumers, it is proposed, shall be left to the commissions of the respective States. The public interests are to be protected by ample provision for revocation proceedings in case of default by a grantee in the performance of the conditions imposed.

Whether such remedial legislation shall be enacted depends upon the extent to which the pseudo-conservationists, above referred to, shall be able to exert their influence against the measures now under consideration. These obstructionists are conducting

[6]Report, National Waterways Commission, Senate document 469, 62d Congress, 2d Session, page 54. For a most illuminating discussion of these questions, see "Water Conservation by Storage," Chaps. I-V, by Professor George F. Swain, Yale University Press, 1915.

an organized campaign for the purpose of creating prejudice in the minds of the general public and in the minds of the members of the Congress against these constructive and remedial measures. In the meantime the leading members of the Congress, most of whom have informed themselves on the question, are working, irrespective of party politics, to join with the present administration in an attempt to have enacted the only legislation which will remove the present legislative obstacles to water power development.

Water Powers at Government Navigation-Dams: There is a third class of water powers, not included in the two foregoing, which are also under Federal control, which control, however, rests upon a basis different from that of the other two. The Federal Government sometimes, at its own expense, builds and operates navigation-dams for the general use of the public. At such dams the water which is not necessarily used for navigation affords, under the head and fall of the navigation-dam, a developed water power. Such water power is incidental. The Government, however, having acquired the riparian rights for its navigation improvements, thereby becomes proprietor of such incidental water power. The scope of its proprietary interest depends upon the extent to which it has acquired the riparian rights; for to such rights, as we have seen, the proprietary interest attaches. It also depends, of course, upon the extent to which the law of the State in which the dam is located vests in the riparian owner the property right to the use of water power incident to his land.

When the Government has acquired all the riparian rights to which the water powers are incident, and has at its own expense constructed a navigation-dam, then the water power incidentally developed thereby is rightfully considered to belong to the Government and may be granted, leased, or sold by the Government as by any other proprietor.

But in many instances the physical conditions are such that the development of water power alone would be so expensive that it would not yield fair returns upon the investment. At the same time improvement for navigation at Government expense might be too costly, either as a navigation or a water power improvement, or both. In such instances the public interests would best be served by a coöperation between the Government, in the interests of navigation, and the private investor, for the purpose of water-power utilization. This class of cases is met by the policy of a coöperative agreement by which the private investor furnishes such part of the necessary investment as he can economically furnish, and the balance is furnished by the Government. Thereby both navigation improvement and the development of water powers are procured. The terms of such agreements vary according to the different conditions in each case. This statement applies to those dams which, from the Government viewpoint, are primarily navigation-dams, as to the construction and operation of which special agreements are necessary.

Where a water power dam in a navigable stream is constructed by private capital under Government consent, the policy of the past, as well as of the proposed legislation, contemplates that, to the extent which is consistent with a fair capital investment and a fair return thereon, the private investor shall construct, maintain and operate, free of expense to the Government, navigation facilities as a part of and in connection with his water-power development. This burden is deemed to be imposed as within the power of control in the interests of navigation.

State Legislation

Subject to the paramount control of the Federal Government to protect navigation, as already defined, the control of water powers upon all streams, navigable or unnavigable, belongs to the States within which the water powers are located. This applies to all the original States and to States since admitted to the Union, and as between the State and individuals the proprietary interest and its character and extent are determined by the law of property rights as established in the respective States.[7] In accordance with these principles, so definitely fixed, the Congress has expressly recognized by Federal statutes the controlling efficacy of local property laws and customs with regard to water rights existing in those States where the common law has been either repudiated or modified, and has in statutory terms confirmed the rule established by the decisions just cited from the Federal Supreme Court.[8]

Accordingly, in order to determine the law of property rights of the individual as

[7]St. Anthony Falls Water Power Co. *v.* Water Commissioners, 168 U. S. 358, and cases cited in opinion.

[8]Act of July 26, 1866, 14 U. S. Stat. L. 253, and other Federal statutes above cited also act of Mar. 3, 1891, repeal of timber culture laws; and act of June 4, 1897, the Forest Service.

against the Federal Government, and therefore to determine the rule by which the Federal Government itself and its courts are bound, we have to resort to the law as established by the respective States. So it is that in Arizona, Colorado, Idaho, New Mexico, Nevada, Utah, and Wyoming the so-called "Colorado doctrine" governs, whereby the common law of riparian ownership and control of water powers is repudiated and the law of control by the State prevails, State statutes allowing and regulating appropriation of waters for power and other private uses with preference in the order of actual appropriation.[9] In others of the far western States there prevails the "California doctrine," by which the common law of riparian rights governs, modified only by appropriation rights vested before the riparian lands passed to private ownership. This is the rule in California, Kansas, Montana, North Dakota, Oklahoma, South Dakota, and other States.[10]

In the States lying east of or bordering upon the Mississippi River the common-law rule of riparian rights generally prevails. In these States, to the extent that the common law of riparian rights has been retained, the right to the beneficial use of the water power appurtenant to riparian land is a part and parcel of the land and belongs to the riparian owner. The State has no right of ownership or control in a proprietary sense. Its rights are confined to that of a sovereign power of control for the public use of navigation. All proprietary interests belong to the riparian and extend to all beneficial uses of the water power, including the revenues therefrom.[11] The distinction as to navigable streams, that in some States the riparian title extends only to high-water mark with the limited sovereign title in the bed and waters, and that in other States the riparian title extends to the middle of the stream, subject to the sovereign control for navigation, is, for practical purposes, merely speculative.[12] The rule is the same whether the stream be intrastate, interstate, or an international boundary.[13]

[9]Land & Canal Co. v. Ditch Co., 1 Colo. 1; Kansas v. Colorado, 206 U. S. 46; Boquillas Co. v. Curtis, 213 U. S. 339; United States v. Rio Grande Co., 174 U. S. 706.

[10]Lux v. Haggin, 69 Cal. 355; Bigelow v. Draper, 6 N. Dak. 152; Sturr v. Beck, 6 Dak. 71, 133 U. S. 541.

[11]St. Anthony Falls Water Power Co. v. Water Commissioners. 168 U. S. 358, citing the property law of Minnesota, which is substantially that of all riparian right States

[12]Union Depot Co. v. Brunswick, 31 Minn. 297; Lamprey v. State, 52 Minn. 181; Hobart v. Hall, 174 Fed. 433, aff'd 186 Fed. 426.

[13]United States v. Chandler-Dunbar Co., 209 U. S. 447; Niagara County v. College Heights Co., 111 N. Y. App. Div. 770; People v. Smith, 70 N. Y. App. Div. 543, aff'd 175 N. Y. 469.

These rights, reserved to and established in the States, and these property rights of beneficial use, fixed by the law of the States in the riparian, are subject only to the paramount control of the Federal Government for the definite and specific purpose of protecting navigation. The authority of the Congress is limited to the prevention of any unreasonable interference with navigation.[14] Although the interests of navigation are paramount, the sovereign right of the Government, National or State, to control or protect for this or other public use, while a conflicting interest, is not inconsistent with the exercise of the private right. Each must have regard for the other, but the private right persists up to the point where its exercise becomes an unreasonable interference with the public right. Both rights are limited, but the exercise of the limited public right can not be used as a means of extinguishing or appropriating the private right.[15]

Each State, subject to the exercise of the Federal power of control, which has been defined, has all the rights of control over all the streams, or parts of streams, both navigable and unnavigable, which are located within the State, and over the water powers therein. This does not mean that each State may by legislation make water powers within its borders the source of direct advantage or revenue to the State itself. Each State and its legislature are bound by the law of property rights with respect to water powers which has become established in that State and under which vested property rights have been acquired. This makes the jurisdiction of the States over water powers somewhat varying. Generally speaking, in any State where the law of public ownership and control of water powers has been established as a property law of the State, a statute based upon such public ownership and control and having regard for the particular property rights there established would be a constitutional and enforcible statute. In such States individual water rights are secured under laws regulating appropriation permits and in various ways controlling and limiting the right of private use. Such States are those among the States west of the Mississippi in which the property law of riparian ownership either has never been established or has been established only in a modified form.

[14]Union Bridge Co. v. United States, 204 U. S. 399.

[15]State ex rel. Wausau Street R. Co. v. Bancroft, 148 Wis., 124; Crookston Co. v. Sprague, 91 Minn. 461. On this and other points see "Limitations of Federal Control of Water Powers," by Rome G. Brown, S. Doc. No. 721, 62d Cong. 2d sess.

But the rule is different in those States which, as I have said, lie generally along, or east of, the Mississippi River, and in which the law of riparian rights, both upon navigable and unnavigable streams, has been established as a property right. In such States a statute would be unconstitutional if based upon the theory that water powers are a resource belonging to the entire State, or that the advantages and revenues from developed water powers belong primarily to the entire State. It would be declared by the courts invalid, as confiscatory of vested private riparian property rights. It should be kept in mind that the vested property rights referred to are not confined merely to the right of advantage in water powers actually developed. The right of development, that is, the right of the use, of water rights which are appurtenant to riparian land, whether the water powers are developed or not, is itself an incident to the real estate. As the books say, it is a right belonging to the riparian land *juræ naturæ*. Under our law the only difference, as between navigable streams and unnavigable streams, is, that this property right is subject, in the case of navigable streams, to the exercise of the paramount Federal control for the specified purpose of protecting navigation interests.

In the formulation of State water power legislation these distinctions are often overlooked. Some States have formed commissions to control water powers under statutes which view the public right of ownership and control too broadly, and which in effect restrict the vested rights of riparian owners to the point of confiscation. The extent to which such statutes may be enforced must yet be determined by the courts.

In some States the courts have already declared against such attempts at confiscation. The legislature of Wisconsin passed a statute two years ago which was based upon the theory of State ownership and control of water powers, and which, in substance, attempted to repudiate the law of riparian ownership. The supreme court of Wisconsin promptly declared that statute invalid on the ground that it infringed the established private property rights belonging to riparian land.[16]

It may be said, however, that the several States are anxious to have their respective water power resources developed and used; and that, if water-power legislation were confined to that of the States, there would have been no lack of progress such as now exists in the United States in regard to water power development. The present demand is for large power sites instead of for small ones such as are found upon the small, unnavigable streams. The demand is for the opening up of the water powers upon the large "navigable rivers" of the country. This does not mean alone those rivers which are at present actually navigable. The term is held to include all rivers, and those parts of rivers, which are reasonably capable of artificial improvement for commercial navigation. Therefore, it includes those streams upon which substantially all of the large water powers of the country are located. State legislation can never open up these water powers to use until Federal legislation shall be so adjusted that private capital may feel reasonably safe in making investments in such water power developments.

Water power capital in the United States is now waiting for the removal of the Federal legislative obstacles which are prohibitive of investment. Until they are removed the great water powers of the United States will continue to waste. Meanwhile the industrial development which would thereby be built up in our country is being driven to foreign countries, where a less suicidal legislative policy is retained.

It would not be consistent with the limited scope of this paper to summarize the laws of each and every Pan-American country upon the subject of water rights. There next follows a summary of the law of those countries which may be taken as fairly typical.[17]

WATER POWER IN SOUTH AMERICA

Before taking up the law regulating water rights and water-power development in different Spanish-American countries it is interesting to note, as stated by Mr. Lewis R. Freeman,[18] a leading American hydraulic engineer and authority on water-power development, that "South America, while affording magnificent water power possibilities, is more sparingly supplied with oil and coal

[16]State *ex. rel.* Wausau Street Railway *vs.* Bancroft, 148 Wis. 124.

[17]The writer desires here to express his obligations to Phanor J. Eder, Esq., 60 Wall Street, New York City, who is an expert in the law of Spanish-American countries. Mr. Eder has kindly rendered great assistance in preparing the statement of Spanish law above given, and of the laws of various countries shown in the Appendix, and here summarized.

[18]What is said here about the physical conditions with reference to water power development in the South American countries is taken largely from the statements of Mr. Freeman in his discussion of "Hydro-Electric Operations in South America," published in Vol. XXXVII, No. 5, November, 1913, of the Bulletin of the Pan-American Union.

than any other of the great continental land bodies of the world, with the possible exception of Africa." This Southern American continent is, taken as a whole, designated as "an especially favorable field for hydro-electrical endeavor." The general scarcity of fuel makes power of all descriptions very expensive. This part of the world is favored with the natural fuel resources of coal and oil to only a comparatively insignificant degree. The most important coal mines on that continent, situated in southern Chile, afford only sufficient fuel to supply the demands of coasting steamers and railways. Almost all of the coal used in South America is imported from abroad. The production of iquid fuel in the form of natural oil is practically limited to northern Peru and one district in southeastern Argentina. On the other hand, the three prime essentials in the generation of energy from water power—fall, volume, and continuity of supply—are found in almost every part of South America; the Pampas country and the rainless district of northern Chile being among the few exceptions. The finest opportunities for water power development in the world, so far as physical conditions are concerned, are on the slopes of the Cordilleras of the Andes in Peru, Bolivia, and Ecuador, where the waterfnlls, cascades and torrential rapids of the river exist, abundantly supplied by the moisture-laden clouds from the Amazon Valley dissolving in rain upon the cold slopes of the lofty Andes, pouring their burden of energy down to the sea.

Chile is stated, by Mr. Freeman, to be the most favorably located country in the world for an easy and comparatively inexpensive hydro-electric development, the only possible exception being Switzerland and Kashmir. The densely populated country between the Cordilleras and the coast presents water-power possibilities, for practical commercial development, equal to those of the Alpine country. But water power development has been slow; although some installations of considerable magnitude have been put in operation. The undeveloped commercial opportunities for the profitable generation and distribution of electrical energy from water power are, economically viewed, in mocking contrast with the losses and sufferings which are continuously endured in Chile from lack of coal and oil fuel.

The Laja River, in Chile, is the Niagara of South America, having a flow of little less than that of the Hudson at Albany, and with falls more than 100 feet high; and the river is ideal for economic hydro-electric installation. In southern Chile there is more undeveloped water power than could be used for several decades. The great Choshuenco river has a fall of 150 feet at one point and presents the practical opportunity for a water power with 1,200 feet fall developing more than 200,000 kilowatts.

Peru has more natural resources for fuel, from coal and oil, than other South American countries; but, for lack of transportation facilities, the price of such fuel is generally prohibitive. The practical opportunities for water power development in that country are nearly as favorable as are those in Chile; and, although there are already in Peru hydro-electric installations developing 75,000 kilowatts, further developments, yet unattempted, are feasible to meet the present unsupplied demand.

Comparatively little has thus far been accomplished in hydro-electric development in Bolivia, Ecuador, Colombia, Venezuela, and Paraguay; but in these countries the retardation of development is due largely to the unfavorable situation of water powers with reference to populous communities creating the demand. In the Argentino-Uruguayan country, feasible water power developments are afforded by the great Mendoza river and its tributaries, flowing down the eastern slope and foot-hills of the Andes to the Atlantic. This river has a fall of 9,000 feet in a distance of 100 miles and presents water-power possibilities, within a comparatively short distance upon a single stream, which are equaled nowhere in North America, except perhaps in Alaska. The population and industries of the surrounding country make, within easy transmitting distance, a demand, yet unsupplied, of over 200,000 kilowatts of power, which is far less than the capacity of the Mendoza.

The greatest center of population in South America, including the great cities of Buenos Aires, Montevideo, La Plata, and others representing nearly 3,000,000 inhabitants, present an unlimited market for power from the streams flowing easterly from the Andes. However, intervening hundreds of miles of Pampas between the Atlantic coast and the foot-hills of the Andes present limitations of transmission which are at present practically impossible to overcome.

In British Guiana, on the Potaro river, a branch of the Essequebo, is the highest fall of great volume in the world. Here the river 300 feet wide, drops 700 feet. The immense energy from this great cataract is wasting until further increase in population and in industrial development shall create such a demand for the power that the expense of the long transmission lines required to bring the wasting energy to the market shall become an economic possibility.

But physical obstacles and the lack of appreciation of the opportunities open to commercial development are not the cause in these southern countries of the waste of water power energy, the utilization of which is already commercially feasible. As in the United States, the first requisite for the promotion of water power development, and therefore for the prevention of waste of this natural resource, is encouragement, by legislation, to the investor who must furnish the capital for hydro-electric development. The hazards incident to such investment, even under the most favorable laws and regulations, are very great. But the physical hazards may be overcome or diminished. Before such dangers capital does not show timidity. What capital demands in such investments is certainty of tenure, and security from confiscation, sufficient to warrant dependance upon reasonable returns. Such security can only be afforded by laws, which at the same time that they protect the interests of the public also protect the investments which shall be made in furtherance of the public interest in the utilization of water-power resources.

In none of the countries of Spanish-America are the laws formulated in such a way as to attract private investment. The fact that there are already such investments only indicates the certainty of much greater development in the immediate future in case unreasonable legislative hazards to investment are decreased or eliminated.

WATER RIGHTS IN SPANISH-AMERICAN COUNTRIES

In this part of the paper there will be presented only a running summary of the status of the law. For a more detailed summary, reference is made to the Appendix* which has been kindly prepared for me by Phanor J. Eder, Esq., of the New York Bar.

ARGENTINA

The Federal power in Argentina is, as in the United States, limited to the power to regulate commerce, and that is, with respect to streams, to regulate and protect navigation; but rivers are held to be the public property of the State. Riparian owners have not the preference due to the location of their riparian land which is recognized in the United States. The uses of water by private parties are regulated by administrative authority under rules which may be modified or repealed. The enjoyment, therefore, of the use of waters is uncertain and the rights of investors, even under authoritative permits, are precarious. Here is presented a defect in the laws and regulation of waters quite similar to those defects which have been experienced in the United States with reference not only to water powers outside the public domain, but especially as to those within the public domain. National control of water powers seems in the first instance to have sprung from the right of national control over commerce, and, as in the United States, by construing that power to include control over navigation. But in the exercise of that power of control, as also in the United States, it seems to have been extended to the assertion of a power, not merely of a control for a specified purpose and to the limit required for the exercise of the limited power, but of an ownership by the State in the beds and waters themselves of streams, both navigable and unnavigable. The reservation of the right to change the conditions of investment, which are made by one who receives a concession from the government, tends to maintain legislative conditions which are in their very nature prohibitive of investment.

CHILE

In Chile, all rivers are "national property of public use." The use of public waters for power and other purposes is acquired by administrative concession. Each concessionaire is subject to the local or general ordnances of the local government, with no special right reserved to the owners of riparian land. This was the law until 1907, when a special statute was promulgated covering the subject of the "utilization of running waters for power." Under this statute the riparian owner may make a reasonable use, that is, a use consistent with the reasonable enjoyment by others of similar rights, of the waters which flow through or over his land. This right of use, however, even under the terms of this law, is not protected by constitutional law against a subsequent law which may have the effect of destroying the owner's investment. The right to develop water power

* Appendix to "Laws and Regulations Regarding the Use of Water in Pan-American Countries" as presented at the Second Pan American Congress.

must, nevertheless, in all instances, be subject to the terms of a concession limiting the quantity and manner of use, and subjecting the concessionaire to all regulations which are in force at the time of the concession, or which may thereafter be enacted.

Here again any prospective investor in water power development is confronted with uncertainty as to his tenure and as to the burdens to which his investment is or shall be subjected.

COLOMBIA

In Colombia, as in Chile, the ownership of the waters of streams is generally held to be in the State for public use. Rights to uses of water for power and other private purposes are, upon application, obtained from the government, and the use of such water power privileges are subject to changes in the statutory law applicable thereto. The rights of riparian owners, known to the English and American common law, are in the first instance recognized, but often their use is subjected to restrictive laws and regulations, present or prospective, which unduly increase the burdens of investment.

CUBA AND PORTO RICO

In these countries the rivers and their natural beds are made part of the public domain, and the use of the waters thereof must be obtained by private persons by administrative concession, unless a prescriptive right for 20 years has been acquired. Riparian owners are held to have no rights except such as have been duly acquired under concessions legally made, or by prescriptive use. In making concessions preferences are observed, first, for the water supply of towns; second, for the water supply of railways; third, for irrigation; fourth, for navigable canals; fifth, for mills, factories, etc.; sixth, for fish ponds or hatcheries. In the exercise of the power of eminent domain indemnity is provided only for a use which has such statutory precedence. The laws of Cuba and of Porto Rico, with reference to water rights, seem upon their face to be more protective of investment than those of any of the countries here discussed. The laws of water rights have been codified, and present a fairly reasonable certainty as to the terms upon which the investor may obtain a concession and operate under it.

URUGUAY

In Uruguay, the general rule is established, that waters of navigable streams are national property of public use, and the use of the waters of such streams for water power requires special authorization from the government. In the case of nonnavigable streams the riparian owner has the rights which are usually recognized under the English and American law. The reservation of the right of the government to issue permits and to fix the terms of such permits is not sufficient to encourage water power development; for the terms thereof are subject to change, and insufficient protection is afforded against changes in the conditions of the authorization.[19]

VENEZUELA

In Venezuela, while rivers are made part of the public domain, nevertheless the right of riparian owners to utilize their beds and waters for industrial purposes is expressly provided. The public rights of navigation are made paramount, as in the United States. By the new constitution of 1914, however, there is reserved to the Federal Government control over the waters of navigable streams; and water power developments thereon can only be made under the consent and approval of the National Congress. Such a situation would leave water power investments subject to the changing legislation of the National Congress or of the authorities to whom the power of that Congress might be delegated.

BRAZIL

The water power law of Brazil is Portuguese rather than Spanish. The general law of water rights follows that of Argentina. The government is expressly authorized to foster the utilization of hydro-electric power for transformation into electrical energy, when applied to "federal" services. Any excess power from such installations may be granted to private investors for use in private industries. This corresponds to the practice in the United States of a construction by the government of navigation dams, and at such height and structure as to afford water power in excess of that required for navigation purposes; and the leasing of such excess to private enterprises. In Brazil, however, it would seem that "federal" service is not limited to the federal promotion of navigation, but may be extended to the federal control and use of water powers as such, rather than as incidental to navigation improvements.

[19]Moreover, the business of supplying electricity to the public for light and power is practically a government monoply, under a statute of 1912.

MEXICO

The laws concerning waters and water rights in Mexico are summarized quite fully in the Appendix.* Navigable and boundary streams are viewed as highways, and therefore among those general "ways of communication" which are under the control and regulation of the Federal Executive. Concessions for the utilization of waters under such federal jurisdiction, for irrigation or for power, are granted by the Federal Executive under conditions as to structures and use of water, including rates—all largely in the discretion of the Executive. Special privileges for five years in order to encourage investment may be granted, and such concessions may be renewed in the discretion of the Executive and upon conditions imposed at his discretion within certain limits. All uses of waters in such streams are subject to the paramount uses of navigation. Even under a stable government, and with all revolutions passed, the uncertainties to investment in water power development presented by the peculiarities of the Mexican law, would, at the very outset, be prohibitive. The terms of concession, by which the rights of development by private capital are obtained, are left too largely to the caprice of the authorities in whose hands the granting lies. Moreover, this practice makes the granting of the concession, its original terms and chances of renewal, too much subject to arbitrary change and control. The lack of security vouchsafed to private investment in water power development in Mexico has kept such investments, to a large extent, out of that country.

CONCLUSION

It is apparent that the conservation of water resources, through the utilization of the wasting water power of the Pan-American countries, including the United States, can only be accomplished by the adoption of a legislative policy which shall invite private investment in such enterprises. The universal fault with existing policies of legislation, in these matters, is that the prospective investor, asking for a grant, or concession, or permit, is viewed as one asking, for his own private benefit, a gift from the public. The theory is too much prevalent that, because water resources are a natural resource they are, for that very reason, a purely public resource, and not by nature or in law for development in any other way than through the direct supervision of public authorities and for the exclusive and direct benefit of the public at large. But water powers are local in their very nature. The assertion of a right of benefit, through direct participation by the general public in the proceeds derived from the utilization of water powers, is an assertion that natural water powers are intended only to produce for the public treasury. Such a view of water power resources leads to the legislative policy of imposing by statute the utmost burdens possible, and even impossible burdens, upon private investment. Experience has demonstrated that utilization of wasting water powers cannot be accomplished by their development by the public authorities; but only through the capital of private investors. Such investors, however, rightly demand that security for their investment which shall afford to them reasonable protection against confiscation and loss of their investment, and against failure to receive fair returns thereon.

There are millions of dollars of capital in the hands of American financiers ready for investment in water power developments, not only in the United States but in all of the Pan-American republics, but which are withheld from such investments because of the financial obstacles presented in these various countries through an almost universal absence of a legislative policy which will allow such investments to be made with reasonable safety.

* Appendix to "Laws and Regulations Regarding the Use of Water in Pan-American Countries" as presented at the Second Pan-American Congress.

PHOTOMETRIC METHODS IN CONNECTION WITH MAGIC LANTERN AND MOVING PICTURE OUTFITS AND A SIMPLE METHOD OF STUDYING THE INTRINSIC BRILLIANCY OF PROJECTION SOURCES

By J. A. Orange

Research Laboratory, General Electric Company

This article is in two parts; the first describes an excellent and convenient method for making a quick determination of the total effective light from a projection outfit, and the second gives a ready means for determining the intrinsic brilliancy of the whole or different parts of the light-giving element. Except for the photometer, the apparatus described is comparatively inexpensive and easily obtainable.—Editor.

There are two ways in which the illumination performance of magic lanterns and moving picture machines may be subjected to precise test.

The first is to take actual measurements of the illumination on a test-plate which can be moved systematically from point to point on the screen. A thorough test of this kind is both troublesome and laborious but it has the advantage of giving a measure of the *evenness* of illumination.

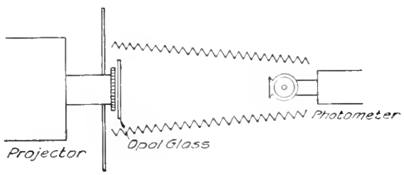


Fig. 1

For most purposes it would seem to be preferable to proceed as described below, at least in those cases where the apparatus is not permanently installed in an operating booth. (Fig. 1).

A sheet of opal glass with flat surfaces finely ground is placed in front of the objective. A portable photometer is set up facing this at, say, a distance not less than four times the objective diameter. Care is taken to avoid shading of the receiving plate of the photometer with respect to the illuminated part of the opal glass. With some photometers this involves unscrewing the shading tube which is normally in place.

In the case of magic lanterns one should use a mask in the slide-holder with an opening representative of the slides used. Moving picture machines have a "mask" corresponding to the film, viz: the aperture-plate. The shutter will naturally be kept in motion while tests are being made; but there is a systematic error depending on the geometry of the arrangement—some 5 per cent in the worst case.

Measurements of the candle-power of the opal glass made in this way give a measure of the total lumens emerging from the system.

The accuracy may be affected by want of uniformity in the opal glass and by departure from Lambert's Law. However, it is an easy matter to have the glass optically ground, while in the most extreme case the incidence is within 15 deg. of the normal and usually

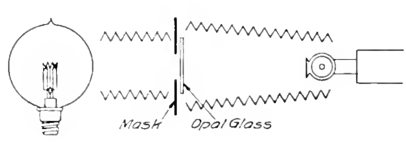


Fig. 2

much closer. The emergence is within about 8 deg. of the normal even if the photometer is as close to the glass as was mentioned above. There is therefore little chance of error from this cause.

Next as regards the constant for the glass there are a number of simple ways of evaluating it. One is to make an illumination survey of a screen, measure the screen and so deduce the total lumens; then test the same projector in the manner here described. Another is to illuminate the opal glass by means of a high candle-power lamp which has been photometered, the filament center being at a distance from the plate about four times the effective diameter of the opal glass. (Fig. 2).

The glass should be provided with a black mask of known area on the face towards the lamp. Again the photometer is used to measure the candle-power of the opal glass. The lumens incident on the opal glass are readily calculated from the candle-power of the lamp in the appropriate direction, the distance from the filament to the opal glass and the area of the mask.

$$\text{Lumens} = \frac{\text{candle-power} \times \text{area}}{\text{distance squared}}$$

very approximately.

Thus the relation between photometer reading and lumens incident on the opal glass is obtained.

It should be noted that it is advisable to use a large, concentrated filament lamp in this standardization and even then it will be found necessary to use reducing screens of very low transmission factor in the measurements with a projector.

The amount of focusing necessary to deal with the various screen distances encountered is very small and it has no significant effect on the amount of light emerging from the projector. If the apparatus gives sensibly uniform illumination over a screen then the total lumens projected would appear to be the best gauge of performance as far as mere illumination goes.

iris diaphragm in the first lens gives latitude in this respect. The diaphragm in the second lens enables one to select different parts and varying extents of the source image for the brilliancy test. The advantage of having a diaphragm in the first lens is that it gives a certain amount of control of the definition of the source image, control which is needed if one takes small areas of the source and measures "local brilliancy." Such a case calls for different distances from those instanced above.

As to the mode of estimating the brilliancies we may notice first:

1. If without changing the set-up or diaphragms one source is substituted for another the candle-power readings on the photometer are a measure of the relative brilliancies of the parts selected by the diaphragm of the second lens.

2. Changing the stop opening of the first lens is significant only as regards definition of the source-image and covering the photometer plate.

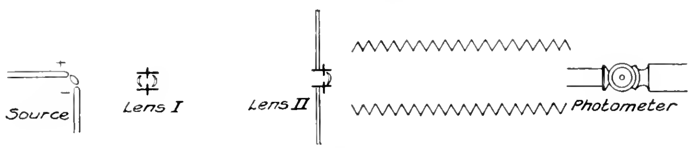


Fig. 3

A SIMPLE METHOD OF STUDYING THE INTRINSIC BRILLIANCY OF PROJECTION SOURCES

This method is convenient for comparing the brilliancies of different sources and for finding the distribution of brilliancy over any form of light source suitable for projection.

Two cheap hand camera lenses equipped with iris diaphragms are used (each of 5-in. equivalent focus). One is set up opposite the light source at about 7½ inches distance. The other lens is deprived of its back component and then mounted in line with the first lens, at a distance of about 15 inches. A portable photometer is arranged at 30 inches from this second lens and readings taken on the candle-power scale. (Fig. 3).

The action is as follows: the first lens casts an image of the source at the position of the diaphragm in the second lens; the second lens casts an image of the diaphragm of the first lens into the plane of the photometer plate.

It should be noted that this latter image is to be larger than the photometer plate; the

3. Changing the stop opening of the second lens is allowed for approximately if each candle-power reading is multiplied by the corresponding U. S. stop number.

4. Changing the system so that the distance from the second lens to the photometer is varied may be allowed for very approximately by multiplying the readings by the square of the distance. (It is sufficiently accurate to measure the distance from the lens diaphragm to the photometer plate.)

In general the mean brilliancy *of the selected part* of the source is given by the relation:

$$B = \frac{I . x^2}{A . T \ 10{,}000}$$

Where

I is the photometer reading in meter-candles.

x is the distance from second lens to photometer, in centimeters.

A is the area of opening of the second lens (in square millimeters).

T is the transmission of the system. (About 70 per cent in the case here described.)

B is the brilliancy in candle-power/sq. mm.

VENTILATION AS A FACTOR IN THE ECONOMICAL DESIGN OF ELECTRICAL MACHINERY

Part I

By Edgar Knowlton

Alternating Current Engineering Department, General Electric Company

This article treats of one of the many ways in which a reduction in the cost of electrical machinery is being attained. The first installment deals with the application of some of the principles of thermodynamics to the study of the conduction of heat energy from the vital parts of a machine to the surfaces. The second installment will describe methods of removing the heat from the surfaces and carrying it to the surrounding atmosphere. Mention is also made of a few of the more common fallacies regarding the ventilation of electrical machinery.—Editor.

Basis of Cost Comparisons

The proper basis for comparing the cost of electrical machines is the ratio of its cost to its capacity.

Tendency of Costs to Rise

Due to the rising prices of material and labor the cost of a machine of given physical dimensions or weight tends to increase.

This tendency may be partially or wholly counteracted by the economical use of materials, reduction in the amount of labor, and by obtaining the highest capacity consistent with other factors of design such as insulation endurance, efficiency, voltage regulation, commutation, starting torque, breakdown load, etc.

Temperature as a Limit of Capacity

In many classes of electrical machines the capacity is limited by the insulation endurance which is dependent largely on the temperature at which it is operated, i.e., the capacity depends on the operating temperature of the machine. This fact has been evident since the early days of the electrical industry but it is only in comparatively recent years that a careful study has been made of the principles of heat flow and ventilation in their application to the design of electrical machinery.

Influence of the Design of Steam Turbine Generators on the Study of Heat Flow and Ventilation

When the design of steam turbine driven generators was undertaken it was found that experience derived from the belt, engine and waterwheel driven machines was not as rigidly applicable as could be wished. Study of the principles of heat flow and ventilation, and careful tests to determine the internal temperatures enabled designers to predetermine the temperature of this class of machines with far greater accuracy than had been attained on the earlier types.

The increase in rotative speeds during the early development of the steam turbine produced radical changes in the proportions and design of the alternators. The diameters decreased, the axial lengths increased, and, the air passages through the rotors being practically eliminated, it was necessary to enclose the machines and provide internal or external fans for circulating the air through the restricted air passages. When attached to the generator rotor the conditions under which the fans operated were radically different from those existing in the usual fan application and a new type of fan was evolved which was very effective as a means of cooling the generator.

A modern steam turbine alternator without some special means of ventilating such as fans would reach dangerous temperatures if run without any load whatever at normal, or even at a lesser voltage.

Heat Flow in Materials

To produce a flow of water or air it is necessary to have a difference in pressure between two points, and for a flow of electrical energy a difference of electrical potential is required. Similarly for a flow of heat energy a difference in temperature is required. The analogy is shown by,

A CURRENT OF	PRODUCED BY
Water or air	A difference in pressure or head.
Electricity	A difference in electrical potential.
Heat	A difference in temperature.

Dr. Carl Hering* has proposed that the unit of thermal resistance be called the thermal ohm and has defined it as the resistance which would allow one watt of heat energy to flow through it when the difference in temperature between the ends is 1 deg. C.

* Trans. A.I.E E., Vol. XXXI, June, 1912, Part I, page 1191.

He has defined specific thermal resistivity as the thermal resistance of one centimeter cube or one inch cube of the material. In this article the latter definition will be used.

Let, W = flow of heat energy in watts.
T = drop in temperature in centigrade degrees.
R = resistance in thermal ohms.
$C = \frac{1}{R}$ = thermal conductivity.

(1) then, $T = WR$

(2) and, $C = \frac{W}{T}$

The resistivities and conductivities given in Table I are principally by Dr. Langmuir.†

TABLE 1

HEAT RESISTIVITIES AND CONDUCTIVITIES OF VARIOUS MATERIALS

	Resistivity Thermal Ohms per Inch Cube	Conductivity Watts per In. Cube per C. deg.
Copper, commercial	0.11	9.
Iron, pure	0.6	1.7
Iron, lam. 0.014 in. each sheet insulated with enamel, right angles to plane of sheet	30.	0.033
Transformer steel, 4 per cent sil.	1.23	0.81
Paper	300.	0.0033
Varnished cambric	157.	0.0064
Varnished cloth (empire cloth)	157.	0.0064
Mica-paper	250.	0.004
Pure mica	110.	0.0091

For bodies of iron laminations, 0.02 in. thick insulated with 0.002 in. paper between every two laminations, T. M. Barlow‡ states that the resistance at right angles is 100 times the resistance parallel with the plane of laminations.

For iron 0.014 in. thick insulated with japan or enamel and very firmly clamped, resistivity values of 0.6 when parallel and 30 when at right angles to the plane of laminations (see Table I) have been closely confirmed by tests.

Since this article deals with the flow of heat from a higher to a lower temperature, the term "temperature drop" will be used instead of the more common term of "temperature rise," when comparing the temperature of the hotter portions of a machine and the surrounding air.

† Trans. A.I.E.E., 1913, Vol. XXXII, Part 1, page 301.
‡ London Elec. Eng., Jan. 23, 1908.

Radiation of Heat from a Surface

Heat passes from a surface to the surrounding air by radiation and convection. The quantity of heat removed by radiation depends on the nature of the surface, the temperature of the body and its surroundings. The color of the surface is especially important; a black surface radiating the most and highly polished white surfaces the least energy. A black body is considered the standard and the Stefan-Boltzman Law for such a body is

$$(3) \qquad Wr = 38\,E\left[\left(\frac{T_2}{1000}\right)^4 - \left(\frac{T_1}{1000}\right)^4\right]$$

where

Wr = watts radiated per sq. in.
E = emissivity of the body.
T_2 and T_1 = temperature of the body and its surroundings in absolute C. deg.

For a theoretically black body $E = 1$, but for other bodies it is always less than unity. For an oxidized iron surface having a temperature of 25 deg. C. above the surrounding air, $E = 0.5$ and

$$Wr = 0.06$$

It is seldom that the difference in temperature between the external surface of a machine and the surrounding air exceeds 25 deg. C., therefore the heat dissipated by radiation is relatively unimportant. Calculations on a certain machine showed it to be less than 1 per cent of the total losses.

Heat Flow from Surfaces Exposed to Still Air

Dr. Langmuir§ has advanced the theory that at the surface of a heated body there is a film of stationary air through which the heat is carried by conduction. Taking the observed values of heat transference, temperature drop and resistivity of air, he has estimated the thickness of film to be, closely 0.17 inches (0.43 cm.).

The existence of this stationary film has been definitely shown by experiments. It is impossible to state its exact thickness as there must be slow movements of air which cannot be detected. However, Dr. Langmuir's theory explains the phenomena and gives a method of calculation which holds true over a wide range of conditions.

Heat Flow from Surfaces Exposed to Moving Air

A movement of air in the near vicinity of a heated surface will reduce the thickness of the stationary film and results in a smaller drop in temperature. Many experiments

§ Conduction and Radiation of Heat, A.E.S., Vol. XXIII April, 1913.

have been made on the surface temperature drop with varying velocities of air. Fig. 1 gives a curve of the relation between air velocity and surface temperature drop.

This curve is an average of four curves by different experimenters.¶ The four curves gave the C. deg. drop to pass one watt per square inch, at various peripheral speeds,

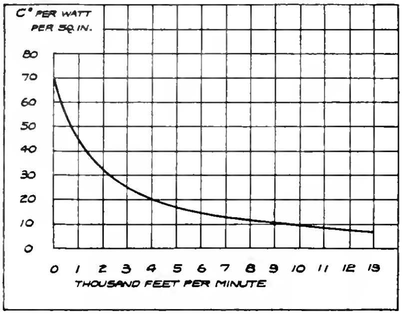


Fig. 1. Thermal Drop at the Surface as a Function of the Air Velocity

from the surfaces of rotors of electrical machines.

If one smooth cylinder is rotated inside of another smooth cylinder the movement of air relative to either surface is one-half the peripheral speed. If an experiment at a peripheral speed of 10,000 feet per minute showed a temperature drop of 10 deg. C. per watt per sq. in. from one of the surfaces this drop would relate to a velocity of air over the surface of 5000 ft. per minute. But the conditions at the air gaps of electrical machines differ greatly from those of smooth cylinders, the air being in much more violent agitation, and in the example above the temperature drop of 10 deg. C. would relate more closely to the full peripheral speed of 10,000 f.p.m. The curve of Fig. 1 is plotted on this basis and abscissa refer either to peripheral speeds or to the velocity of air over stationary surfaces.

The shape of this curve explains why in some cases a marked reduction of temperature follows a slight increase in air volume while in other cases the volume of air must be greatly increased to obtain even a small temperature reduction. It depends on whether the conditions apply to the upper or lower part of the curve.

¶ Heat Paths in Elec. Machinery, Symons and Walker British Institution of E. E., Nov., 1911.

For velocities of 500 f.p.m. and lower it is probable that the surface drops are considerably greater than given by the curve. Results of experiments at low air velocities vary widely due doubtless to the difficulty of ascertaining the exact velocity of the air.

Characteristics of Air as a Cooling Medium

In previous sections the thermal resistance of air has been considered. Another important characteristic is the specific heat, as this determines the quantity of air which must be used to ventilate an electrical machine. The density of the air as it passes through a machine is constantly changing due to the absorption of heat, the effects of the moving parts, and the resistance of the air passages. At the exit the density is about 6 per cent less than at the entrance, due to the rise in temperature of the air. Therefore the average density while in the machine will not vary more than 3 per cent from the density at the entrance. For the usual conditions of ventilation, no appreciable error is introduced if the quantity of air is calculated on the basis of dry air at 25 deg. C. (77 deg. F.) and the standard barometric pressure of 29.92 in. of mercury. Under these conditions 13.5 cu. ft. of dry air weigh 1 lb. Taking specific heat as 0.24, 1 kw. will raise the temperature of 100 cu. ft. of air per minute, 17.8 deg. C. An allowance of 100 cu. ft. of air per minute per kw. of loss including air friction is the result of the experience of a considerable number of designers working independently and although for special cases the quantity of air may vary considerably from this, the value is generally correct.

Heat Absorption of Dry and Damp Air

This subject is mentioned in order to correct some false impressions. It is sometimes stated that damp air is more effective than dry air for cooling electrical machinery. This statement is based on the knowledge that water vapor has a higher specific heat than air, and it is assumed that the more water vapor in the mixture the greater is its specific heat. This is true, but the quantity of water vapor, even in a saturated mixture, is too small to have an appreciable effect on the specific heat.

As an example, consider three mixtures of air and water vapor, *A*, *B* and *C*, each having a volume of 100 cu. ft. and relative humidities of 100 per cent. 50 per cent and 0 per cent. Sample *A* is saturated with water vapor, sample *B* has one-half as much water as sample A, and sample C is absolutely dry, having no water vapor. (See table below.)

The last item in the table shows that the energy absorbed by the saturated air is only 1½ per cent greater than the energy absorbed by perfectly dry air.

Tendency of Heated Air to Rise

It is well known that air heated to a temperature above the surrounding atmosphere tends to rise and it is sometimes believed that a method of ventilating should not operate against this pressure. This belief is erroneous due to a lack of appreciation of the value of this force, which is measured by the difference in weight of two columns of air, one at the average temperature of the air in the machine and the other at atmospheric temperature. The height of the air column is the distance between the entrance and exit opening for the air. For a height of 10 ft. and an average difference of temperature of 10 deg. C. the force producing an upward movement of air is equal to 0.0027 oz. per sq. in. (0.0047 in. of water). To force air through a machine, several hundred times this pressure is required; therefore the tendency for heated air to rise may be neglected. When it is more convenient to take the air in at the top and discharge it from the bottom of a machine the designer need not hesitate to adopt this plan.

Heat Flow in Electrical Machinery

The locations of the hotter and cooler spots of an electrical machine are dependent on many factors, a variation in any one of which may materially change the positions of these spots. The lower temperatures are at the surfaces, but necessarily some parts of the surfaces will be at a higher temperature than others. The highest temperatures of a machine are generally found in the copper of the windings although there are exceptions which will be mentioned later.

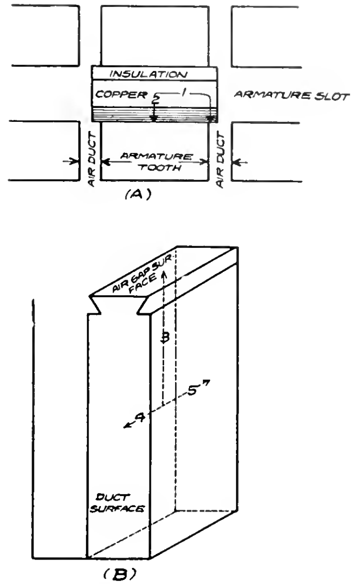


Fig. 2. Heat Paths in Armature Winding and Tooth

For the present consider the stationary armature of an alternator having its hottest point in the copper of the winding at the transverse center line of the armature core.

The calculations are on the basis of:		
Original temperature	32.2 deg. C.	(90 deg. F.)
Rise in temperature of the mixtures	20.0 deg. C.	(36 deg. F.)
Final temperatures	52.2 deg. C.	(126 deg. F.)
Specific heat of air	0.238	
Specific heat of water vapor	0.475	

Sample	A	B	C
Relative humidity	100 per cent	50 per cent	0 per cent
Weight of dry air in mixture, lb.	6.896	7.067	7.22
Weight of water vapor in mixture, lb.	0.212	0.106	0.00
Weight of mixture	7.108	7.173	7.22
B.t.u. to raise air 36 deg. F. (20 deg. C.)	59.06	60.52	61.83
B.t.u. to raise vapor 36 deg. F. (20 deg. C.)	3.63	1.815	0.00
B.t.u. to raise mixture 36 deg. F. (20 deg. C.)	62.69	62.335	61.83

Assume the armature core to be long axially, from 6 to 10 feet, then practically no heat will flow axially in the copper from the longitudinal center line to the ends of the winding outside of the core. As a unit for consideration take one tooth having an axial length of

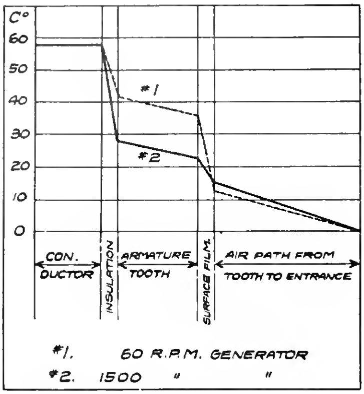


Fig. 3. Temperature Drop from Armature Conductor to the Air at the Entrance to the Generator

one armature section and the armature coils in one slot having an axial length from center to center of adjacent air ducts, see Fig. 2. Heat energy leaves the copper by two main paths, part flowing to the air duct by Path 1, and the rest flowing through insulation by Path 2 to the armature tooth where it combines with the tooth loss. The energy in the tooth has three paths to the air:

Path 3 to the air gap.
Paths 4 and 5 to the two air ducts.

Experience indicates that little if any heat flows from the tooth to the armature body with the magnetic densities usually employed.

In estimating the temperature rise of a machine it should not be overlooked that the temperature of the air is constantly increasing as it passes through the machine and when it reaches the locality of the hottest parts of the machine its temperature may be from 8 to 15 deg. C. higher than when entering.

Knowing the resistivities of the various materials and the resistances of the air surfaces, the resistances of the various air paths may be calculated. When the heat paths are in parallel they may be treated similarly to parallel electrical circuits. By these methods the temperature drop may be calculated with considerable accuracy as has been stated.

If the axial length of the core is much shorter some allowance should be made for the heat energy passed to the ends of the winding outside of the core.

Comparison of Temperature Drops in Two Widely Varying Types of Alternating Current Generators

In Fig. 3 are shown temperature drop curves of two widely different types of alternating current generators. Both are 25-cycle, 11,000-volt generators, one operating at 60 and the other at 1500-r.p.m. The lower part of the figure shows diagrammatically the heat path at the longitudinal center-line of the machines, from the copper through insulation, armature tooth, air film at the surface, to the air at the entrance. In the part of the diagram marked "Air Path from Tooth to Entrance" there is of course no flow of heat energy from the air film to the air at the entrance since the air is moving in the opposite direction, but there is a difference in temperature which should be taken into account and the continuation of

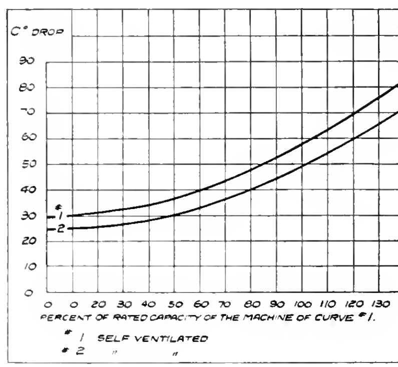


Fig. 4

the curve through this part of the path is thereby justified.

The knowledge that the total temperature drop was 58 deg. C. would be insufficient for an economical redesign of either machine. In Fig. 4 are shown the temperature capacity curves of two designs having the same cost.

Curve 1 is for the design whose temperature drop curve is shown in Fig. 3, Curve 1. Curve 2, Fig. 4, is a new design whose increased capacity for the same temperatures is due to providing a heat path of lower resistance which allows either a lower temperature at the same capacity or a higher capacity for the same temperature. It is interesting to note that for a limited distance each side of 100 per cent of rated load the temperature drop is practically proportional to the load. The difference between the temperature at any load and the temperature at 0 load is proportional to I^2 in a well designed machine, but it is incorrect to consider that the temperature difference between the copper and the ingoing air follows this law.

The foregoing has considered the application of the principles of thermodynamics to the reduction of the cost of alternating current generators but they may be as advantageously employed in other classes of electrical machinery

(To be Continued)

PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

PART XVIII (NOS. 73 TO 75 INC.)

BY E. C. PARHAM

CONSTRUCTION DEPARTMENT, GENERAL ELECTRIC COMPANY

(73) FLASHOVERS ON COMMUTATOR

Voltage distribution curves plotted from the bar-to-bar voltage readings taken around the commutator of an armature turning in a magnetic field will indicate the mode of the flux distribution in the air-gap. When the armature carries no current, the flux distribution will be uniform and the curve will be symmetrical on both sides of the maximum. The presence of armature current, however, will distort the flux and make its distribution non-uniform, under which condition the curve will have a sharper slope on one side of the maximum than on the other. This means that across the commutator bars that correspond to the steep slope part of the curve a much greater potential difference will be present than across the same number of bars anywhere else on the commutator. If the conditions are such as to make this discrepancy exceed a certain value, sparking or flashing, or both may result. These results are especially likely to take place on circuits of variable voltage—railway circuits for example.

The owner of a 250-volt continuous-current motor concluded to rewind it for 500-volt service, so that he could obtain power from a railway circuit. Accordingly, the armature and the field coils were rewound. After the rewinding, the motor always operated normally at no-load and most of the time it gave no trouble when operating under load, but frequently when continuous operation of the motor was most urgent it would flash over; this generally meant blowing of the breaker and delaying production. Finally, as the result of the railway company putting on heavy cars which produced violent fluctuations in the line voltage, the interruptions in the operation of the rewound motor became so frequent as to be intolerable.

The owner then consulted the manufacturer of the motor to find out what was the trouble. He stated the history of the motor fairly; and he was informed as follows: "Almost any motor will flash at the commutator if the voltage impressed on it is greatly reduced and then is suddenly raised to its former value. In this particular case the sparking conditions were aggravated by the mistake of having greatly increased the number of turns in the armature winding (to meet the requirements of the increased voltage) without increasing the number of bars in the commutator." As a relief measure, he bought a new armature and sent the old one to the factory for a new commutator. This did not entirely eliminate flashing, but it greatly decreased the frequency of its occurrence.

(74) MOTOR SPARKED AND HEATED

A sewing machine operator requested that he be informed as to whether he had adopted the correct method of remedying sparking and heating in one of the many motors that he used. He stated that he had opened the motor and had found two fingers or contact

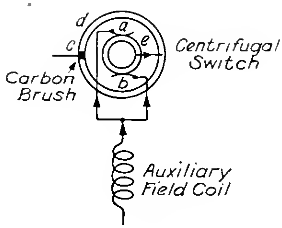


Fig. 1

arms, one of these being considerably blistered and the other appearing to be in good condition. He further stated that he had removed the blistered finger and that the motor had been running all right ever since.

The motor referred to was a single-phase machine of the type that is started by means of an internal centrifugal switch, the operation of which depends on the speed of the motor. Fig. 1 indicates the connections of this automatic starting switch and of the starting winding. Here *d* and *e* are brass rings which are mounted on the rotor shaft and which turn with it; a small carbon brush, *c*, bears sidewise on ring *d;* and two brass contact fingers or arms, *a* and *b*, connected in parallel are pressed onto ring *e* by means of two springs, as long as the speed of the rotor is below a certain value. Above this speed, centrifugal force throws *a* and *b* outward thereby interrupting the circuit of the starting coil which is not designed for continuous duty.

The operator's trouble was due to the fact that abnormal pivot friction in one of the fingers prevented its throwing out far enough to break the arc established when it left ring *e*.

The proper corrective measure would have been to relieve the friction so as to give both fingers the same freedom of action; but in as much as one finger was amply large for the work and the removal of the other finger did not unbalance the rotor mechanically, the operator's remedy might be called a success.

(75) MOTORS IN SERIES

So far as the current-limiting effect in a circuit is concerned, a counter e.m.f. acts the same as a resistance except that it does not waste energy as does a resistance. Also, as in the case of series resistance, if a circuit includes two counter e.m.fs., the sources of which are connected in series, the applied e.m.f. of the circuit will be distributed between the counter e.m.fs. according to their respective values, the larger voltage drop taking place across the greater counter e.m.f. If the values of the counter e.m.fs change so that one becomes far greater than the other, then the voltage drop across the counter e.m.f. of negligible value will become negligible and practically all of the applied voltage will become located across the counter e.m.f. of increased value.

An electrical repairman who had been getting rather unsatisfactory power service from a low-head waterwheel concluded to try the power from the city 220-volt service. He had available two 110-volt motors which he belted independently to the countershaft, the motors being connected in series and to the same starting box. On applying voltage, both motors immediately started but one of them gradually slowed and stopped while the other motor began to race. The shifting of brushes and the tightening of belts helped matters somewhat, but in order to secure operation that was at all tolerable the belts had to be drawn so tight that the bearings heated. Taking as a cue the improvement effected by the tightening of the belts, he set the motors end to end and coupled their pulleys together so that whatever happened to the speed of one armature had to happen to the speed of the other. Operation then proved to be satisfactory, for by shifting of the motor brushes the voltage drop of the motors could be made the same thereby equally dividing the work between them.

The irregular action obtained in the first place can be explained as follows: Assuming an initial slight difference in the counter e.m.fs. of the two motors, due to a slight difference in speed for example, the greater counter e.m.f. would absorb the greater part of the line voltage. This would increase the speed of the higher speed motor which would further increase its counter e.m.f. and, simultaneously, the speed and counter e.m.f. of the other motor would be decreased. These effects were accumulative, so that one speed gradually became a condition of racing while the other gradually approached zero.

IN MEMORIAM

MR. DÁMASO MAZENET

We greatly regret to have to record the death of Mr. Dámaso Mazenet, which occurred in Mexico City on March 17th, 1916. The subject of our notice was born in the Republic of Colombia, at Santa Marta, on December 11, 1852. Mr. Mazenet came to the United States when he was only about 17 years of age and completed his education at Mason's School, Yonkers, and finally at a military school in Elizabeth, N. J., from which he was graduated.

For a number of years he was engaged in the shipping and commission business in New York City with Hoadley & Company and Perez Triana, who carried on business with Central and South American countries. It was here that he received the training which made him a thoroughly capable business man and gave him that foresight and sound judgment for which he was so well known. It was when Mr. Mazenet was with Hoadley & Company in New York, during 1889, that Mr. George W. Davenport, then General Manager of the Thomson-Houston International Electric Company of Boston, induced him to join the company as his assistant.

Shortly after the General Electric Company was formed, in 1892, Mr. Mazenet was made Manager of the Foreign Department, with offices in the Edison Building, at 44 Broad Street, New York. In 1896, on the death of Mr. S. C. Peck, who was then the General Electric Company's agent in Mexico, Mr. Mazenet went to Mexico City to arrange the settlement of certain important accounts and to organize the Mexican General Electric Company, of which he was appointed Managing Director. He held this position up to the time of his death.

It is interesting to note that Mr. Mazenet had been connected with the General Electric Company only seven years when he went to Mexico, but during this short period he became one of the most popular men in the organization. It was characteristic of the man that all who met him carried away an impression of his kindly personality and sterling qualities.

Mr. Mazenet was an accomplished organist, playing regularly at prominent churches in Boston, New York and Mexico City. He was a pupil and a close personal friend of the late Samuel P. Warren. His collection of organ music is considered to be one of the best amongst private collections.

Amongst his hobbies Mr. Mazenet was an enthusiastic collector of timepieces and his collection of old clocks and watches gathered together during a period of twenty-five years probably cannot be duplicated outside any of the larger of our museums.

He was a linguist of no mean ability, speaking French, Spanish and English fluently. His vocabulary in both Spanish and English was unusually extensive.

As everyone must be well aware, the past five years in Mexico have been trying, especially for any foreigner living there. Mr. Mazenet went through the ten days' fighting in Mexico City, in February, 1913, and also through the disturbances caused by the landing of the American forces at Vera Cruz in April, 1914, and also through the numerous changes of government since that date. Though urged to return to the United States pending a resumption of normal conditions he remained at his post; kept there in that much troubled city, by his very keen sense of duty, to safeguard and protect the Company's large interests in Mexico. It is not too much perhaps to say that his conscientiousness and devotion to duty were responsible for his death. He was taken ill during the early part of March; on the 12th of that month the doctors diagnosed his ailment as typhus fever, and five days later he passed peacefully away at 3:40 p.m.

Besides his widow Mr. Mazenet leaves a step-son, Mr. C. F. Beames, and a step-daughter, Mrs. Edward E. Bashford, who are now residing in Yonkers, N. Y.

His personal friends and associates have suffered a great loss in Mr. Mazenet's death, and the Company has lost a most faithful and efficient employee.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

THE FIRST ELECTRICALLY LIGHTED VACUUM TUBE

Jean Piquard was a celebrated French astronomer and scientist in the 17th century. It is related in his notes dated in 1675 that while he was carrying a barometer through a dark passageway in the Royal Observatory of Paris he noticed a pale flickering light playing in the Torricellian vacuum above the surface of the mercury column. When the barometer was held steady the light disappeared, but shaking the tube provoked its appearance. Piquard was utterly at a loss to account for this strange phenomenon, and so also were his confreres to whom he showed the experiment.

A short time previous to this event a German Chemist named Brandt had prepared a crude form of phosphorus, which naturally glowed in the dark, and the French scientists jumped to the conclusion that there was a close connection between the light seen in Piquard's barometer tube and the glow of Brandt's phosphorus, so they named the former the "mercurial phosphorus" and it passed by that name for many years thereafter. The experiment was repeated over and over again by other scientists, and some barometer tubes would lighten up on shaking, while others would not and so the mystery deepened. The true cause of the flickering blue light of Piquard's *mercurial phosphorus* was finally discovered by Hawsbee early in the 18th century.

It is well known that when mercury is shaken in a *perfectly dry* glass tube, flashes of light may be seen in the dark, which are caused by the static electricity generated by the friction of the mercury against the glass wall of the tube. This condition of *absolute* dryness determined the success or failure of the old experimenters because the least trace of moisture in their tubes effectually damped out the weak static charge that caused the glow. We thus see that Piquard really produced *the first recorded electric light in a vacuum tube*, but the knowledge of electricity was so vague in his day that nobody conceived its electrical origin.

About ten years ago the writer made up some vacuum tubes specially designed to cause considerable mercurial friction when shaken and these tubes emitted quite an appreciable amount of light. These experiments were recently repeated, the tubes being filled with *neon* at a pressure of about 15 m.m. and owing to the high sensitivity of this gas to electrical excitation, the amount of light emitted on shaking them was greatly augmented and it assumed the bright red glow that is the characteristic color of an electric discharge through this gas.

When an air vacuum is used and the exhaustion is carried to a very low pressure, say, 0.001 of a m.m. (1 micron) or lower, the tube will glow with a pale blue light that probably shows a pure mercury spectrum, but this glow may be intensified and changed to almost any color by putting into the tube before it is exhausted some suitable fluorescent substance such as zinc sulphide. This compound under different methods of preparation can be made to fluoresce in a variety of different colors such as blue, green and various shades of yellow. The writer, by these means, has made "Shaker" tubes that exhibit many different colors of light.

Although any commercial application of this device is remote it is at least an interesting scientific development of Jean Piquard's "Mercurial phosphorus."

W. S. Andrews.

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.

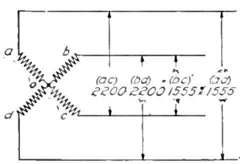
QUARTER-PHASE: VOLTAGE BETWEEN LINES

(166) Given a four-wire, quarter-phase generator of a certain rating, what will be the voltage between each pair of terminals?

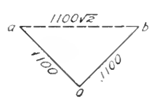
The values of voltage between lines will primarily depend upon whether the two single-phase windings of the generator are interconnected at their neutral points as shown in Fig. 1 or isolated from each other as in Fig. 2. In these diagrams, 2200 volts has been taken as the rated voltage of the generator and the windings are assumed to be carrying equal loads.

Interconnected Windings

The diametral voltage, for example, *ac*, is the rated voltage of the machine and has been assumed to be 2200. The value of the voltage between adjacent terminals, for example, *ab*, is determined in the following manner. The windings *ao* and *bo* generate $\frac{2200}{2} = 1100$ effective volts each, but there is a phase-angle displacement of 90 electrical degrees between these two voltages. Because the windings are connected at *o*, the voltage *ab* is represented by the hypothenuse of a right triangle; this is $1100\sqrt{2}$ or 1555 volts as shown in Fig. 1a.



(166) Fig. 1



(166) Fig. 1a

A complete list of the voltages will therefore be: $ac = 2200$, $bd = 2200$, $ab = 1555$, $bc = 1555$, $cd = 1555$, and $da = 1555$. These readings will be indicated by either an electrostatic or an electrodynamic voltmeter; the latter is the ordinary type of meter.

It should be noted that with the single-phase windings interconnected as shown in Fig. 1 a complete metallic connection is afforded between adjacent terminals, for instance, between *a* and *b* is the unbroken path *aob*.

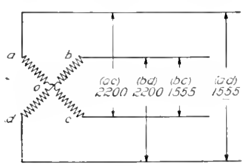
Isolated Windings

Although the two single-phase windings of the generator in this case are not metallically connected, their potentials with regard to each other assume the same relations as those in Fig. 1; this is caused by the capacities between windings being balanced and the capacities of the windings to ground being balanced. Thus, as in Fig. 1, the potential of both windings at *o* is the same and the voltages actually existing are as listed in Fig. 1.

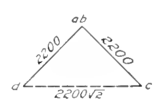
In connection with the case of metallically isolated windings, the following important point should be borne in mind. When each winding is supplying the same load current, the potential relations of the points of one winding to those of the other are affected by capacity only. Therefore, the potential balance between the pair of single phases is likely to be a delicate one and may be greatly altered by a change in capacity at any point. This fact must not be overlooked when *measuring* the voltages between the pairs of conductors of Fig. 2, for the measuring instrument applied may completely alter the equilibrium balance between the two windings.

If an electrostatic voltmeter is applied to measure the voltages between the pairs of conductors, the voltages named (which are the *actual* voltages) will be indicated by the instrument, because it does not appreciably disturb the capacity balance of the system.

If, however, an electrodynamic (ordinary) voltmeter is applied, the normal potential equilibrium will be completely changed and the reading given



(166) Fig. 2



(166) Fig. 2a

on the instrument will be misleading, therefore valueless. For example, assume a dynamic voltmeter connected between *a* and *b*. The voltmeter will be the only metallic connection between the two windings and the potential of two points thus joined will differ only by the impedance drop through the meter, which is so comparatively small that it has been omitted in Fig. 2b. Thus the previous point of common potential *o* between the windings has been supplanted by the common point *ab*, as the result of which the potential equilibrium arrangement shown in Fig. 2b has become established. The dynamic voltmeter between *a* and *b* will give a deflection because of the charging current passing through it, but its indication of volts will not give the *ab* voltage of Fig. 2. The application of the meter, also, has changed the voltage *dc* from 2200 to $2200\sqrt{2}$. Corresponding alterations will take place with each application of the dynamic voltmeter to the other terminals, *bc*, *cd* and *da*.

If four like dynamic voltmeters were applied at once to the terminals, one between *a* and *b*, another between *b* and *c*, etc., correct readings would be obtained for the system would be balanced, the point of common potential between the windings remaining at *o*.

On a very large system the application of a dynamic voltmeter would not have as great a distorting effect as just described.

E.C.S.

CRANE MOTOR: ECONOMICAL HANDLING

(167) Which of the following methods of handling a crane motor will effect the greatest possible saving in current consumption? Give explanation.

(a) To bring the motor up to speed as fast as possible without abusing it.

(b) To bring the motor up to speed slower than described in (a) by making a decided pause on each point of the controller.

The method which will be the more economical depends largely upon whether the motor is a direct- or an alternating-current machine and upon the type of controller that is used.

For example: a series-wound direct-current motor with a standard reversible rheostatic controller will require a smaller consumption of power if method (a) is used, for two reasons:

(1) The torque per ampere of the motor is greater when its fields are fully saturated by a large amount of current than when not so fully saturated. Therefore, the work will be accomplished in a time that is proportionally shorter than the increase of current.

(2) When the controller is advanced as rapidly as possible without injuring the motor, the work of starting the motor is performed in the shortest practicable time; therefore, current is being dissipated in the rheostat for a minimum time only. Of course, the average value of the current taken by the motor through the rheostat during the starting period will be greater for method (a) than method (b), but it will usually happen that, in the apparatus under discussion, the "time" factor of energy consumption has a greater influence than the "current value" factor.

For an alternating-current motor the reasoning given in (1) and (2) would apply only to a limited extent, because when this type of motor draws about 200 per cent normal current or more its torque-per-ampere efficiency will be much less than for a current nearer its normal rating. Therefore whatever will be gained by diminishing the rheostatic losses will be sacrificed by an increase in the motor losses. Consequently, the least possible total current consumption at starting will probably be secured when the controller is advanced just rapidly enough to cause a flow of from 150 to 175 per cent full-load current.

On direct-current series-wound motors the split-circuit type of dynamic braking controller will give results for hoisting similar to a straight direct-current series-wound motor, and for lowering results similar to an alternating-current motor. The power consumption reasoning that applies to machines of these types has been stated in the foregoing.

R.H.McL.

TRANSMISSION LINE: PER CENT VOLTAGE DROP *vs.* APPLIED VOLTAGE

(168) How does the per cent voltage drop in a line vary with a change in the applied voltage?

There is more than one relationship of "per cent voltage drop" to "applied volts," consequently certain limiting assumptions will have to be made.

(1) **Assume Constant Current** (Direct or alternating)

Let V = voltage impressed on line
I = line current
and Z = ohmic impedance of line (equal to square root of sum of ohmic resistance squared and ohmic reactance squared). This can be determined by the physical dimensions of a line and is therefore constant for any given line.

Line drop in volts $= IZ$

$$\text{Therefore per cent line drop} = \frac{IZ}{V}$$

From this formula it will be observed that, *for constant current, the per cent voltage drop varies inversely in proportion to the applied voltage.*

(2) **Assume Constant Kilowatts** (Direct current, or alternating current at unity power-factor)

Let KW = kilowatt input to line
and all other symbols be as previously designated.

$$\text{As before, per cent line drop} = \frac{IZ}{V}$$

$$\text{Now } I = 1000\,\frac{KW}{V}$$

$$\text{Therefore, per cent drop} = 1000\,\frac{KW \times Z}{V^2}$$

From this formula it will be noted that, *for constant kilowatts input, the per cent voltage drop varies inversely as the square of the applied voltage.*

(3) **Assume Constant Kilowatts and Power-factor** (Alternating current)

Let all symbols be as previously designated.

$$\text{Per cent line drop} = \frac{IZ}{V}$$

$$I = 1000\,\frac{KW}{PF \times V}$$

$$\text{Therefore per cent line drop} = 1000\frac{KW \times Z}{PF \times V^2}$$

This formula shows that, *for constant kilowatts and power-factor, the per cent voltage drop varies inversely as the square of the applied voltage.*

(4) **Assume Constant Kilovolt-amperes** (Alternating current)

Let KVA = kilovolt-amperes input to line
and all other symbols be as previously designated.

$$\text{Per cent line drop} = \frac{IZ}{V}$$

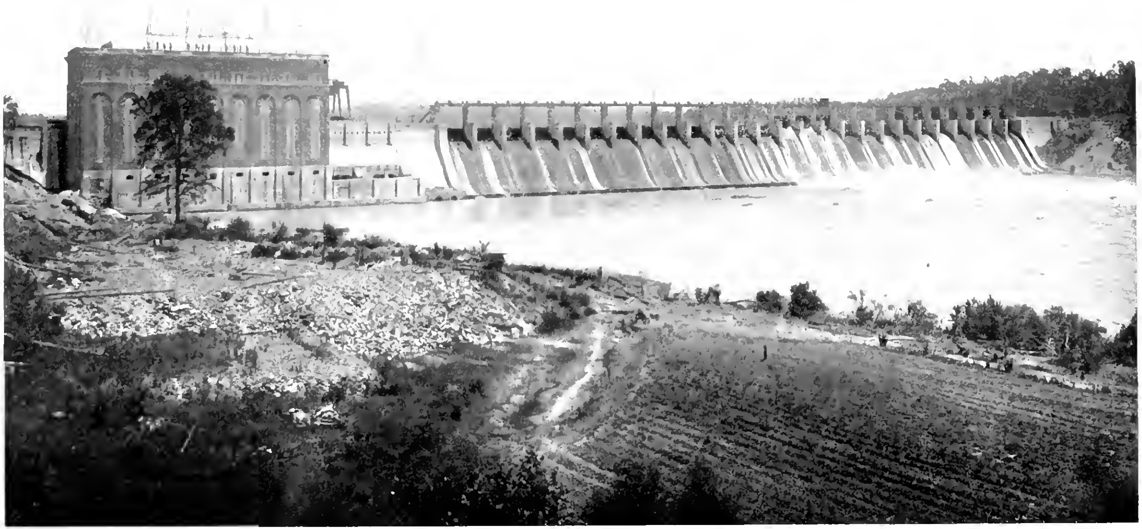
$$I = 1000\,\frac{KVA}{V}$$

$$\text{Therefore per cent drop} = 1000\frac{KVA \times Z}{V^2}$$

This formula shows that, *for constant kilovolt-amperes, the per cent voltage drop varies inversely as the square of the voltage.*

E.C.S.

CONTENTS Continued



HYDRO-ELECTRIC DEVELOPMENT OF THE ALABAMA POWER COMPANY, ON THE COOSA RIVER

(See page 518)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

At about the time the National Electric Light Association holds its annual convention, we usually devote an issue of the Review to subjects especially interesting to those whose activities are devoted to the generation, distribution, and the various applications of electric power. We find it increasingly difficult to write an editorial for such an issue dealing only with generalities as so many articles of this nature are published. But it may be of interest to devote a little space to the prospects of the electrical industry.

We all know that the growth of the electrical industry has been one of the most phenomenal and spectacular of the many great American industrial triumphs, and we all know more or less roughly what has been accomplished in the last twenty-five years, but none can predict with any degree of accuracy what will occur in a few decades. We can, however, have both foresight and faith in our work. We think that there is good cause for the belief that the progress in the future will fully equal that of the past; in fact, there are many indications that in certain directions the slope of our curve of progress will become even steeper.

The inherent characteristics of electric energy that have led to its dominating position in our commercial and domestic life will lead to a greater extension of all its present uses and a continual growth in new applications. There are some fundamental reasons for this. Since the introduction of machinery for manufacturing purposes there has been a constant supplanting of manual labor by machinery—each successive step, although opposed strenuously at the outset, has ultimately proved a benefit to all concerned—the employer, the employee and the consumer. The higher the cost of labor, the more essential it becomes to do as great a percentage as possible of the work entailed in the production of any article by machinery. This means more machines and very specially more electrical machines, as over and above the increase of electric motors necessary to drive machinery of all descriptions we shall constantly witness the supplanting of mechanical operations by electrical operations, such as electric welding as a substitute for riveting, etc.

In the realm of electric lighting the field as yet uncovered is much greater than is often appreciated. There is still a great deal of gas and other illuminants used, especially for street lighting in certain parts of older cities, and for domestic use in localities as yet unreached by central station power. The present day electric lighting industry is enormous, but with the field still left to be covered by both old and new electric lighting units the future seems to hold most brilliant prospects and unlimited possibilities.

In the broad field of traction, where to city, interurban and heavy railroad work we must add industrial railways, electric trucks of all descriptions, the multifarious devices for handling freight, the propulsion of ships, etc., the scope for future developments is as varied as it is immense. Some of these fields, notably city and suburban railways, have for years played an all-important part in our industrial development. The electrification of steam roads is an accomplished fact and the extension of this work in future years is impossible to predict, but it seems safe to assume that this development alone will be enormous. The electric truck, freight handling devices and ship propulsion, although all are more or less well developed up-to-date in certain applications, seem to us to be only in an embryo state compared with what we may expect in the future. The possibilities of the future in these fields seem absolutely limitless.

Electro-chemistry is an extensive industry today, but the future developments in a thousand different lines seem to know absolutely no bounds.

Speculation as to the future of the electrical industry might be extended indefinitely, but the limits of its future possibilities could never be set. Has there ever been an industry that was so all-embracing in its scope—has had such a career—and still possess such infinite possibilities for the future?

ENERGY

By David B. Rushmore

Chief Engineer, Power and Mining Department, General Electric Company

The whole fabric of civilization is so thoroughly dependent upon energy—mechanical energy, as distinguished from the energy of man and animals—that it is impossible to picture the chaos that would result were its sources to become suddenly depleted. About the only sources of energy utilized by the ancients were the winds and waterfalls; but inventions and discoveries have made available to us the vast stores of energy that are cumulated in the fuel deposits of the earth; and where the brook but poorly provided power for simple tasks in the past, our largest rivers are now made to efficiently and economically perform a considerable portion of the world's work. The author has compiled some interesting data on the sources, forms and classifications of energy, and has included discussions and tabulations of the energy that is theoretically available from winds, waves, tides, and solar radiation. The unit of energy, dimensions of energy, energy density, and the conservation and transformation of energy are precisely defined. The article is concluded with some remarks on electric energy, energy storage and transportation of fuel versus electric transmission.—Editor.

D. B. Rushmore

THE electrical industry is becoming one of the most important enterprises of our times. The following figures from the last census give an idea of the magnitude of the electric light, power and railway activities. These are based on the manufacture and sale of electric energy as a commodity.

Central Electric Light and Power Stations
1912

Number of stations	5,221
Total income	$302,115,599
Cost of construction and equipment	$2,175,678,266
Number of persons employed	79,335
Total horse power	7,528,648

Street and Electric Railways
1912

Number of operating companies	1,260
Total income	$621,535,884
Cost of construction and equipment	$4,596,563,292
Number of persons employed	282,461
Total horse power	3,665,051

In the manufacturing and mining industries, figures of which follow, energy in some form is a more or less important part of the cost of the product, and in these fields electrical energy is rapidly displacing other forms for transmission and application.

Manufacturing Industry
1909

Number of establishments	270,082
Capital	$18,490,749,206
Value of product	$20,767,545,597
Number of persons engaged	7,707,751
Total horse power	18,680,776

Mining Industry
1909

Number of mines, quarries, oil wells, etc.	193,688
Number of operating companies	23,664
Capital	$3,662,527,064
Value of product	$1,238,410,322
Number of persons engaged	1,166,948
Total horse power	4,699,910

This large concentration of men and capital in a single industry makes the commodity which they produce, electric energy, of special interest. In this connection a review of the subject of energy in general will be of interest.

The development of civilization has been marked by certain ages or epochs which have been associated with the materials which have been used for weapons or implements, such as the ages of stone, bronze, iron and steel. The progress of the human race has either been the result of or been closely associated with certain inventions and discoveries, such as the bow and arrow, fire, pottery, spinning and weaving, gun powder, the printing press, the steam engine, the telegraph and telephone, electrical machinery, and recent inventions too numerous to mention.

The necessities and common luxuries of life may be said to consist of food, shelter, clothing, transportation, communication, publications, artificial light and heat, etc. These are all composed in part of labor, material and energy, labor consisting of a combination of intelligence and human energy.

The conception of energy is of comparatively recent times, and it is within the last century that the definitions of it have become clear. Energy—often miscalled power—is variously defined as follows:

Kent
"Energy or stored work, is the capacity for performing work."

Barker
"Energy is a condition of matter in virtue of which any definite portion may effect changes in any other definite portion."

Americana
"Energy, in physics and theoretical mechanics: that attribute of a body, or of a material system by virtue of which the body or system can do work; work being simultaneously defined as the overcoming of resistance through distance."

Britannica

"Energy is a term which may be defined as accumulated mechanical work, which, however, may be only partially available for use."

Smithsonian

"When the point of application of a force, acting on a body, moves in the direction of the force, work is done by the force, and the amount is measured by the product of the force and displacement numbers. The dimensional formula is therefore FL or $ML^2 T^{-2}$.

"The work done by the force either produces a change in the velocity of the body or a change of shape or configuration of the body or both. In the first case it produces a change of kinetic energy, in the second a change of potential energy. The dimension formulae of energy and work, representing quantities of the same kind, are identical, and the conversion factor for both is $m^2 t^{-2}$.

Power is the rate of expenditure of energy.

Our whole civilization at present is built upon the use of energy, and were the sources of this suddenly withdrawn a collapse would follow which would bring about a reversion to a very primitive condition.

Most of the energy which we utilize is obtained from coal and petroleum, and on these resources we are drawing in a very reckless manner. As has been said, "The age in which we live—the age of coal—draws its vivifying stream from the dwindling puddle left between the comings and goings of the cosmical tide."

SOURCES OF ENERGY

Energy, as we know it, must all have come originally from the same source. As available today, the sources of energy are as follows:

1. Energy received directly from the sun.
2. Mechanical energy stored in the rotation of the earth on its axis and available from the tides.
3. Energy stored in the form of heat in the interior of the earth.
4. Radio-active substances.

DIFFERENT FORMS OF ENERGY

The different forms of energy as related to the sources listed above may be classified as follows:

The Sun
Direct radiation: Heat and light.
Plant life.
Fuel: Coal, oil, gas, etc.
Muscular energy: Man, animal.
Flowing water.
Wind (in part).

Earth's Rotation
Tides
Winds and waves (in part).

Internal Heat
Volcanoes.
Hot springs.
Geysers.

Radio Activity
Radium.

The Sun

The computed effective temperature of the sun is somewhere between 6000 and 7000 deg. C. and the total quantity of sunlight equals 1575 times 10^{24} candle-power. Its intensity at the sun's surface is enormous; 190,000 times that of a candle flame, 5300 times that of the metal in a Bessemer converter, 146 times that of the calcium light and 3.4 times that of an electric arc.

Disregarding the earth's atmosphere, the energy received per minute per square centimeter exposed perpendicularly to the sun's rays at the mean distance equals 2.1 calories. The earth is therefore receiving energy from the sun at the rate of 1.47 kilowatts per square meter, or 1.70 horse power per square yard. The corresponding intensity at the sun's surface is 4.62×10^4 as great, or 6.79×10^4 kilowatts per square meter $= 7.88 \times 10^4$ horse power per square yard—enough to melt a thickness of 13.3 meters (=39.6 ft.) of ice, or to vaporize 1.81 meters (=5.92 ft.) of water per minute.

The Earth

The earth rotates at a velocity of 15 degrees an hour (about 17.366 miles a minute at the equator); 1 deg. is therefore equal to four minutes. The energy stored up in the rotation of the earth amounts to 10^{23} horse power hours; its orbital energy being about 10^{27} horse power hours. If it were possible to increase the length of day to the extent of only five minutes by decreasing the rate of rotation of the earth, a billion horse power for 70,000 years would be liberated.

The temperature increases on the average about 1 deg. F. for every 60 feet descent, and on this basis the earth would be at a red heat about 10 miles below the surface, while at 30 miles a temperature would be reached at which all known substances would be in a molten state. This increase of temperature is, however, solely a matter of conjecture and many theorists deny the possibility of this thin crust of solid earth enclosing so vast a bulk of molten and liquid matter.

CLASSIFICATION OF ENERGY

From a practical standpoint energy may be classified as *available energy*, or that which can be turned into mechanical energy, *and unavailable energy*, or that which is practically useless for the purpose. To the latter belong the enormous sources of energy stored in the earth's rotation, as well as the interior heat of the earth.

Energy may further be divided into two classes, *potential energy* and *kinetic energy*.

Potential Energy: The energy which a system possesses by virtue of the relative positions of its parts. The word potential does not imply that this energy is not real; it exists in potentiality only in the sense that it is stored away in some latent manner, but it can be drawn upon without limit for mechanical work.

Kinetic Energy: Energy in motion. Available kinetic energy is possessed by a system of two or more bodies in virtue of the relative motion of its parts. Energy may also be classified as

Mechanical
Electrical
Chemical

and also according to the extent with which the various forms are used, such as

Fuel
Flowing water
Winds
Tides
Ocean waves
Solar radiation

and besides these, the muscular energy of man and animals.

FUEL

The most important form of energy is the fuel supply, comprising coal, oil, gas, wood, alcohol, etc. The yearly coal and oil production of the United States is shown in the diagram of Fig. 1, this being approximately 40 and 65 per cent respectively of the world's entire production. This enormous output and drain on these natural resources brings up the question of how long is our coal supply going to last? In answer to this, estimates have been made that there still remains unmined in the world four million million tons of bituminous coal, of which about two hundred seventy-five thousand million tons is in America. The energy densitites of the various fuels are compared

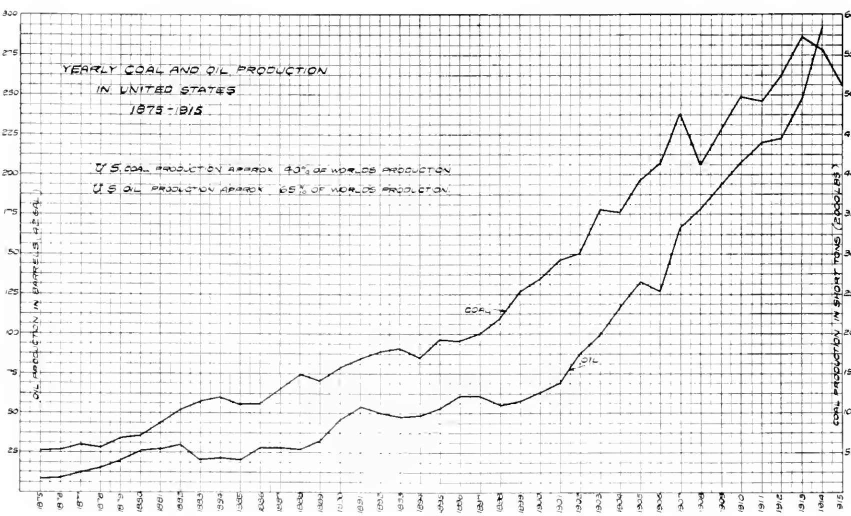


Fig.

on the basis of their heat values, some of these being given in the following table:

COALS

		Calories per Gramm	B.T.U. per lb.
Lignite	low-grade	3526	6347
	high-grade	3994	7189
Bituminous	low-grade	6088	10958
	high-grade	7852	14134
Anthracite	low-grade	12577	6987
	high-grade	7417	13351

Peats (Air Dried)

From Franklin Co., N.Y.	5726	10307
From Sawyer Co., Wis.	4967	8761

Liquid Fuels

Petroleum ether	12220	21996
Gasolene	11400	20520
Kerosene	11200	20160
Fuel oils, heavy petroleum	10500	18900
Alcohol, 7–9% denatured	6470	11646

WATER POWER

It is estimated that the water powers of the world represent about seven hundred million horse power, this estimate being based on the assumption that the water power per square mile is approximately 14 horse power.

Water Powers of the World

Africa	150 millions h.p.
North America	150 millions h.p.
South America	100 millions h.p.
Asia	225 millions h.p.
Australia	10 millions h.p.
Europe	65 millions h.p.

The surveys and examinations necessary to a through and accurate report of the water power resources of the United States have never been completed. Approximate figures, however, place the minimum water power of the country at approximately 31 million horse power and the maximum at 56 million.

In arriving at this minimum value of horse power, the minimum flow for the two lowest seven-day periods in each year for seven years was determined and the mean of these values for the period of record was taken as the minimum flow. It is obvious that this is somewhat higher than the absolute minimum, but the latter is usually of such short duration that it does not equal the capacity in generating apparatus that may be profitably installed. The efficiency of the hydro-electric equipment has been assumed to be 75 per cent.

The assumed maximum power has been based upon the continuous power indicated by the flow of a stream for the six months of the year showing the highest flow. The average flow for the lowest week of the lowest month of these six highest months was then taken as the assumed maximum for the year. The yearly averages thus obtained were then averaged for a series of years. It is common practice, however, to estimate on the continuous power for nine months instead of six, which would of course reduce the amount of maximum power available.

These estimates do not include any storage possibilities, and a commercial development of the maximum power would have to be based on the assumption that it would be profitable to install extensive storage reservoirs as well as auxiliary fuel plants to supplement the divisions during the dry seasons. It may therefore be assumed with confidence that with all practicable storage sites utilized and the water properly applied there might eventually be established in the country a total water power installation of at least 150 million horse power and possibly more. It should, however, not be assumed that all this power is economically available today. Much of it, indeed, would be too costly in development to render it of commercial importance under the present condition of the market and the price of fuel power. It represents, on the other hand, the maximum possibilities in the day when our fuel shall have become so exhausted that the price thereof for production of power will be prohibitive, and the people of the country shall be driven to the use of all the water power that can reasonably be produced by the streams.

Wind

The daily wind velocity at nearly all places in the United States is least from 1 a.m. to 7 a.m. and greatest from 10 a.m. to 5 p.m.; it then decreases to about the same velocity as in the early morning hours. As a general rule the wind velocities are higher at all hours during the winter than during the summer. The highest wind velocities in the eastern half of the United States usually occur in

March, and in the western half in April. The month of least wind is August at nearly all places.

The highest wind velocities recorded have been from 50 to 138 miles an hour on the Atlantic coast, and from 50 to 70 miles an hour in land. On the Pacific coast they increase from 40 miles an hour in southern California to 90 miles an hour at Oregon and Washington. At elevated places and in individual storms the wind velocities have greatly exceeded the general rates given for districts. The highest recorded velocity on the Atlantic Coast was 138 miles an hour at Cape Lookout, which occurred during the great hurricane of August 17, 1879. At Mount Washington it is no unusual occurrence to have a wind velocity of 100 miles an hour. The highest wind velocity ever recorded was 186 miles an hour, at this place, on January 11, 1878.

There is no reason to doubt that wind velocities of severe tornadoes exceed three hundred and probably reach five hunded or more miles an hour.

VELOCITY OF WINDS IN THE UNITED STATES

Average hourly velocity of the wind at selected stations of the United States Weather Bureau; also the highest velocity ever reported for a period of five minutes.

Stations	Miles per Hour: Average Hourly Velocity	Miles per Hour: Highest ever Reported
Albany, N.Y.	6	70
Atlanta, Ga.	9	66
Boston, Mass.	11	72
Buffalo, N. Y.	11	90
Chattanooga, Tenn.	6	60
Chicago, Ill.	9	84
Cincinnati, Ohio	7	59
Cleveland, Ohio.	9	73
Denver, Col.	7	75
Detroit, Mich.	9	86
Duluth, Minn.	7	78
Jacksonville, Fla.	6	70
Knoxville, Tenn.	5	84
Memphis, Tenn.	6	75
New Orleans, La.	7	66
New York City, N.Y.	9	96
Omaha, Neb.	8	66
Philadelphia, Pa.	10	75
Pittsburgh, Pa.	6	69
Portland, Me.	5	61
Rochester, N.Y.	11	78
St. Louis, Mo.	11	80
St. Paul, Minn.	7	102
Salt Lake City, Utah	5	66
San Francisco, Cal	9	60
Spokane, Wash.	4	52
Toledo, Ohio	9	84
Washington, D.C.	5	68

TABLE SHOWING VELOCITY AND FORCE OF WINDS

Description	Miles per Hour	Feet per Minute	Feet per Second	Force in lb. per Sq. Ft.
Perceptible	1	88	1.47	.005
Just perceptible	2	176	2.93	.020
	3	264	4.4	.044
Gentle breeze	4	352	5.87	.079
	5	440	7.33	.123
Pleasant breeze	10	880	14.67	1.492
	15	1,320	22.0	1.107
Brisk wind	20	1,760	29.3	1.968
	25	2,200	36.6	3.075
High wind	30	2,640	44.0	4.428
	35	3,080	51.3	6.027
Very high wind	40	3,520	58.6	7.872
	45	3,960	66.0	9.963
Storm	50	4,400	73.3	12.300
Great Storm	60	5,280	88.0	17.712
	70	6,160	102.7	24.108
Hurricane	80	7,040	117.3	31.488
	100	8,800	146.6	49.200

TIDES

The tide is the periodical rising and falling of oceanic and other large bodies of water, due mainly to the attraction of the moon and sun as the earth rotates on its axis. The tide rises until it reaches a maximum called high water and then falls until it reaches a minimum height called low water. The difference in height between high and low water is called the range of tide. At most ports two high waters and two low waters occur each lunar day, the average interval from high water to high water is about twelve hours and 25 minutes. (Note that the average retardation from day to day is about 50 minutes.)

The range of rise and fall water is also subject to great variation. At the times of new and full moon the tidal forces of moon and sun act in the same direction, whereas at the first and last quarters they oppose each other. When they unite their forces we have *spring tides*, characterized by large ranges of the tide; when they are opposed, *neap tides*, having small ranges.

Attempts have been made to estimate the actual amount of retardation of the earth's rotation caused by tides, but without much success and all that can be said is that the amount is very small. The effect of tidal friction is that the angular motion of the moon around the earth is retarded, but not to so great an extent as the earth's rotation.

AVERAGE RISE AND FALL OF TIDE IN UNITED STATES

Places	Feet	Inches
Baltimore, Md.	1	3
Boston, Mass.	9	8
Charleston, S.C.	5	1
Eastport, Me.	18	2
Galveston, Tex.	1	1
Key West, Fla.	1	2
Mobile, Ala.	1	2
New London, Ct.	3	9
New Orleans, La.	None	None
Newport, R.I.	9	8
New York, N.Y.	4	4
Old Point Comfort, Va.	2	5
Philadelphia, Pa.	6	0
Portland, Me.	9	1
San Diego, Cal.	3	7
Sandy Hook, N.J.	4	7
San Francisco, Cal.	4	9
Savannah, Ga.	6	5
Seattle, Wash.	12	2
Tampa, Fla.	2	2
Washington, D.C.	2	9

The highest tide at Eastport, Me., is 218 inches, while the lowest tide at Galveston, Texas is only 13 inches.

At Rupert Harbor, B. C., the spring tide range is 24 feet and the neap range is 17 feet, the corresponding figures at Burntcoat Head, Nova Scotia being 50.5 and 37.4 feet.

THE ENERGY OF OCEAN WAVES*

The total energy of one whole wave-length of a wave H feet high, L feet long, and one foot in breadth, the length being the distance between successive crests, and the height the vertical distance between the crest and the trough, is

$$E = 8\,L\,H^2\left(1 - 4.935\,\frac{H^2}{L^2}\right)\text{foot-pounds.}$$

The time required for each wave to travel through a distance equal to its own length is

$$P = \sqrt{\frac{L}{5.123}}\ \text{seconds,}$$

and the number of waves passing any given point in one minute is

$$N = \frac{60}{P} = 60\sqrt{\frac{5.123}{L}}.$$

Hence the total energy of an indefinite series of such waves, expressed in horse power per foot of breadth, is

$$\frac{E \times N}{33{,}000} = 0.0329\,\frac{H^2 L}{\sqrt{L}}\left(1 - 4.935\,\frac{H^2}{L^2}\right).$$

By substituting various values for $H \div L$, within the limits of such values actually occurring in nature, we obtain the table on the following page.

The figures are correct for trochoidal deep-sea waves only, but they give a close approximation for any nearly regular series of waves in deep water and a fair approximation for waves in shallow water.

The question of the practical utilization of the energy which exists in ocean waves divides itself into several parts:

1. The various motions of the water which may be utilized for power purposes.
2. The wave-motor proper. That is, the portion of the apparatus in direct contact with the water, receiving and transmitting the energy thereof, together with the mechanism for transmitting this energy to the machinery for utilizing the same.

* From Kent's Handbook.

TOTAL POWER OF DEEP-SEA WAVES IN TERMS OF HORSE POWER PER FOOT OF BREADTH

Ratio of Length to Height of Waves	Length of Waves in Feet				
	25	50	100	200	400
50	0.04	0.23	1.31	7.43	42.01
40	0.06	0.36	1.00	11.59	65.58
30	0.12	0.64	3.64	20.57	116.38
20	0.25	1.44	8.13	15.98	260.08
15	0.42	2.83	14.31	80.94	457.09
10	0.98	5.53	31.29	177.00	1001.25
5	3.30	18.68	105.68	597.78	3381.60

3. Regulating devices, for obtaining a uniform motion from the irregular and more or less spasmodic action of the waves, as well as for adjusting the apparatus to the state of the tide and condition of the sea.

4. Storage arrangements for insuring a continuous and uniform output of power during a calm, or when the waves are comparatively small.

The motions that may be utilized for power purposes are: (1) Vertical rise and fall of particles at and near the surface; (2) Horizontal to-and-fro motion of particles at and near the surface; (3) Varying slope of surface of wave; (4) Impetus of waves rolling up the beach in the form of breakers.

SOLAR RADIATION

Very little has been done in the way of mechanically utilizing the direct radiation of the sun by means of heat engines. It is well known that such engines, in which the solar radiation is concentrated on a boiler by mirrors, are capable of yielding during six or eight hours of sunshine about one horse power per 100 square feet of mirror surface. This country is, of course, not as suitable for such a direct utilization of the sun's energy as the tropical countries.

Much larger possibilities for the fixation of sunshine lie in the artificial reproduction of plant processes. For instance, an obvious cycle which suggests itself is the use of mineral fertilizer to reap a harvest which, dried by the sun, could be converted entirely into gaseous fuel, the ammonia being fixed and returned to the soil as fertilizer together with all the ash. The gaseous fuel could be utilized on the spot in gas engines and energy transmitted wherever it might be needed. Thus with a cycle of forced crops energy might be available even in very large aggregate amounts without making inroads on previously stored energy.

Still larger possibilities of the fixation of sunshine lie in the artificial reproduction of plant processes by the utilization of solar energy in connection, perhpas, with catalytic substances. It has thus already proved possible to obtain ammonia directly from atmospheric nitrogen and hydrogen in this way, and the process thus established should be capable of modifications of even greater importance.

CONSERVATION OF ENERGY

The fundamental principles of energetic conservation are these, stated in terms of mechanical energy as the simplest and most familiar form, but interpretable in terms of any and all known energy-forms.

I. *The First Law of Energetics: the Conservation of Mass.* Mass is *quantity* of matter. It exists eternally. It undergoes local and temporary aggregation or disgregation, ceaselessly; but it is never destroyed nor created.

II. *The Second Law of Energetics: the Conservation of Energy.* Energy is the space-and-motion relationship between separate *portions* of mass. It exists eternally. It undergoes local and temporary accumulation, dissipation and transformation, ceaselessly; but it is never destroyed nor created.

III. *The Third Law of Energetics: the Conservation of Intensity or Availability of Energy.* Intensity is the degree of special *propinquity* and of linear *motion* between the separate mass-portions. It exists eternally. It undergoes local and temporary concentration or diffusion, ceaselessly; but it is never destroyed nor created.

IV. *The Fourth Law of Energetics: the Conservation of Extensity of Energy.* Extensity is the extent of *relationship*, or *mass-pairing*, between the interacting portions of mass. It is what embodies the intensity of energy, to give the latter a habitation and a name with which to do its work. It exists eternally. It undergoes local and temporary accentuation or disguise, through the aggregation or disgregation of mass, ceaselessly; but its sum total is never created nor destroyed.

centimeter. It is called the erg, and is the amount of work required to raise $\frac{1}{981}$ of a gramme vertically through one centimeter. For practical purposes the unit of work is generally expressed in foot-pounds, which equals the work done in lifting a pound one foot from sea level.

TRANSFORMATIONS OF ENERGY

Thermal to mechanical.	Expansion under heat; the steam-engine.
Thermal to chemical.	Dissociation; the lime-kiln.
Thermal to electrical..	The electropile.
Thermal to radiant...	Incandescence; all flames and lamps.
Thermal to biological..	The direct effect of sun-heat upon vegetable and animal life.
Mechanical to thermal.	Impact and friction; compression.
Mechanical to chemical...	Detonation.
Mechanical to electrical.	The dynamo or glass-plate machine.
Mechanical to radiant	(None known.)
Mechanical to biological	(None known—unless the stimulative effect of the slipper of the shingle be admitted to scientific dignity.)
Chemical to mechanical...	The chemical fire-engine.
Chemical to thermal.	Combustion.
Chemical to electrical	Primary and secondary batteries, discharging.
Chemical to radiant	Phosphorescence
Chemical to biological ..	The consumption of animal tissue.
Electrical to mechanical.	The electric motor.
Electrical to thermal	Electrical resistance.
Electrical to chemical.	Secondary batteries undergoing charge.
Electrical to radiant..	Crookes tubes.
Electrical to biological.	Galvanism in medicine.
Biological to mechanical.	Animal activity.
Biological to thermal.....	Animal heat
Biological to chemical	The accumulation of fat and tissue.
Biological to radiant.	Animal phosphorescence; the glow-worm.
Biological to electrical.	Animal electricity; the electric eel.

UNIT OF ENERGY

All kinds of energy are ultimately measured in terms of work, which varies as the resistance overcome and the distance through which it is overcome.

Energy is the capacity or power of doing work. The most appropriate unit for scientific purposes is one which depends only on the fundamental units of length, mass and time, and is hence called the absolute unit. This is independent of gravity or any other quantity which varies with the locality. Taking the centimetre, gramme and second (c.g.s.) as the fundamental units, the most convenient unit of force is that which, acting on a gramme for one second produces in it a velocity of a centimeter per second; this is called the dyne. The unit of work or energy is that which is required to overcome a resistance of a dyne over a distance of one

DIMENSIONS OF ENERGY

Energy has been defined as always consisting of the arithmetical product of two variables. One of these variables has been named the *intensity*, and the other the *quantity*, of energy.

1. Intensity has been shown to be a function of either the *space*-relationship or the *motion*-relationship between two or more mass-portions. The intensity of motion-relationship is proportional to velocity-squared-divided-by-aggregate-mass-involved.

2. Quantity has been shown to be the measure of the amount of *mass-pairing* involved. It is proportional, other things being equal, to the square of the total mass involved. For any given total mass it increases, but not proportionally, with the degree of subdivision of that mass, into mass-pairs capable of embodying the relationships defined above.

ENERGY*

Form of Energy	Factor of Intensity: Name	Factor of Intensity: Unit	Factor of Extensity: Name	Factor of Extensity: Unit
MECHANICAL:				
Potential				
Approx.	Distance	Feet	Force	Pounds
Exact	Propinquity $\left(=\frac{1}{\text{distance}}\right)$	. . .	Mass-squared	c $(\text{lb.} \div G)^2$
Kinetic				
Approx.	Velocity	Feet-per-sec.	Mass	Lb. ÷ G
Exact	$\frac{(\text{Velocity})^2}{\text{Total mass}}$	$\frac{(\text{Feet-per-sec.})^2}{\text{Lb.} \div G}$	$(\text{Mass})^2$	$(\text{Lb.} \div G)^2$
ELECTRICAL:				
Potential	Potential	Volt	Charge	Coulomb
Kinetic	Potential	Volt	Current	Ampere
CHEMICAL				
Potential	. . . .	. . .	Mass	Molecular wt.
THERMAL				
Kinetic	Temperature	Degree (abs.)	Entropy	$\frac{\text{B.t.u.}}{\text{Abs. temp.}}$
Potential	Disgregation	Degree (abs.)	Entropy	$\frac{\text{B.t.u.}}{\text{Abs. temp.}}$

* From Reeves "Energy."

ENERGY DENSITY

The following densities reached by means of different form of energy storage may be of interest:

$$\left(\text{Energy} = \frac{W \times V^2}{2g}\right)$$

Mechanical

Cannon Ball

The energy of a cannon ball *per pound weight* with an initial velocity of 3000 feet

$$= \frac{9,000,000}{2 \times 32.16} = 140,000 \text{ ft. lb.} = 52.7 \text{ watthrs.} = 0.053 \text{ kw-hr.}$$

Steam Turbines

Energy in revolving element, running at a peripheral speed of 1200 feet per second, per pound

$$= \frac{1,440,000}{2 \times 32.16} = 22,400 \text{ ft. lb.} = 0.0084 \text{ kw-hr.}$$

Train

Energy of a train weighing 750 tons running at 60 miles per hour

$$= \frac{750 \times 220 \times 88^2}{2 \times 23.16} = 200,000,000 \text{ ft. lb. approx.}$$
$$= 75 \text{ kw-hr.}$$
$$= 0.00005 \text{ kw-hr. per pound.}$$

Storage Reservoir

A reservoir of 250,000 acre feet capacity and a head of 430 feet with an eff. of conversion = 0.65 contains:

$$\frac{250,000 \times 43560 \times 62.36 \times 430}{2,655,403} \times .65$$
$$= 72,000,000 \text{ kw-hr.}$$

Chemical

Coal	4.1 kw-hr. per lb.
Wood	2.5 kw-hr. per lb.
Petroleum	5.9 kw-hr. per lb.
Gasolene	6.2 kw-hr. per lb.
Alcohol	3.5 kw-hr. per lb.
Natural gas	0.32 kw-hr. per cu. ft.
Coal gas	0.22 kw-hr. per cu. ft.
Water gas	0.10 kw-hr. per cu. ft.
Producer gas	0.05 kw-hr. per cu. ft.
Storage battery, lead	4 watthrs. per lb.
Storage battery, nickel	15 watthrs. per lb.

Electrical

Electrostatic

The energy stored in an electrostatic field with a dielectric strength of one million volts per centimeter is equal to **1.5** watthours per cu. ft.

Electromagnetic

The energy stored in an electromagnetic field with a density of 60,000 lines per cm.^{2} is equal to 800 watthours per cu. ft.

CHEMICAL AND PHYSICAL PROPERTIES OF EXPLOSIVES

Substance	Large Calories Developed by 1 kg. of Explosive	Pressure developed in own Volume, kg. per cm²
40% nitroglycerin dynamite	1221	8235
F. F. F. black blasting powder		
Permissible explosive	780	4817
Nitroglycerin class	760	5912
Ammonium nitrate class	993	730
Hydrated class	610	6597

CHEMICAL ENERGY

Heat of combination of elements and compounds expressed in units, such that when unit mass of the substance is caused to combine with oxygen or the negative radical, the numbers indicate the amount of water, in the same units, which will be raised in temperature from 0 deg. to 1 deg. C., by the addition of the heat.

Substance	Combined with Oxygen		Combined with Chlorine		Combined with S+O⁴		Combined with N+O³	
	Forms	Heat Units	Forms	Heat Units	Forms	Heat Units	Forms	Heat Units
Calcium	CaO	3284	$Ca\ Cl_2$	4255	$CaSO_4$	7997	$Ca(NO_3)_2$	5080
Carbon	CO_2	7796						
Chlorine	Cl_2O	−254						
Hydrogen	H_2O	34154	HCl	22000	H_2SO_4	96450	HNO_3	41500
Magnesium	MgO	6077	$MgCl_2$	6291	$MgSO_4$	12596		
Nitrogen	NO	−1541						
Phosphorous	P_2O_5	5272						
Sodium	Na_2O	3293	$NaCl$	4243	Na_2SO_4	7119	$NaNO_3$	4834
Zinc	ZnO	1314	$ZnCl_2$	1495	$ZnSO_4$	3538		

ELECTRIC ENERGY

When electric energy flows through a circuit, phenomena take place inside of the conductor as well as in the space outside of the conductor. In the conductor, during the flow of electric energy through the circuit, electric energy is consumed continuously by being converted into heat. Along the circuit, from the generator to the receiver circuit, the flow of energy steadily decreases by the amount consumed in the conductor, and a power gradient exists in the circuit along or parallel with the conductor. In the space outside of the conductor, during the flow of energy through the circuit, a condition of stress exists which is called the electric field of the conductor. That is, the surrounding space is not uniform, but has different electric and magnetic properties in different directions. No power is required to maintain the electric field, but energy is required to produce the electric field, and this energy is returned, more or less completely, when the electric field disappears by the stoppage of the flow of energy. Thus, in starting the flow of electric energy, before a permanent condition is reached, a finite time must elapse during which the energy of the electric field is stored, and the generator, therefore, gives more energy than is consumed in the conductor and delivered at the receiving end; again, the flow of electric energy cannot be stopped instantly, but first the energy stored in the electric field has to be expended. As a result thereof, where the flow of electric energy pulsates, as in an alternating-current circuit, electric energy is stored in the field during a rise of power, and returned to the circuit again during a decrease of the power.

The energy relations of an electric circuit are characterized by Steinmetz by four constants as follows:

r = effective resistance, representing the power or rate of energy consumption depending upon the current, i^2r; or the power component of the e.m.f. consumed in the circuit, that is, with an alternating current, the voltage, ir, in phase with the current.

L = effective inductance, representing the energy storage depending upon the current, $\frac{i^2L}{2}$, as electromagnetic component of the electric field; or the voltage generated due to the change of the current, $\frac{L\,di}{dt}$, that is, with an alternating current, the reactive voltage consumed in the circuit $-jxi$, where $x=2\ fL$ and f = frequency.

g = effective (shunted) conductance, representing the power or rate of energy consumption depending upon the voltage, e^2g; or the power component of the current consumed in the circuit, that is, with an alternating voltage, the current, eg, in phase with the voltage.

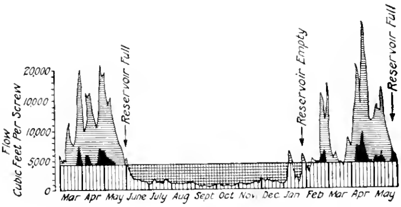


Fig. 2

C = effective capacity, representing the energy storage depending upon the voltage, $\frac{e^2C}{2}$, as electrostatic component of the electric field; or the current consumed by a change of the voltage, $C\frac{de}{dt}$, that is, with an alternating voltage, the (leading) reactive current consumed in the circuit $-jbe$, where $b = 2 fC$ = frequency.

Storage

It is fortunate that energy may be conveniently stored in several ways and drawn upon according to the demand. The simplest form of energy storage is thus found in the chemical energy of our vast natural fuel deposits. Water storage is the next important form. It is of vital importance in increasing the capacity of hydroelectric developments at times of low water, the extent to which a regular stream flow can be utilized depending to the greatest extent upon the quantity of such a storage. The influence of storage reservoirs on such an irregular stream flow is shown in Fig. 2. Electric energy is readily stored in storage batteries, although much is to be expected in improving this method.

The function of flywheels in storing mechancial energy during periods of light load and delivering a part of this stored energy during periods of heavy load has been well understood for a long time. In many cases, however, full advantage has not been taken of the benefits of flywheels because their exact action has not been fully known. Flywheels in recent years are being utilized increasingly either to secure a more uniform speed or to reduce the fluctuations in the power required to drive some machine.

Transportation of Fuel vs. Electric Transmission

An interesting similarity exists between the transmission of electric energy and the transportation of commodities. Energy may be transmitted electrically or transported mechanically as is done with coal and oil. Every industry has its waste products and economy is best obtained where these are utilized. In the preparation of commercial sizes of coal there is obtained from the breakers and crushers a refuse known as culm which is unmarketable and which at present has no commercial value except as it may be made into briquettes. In connection with the use of electricity in coal mines it is therefore interesting to consider the economical use of this by-product or waste coal in commercial form. The best and largest development of the kind in this country is that of the Lehigh Navigation Electric Company at Hauto, Penna. The refuse from preparing the marketable coal of the Lehigh Coal & Navigation Company is sufficient, it is estimated, to supply continuously a power house of 100,000 kw. rated capacity. This power will be used for the company mining operations, and also sold to neighboring industries as well as to public utilities that are accessible.

Other developments, both in this country and Europe, have been and are being made to sell not only the refuse coal but also the output of the mine as a whole in this way. Especially noteworthy are the many studies which have thus been made with regard to the possibility of utilizing the culm piles of of Pennsylvania in this manner, but the burning of the finest coal dust alone has not yet met with complete success.

THE INHERENT ECONOMIC ADVANTAGES OF ELECTRIC POWER

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

Electrical energy has certain inherent characteristics which have led to its displacing the steam engine for innumerable purposes, and to its occupying many new and hitherto undeveloped fields in industrial and domestic life. Dr. Steinmetz shows what these characteristics are, and how they have brought electric energy to occupy the place that it does in our modern civilization. He not only talks of the past and present tendency, but shows what some of the future tendencies are likely to be.—Editor.

Charles P. Steinmetz

Considering that the first attempts at the industrial use of electric power were made within the memory of the present generation, the enormous development of electric power application appears one of the greatest wonders of modern civilization. In mill and factory, in home industry and domestic use, the electric motor is replacing the steam engine and finding new applications. And still we realize that we are only in the beginning of the electrical development, and are progressing with increasing rapidity. We can see the direction in which progress tends and estimate with fair accuracy what the outcome will be, for indeed in some places the development has progressed far enough to see the plans of the complete structure of electrical development which economic laws are erecting before our eyes—the universal energy supply by electricity, for all purposes of our civilization, from a network of electric transmission lines fed by huge steam and water-power stations.

The characteristics of electric energy, which have made it available in the huge problem of organizing the world's energy supply, are the high efficiency and simplicity of transmission over practically unlimited distances, the economy and simplicity of distribution, the practically unlimited subdivision of electric power without material loss of efficiency, and the very great simplicity and high efficiency of conversion of electric energy into any other form of energy: power, light, heat, chemical energy, etc.

Large sources of power have been made available by electrical transmission, such as the water powers, cheap fuel, etc., which were practically useless before, as the power could not be transmitted, and the industry or city as user of power could rarely be located at the source of power, the water-fall or coal mine. The location of the power generating plant became more independent of the place of power use, and could be so chosen as to secure the highest economy of generation. Various demands for power could be supplied from one generating station, and thereby the higher economy of large production realized. All this tended to increase the amount of power available for industrial use, increase the economy and production, and thereby reduce the cost of industrial power.

More important still is the possibility of economic distribution and unlimited subdivision of electric power. By far the largest amount of power used in the country today is generated by the steam engine or steam turbine, whether used directly at the place of generation, or transmitted and distributed electrically. The steam engine—and more so the steam turbine, which is rapidly taking its place—has a high economic efficiency in large sizes, but its economy decreases with decreasing size, until finally for small sizes its use becomes economically impractical. The gas engine is available for still smaller sizes, but finally also reaches its economic limit, and for many industrial power demands and for purposes practically domestic there is no available source of power but electric energy.

Numerous causes combine to produce this formidable dropping off in economic efficiency of steam power: the rapid decrease of conversion efficiency with decreasing size, the increase of investment, of space occupation, etc., the increasing cost and inconvenience of care and operation, more particularly in such features as the handling of coal and ashes, the increasing cost of maintenance, and especially, the requirement of skilled attendance and supervision, which is economically feasible in large plants, but impracticable in the small plant, due to the cost of such attendance. It is this last feature, which, though very difficult to reduce to exact figures, and more difficult still to defend in controversies regarding relative economy of steam power generation and electric central station service, is the most formidable disadvantage of the small plant, and the most frequent cause of economic failure of small isolated plants and small municipal stations, however superior in cost of power generation they may appear in the financial estimate of cost of power production.

On the other hand, the electric motor requires no skill in operation, hardly as much as is required in the steam plant to shift the belt from the idler to the working pulley, and its efficiency does not appreciably fall off with the size, for a small fractional horse power motor converts practically all the electrical energy into mechanical work, just as does the big 10,000-horse power motor: the one may lose 5 to 10 per cent, the other 10 to 15 per cent of the energy—hardly as much as would be lost in the belt driving from a counter shaft.

Thus electric power can be subdivided, numerous motors used, of all sizes from that driving a single spindle in a cotton mill to the 10,000-h.p. motor driving the rolls in the steel works, and each can be located at the place where the power is used, receiving its electric power from the steam turbine plant conveniently located in the works, or, as is becoming more and more the case, from the transmission system supplying cities and industries.

The unlimited subdivision of electric power has made energy available where it is very badly needed, but needed in such small individual amounts that it can not be supplied by any other means, such as in small shops and industries, and especially in domestic applications, in fan motors, for driving sewing machines, vacuum cleaners, washing, refrigeration and numerous uses of power in the domestic household—a field which is just being opened up, and where electric power is and must remain without competition, and where the absence of an available source of power was really the most serious handicap in our modern civilization.

However, it was not alone the subdivisibility of electric energy which opened this vast field of power application; chemical energy also can be subdivided without practical limit. Thus in a small piece of coal we have an energy supply not greater than that required by the domestic fan motor of our homes, but we can not run a fan or a sewing machine with a piece of coal as supply of energy, as we can run it with a kilowatt hour of electric energy.

It is the simplicity and reliability of conversion of electric energy into practically any other form of energy that has made its subdivisibility so essentially useful; while the subdivisibility of chemical energy is of little use, as we can not convert it into other forms of energy, except perhaps heat, and even there we meet limitation when coming to small energy demands. Thus the usefulness of electric energy is essentially the result of its convertibility.

If we use the steam engine as source of industrial power, we have one engine for the factory, or at most one engine for every shop, located in an engine room, under skilled attendance and supervision, and from there the power is distributed by shafts and counter shafts, with numerous belts, all eating up power, whether all the machines in the shop are going, or only one. We can not put a steam engine, with boiler and condenser, ash and coal handling devices, at every lathe or loom, and start it whenever we start the lathe: it takes hours to start the steam plant, so long indeed, and so wasteful is it, that it is not economical to completely shut down over night, so we keep the boilers hot, the fires banked. But we can, and do have a motor at every loom or lathe, starting whenever we need the machine, and stopping when we are done with it; no more power is consumed than is demanded by the work done; no big engine wasting hundreds of horse power, to supply a horse power to a single machine kept at work on overtime. The electric motor thus has made it possible to produce the power where it is used, and only when it is used, without requiring skill or attention, and this is probably the foremost advantage of electric power—anybody can use it.

Therefore, even where steam power generation is used, experience has shown it to be more economical to convert to electric power in the steam station located within the industrial plant, and transmit and distribute as electric power to the places of power demand, even where the distance of electric transmission is only a few feet, as from the turbo alternator to the induction motors driving the propellers of the battle ship.

The same advantages, of being there all the time, available for instant use and instant stoppage, with the highest reliability and without requiring special skill and knowledge, apply also to all other uses of electric energy, in its conversion into light, heat, chemical energy, etc., etc.

But there is a far broader aspect in the relation of electric power to modern industry, beyond the superiority in efficiency, reliability, simplicity and convenience of operation, and no requirement of special skill.

Modern industrial civilization is based on specialization by subdivision of production, to secure the economy of standard production on a large scale. Thus while in the colonial days the furniture maker may have cut down the trees for timber, sawed them into boards, shaped them, made his glue and his varnish, all this is now subdivided into a number of separate industries, from the lumber industry and saw mill to the varnish making, each a big industry in itself. It is true, the furniture industry may control saw mills and lumber rights, as the electrical industry may own copper mines and control steel mills, but this is to safeguard supply, and the relations between the coordinate industries is financial and administrative only; they remain separate and distinct industries, separate in management and operation, each within its specific work, to secure maximum economy. In reality each of these industries, the cattle raising, slaughtering, tanning and leather making, shoe making, etc., which go together to produce a pair of shoes, really comprise two separate industries: each requires power, and each thus has attached to its specific industrial production the production of power.

But power production has no more relation to shoe making than to cattle raising, and thus under the present—or rather, under the pre-electric condition—the subdivision of industrial production was not carried as far as best economy demanded, but two heterogeneous industrial productions were still joined together, and one necessarily had to suffer in economic efficiency. Usually, this was the power production. The management and organization, competent to give best economy in shoe manufacture or furniture making, can not expect the same economic results in power production as are possible to a specific power producing industry. If it could, the economic principle of subdivision of industrial operation would be a fallacy.

With the enormous power demand of modern industry, power production thus must become, and has become a separate industry, and can no longer be handled as an incidental side issue of other industries, if highest economy is to result. This has become possible by the use of electrical energy.

The foremost economic advantage resulting from the development of electric power in modern industrial civilization is, therefore, the complete subdivision of industrial operation, by segregating power production and supply from other industrial operations, and it is only electric energy that has the qualifications in transmission, distribution, and conversion which make possible such segregation of power production and supply from industrial power use, and thereby can give that higher economic efficiency resulting from specialization.

MODERN SWITCHBOARD PRACTICE

By John W. Upp

Manager Switchboard Department, General Electric Company

The author deals with the modern trend of switchboard development, showing particularly to what degree switchboard design is affected by the consideration of safety to operators and reliability of service. Some of the different types of apparatus are discussed in detail and are illustrated. He strongly recommends the use of standard apparatus, showing the advantages to both the user and the manufacturer of eliminating the unnecessary expense entailed in the design and construction of special devices.—Editor.

John W. Upp

THE development of switchboards and control equipment has never received more active attention than is required at the present time. The demand for circuit interrupting devices of large capacity, the increasing size of generating stations and individual units, the necessary protection of interconnected stations, substations and systems, the use of control apparatus for outdoor installations, and the highly commendable nation wide safety first campaign give designing and operating engineers a hundred problems today where they had but one problem ten years ago and demand the maximum skill in mechanical and electrical construction.

Safety and dependability specifications predominate in every proposition for a modern switchboard control equipment, and while these specifications may vary in degree, being determined by the character of the service, they are always factors of prime importance Not only must the largest unit in the central station be controlled, but the smallest machine in the customer's premises must be operated and protected.

The oil break circuit breaker is the most important control and protective device used in switchboard work, and because different types vary materially in cost, dimensions and design, it is necessary for the purchaser to analyze his requirements most care-

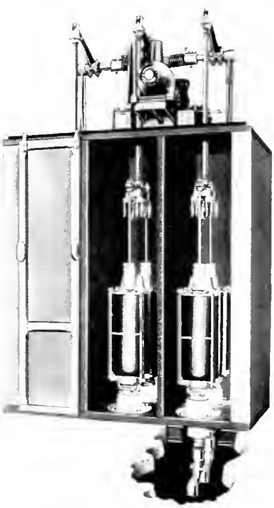


Fig. 1. Oil Break Circuit Breaker with Two Tanks in each phase, and phases isolated from each other

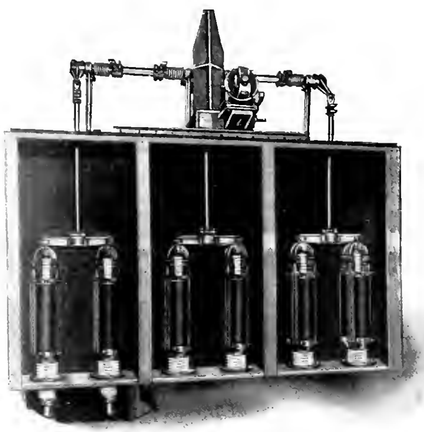


Fig. 2. Oil Break Circuit Breaker with Tanks Arranged in Tandem and Separated by Barriers

fully. He will study service conditions and when selecting his control equipment will give attention to his immediate and future requirements, a greater first cost being warranted if the near demand is likely to be of such proportions that the first installation can be considered as a part of the complete system rather than on its individual merits. The manufacturer is always ready to co-operate by giving advice and assistance in the selection of the type of circuit breaker best adapted to the stated conditions and freely furnishes information on the service operation of the types of circuit breakers recommended.

In the more important stations where it is necessary to prevent trouble in any one circuit or phase being communicated to other parts of a station or system, the oil break circuit breakers are located in separate compartments; and in some cases barriers isolate each phase, and even each oil tank is separated if additional safety factors are desired.

Fig. 3. 35,000-Volt Oil Break Circuit Breaker Mounted on Framework. Each phase in a separate oil tank

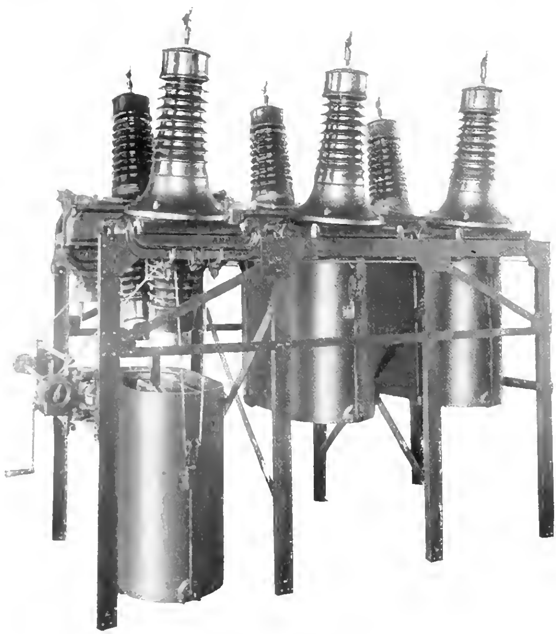


Fig. 4. 70,000-Volt Oil Break Circuit Breaker Mounted on Framework. Each phase in a separate oil tank

The oil break circuit breaker with the highest rupturing capacity which has so far been put into service is of the general type shown in Fig. 1, and its ultimate development with maximum isolation in Fig. 2.

It will be noted that there are two oil tanks in each phase. These are of maximum strength to withstand the shock of short circuit and of minimum size to reduce the amount of oil. This form of circuit breaker is more expensive than those in which each phase is opened in a single oil tank, but adds such a large factor of safety for general operating and emergency conditions that the extra expense is fully warranted.

For stations of lower capacity, circuit breakers of the form shown in Figs. 3, 4, 5 and 6 are more frequently recommended. Such breakers are subject to many modifications, round, oval and rectangular tanks being used, but the illustrations are typical. Stations of medium size have combined single-phase switches for each circuit and

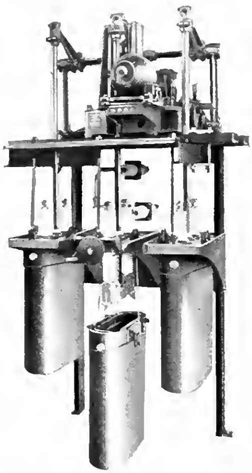


Fig. 5. Motor Operated 15,000-Volt Oil Break Circuit Breaker for Cell Mounting

those of less importance have all phases in one oil tank. This form of circuit breaker, because of its simplicity, is less expensive, but cannot give the high protective value of the form first mentioned and shown in Figs. 1 and 2.

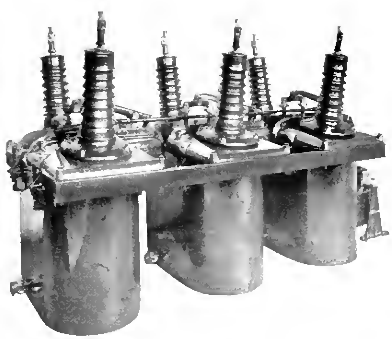


Fig. 6. 45,000-Volt Oil Break Circuit Breaker. Four breaks in each phase, and each phase in a separate oil tank

All the circuit breakers previously illustrated lend themselves to installation in, or as a part of, the bus structure and can be either controlled at that point or electrically or mechanically controlled from a distance. As they can be operated in a similar manner, there is less difference in the structure of the control panels in stations of different capacities than there is in the oil break circuit breaker construction. In Fig. 7 a very good illustration is given of a bench control board which is adapted to be located in a station gallery. This, of typical construction, is but one of many types in general use in both main and substations of moderate voltage. The control board groups all the instruments and control switches in convenient form and gives both mechanical and electrical indications of the position and condition of each device which is operated from the board. The live parts, if any, operate at low voltage and no special precaution is necessary to keep the operator from coming accidentally in contact with live circuits.

Where the distribution stations are located at such a distance from the generating station that the generating voltage can no longer be

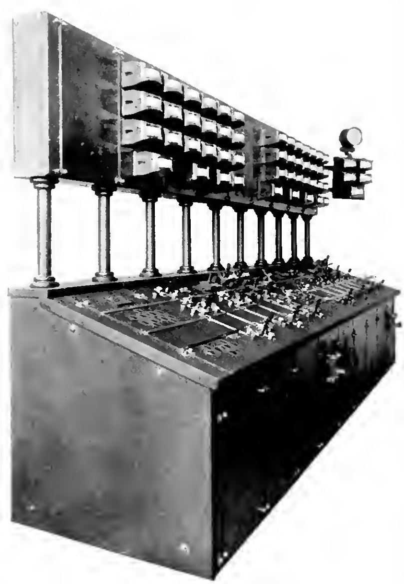


Fig. 7. Gallery Type Benchboard

economically transmitted, it is usually found economical to place the control equipment out of doors, as the indoor station space factor involved with voltages of 45,000 and above adds materially to the installation cost. While there are still some unsolved problems in outdoor equipment, the results so far obtained from these installations have removed the doubts of a few years ago and have replaced fear with confidence, and the experience which has been obtained from hundreds of outdoor installations enable the engineer to state that his designs for systems of this character will be as free from operating difficulty as the reliable devices which have been used for indoor service.

The type of oil break circuit breaker recommended for outdoor installations is shown in Fig. 8, and a complete installation of outdoor apparatus in Fig. 9.

In all switchboard designs the protection of the employee is given careful attention, but it is not so necessary to protect each device against accidental contact in a central station as it is in the industrial plant. It is, therefore, for industrial establishments that there has been the greatest change in the character of switchboard panel construction. These plants are usually of moderate voltages, rarely less than 440 or more than 2300 volts. The employees have less experience with electrical

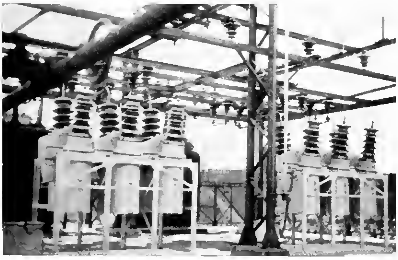


Fig. 8. Outdoor Oil Break Circuit Breakers

devices and the panels must frequently be so located that employees without any electrical knowledge whatever have access to them. For these plants the development illustrated in Figs. 10 and 11 is peculiarly adapted. The first cost is slightly higher than for the type of industrial switchboard shown in Fig. 12, but it has the advantage that when once installed it protects every employee from every sort of accidental contact with live parts. It also has a marked advantage because of the ease with which inspection or replacement can be

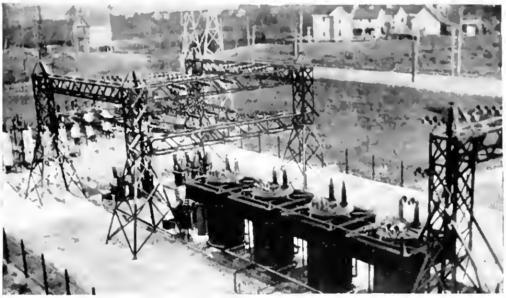


Fig. 9. Outdoor Substation

effected, since a panel can be completely removed from the switchboard. As the illustration shows, the panel is mounted on a carriage and can be easily removed from the complete structure. This carriage cannot be removed, however, until the oil break circuit breaker is opened, neither can it be put in place if the oil break circuit breaker is closed. In industrial plants of importance where feeders are standardized, spare panel carriages are provided, permitting the systematic inspection of equipment without interruption of service. Switchboards of this type are coming more and more into general use, because there is an earnest desire on the part of the employer to protect his workmen, and because it gives simplicity in operation that cannot be obtained by other construction.

In the industrial plant it is also necessary to provide control equipment for the individual machine. This has been taken care of by the design of completely protected switches such as those illustrated in Figs. 13 and 14.

With this form of protected switch it is not only impossible for the workman to come into accidental contact with the live parts, but the switch can be locked in the open position so that he can inspect or make repairs on his machine without danger of it being started during the time of such inspection. It also prevents the workman changing or modifying the fuses as the switch box can only be opened by an authorized employee whose business

Fig. 10. Safety-First Switchboard Unit. Removable Element just entering compartment

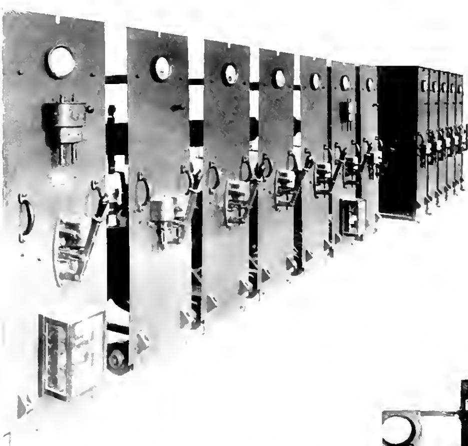


Fig. 11. Safety-First Switchboard Units in Process of Assembly

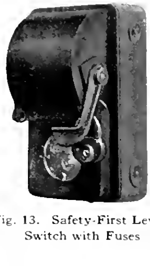


Fig. 13. Safety-First Lever Switch with Fuses

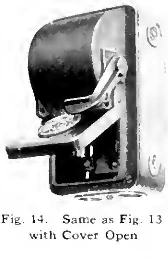


Fig. 14. Same as Fig. 13 with Cover Open

it is to make such adjustments or replacements.

It is the aim of the designing engineer to encourage conservatism in the selection of circuit interrupting devices, for he realizes that interruptions in service which are serious in stations of small capacity are possibly disastrous when they affect a 50,000-h.p. turbine generator. A customer's best interests are safe guarded when the apparatus recommended has a liberal factor of safety, for the cost of control equipment is but a fraction of the cost of the whole station, and the failure of a circuit interrupting device may jeopardize the total capital invested in the station. Fortunately, interruptions to service in the modern station are of rare occurrence. But there are cases where the purchaser has not been over conservative in selecting his control equipment, and while he may have satisfactory operation for a time, the emergency may arise which will make this lack of conservatism very expensive.

The designing engineer is also doing everything in his power to encourage the standardization of equipment. There is a distinct effort being made on the part of the operating engineer to co-operate in this effort, for there are now entirely too many kinds of apparatus to warrant the economical manufacturing costs which would be possible if a greater effort were made in this direction. If more complete standardization can be

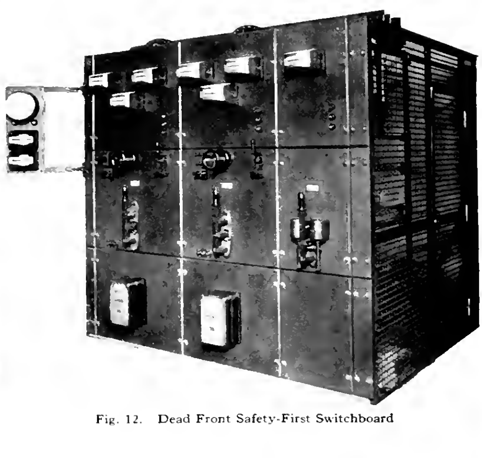


Fig. 12. Dead Front Safety-First Switchboard

effected, the purchaser will be the one who will receive the greatest benefit. His stations will cost less, they can be designed with greater uniformity and the manufacturer will in turn benefit because he will be able to produce a larger quantity of apparatus with given equipment. It is to be hoped that the work now being done by the several engineering societies through, the appointment of committees for this purpose, can be greatly enlarged and speeded up, and that the day will come when the purchaser can buy his station apparatus in unit design and in such quantities that there will be a minimum cost for his total equipment.

MODERN TRANSFORMERS FOR USE IN LARGE SYSTEMS

By W. S. Moody

Engineer Transformer Department, General Electric Company

This article discusses many important features of transformer design. The mechanical forces, both normal and abnormal, are dealt with. Thermal considerations are discussed, and the general features and relative advantages of the core type of construction are considered, entering into details concerning the core, windings and tanks.—Editor.

W. S. Moody

General

The principal magnetic, electrical and mechanical features involved in the design of a static transformer have, of course, been well known to engineers for years. Recent extended research and investigation by both the designing and operating engineers has, however, added a vast amount to this accumulated data. Study and analysis of this information has exerted a great influence on the modern design of transformers suitable for use in large power systems.

Mechanical Forces

The familiar statement that a static transformer has no moving parts is, or at least should be true, but the magnetic forces exerted even at normal load are capable of moving large masses, and as such forces increase as the square of the current flowing through the winding, they may assume great magnitude should the transformer be called upon to withstand a short circuit.

Formerly it was general, and even now is the too common practice with some designers, to assume the magnitude of these forces and to provide such mechanical supports as might be sufficient, *provided too severe a short circuit was not developed.* With the capacity of generators now often found in a single station, a complete short circuit, i.e., one in which the external resistance is zero and the primary voltage is sustained at practically normal (even if the transformer is several thousand kv-a. capacity), is not an uncommon occurrence. To guess at the magnitude of the forces created by such conditions is inexcusable.

The most natural procedure to follow to prevent damage is to increase the strength of the supporting structure. This may be called a brute force method of designing, as it is based principally on impressions made by previous unfortunate experience and does not go back to the sources.

The logical and more scientific procedure to follow is first to so design the windings as to reduce these forces as much as possible, and then after a determination of their magnitude, by calculations checked by test, to design both the coils and the supporting structure to withstand the stress. The first step in the reduction of the forces is to increase the reactance of the transformer to as great a value as is allowable for the voltage regulation. From four to six per cent is seldom objectionable, and still higher values are perfectly practical on high voltage systems, unless accompanied by unusually low power factor; and in such installation the operating engineers are now quite generally appreciative of the disadvantages of transmitting wattless current for any great distance when synchronous motors or rotary condensers, placed at the receiving end will

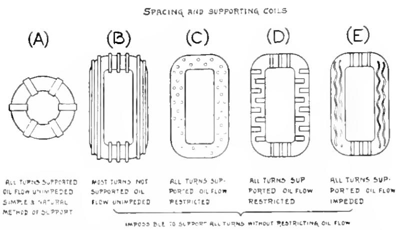


Fig. 1. Samples of different methods of supporting turns in different coil structures. (A). Circular disk coil having all turns properly supported, without impediment of oil circulation. Coil and supporting structure ideal from electrical, mechanical and thermal considerations. (B). Poor supporting structure for rectangular coils, except end portions. Weak mechanically, has blanketed turns which give high local temperatures. (C). Disk or button construction for supporting structure. Every turn is supported. Gives slight impediment to oil circulation. (D). Good mechanical construction for rectangular coils, but highly objectionable because of interference with oil circulation. (E). Effective mechanically, if all turns are supported; otherwise weak mechanically. Generally objectionable because of impediment to oil flow.

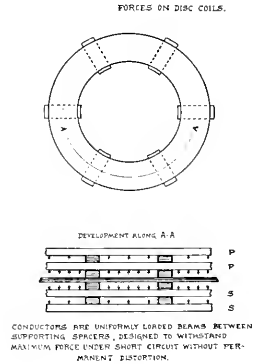


Fig. 1A

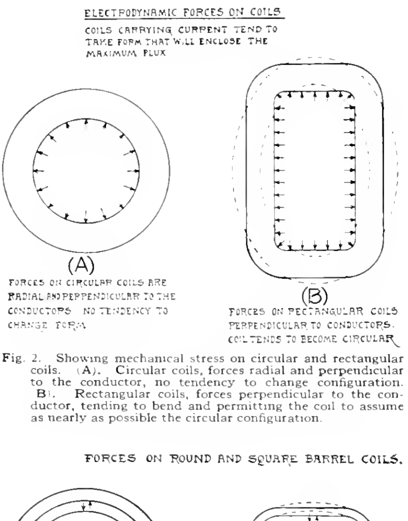


Fig. 2. Showing mechanical stress on circular and rectangular coils. (A). Circular coils, forces radial and perpendicular to the conductor, no tendency to change configuration. (B). Rectangular coils, forces perpendicular to the conductor, tending to bend and permitting the coil to assume as nearly as possible the circular configuration.

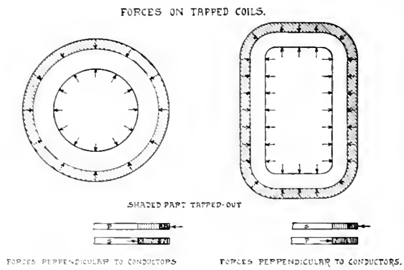


Fig. 2A

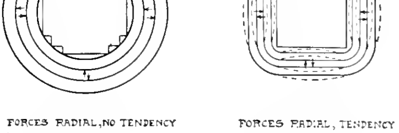


Fig. 3

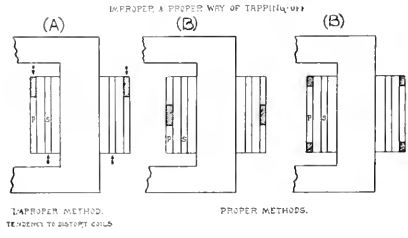


Fig. 4. Incorrect (A), and correct (B) methods of tapping cylindrical coils of core type transformers to maintain magnetic balance between windings and to prevent magnetic forces destroying coil structure.

so easily avoid the necessity of so doing, and at the same time will give so greatly improved voltage regulation to the system.

The next step is to choose such a shape for the conductor and coils and so to group the coils as to give a maximum strength and a minimum stress within the structure. It should not be assumed that a high reactance design is for that reason alone, a safe design. Coupled with the high reactance must be moderate stresses and ample inherent strength in coil structure and external supports.

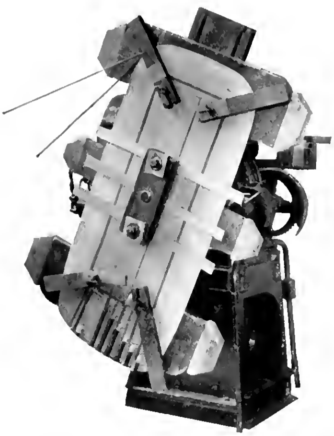


Fig. 5. The difference in tension applied in winding a rectangular coil is illustrated by the difference in lever arm, i.e. the difference in distance from the spindle to the corner and the distance from the spindle to the sides. Uniform tension is impossible to result in such a coil structure.

Excessive Voltage and Frequency Strains

Practically no well designed high voltage transformer fails from excessive voltage if protected by suitable lightning arresters. Even should no lightning arresters be used, arcing over the line insulators will usually prevent the accumulation of any great excess voltage from line to ground or line to line at normal or moderately high frequency. Failure of the insulation of a high voltage transformer is, therefore, almost always due to relatively low potentials at excessive frequencies, occasioned by switching or by arcing grounds and at frequencies many hundred times the normal of the system. These high frequency stresses being imposed upon, or generated within the transformer, may be of so high a frequency as to have several wave lengths within the mechanical length of the conductor constituting the winding, in which case the arithmetical sum of the voltages across different and frequently adjacent portions of the windings may be many times the voltage across the whole winding. Still higher voltage per unit of length may be thrown on the end turns and coils by a steep wave front, which is simply a voltage of such high frequency that it cannot penetrate the windings until its wave form is changed.

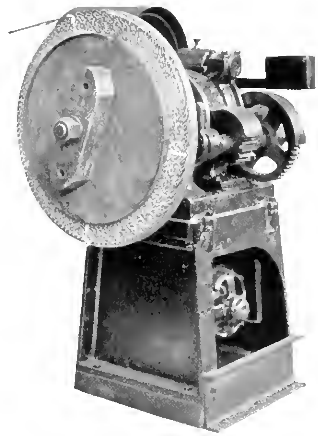
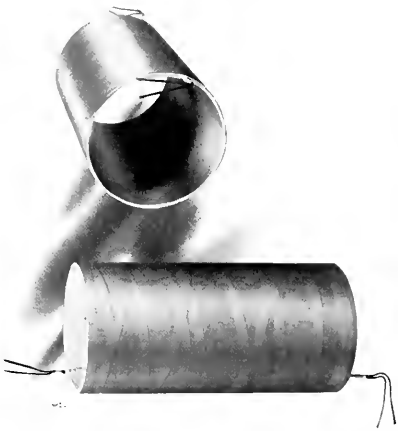


Fig. 6. Uniform pressure on the insulation and tension on the conductor in all parts of the winding is indicated by the constant distance, i.e. the lever arm, between the conductor and the spindle of the winding form.

The distribution of such high frequency and steep wave front voltages within the winding is dependent on the self-inductance and the capacity of the windings themselves, and much may be done to avoid concentration of these voltage stresses at objectionable points by a proper and scientific consideration of these factors in selecting the coil configuration and grouping. The present accepted and standardized practice of testing windings at double normal excitation, considered as a test for these high voltage strains, is so insufficient as to be rather a disgrace to the profession, in the face of experience that has shown the necessity of insulation from 50 to 1000 times as much as this test voltage requires. The writer is confident that some practical and rational method for testing internal insulations will soon be developed.

Thermal

The two sources of heat generation in the transformer are the core and the winding.



Mig. 7. Cylindrical coil construction for core-type transformers used principally with conductors on edge as the low voltage winding for core-type transformers, the high tension winding generally being circular disk coil.

Thanks to the non-aging silicon steel, the dissipation of heat from the core is no longer a serious problem. All that is essential is sufficient core surface to prevent the disintegration of oil which may come in contact with it. Internal high core temperature is entirely unobjectionable, in fact may be desirable, in that it slightly reduces the eddy current loss. In the windings the antithesis of this condition exists. Not only should high temperatures be avoided, but uniformity of the temperature throughout the structure should be absolutely maintained. The problem of properly ventilating, and yet effectively supporting, the windings gives the greatest opportunity for the exercise of skill in arranging ducts around the winding as a whole and throughout the coils so as to prevent any local hot spots. The trite expression that a chain is no stronger than its weakest link seldom has better application than in a transformer winding which has one or more local hot spots.

General Types

From earliest days the two general classifications of transformer structures have been designated as "core type" and "shell type," which are dependent upon the configuration of the magnetic circuit and the location of the windings. The shape of the core is of minor consequence, but the forms of winding which the General Electric Company has

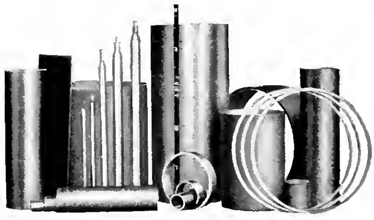


Fig. 8. Insulating material of highest grade, combined with great mechanical strength, the development of which has contributed materially to the recent advance in circular coil transformers for high voltage and large capacity.

from time to time developed since it began to exploit the "core type" construction, some twenty years ago, are so distinct and superior

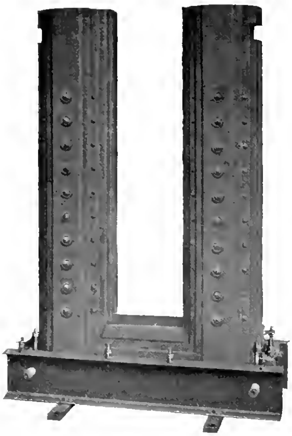


Fig. 9. Bolted laminations of circular disk coil, core type transformer, 5000 kv-a. Ventilating channels in yoke and leg members clearly shown. Rigid core structure well illustrated.

as to popularly be considered synonomous with "core type" designs.

Core

Magnetically, the mere form of core structure; e.g., whether circular, cylindrical or rectangular coils are used is of little consequence. With the same density of magnetization and with the same mass of iron surrounding a given winding space, the core loss will not differ greatly and the temperature rise of the core will be the same provided an equal surface is exposed.

Windings

The winding with its insulation is the vital part of the transformer, and herein is where the core type construction, which has popularly come to mean an approximately circular cross section in the core and a circular shape in the coils, evidences its superiority over the shell type (rectangular core and rectangular coil) construction. While it has been found possible to design transformers using rectangular cores and rectangular coils that will successfully withstand the mechanical stresses due to short circuits and the voltage stresses resulting from high frequency, such designs are generally needlessly difficult of execution, and cannot have, with a commercial cost, any such factor of safety as is desirable.

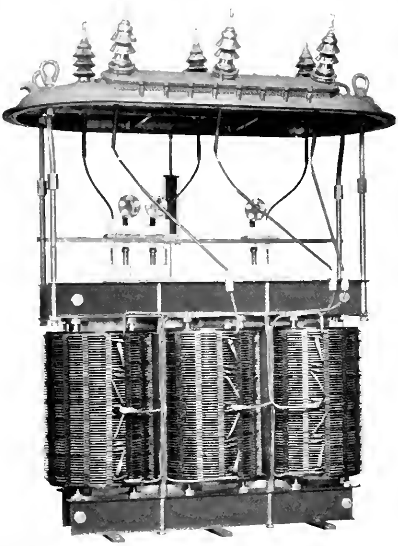


Fig. 10. Circular disk-coil, core-type, three-phase, 2300 volt, 5000 kv-a. transformer.

Cores with a round or approximately round section, round coils, disk or cylindrical in shape, and cylinders for the principal solid insulation, all combine to make it possible to design with extraordinary margins of safety without prohibitive costs.

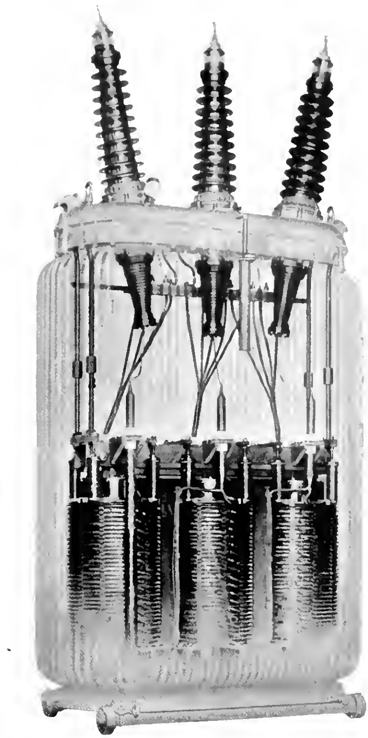


Fig. 11. Three-phase, 2500 kv-a., 100000 volt delta connected self cooled transformer using circular coil construction throughout; low tension winding consisting of cylinder coils; high tension winding consisting of circular disk coils. Successfully operating on the Chicago, Milwaukee and St. Paul electrification.

Circular disk coils wound with rectangular strip and a single turn per layer, stacked to form a high tension winding of great length with reference to its width and assembled concentrically with the low tension winding, form an extremely simple and safe structure for very high voltage designs.

Such coils have their points of greatest potential difference very widely separated and all abrupt changes in self inductance or electrostatic capacity are avoided. Consequently arcing at normal or high frequency voltages across the coil terminals of such windings is practically impossible. Such windings easily permit of extreme re-enforcement of the end turn insulation and thermally are most superior. The heat created in the windings need pass through only a negligible amount of insulation to reach the oil. The cylindrical configuration permits of solid cylindrical insulating barriers separating the high and low tension windings, and the recent advance made in the manufacture of such insulations, which now, instead of being supported by the windings, actually contribute greatly to the mechanical strength of the coil structure, has contributed very materially to the pronounced success attending the satisfactory operation of high voltage core type transformers.

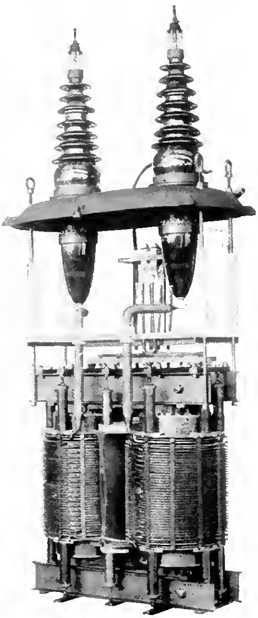


Fig. 12. 3000 kv-a. water-cooled core-type transformer, low tension winding cylindrical coil structure. High tension winding circular disk coil structure with oil channels, collars between coils and reenforced end turns. Note porcelain support for high tension windings. Successfully operating for several years on the highest delta connected transmission systems in the World.

Where current and capacity rating demands a conductor of round wire wound in many layers the circular coils still afford the most satisfactory construction possible. While mechanically weaker than the cylindrical edge wound or single turn per layer disk with flat conductor, a winding of round wire coils can be readily made sufficiently strong to withstand any mechanical strain and electrical strain to which they may be subjected. By mechanically re-enforcing the layer insulation of such multi-layer coils and supplying metallic plates as end supports, the windings can be largely relieved of mechanical strain and all of the strain applied to the supporting structure of the coils.

Where capacity and current rating permit both windings to have circular disk coils, a structure results which is far superior to any other offered for moderate capacity transformers. For such a transformer, a stack of interleaved circular disk coils leaves nothing to be desired, either mechanically, electrically or thermally. Mechanically, such coils are best able to withstand any stress applied radially. The uniform tension of the winding insures uniform mechanical strength throughout and prevents distortion in a radial direction. The mechanical force due to flux between windings, being radial, subjects the structure to stresses parallel to the axis of the coils, i.e., in such a direction as the coil is best able to resist. By proper spacing of the supports the beam strength of each conductor,

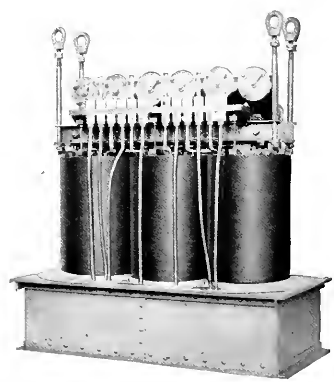


Fig. 13. Circular coil, core type, 750 kv-a., air-blast transformer, with external casing removed to show terminals and provision for changing ratio by tap connections.

easily calculated, can be made sufficient to withstand any mechanical stress occasioned by the most severe short circuit, even with moderate reactance.

With oil flowing on all sides, top, bottom, inside and outside perimeter, no better ventilation of coil structure is possible.

desired than the tank with fluted steel sides, amalgamated into a cast iron base. This design was originated by the General Electric Company some twelve years ago and has stood the test of time most remarkably.

For somewhat larger sizes the tubular construction, with tubes welded to a heavy

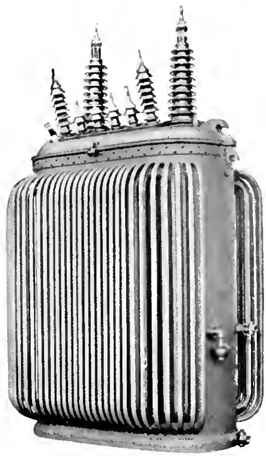


Fig. 14. Transformer designed for operation as either a self-cooled or a water-cooled unit for outdoor installation. Where heavy overloads for extended periods are expected such designs are invaluable for increasing flexibility of large central stations.

sheet steel tank, fills the requirements excellently. For a still larger size, say over 3000 kv-a. where the tank with attached radiators becomes rather large for transportation, separate radiator sections of welded fluted steel, detachable during transportation, admit of the use of the self-cooled designs without limit in capacity.

Formerly large self-cooled units were avoided because of the resulting high ambient temperature in the room where they were located, but the demonstrated practicability of outdoor installations leaves no good reason to avoid self-cooled units in any capacity, if difficulty exists in obtaining a sufficient supply of cooling water.

Tanks

Two points stand out prominently as the best practice in modern tank construction, viz., that all joints shall be welded rather than soldered or riveted, and that all covers and fittings be absolutely weatherproof. The latter is of course not necessary for indoor installation, but so large a percentage of all transformers are now installed without protection, and it is so likely that many of those installed indoors at first will later be moved outside, that it is highly desirable that the weatherproof construction be made universal.

For moderate sized (1200 kv-a. and less) self-cooled transformers, no better tank can be

NOTES ON WATERWHEEL DRIVEN GENERATORS

By H. G. Reist

Designing Engineer A-C. Department, General Electric Company

This contribution gives many interesting facts concerning the design of modern waterwheel generators. The author discusses in turn the relative advantages of the vertical shaft, the use of brakes, the limit of overspeeds, the problem of ventilation, the insulation requirements and the desirability of good efficiency.—Editor

H. G. Reist

Vertical Shaft

The vertical type of waterwheel driven generators is increasing in popularity due to the satisfactory solution of the former thrust bearing problem and to the advantage of the vertical over the horizontal waterwheel in handling large quantities of water such as exist at powers of low head.

It is sometimes possible to build vertical generators with a short length of iron parallel with the shaft and a very low frame; thus reducing to a minimum the height to which the rotating parts of the generator and waterwheel have to be lifted in assembling the machinery. Sometimes advantage may be taken of this, and a low power house be built at a considerable saving in the cost of construction. This type of construction is well exemplified in the Cedars Rapids Manufacturing & Power Company's development, as will be seen by reference to the illustrations in Mr. R. C. Muir's article in this issue.

At present it is usual to place the step bearing supporting the rotating part of the generator and waterwheel at the top of the generator. This avoids building a supporting floor for this purpose, saves room in height and in the amount of concrete needed. In some installations the generator floor may be brought so low that there is no need for an intermediate guide bearing on low speed generators. The use of a guide bearing at this point is, however, an advantage sometimes where calculation shows it to be unnecessary. Its use may prevent trouble if the coupling is not fitted perfectly, or if the generator or waterwheel is a trifle out of balance. Again, there may not be a balance of the water around the wheel, or the generator rotor may not be exactly central, causing a magnetic side pull. If a coupling is used between the generator and wheel shafts, probably the best form is the ordinary flange coupling. The flanges should be forged solid on large shafts. On small shafts separate flanges may be used but these should be carefully pinned to the shaft to carry the load they are called upon to support. With this form of coupling, it is easy to determine whether the two parts of the shaft are lined up. This may be done by loosening the bolts

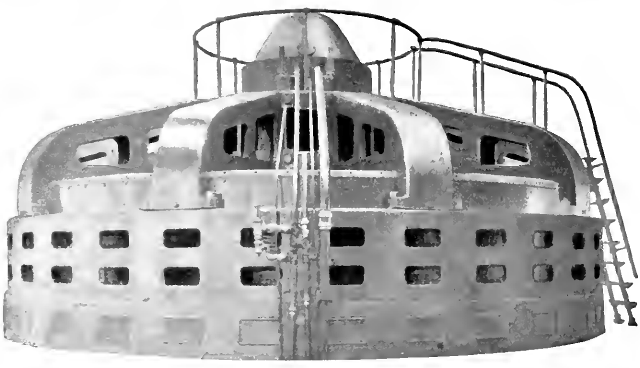


Fig. 1. A 6250-kv-a., 100-r.p.m., 6600-volt Generator with massive superstructure for supporting the weight of its rotor and that of the waterwheel

and measuring the opening between the faces of the coupling all around. With the clamped couplings sometimes used, the alignment of the shafts is much more difficult.

Brakes

On vertical generators it is usual to apply brakes to the rotor to stop the machine in case of leakage of water through the gate after it is closed. Sometimes the leakage at this point is sufficient to keep the generator rotating at a low speed for an indefinite period. The brake-shoes are faced with wood and are operated by air or oil pistons, the former generally being preferable. The brake supports are generally designed so that the total rotating part may be supported from these brackets on blocks when it is desired to examine the step bearing or to remove the bearing spider.

Over-speed

Generators should always be built with the runaway speed of the waterwheel in mind. This is usually from 60 per cent to 80 per cent above normal speed,—sometimes as much as double speed. Most wheels at one time or other will run at over-speed, due to the failure of the governor or to the gates sticking. Sometimes a log, ice, or other obstruction, will prevent the gates from closing.

Ventilation

At the present time it is usual to have waterwheel generators open and self-ventilated, but there are advantages in enclosing some machines, as in this way it is possible to control the supply of air to the generator. Cooler air may be obtained by taking it from outside of the power station or near the floor of the operating room. In many installations it is desirable to filter the air for removing mechanical impurities and for cooling the air. Filters are now used so generally in installations of steam turbine generators, that they will no doubt be rapidly introduced in connection with waterwheel driven generators. In dry, hot climates, cooling the air is of especial importance, as the temperature of the air may be lowered 12 deg. to 15 deg. below the water used in the spray filters. At some places there are occasionally dust or sand storms which carry much material that is better kept out of the generators. At an installation known to the writer it was planned to screen the air to avoid an accumulation of insects which occur there at certain seasons of the year. On low speed machines, which are enclosed, it is possible to supply air by means of a separate fan, thus producing more pressure than can be obtained from the generator itself, and greatly increasing the value of the radiating surfaces. Ventilation supplied by a separate fan, with greater force than may be obtained from the generator itself, is more positive and, if the air is taken from the outside of the building, is less dependent on the direction of the wind. High speed generators can usually be cooled with fans on the rotor, as these give a positive supply.

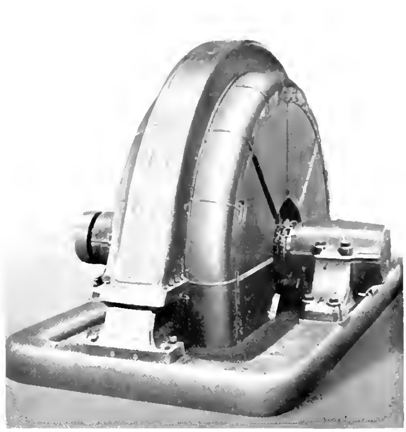


Fig. 2. A 10,000-kv-a., 300-r.p.m., 5000-volt Generator enclosed so that it may be ventilated by air from without the station brought to it by ducts

The large generators at Cedars Rapids Power Station have the air drawn through screens and forced into the generator pit by means of motor-driven blowers.

Insulation

The requirements for the insulating of large generators are somewhat conflicting, making it difficult to provide any material that is satisfactory in all particulars. The heavy coils which are used in modern large generators seem to demand an insulation that has greater mechanical strength against compression than the varnished cambrics which are extensively used on smaller machines. This is one of the reasons why mica insulation is somewhat more extensively used than formerly. Whatever the material used, it is very desirable that the insulation should be flexible under all conditions of operation, so that it will accommodate itself to the expansion and contraction of the coil as it heats and cools, will not crumble due to vibrations of the coils in case of short-circuits, and will not be injured in handling, storing and placing spare coils in position when repairs are necessary. The insulation should not absorb water readily and the envelope of insulation should preferably be as nearly complete as possible so as to afford no places for moisture to enter between the layers of insulation at the ends.

Efficiency

In the design of electric generating apparatus for general use, the reduction of the losses and consequent increase in efficiency is receiving more and more attention. This is especially important where the amount of power that may be generated is limited, as is usually the case when machines are driven by water-power. Any reduction of losses is the equivalent not only of having a bigger generator but of having a larger waterwheel, power house, water supply, etc., to the extent of the power that may be saved.

With high load factor, the advantage of having apparatus of high efficiency is of greater importance than when the load factor is low, because the value of the product relative to the first cost is greater. The value of generators of high efficiency rather than low first cost is gradually becoming more and more appreciated by purchasers. The engineers of large plants give the design of the stations sufficient study to realize this advantage, and are usually perfectly willing to pay for a very liberal amount of copper in generating apparatus.

The use of a voltage regulator in power plants has overcome the need of close inherent regulation formerly demanded. This, by reducing the amount of magnetic iron and the core losses, enables an increase in efficiency. Other improvements that have made further contributions in this direction are, the use of special steels for cores, rectangular copper for the windings which greatly improves the space factor over round conductors, and, by various precautions in the design of the generators, a radical reduction in the large eddy current losses which formerly existed. In many cases the eddy, or load, losses have been reduced to so low a quantity on multiphase machines as to be almost negligible. On single-phase machines these losses are greater than on multiphase generators, and it is difficult, if not impossible, to reduce them to as great an extent.

SOME FEATURES OF SYNCHRONOUS MOTOR DESIGN

By W. J. Foster

Alternating-current Engineering Department, General Electric Company

The author discusses at length the characteristics of synchronous machines and in many cases compares them with alternators to bring out their points of similarity and difference. Many phases of design, construction and operation are dealt with, but the article covers too broad a field to permit writing a comprehensive abstract.—Editor.

W. J. Foster

GREAT progress has been made during the last few years in developing the art of synchronous motor design. There still remains much to be done before synchronous motors are on the same basis as induction motors, as constituting a class of apparatus with recognized characteristics. This slowness is undoubtedly due to the close relationship of the synchronous motor to the alternating current generator, which has resulted, in most cases, in the modification of an alternating current generator, instead of the development of an entirely new machine—built with reference to motor characteristics alone, as in the case of induction motors. The consequence of building synchronous motors from alternating current generators, or the making of "modified design" machines, is some uncertainty and inconsistency in certain characteristics.

The purpose of this article is not to discuss the theory of the synchronous motor, nor the methods of calculation most approved by designers, but to call attention to some of the characteristics of the synchronous motor, and to the classes of work it is well qualified to perform, and to certain features of construction as applicable to different kinds of service.

From the standpoint of design, synchronous motors may be considered with reference to their two parts—the armature and field. It may be broadly stated, with reference to the armature, that there is not a detail in a good synchronous motor that may not be incorporated in a good alternating current generator. This statement does not mean that the armatures of all well designed generators are the best possible for the corresponding motors. They may or may not be. It means that armatures developed for the best performance as motors, are, at the same time, as good as can be made for generators.

The distinctly synchronous motor features are found in the field structure. Since practically all synchronous motors built at the present time for commercial work are of the "revolving field" type, we will speak of the field as the "rotor." The rotor may be either salient pole, Figs. 1 and 2, or the so-called cylindrical or induction motor type, Fig. 3. The great mass of motors are salient pole. Looked at electrically, the salient pole may be said to be single-phase wound, while the cylindrical type may be either single-phase or polyphase. There is little excuse for the cylindrical rotor, except as it is polyphase in its windings and operated polyphase in starting up. Once in synchronism and carrying load, it is inferior in certain respects to the salient pole rotor.

The motor features in the salient pole rotor may consist of a complete squirrel-cage winding, uniformly distributed around the circle and, consequently, almost perfectly polyphase in its function; or, they may consist of complete windings throughout the pole faces, with conductors omitted in the interpole spaces, but with continuous end rings; or, they may consist simply of bars in the pole faces, connected together electrically at the ends of the pole but with no connections across from pole to pole; or, they may consist of special material, such as solid steel, with no inlaid conductors to give direction to the currents. For certain service, synchronous motors may be used that have absolutely no special features that are not found in alternating current generators. Such machines are nothing more nor less than alternating current generators operating reversed.

A wide range of characteristics may be given to any synchronous motor, by simply modifying the amortisseur windings. The complete symmetrical squirrel-cage of extremely low resistance, as is well known, is the proper construction to give stability when operating at the ends of long lines in distribution systems (Fig. 4). On the other hand, when starting conditions are important, such low resistance winding cannot be used. It is interesting to note that widely different characteristics in the matter of starting and operating can be given to any synchronous motor by the use of different materials in the amortisseur windings. Copper may be used for low resistance, brass for medium, and monel metal, or some similar alloy, for extremely high resistance. Fortunately, as far as efficiency under running conditions is concerned, high resistance does not detract, as in the case of the induction motor. It is, of course, always possible to alter the resistance by simply changing, within certain limits, the cross section of the conductors. However, there are other ways of obtaining the desired results, by attacking other details than those pertaining to the conductors themselves;—such as the number of slots, the size, shape and location of the slots with respect to the surface or face of the pole. As a rule, the squirrel-cage is more effective with slots that break through to the surface, although such openings sometimes injure the potential wave and sometimes have a tendency to create "dead points" at the instant of starting. Slots that are deep and narrow, give, to a certain extent, an automatic change in the resistance as the motor speeds up (Fig. 5). When at rest, the full periodicity causes the current to crowd to the top of the winding and has the same effect as a higher resistance winding, which is the condition desired at the instant of starting. As synchronism is approached, the periodicity of the current in the winding becomes low and the resistance is, consequently, reduced—the condition most favorable to torque just before synchronism is attained.

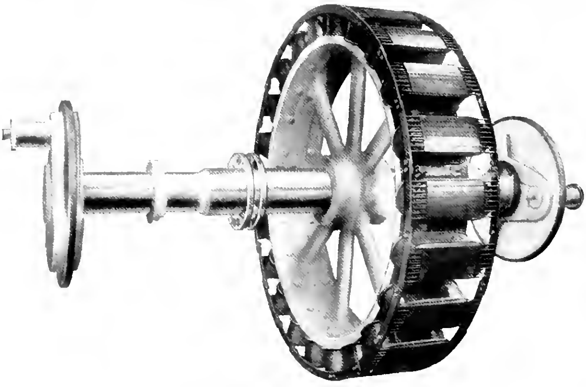


Fig. 1. Rotor of 950-h.p., Three-phase, 25-cycle, 2200-volt, 136-r.p.m. Synchronous Motor, showing open slots in poles and squirrel-cage winding with long bars. Air compressor drive

As far as starting characteristics are concerned, motors with solid steel poles and open slots may be built that make a good showing. Such motors with the ordinary air gap clearance, have much lower efficiency when running than the same motors with laminated poles and amortisseur windings. While it is true that properly designed magnetic wedges will reduce these losses, it is, at the same time, true that the magnetic wedge detracts somewhat from the starting properties.

The discussion of characteristics of synchronous motors can probably best be carried on by comparing them with induction motors.

It is almost superfluous to discuss the matter of speed, as it is well known that the synchronous motor, as its name implies, maintains absolutely the same speed, no matter how little or how great the load within the limits of its ability to operate, provided the periodicity of the supply remains unchanged; whereas the induction motor varies slightly in speed for every change of load.

As to the effect on the system from which the motors are operating, it is well known that the induction motor is always a drag, in that it takes magnetizing current as well as energy, and thus tends to lower the potential, whereas the synchronous motor need draw only energy from the system. It takes care of itself, as far as magnetizing current is concerned, or it may even return to the

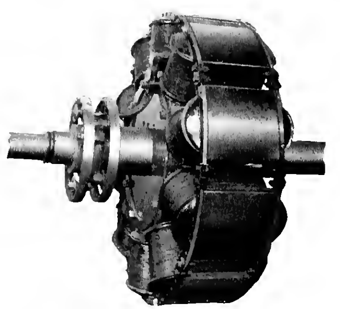


Fig. 2. Rotor of Three-phase, 60-cycle, 2300-volt Synchronous Motor of 300-kw. Motor-generator Set, showing closed slots in the poles, and heavy squirrel-cage winding with double strap connections between poles

system more or less magnetizing current to be used elsewhere.

With regard to starting, it is well known that the induction motor has a decided advantage. It is comparatively easy in certain types of induction motor to so design them that they can come up to full speed with the full load, and not cause a severe drain on the system. Synchronous motors that can develop as good torque in starting up are generally of quite special construction. It is quite evident that the synchronous motor that is best adapted to give good results in starting must approximate in construction the induction motor. Hence, if the very best results in starting are required, the motor must be of the cylindrical rotor type with polyphase windings and external resistance.

In the matter of auxiliary apparatus required, both synchronous and induction motors must have starting compensators or starting reactances or resistances. They also require about an equal complement of switches, but the synchronous motor must be supplied with a small direct current generator to furnish excitation.

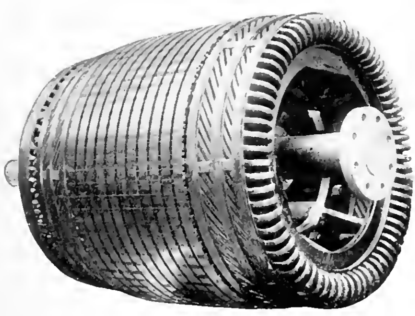


Fig. 3. Synchronous Motor Rotor of the Cylindrical or Induction Motor Type, Coupling End. Such rotors are usually wound three-phase with three collector rings and external resistances for starting. Excitation may be applied to the rings only, the third phase remaining idle. It is preferable, as a rule, to use all three phases, one of them carrying the entire exciting current, the other two one-half each

As to convenience in operating, the induction motor has the advantage when self-started motors are considered, as it is not necessary to supply exciting current from an outside source.

With regard to the possibilities in efficiency,

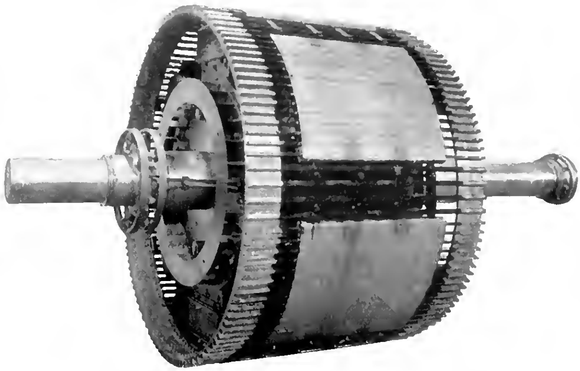


Fig. 4. Rotor with unusually heavy squirrel-cage winding, continuous between poles. Well adapted for operating on unbalanced system., 7000-h.p., three-phase, 25-cycle, 13200-volt, with peripheral speed of 10100 ft. per min.

the synchronous motor in its nature has the higher efficiency at the higher loads and the induction motor at the lower loads. This difference is due to the energy required for excitation for the synchronous motor as contrasted with the rotor or secondary losses of the induction motor. In case of the synchronous motor, with the larger gap clearance and the limitations in heat dissipation due to the massing of the exciting coils, the excitation at no load is relatively high and at the greatest load it is not increased to a great extent over the no load value. In the case of the induction motor, the secondary losses at no load are very small. A comparison of certain standard lines of belt driven 60-cycle induction and synchronous motors covering the range 40- to 300-h.p., reveals average efficiencies as follows:

	Synchronous	Induction
100 per cent load	91.8 per cent	90.0 per cent
75 per cent load	90.6 per cent	90.7 per cent
50 per cent load	88.0 per cent	90.0 per cent

The core losses of induction motors, as regularly built—with open stator slots—are higher than those of the corresponding synchronous motors. The following is a comparison of the segregated losses of 250-h.p., 60-cycle, 2200-volt, 1200-r.p.m. motors with two bearings for direct connection to pumps. It is only fair to say that the small core loss of the synchronous motor is due, in part, to the especially fine grade of iron used. It is to be noted in this particular case that the synchronous motor has the higher efficiency at light loads as well as at heavy loads.

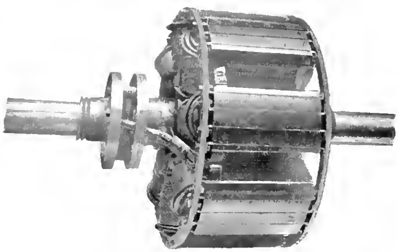


Fig. 5. Rotor of 133-h.p., Three-phase, 60-cycle, 2300-volt, 900-r.p.m. Synchronous Motor showing deep bar squirrel-cage winding.

	WATTS LOSS					
	¼ Load		½ Load		Full Load	
	Sync.	Ind.	Sync.	Ind.	Sync.	Ind.
Fric. and wind.	2930	2100	2930	2100	2930	2100
Core losses	1800	4570	1800	4570	1800	4570
Stator I^2R	180	350	720	680	3080	2000
Rotor I^2R	600	215	710	850	1130	3350
Totals	5510	7235	6160	8200	8940	12020

One of these 250-h.p. synchronous motors, wound for 4000 volts, with direct connected exciter, (see Fig. 9) for driving a pump in an irrigation project, gave efficiencies in test as follows:

Full load	95.3 per cent
¾ load	94.8 per cent
½ load	93.4 per cent

These efficiencies are over all, that is, they include the exciter losses. Such figures for a motor of only 250-h.p., show how great the possibilities are of attaining high efficiency in synchronous motors.

There are certain characteristics of synchronous motors that are not so well known as those outlined above, when comparison is made with induction motors, such characteristics as their ability to remain operating or to stay on the line under such provocations as partial short-circuit, or even the dead short-circuit to ground of one phase of the line running to the motor. It is the general experience in practice, that synchronous motors behave much better under these circumstances than induction motors. This is due to the fact that the motor has its excitation supplied from an outside source and this excitation tends to raise the voltage at its terminals, rather than to reduce it, when there is any cause at work on the lines tending to drop the voltage; and, furthermore, to the fact that any given strength of field on a motor tends to maintain the ability of the motor to carry load when the potential back of the motor is reduced. On the other hand, in the case of the induction motor, any drop in voltage in the lines leading to the motor must result in a still greater reduction of the voltage at the motor, and, consequently, an increased current to carry the load, and this increased current, in turn, to a still further reduction of the voltage.

It has been found in connection with synchronous and induction motors that are not self-starting but brought up to speed from some external source and then thrown on the line, that it is far easier to handle the synchronous than the induction motor. This is for the reason that the synchronous motor may be excited and synchronized and thus brought into step without any jolt whatever,

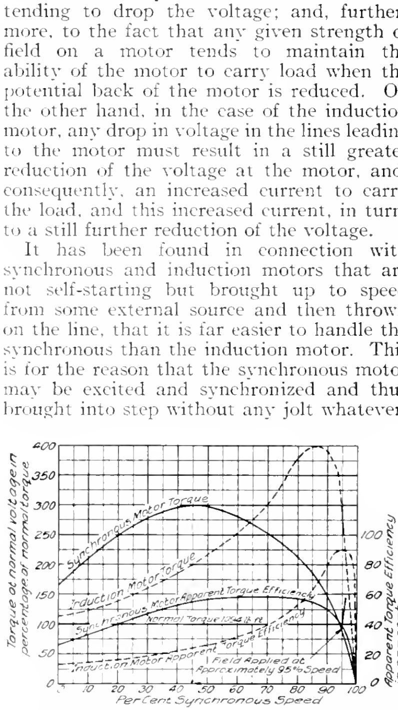


Fig. 6. Comparative Torque Characteristics of 250-h.p., 1200-r.p.m., 60-cycle, 2200-volt Synchronous Motor and squirrel-cage induction motor

whereas in the case of the induction motor there is no good means of judging the proper time to close the switch that throws it on the line.

A valuable characteristic of the synchronous motor is the possibility of arranging

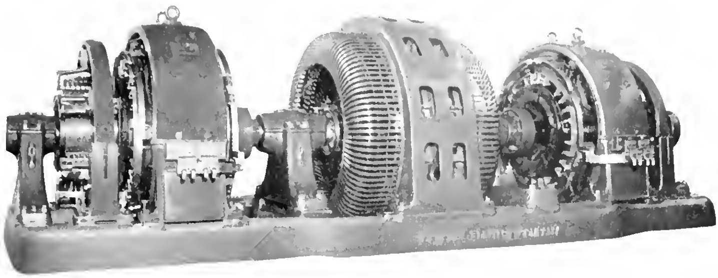


Fig. 7. 720-r.p.m. Motor-Generator Set. 2100-h.p., Three-phase, 60-cycle, 6600 volt Synchronous Motor driving two 750-kw., 600-volt direct current generators. This set illustrates a favorite arrangement of a three-unit motor-generator set well adapted for use in three-wire direct current lighting systems, as well as for high voltage direct current railway systems.

its excitation in such manner that the motor is not in danger of breaking down. It is well known that the amount of load that may be carried momentarily by any synchronous motor is limited only by its mechanical strength, provided the excitation is automatically increased with increase of load. Automatic control of excitation may be accomplished by means of a field regulator actuated from relays adjusted for load or power-factor. It may be accomplished in the case of motor-generator sets by series coils on the motor fields excited direct from generator armature, or by the use of the standard shunt fields alone on motors with a special compound exciter whose compounding is obtained from the armature of the generator.

The induction motor obtains its excitation from the current that supplies the energy to the primary windings. The current supplied to the induction motor resolves itself into two components, one of which establishes the magnetic field and the other supplies the energy which does the work. The synchronous motor has its main magnetization supplied from an outside source in the form of direct current, but the alternating current in its armature may be so

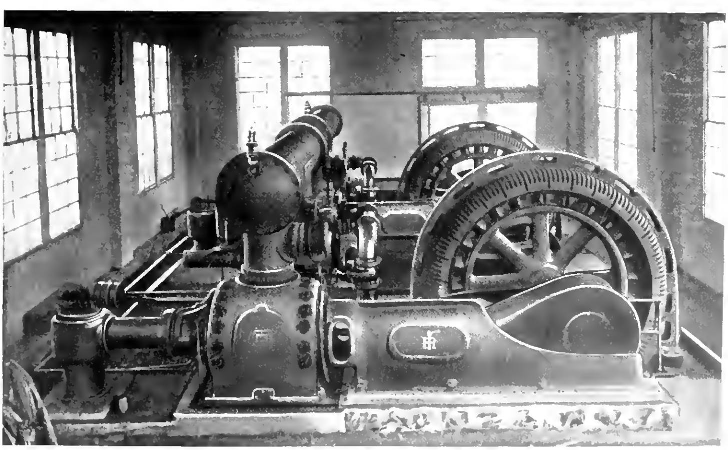


Fig. 8. Air Compressor Units driven by 450 h.p., Three-phase, 25-cycle, 600-volt, 125-r.p.m. Synchronous Motors

adjusted that it is entirely energy current, or it may be made up of two components, one of them energy current and the other magnetizing current that may either work with or against the direct current magnetization. A simple adjustment of the magnitude

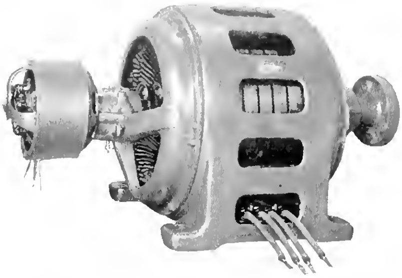


Fig. 9. 250-h.p., Three-phase 60-cycle, 4000-volt, 1200-r.p.m. Synchronous Motor with Direct Connected Exciter for driving centrifugal pump.

of the direct current decides the nature of the alternating current, as to whether it is entirely energy or made up in part of magnetizing or demagnetizing current. Adjustment may be so made as to be helpful to the motor itself and of use to the system external to the motor at the same time, or it may be burdensome to the motor itself and of great help to the system, In the matter of the internal losses of the motor and, consequently, its efficiency, the excitation that causes all of the a-c. current to be energy current is the best, but, as far as stability in operation and freedom from the danger of falling out of step are concerned, an over-excitation is desirable. A synchronous motor underexcited is more or less of a burden to the system; it is more sensitive to increase in load and, as a rule, is not so efficient. It is seldom that a motor is thus operated. It may be desirable to so operate it in the case where there is capacity in the line or where many synchronous motors have been installed and some induction apparatus is needed to restore the balance.

The speed-torque curve of the 4000-volt, 250-h.p., 60-cycle synchronous motor (Fig. 6) may be taken as characteristic of the salient pole synchronous motor with squirrel cage of average resistance, or that most common in commercial machines. For comparison, curves of the corresponding induction motor have been added. By using the curves of "apparent torque efficiency" we find that for the same input, the torque of the synchronous motor is greater than that of the induction motor, up to about 80 per cent of speed. It then falls off rapidly until at 90 per cent of speed it is not much more than one-half that of the induction motor. Beyond this point the torque of the synchronous motor becomes feeble in comparison with that of the induction motor until about 95 per cent of speed is attained and the motor is excited, when it rises abruptly to full strength.

It is customary to speak of the torque through the region 90 to 95 per cent of speed as the "pull in" torque. Salient pole motors with good static torque have low "pull in" torque. A simple means of increasing the "pull in" torque when the motor has come well up in speed, is to short circuit the field through a resistance which may be its own field rheostat. This idea may be carried out somewhat more elaborately to obtain the best results, both

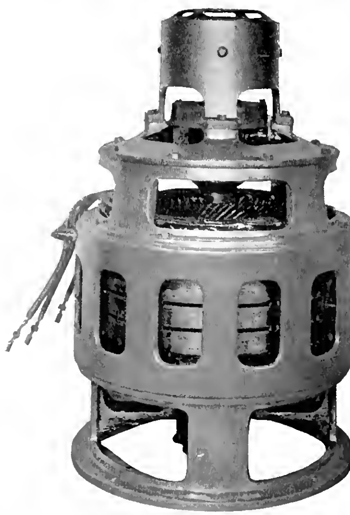


Fig. 10 150-h.p., Three-phase, 60-cycle, 220-volt, 1200-r.p.m. Stator Parts of Vertical Synchronous Motor with Ball Thrust Bearing and Direct Connected Exciter at extreme top. For driving Centrifugal Pump

in the matter of good starting torque and freedom from line disturbance, by arranging a short-circuiting resistance, possibly several times that of the field rheostat, with a control switch in such manner that the operation of passing from induction to synchronous condition may be done in steps. The control switch first closes the motor field on the resistance. It then throws the excitation on both motor field and external resistance in parallel and, lastly, cuts out the external resistance and leaves the motor normally excited.

It is well known that once a synchronous motor has fallen out of step the excitation must be reduced or entirely removed in order to get back into synchronism. A motor-generator set, in which the generator is self-excited and also furnishes excitation to the synchronous motor driving it, will often come back to speed after short-circuit occurs on the line, whereas if the motor were excited from an outside source, where the voltage of the exciting current was not affected by the disturbance, the set would shut down altogether.

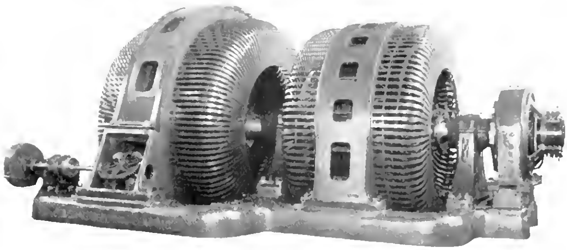


Fig. 12. 5333-kv-a., Three-phase, 50-cycle, 500-r.p.m., 13000-volt Synchronous Motor (at left) of 50-25-cycle Frequency Converter with motor operated mechanism for adjustment of load with other frequency converters operating in parallel

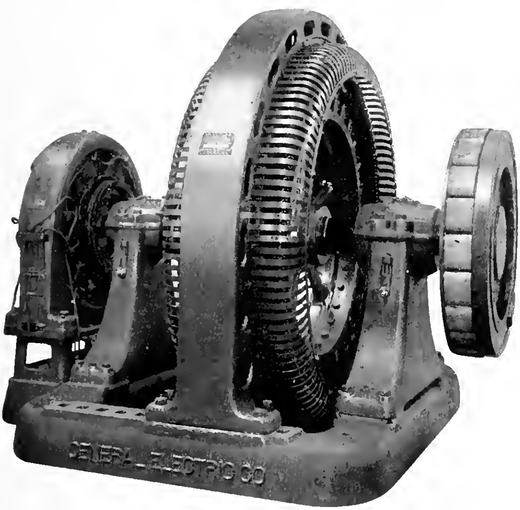


Fig. 11. 500-h.p., Three-phase, 60-cycle, 2200-volt, 240-r.p.m. Synchronous Motor with Direct Connected Exciter and G-E. Standard Flexible Insulating Coupling for driving Pulp Grinder

An interesting recent application of synchronous motors is in connection with the Chicago, Milwaukee & St. Paul Railroad electrification, where the electric energy is supplied by a power company. The motor-generator sets in the substation operate at times reversed in order to return energy to the system. Here the motor-generator set has a direct connected exciter with fields compounded from the generator of the set. The compounding is arranged with reference to the power-factor requirements of the high tension long-distance distribution system and, at the same time, with reference to stability under the load imposed by the railroad trains.

The largest fields of application of synchronous motors at the present time are: first, motor-generator sets (Fig. 7), including frequency; second, slow speed motors direct connected to air compressors (Fig. 8) and reciprocating pumps; third, high speed motors direct connected to centrifugal pumps (Figs. 9 and 10). There is also a considerable demand for intermediate speed motors for pulp grinding. In practically none of these applications is the starting condition very severe. In motor-generator sets all that is required is sufficient torque to bring up the motor itself and the generator, which requires, as a rule, about the same torque effort. In the case of motors direct connected to air compressors and pumps, by-passes are generally arranged so that the synchronous speed is attained before the load is put on. It has been found desirable in certain pulp grinding motors to have very high initial starting torque, since pulp grinders sometimes shut down in such manner as to leave the pockets clogged. Unless the motor is capable of exerting great torque at the instant of starting it becomes necessary to open up the grinder and clean out the pockets (Fig. 11).

The requirement is often made of frequency converters that the set operate reversed. Hence, both machines are usually designed as motors. Occasionally, the same requirement is made where the set consists of a synchronous motor and direct current generator.

In connection with air compressor drive and all other applications where reciprocating torque is involved, it is necessary to take into consideration the flywheel effect of the unit as a whole and the relation which it bears to the electrical constants of the motor and the system upon which it is operating. It is now customary to take up the question of "natural period" with both the customer and the manufacturer of the air compressor or the reciprocating pump, in the same manner as when coupling an a-c. generator to an engine to operate in parallel with other units. An exchange of data takes place before work is placed in the shops. The attempt is made to so arrange the unit that the natural period will be safely removed from the forced period of the motor itself and from any other forced period in the operating system. With reasonable care and foresight, "hunting" troubles may be avoided. It occasionally happens that a motor-generator or frequency-converter set requires adjustment after installation due to some combination of constants in the system upon which it is operating, that could not well be foreseen.

It is difficult to lay down absolute rules for the operation of synchronous motors. What is found best in one place may not be best in another. Sometimes in starting up by means of a compensator or auto-transformer, it is best to throw the motor over to full line potential before exciting, but more often it works out best to excite at as low a voltage on the auto-transformer as will bring the motor within "jumping" distance of synchronism.

Many motors when excited on the tap voltage, must be given time to "settle down" before they are thrown over to the line potential. The act of throwing on excitation causes the rotor to oscillate back and forth, and, if thrown over while in this condition, the motor is liable to fall out of step.

One of the most interesting cases in station operation requiring skill and close attention, is in connection with "phasing in" a frequency changer with one or more already under load. Ordinarily, in paralleling alternating current synchronous machines, the switch is thrown when the synchronizer indicates synchronism, but in the case of two frequency changers, one without load and the other already carrying load, the switch must not be thrown at the instant of perfect synchronism. The reason for this is that the effect of the load is to act like a mechanical lag on the rotor. The operator must learn to close his switch when the needle of the synchronizer is removed a certain angle from zero; the angle depending upon the amount of load on the frequency changer set already in service.

Frequency converters to operate perfectly in parallel, must either be made with extreme accuracy both mechanically and electrically, or one of them must have means for mechanical adjustment of stator with respect to rotor. This is often accomplished by providing one of the two machines of the set with adjustable feet. The setting for division of load is made once for all at time of installation. However, there is an advantage in some cases in arranging frequency converters so that adjustment of load may be made at any time during operation. This may be accomplished by the use of a little motor with necessary gearing to rotate the stator through a small angle. (See Fig. 12). The motor is usually controlled from the switchboard. By means of this control when it is desired to shut down the frequency converter the load may be transferred before the switches are pulled.

SYNCHRONOUS CONVERTERS AND MOTOR-GENERATOR SETS

By J. L. Burnham

Direct-Current Engineering Department, General Electric Company

Synchronous converters and motor-generators are practically the only kinds of apparatus that are commercially satisfactory for converting large amounts of alternating current to direct current. It is therefore of interest to compare these two types of machines. The following article, written for this purpose, is clear and instructive. It treats the subject under the headings: Voltages and applications, speeds, power-factor, voltage control, efficiency, and reliability and adaptability.—Editor.

J. L. Burnham

Voltages and Applications

The highest voltage that a direct-current machine will deliver successfully from a single commutator is a function of surface speed, voltage between segments, and width of segments. The surface speed is limited by the strength of the materials used in the construction of the commutator; the maximum voltage between adjacent segments is determined by experience principally with relation to flash-over tendencies; and the minimum width of commutator segments is fixed by mechanical considerations relating principally to the space for making joints with leads and the insulation of leads with proper clearances. Fig. 1 shows the approximate maximum voltages that can be obtained from one commutator at different frequencies in accordance with present practice.

The generator of a motor-generator set can be made for a speed and number of poles (or frequency) suitable to a higher voltage from a single commutator than can be obtained from a converter of standard frequency; but it will be found in general that the cost for a given voltage above about 2000 will be greater for a single-commutator machine of lower speed than for two higher speed machines with commutators connected in series. The higher speed at which the sets with series connected commutators may be operated also reduces the cost of the alternating current motor.

The principal uses of power supplied by synchronous converters and by motor-generators may be classified according to voltage required as follows

110 / 125 volts—Exciter, small industrial, electrolytic.

240 / 300 volts—General lighting and power distribution. Mining. Industrial. Electrolytic and exciter.

500 / 650 volts—Railway. Industrial and Power. Electrolytic.

1200 / 1500 volts—Interurban Railway. (Few Hoisting.)

2400 / 3000 volts—Interurban and Main Line Railway.

Speeds

The speeds of the latest 60-cycle motor-generator sets are approximately the same as for 60-cycle converters of the same voltage. For instance, the 1000-kw., 270-volt machines

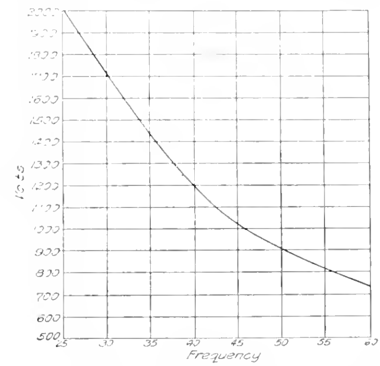


Fig. 1. Approximate voltages that may be obtained from a single commutator at various frequencies for average commercial conditions according to present practice

both run at 720-r.p.m. and the 1000-kw., 600-volt machines both run at 900-r.p.m. In sizes above 1500 kw., it is becoming quite general practice to use two generators with one motor, which design permits about twice the speed that would be operat ve with a single generator.

The tendencies in speed of motor-generators and synchronous converters are illustrated in Table I.

TABLE I

Kw.	Voltage	SPEED 60-Cycle Motor-Generator	60-Cycle Converter	25-Cycle Converter
500	270	1200	1200	750
500	600	1200	1200	750
1000	270	720	720	500
1000	600	900	900	500–750
1500	270	514	514	375
1500	600	514	600	500

Power-factor

The power-factor may be maintained at unity for both synchronous converters and synchronous motor-generator sets. It is not usually recommended to correct the power-factor of the system by exciting for the required wattless current when a converter is employed, for the heating is materially increased and the direct-current voltage is changed thereby. Power-factor correction may be obtained with a lesser increase in heating and with no effect on the direct-current voltage in the case of a synchronous motor-generator.

Voltage Control

The voltage of the generator of a motor-generator set can be readily controlled by hand or automatically with devices that are well known.

The direct-current voltage of the usual type of converter is approximately proportional to the alternating-current voltage. With the split-pole converter, the ratio of alternating-current to direct-current voltage may be changed in the armature by changing the flux distribution in the poles. Thus, with a fixed alternating-current voltage, the direct-current voltage may be changed.

To obtain a variation in the direct-current voltage of the usual type of converter, some means must be provided to vary the applied alternating-current voltage correspondingly. The methods that are now in use for varying the alternating-current voltage employ:

(1) Taps on transformers.
(2) Reactance
(3) Induction Regulators.
(4) Synchronous booster, (a) direct-connected, (b) motor-driven.

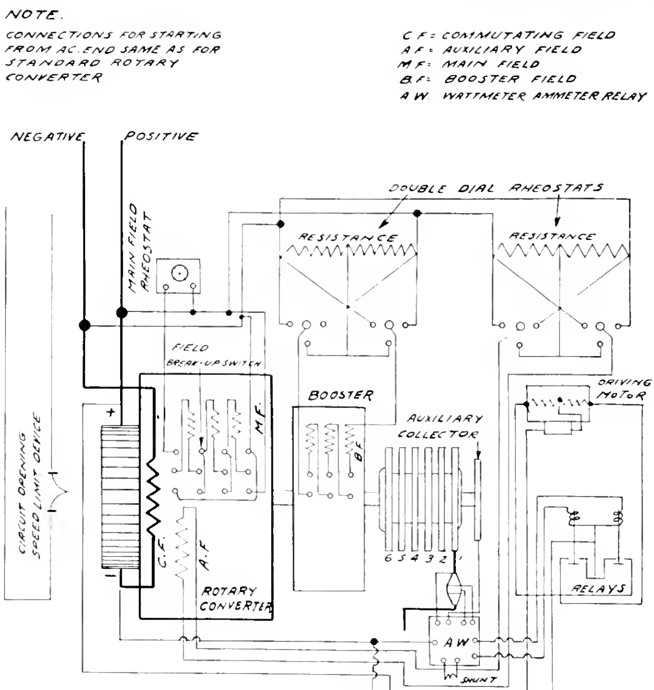


Fig. 2. Connections of synchronous converter with a-c. booster, commutation control relay and extra small ring for obtaining booster voltage. (Voltage of revolving field booster obtained from stator)

(1) When regulation of voltage by steps is permissible, taps on the transformers may be used for the units of smaller capacities. For units of larger capacities, the equipment for changing tap connections when under load becomes so expensive that this method

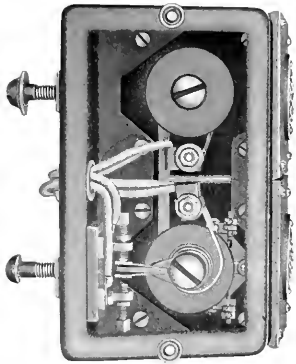


Fig. 3. Commutation control relay

is not desirable; and, unless the conditions of service will permit removing the load before the voltage is changed this scheme is not generally recommended—although it is the most efficient.

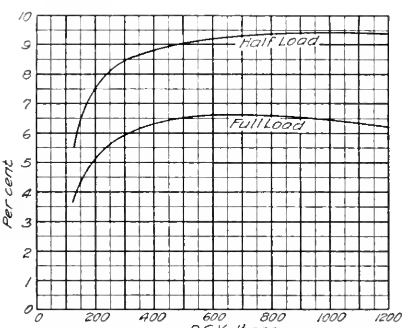


Fig. 5 Per cent efficiency of 25-cycle synchronous converter in excess of 60-cycles synchronous motor-generator efficiency

(2) The component of reactive voltage induced by wattless current will add to the delivered alternating-current voltage if the current is leading and subtract if lagging. The reactive voltage available for voltage regulation is approximately proportional to the wattless current and to the amount of the reactance.

The limitations of this method are the increased heating of the apparatus and, in general, the decrease of stability with increase of reactance. The most favorable and usual

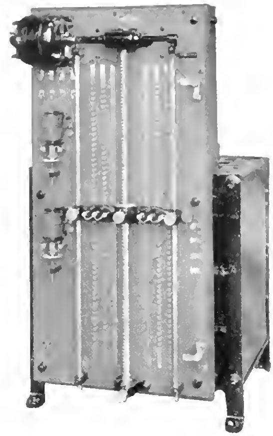


Fig. 4. Motor operated rheostat controlled by commutation relay

application is for compounding. The excitation of a compound converter can be adjusted at no load to give a lagging current which will decrease with increasing load, due to the

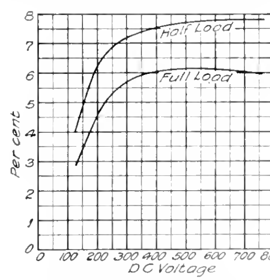


Fig. 6. Per cent efficiency of 60-cycle synchronous converter in excess of synchronous motor-generator efficiency

series-field excitation, so that unity power-factor or even a small leading current may be obtained at the heavier loads. Thus, the increase in heating is not important and the regulation of the alternating-current system is improved.

In combination with method (1) exact voltages between steps may be obtained with reactance and field control at a sacrifice of unity power-factor.

(3) Induction regulators are used where it is necessary to have an exact adjustment of the direct-current voltage within a given range. By this equipment unity power-factor may be obtained.

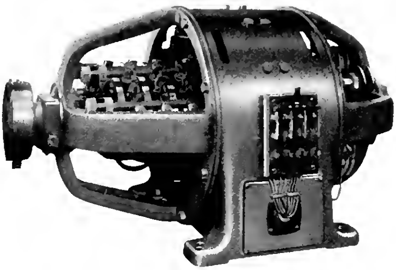


Fig. 7. A new construction for small commutating pole 60-cycle converters used mostly for 300 and lower d-c. voltage.

(4) A synchronous booster, having the same number of poles as its driving machine, will raise or lower the applied alternating-current voltage according to the amount and direction of its field excitation. The usual arrangement is to direct connect the booster to the converter; but when the converter has a large number of poles it becomes more economical to drive the booster at a higher speed by a separate synchronous motor with a smaller number of poles. A further advantage of the separate motor drive of the booster will be later explained in reference to commutating field excitation.

When direct-connected to the converter, a booster is driven as a series generator when it adds its voltage to the line voltage (the converter acting as a synchronous motor in addition to its usual action). When the booster voltage subtracts from the line voltage, the booster acts as a motor driving the converter as a direct-current generator. Since in the simple converter the armature currents at unity power-factor have practically no resultant reaction or magnetizing effect on the poles, it will be seen that the action of a direct-connected booster, requiring additional current in the converter armature, will produce an armature reaction on the fields proportional to the additional current. When the booster raises the direct-current voltage, the additional armature current will act directly on the commutating poles and magnetize in the same direction as the main series coils. When the direct-current voltage is lowered the additional armature current demagnetizes the commutating poles. To secure good commutation, it is necessary to oppose the magnetization of the additional armature currents in the converter armature by an equal magnetomotive force on the commutating poles so that the main series commutating pole windings only will be effective in producing a commutating field proportional to the direct-current load.

A number of schemes for automatically exciting a second winding on the commutating poles in proportion to the booster input or output, to cancel the effects of the additional converter current have been devised and proved to be practical. All but one act in steps and do not give accurate excitation for all loads and voltages. The one arrangement that does give correct excitation of the

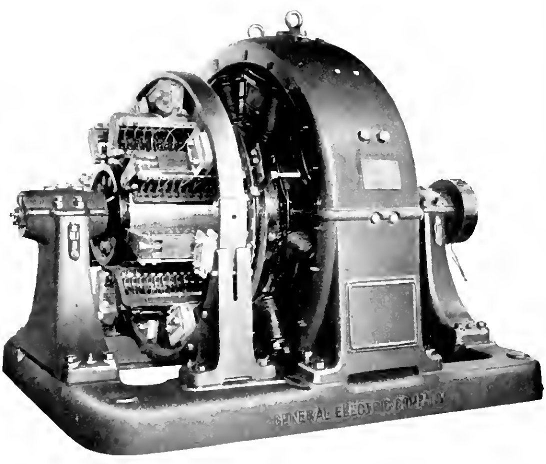


Fig. 8. 1000-kilowatt, 60-cycle, 600-volt converter. Typical of latest construction.

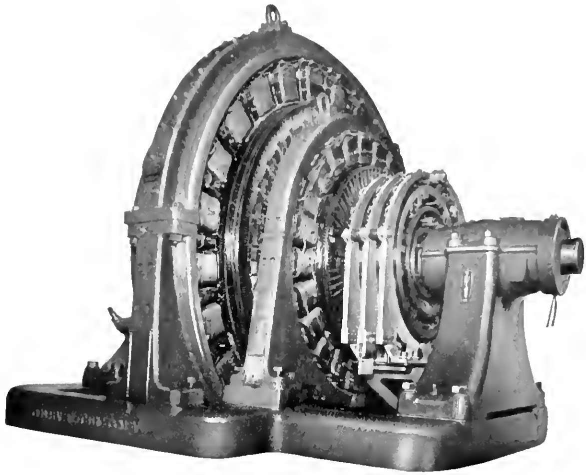


Fig. 9. A-c. end of Converter of Fig. 10

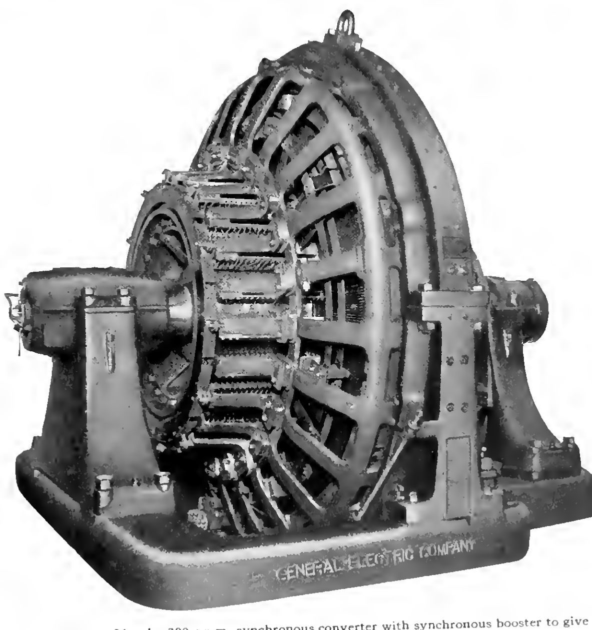


Fig. 10. 2600-kilowatt, 24-pole, 300-r.p.m. synchronous converter with synchronous booster to give d-c. voltage regulation from 240 to 300. This is the largest 60-cycle converter in operation to date

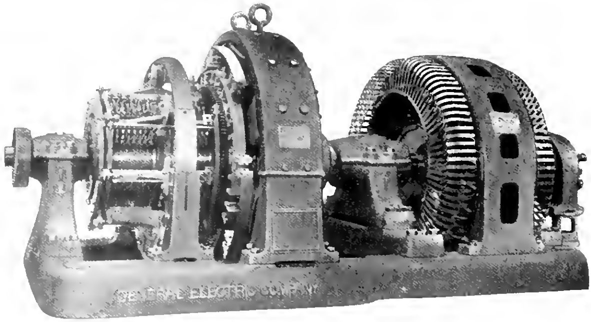


Fig. 11 1000 kilowatt, 250-volt d-c. 60-cycle motor-generator with commutating pole and compensating winding

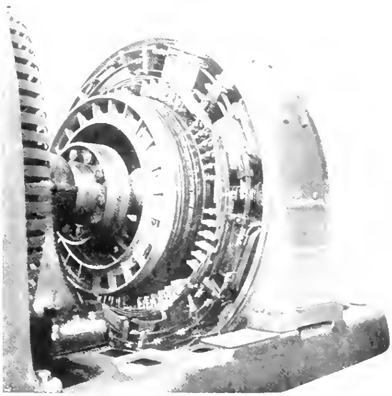


Fig 12. Cover of ventilating ducts removed, showing ventilating openings and arrangement of armature windings with equalizers and commutating, compensating and main field winding

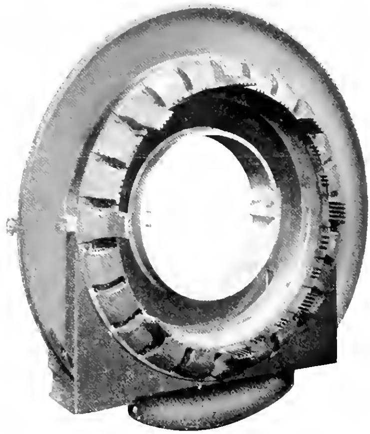


Fig. 13. Air Distributor for Set of Fig. 14

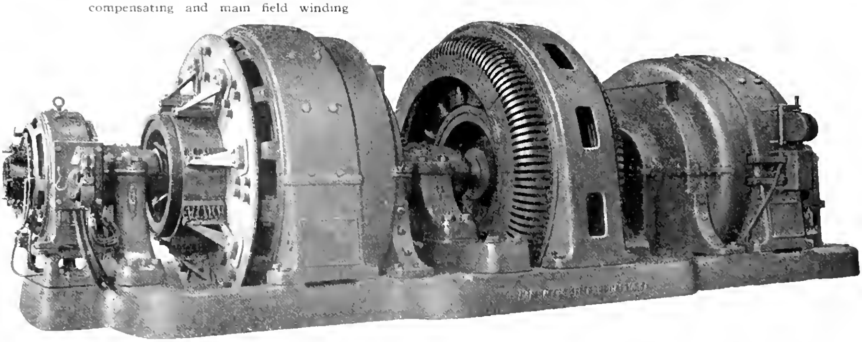


Fig 14 2000-kilowatt, 3000-volt, 60-cycle motor generator set having two 1000-kilowatt, 1500-volt generators connected in series second winding on the commutating-pole for all conditions is now used and depends upon a special relay for its control. This relay has two members, one an alternating-current and the other a direct-current, which are balanced in torque against each other when correct excitation of the shunt-winding commutating field is obtained. The torque of the alternating-current member is proportional to

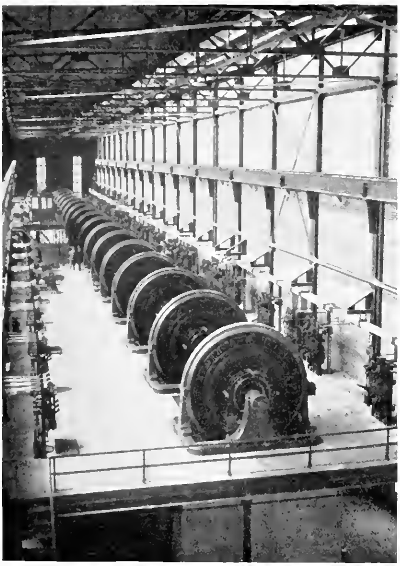


Fig. 15. Massena substation of the Aluminum Company of America now containing twenty-two 60-cycle, 525-volt d-c. converters having a total continuous capacity of 70,000 kilowatts. Direct current output of this station is greater than any other in the world. Power is transmitted at 110,000 volts over a 50 mile line

the main alternating-current and to the voltage of the booster. The torque of the direct-current member is proportional to the current in the commutating field and to the direct-current voltage. When the torques are not balanced a contact point is moved one way or the other, thereby closing a circuit which operates a motor-driven rheostat in the shunt-winding commutating field circuit. The connections are so made that the change in the shunt-winding commutating field current (which also passes through the relay) restores the balance of the relay members. Fig. 2 shows the scheme of connections and Figs. 3 and 4 show the relay and motor-driven rheostat.

Efficiency

The difference in efficiency to be expected between modern 60-cycle motor-generator sets and synchronous converters of 1000 kilowatt capacity, which represents average conditions, is shown by the curves in Figs. 5 and 6. This comparison is an average one and the values given might differ about one per cent from those for different alternating-current motor voltages, types of generator, and converter and speed.

When the motor takes the line voltage directly, the difference in efficiency of the equivalent equipment will be reduced about 2 per cent for the loss in the transformer which is always necessary for the converter.

Reliability and Adaptability

There is very little choice between converters and motor-generators in general operating characteristics within the limits of voltage and frequency prescribed. The principal difference in favor of the motor-generator is that the alternating-current circuits are separated electrically from the direct-current circuits. An alternating-current disturbance that does not throw the motor out of synchronism will not usually interfere seriously with the commutation of the generator, whereas this same disturbance might cause a converter to flash at the commutator. Even with this handicap, converters are being used very satisfactorily to transform the largest blocks of power from some of the largest 60-cycle long-distance high-voltage systems. The principal factor favoring the choice of the converter is its higher efficiency.

In addition to the voltage limits of a converter being narrower, the machine is also more limited in range of voltage control. For a service requiring more than a 2 to 3-voltage range, a motor-generator would usually be preferable to a converter on account of the greater simplicity of the generator accessories. The losses in the control equipment of a converter for such a large voltage range would reduce the machine's efficiency to a value approximating that of the motor-generator for the average commercial voltage.

Probably the best index of the relative advantages of synchronous converters and motor-generators for all classes of service is the comparison of total capacities installed in the past five years, which shows approximately 2 kilowatts of converters for every kilowatt of motor-generators.

TEST OF LARGE HYDRO-ELECTRIC GENERATORS

By R. Treat

Power and Mining Engineering Department, General Electric Company

This article should be of great value to all station engineers interested in the testing of large hydro-electric generators as the author deals quite fully with the method of testing such machines after installation. After showing the method of preparing the saturation and synchronous impedance curves he deals at length with the tests necessary to determine efficiency. Motor core loss, core loss with direct connected motor, no load normal kv-a. losses, regulation, and heat runs are also considered in detail.—Editor.

R. Treat

In making tests on electrical apparatus, especially the larger size units, it is a curious fact that those tests most easily performed at the factory are the most difficult to make after installation in the customer's plant, and vice versa. At the factory, tests showing the efficiency of large alternators can be made with great accuracy, while it is next to impossible to ascertain the operating characteristics under actual load except by calculation and approximation. In the power station, on the other hand, loading can be accomplished with no trouble at all, while efficiency tests are more or less difficult to make. In view of these facts, it is quite common practice to accept the manufacturer's figures for efficiency, and make heat runs and other load tests while in commercial operation in the station.

There are occasions, however, when it is desirable to make efficiency tests at the destination, either on new installations or on machines which have been in service for some time. The ease of making these tests depends to a large extent upon the size and general arrangement of the station, and the flexibility of its bus, switchboard, and exciter arrangements. In the following discussion, the writer endeavors to describe a few of the more common methods of making standard tests on hydro-electric generators after installation.

General

For testing purposes, station or switchboard type meters are to be avoided wherever possible, as they are neither so accurate nor so close reading as portable meters especially designed for the purpose. It is very desirable that all meters shall have been recently calibrated, or compared with semi-standard instruments, and, as an additional precaution, it is well to have a duplicate set of meters at hand, so that each instrument can be checked against a similar one at the time of making the test. To check meters in this way, both should be connected in the circuit at the same time—ammeters in series and voltmeters in parallel—so that they can be read simultaneously, rather than trust to the circuit remaining perfectly constant while the meters are being interchanged. Care should be taken to see that instrument transformers are not overloaded. If it is necessary to use several voltmeters and wattmeters at the same time, more than one pair of potential transformers should be used, in order not to overload the transformers. The different transformers can be checked against each other by comparison. If meter shunts and millivoltmeters are used for reading current, the tester should be careful to see that the proper meter, leads, and shunt are used together. In general, all meters, shunts, and current and potential transformers should be so chosen that a good deflection is obtained on the meter, for not only are all classes of measuring apparatus the most accurate when working near their normal rating, but the human error of inaccurate reading is less with a good scale deflection. For instance, if a man can read a meter to within 0.4 per cent of full scale deflection he will make an error of no more than 0.4 per cent near the normal rating of the meter, whereas, if he has only 10 per cent deflection the error may be 4 per cent.

Saturation

One of the first and most common tests taken on nearly all classes of electrical apparatus is the saturation curve. This is ordinarily taken by driving the machine by its wheel at normal speed on open circuit, and varying the field excitation by any desired number of steps, reading the armature volts and the field volts and amperes simultaneously, to at least 125 per cent of the normal voltage. A curve should be plotted with armature volts as ordinates and field amperes as abscissæ.

Synchronous Impedance

After taking the open circuit saturation curve, a synchronous impedance curve may be taken. For this test the generator terminals should be short circuited through current transformers of suitable capacity, and a curve taken to at least 150 per cent of the normal rated current of the machine, reading field volts and amperes, and armature amperes simultaneously. The curve may be plotted on the same sheet with the saturation by making a new scale of ordinates representing armature current.

Efficiency

Probably the most general method used for determining efficiency is by taking deceleration core loss. This test is based on the principle that every moving body possesses a certain definite amount of energy, due to its motion, known as kinetic energy. The mathematical expression for kinetic energy is $E_k = \frac{1}{2} M V^2$, where M = the mass and V the velocity. M is equal to the weight in pounds divided by 32.2 (acceleration due to gravity). If then, V be expressed in feet per second and W in pounds, the expression above will give the kinetic energy in foot pounds.

For a rotating body, particles at different distances from the center have different velocities, and we cannot use this expression as it stands. But the velocity of any one particle at a distance r from the center of rotation is $r\omega$, where ω is the angular velocity $\left(=\frac{2\pi S}{60}, S = \text{speed in r.p.m.}\right)$, substituting this value of velocity in the above, the formula becomes

$$E_k = \frac{1}{2} \times \frac{W}{32.2} \times r^2 \omega^2 = \frac{1}{2} \times \frac{W}{32.2} \times r^2 \left(\frac{2\pi S}{60}\right)^2$$

Combining all the numerical parts of this expression, we have—$E_k = 0.00017\, W r^2 S^2$

(This value of E_k is expressed in foot-pounds.) To reduce to kw. multiply by $\frac{746}{1000} \times \frac{1}{550}$ which brings the expression to the form

$$E_k\,(Kw.) = \frac{2308}{(10)^{10}} W r^2 S^2$$

where Wr^2 known as the moment of inertia can usually be obtained from the manufacturer. Note, particularly, that if a deceleration core loss is taken with the waterwheel connected the Wr^2 to be used is of the sum the separate "Wr^2's" for the generator field and the waterwheel. Generally both the manufacturers of generator and waterwheel can furnish the desired information, but if not, another mode of procedure will be described later.

It will be seen from the above, that the amount of energy in a revolving field varies only with the speed, and thus the energy dissipated through friction in "slowing down" or decelerating from a higher to a lower speed can be accurately determined simply by measuring the speeds, once the Wr^2 has been determined. Suppose the field has an initial speed of S_1 and, with no excitation, it "decelerates" to a speed of S_2 after the elapse of "t" seconds. Then the average friction and windage loss per second is found from

$$F + W = \frac{2308}{(10)^{10}} \frac{S_1 - S_2}{t} W r^2$$

If S_2 and S_1 are sufficiently close together, the average loss per second will not vary much from the actual loss during each second, and if S_1 is as much above normal rated speed as S_2 is below, the average loss as found above will be *very* close to the actual loss at normal speed. It is customary to choose S_1 as 2 per cent above and S_2 as 2 per cent below normal speed. If the friction and windage loss is so great compared with the moment of inertia, as sometimes occurs on small machines, that the time interval is too short to measure accurately, it may be necessary to choose a greater difference in speeds; but if possible they should always be so taken that the average of the two is equal to the normal.

After determining the friction and windage losses, the core loss may be found simply by repeating the operation with the field excited. The loss in kinetic energy in this case will represent friction, windage and core loss, from which the latter may be segregated by subtracting the friction and windage loss found above. The core loss corresponding to any voltage may be found by repeating the test a number of times with the field excited to give the desired voltages at normal rated speed. Care should be taken to hold the field current constant during the entire period of deceleration. In taking core loss by deceleration or any other method, a direct connected exciter, if the generator has one, should never be used for excitation, for then the loss in kinetic energy would be dissipated in the output and losses of the exciter, as well as in the generator losses. The task of separating out the loss chargeable to the exciter is extremely laborious and should be avoided if possible.

This method of determining the no load losses is very commendable, since it requires a measurement of only time and speed, except for the simple matter of holding the field current constant during deceleration. However, as the time element is usually very short, and the change in speed small, both quantities must be measured with the greatest accuracy possible. It is the best practice to bring the machine to 5 or even 10 per cent overspeed, allow it to coast past the points S_1 and S_2 and read the time interval, t, with a stop watch. A suitable tachometer, of the centrifugal or electric type should be belted to the shaft, and the scale marked for points S_1 and S_2 so the tester can easily tell when the needle or liquid column passes these points. The tachometer should be checked with a speed counter at both points, holding the speed constant long enough to get a good check. A stop watch with its face divided to fifths of a second is usually accurate enough to determine the time. The time interval should not be less than 10 seconds, and preferably much more, as the greater the time, the less error in reading it. The test should be repeated six or eight times, and the average of all consistent readings taken as the true value.

It should be remembered that this method gives the friction and windage of both generator field and turbine wheel. If these losses are desired separate, there is no recourse but to disconnect the wheel and take deceleration on each separately. This is sometimes impossible, especially on vertical machines supported from one thrust bearing, or on horizontal machines where either turbine or generator has only one bearing. However, it can usually be taken on one or the other, and the difference from the total will give the losses in the other unit. In the case of a vertical generator with suspension thrust bearing, it will be necessary to run the machine as a synchronous motor from some other generator and then drop it off the line. If the station arrangement is such that another machine can be isolated and devoted to the machine being tested, there is no particular disadvantage in doing this. In a large number of cases, however, it would be necessary to run the machine under test directly off the station bus, which would prevent carrying it above normal speed, besides presenting a condition in which it would be next to impossible to start up in the first place. In general, unless there is some special reason for getting this information, it is doubtful if the value of separating the generator and wheel losses will warrant the extra expense and trouble incurred.

In taking deceleration, or any other form of core loss, one point must always be kept in mind, and that is to drain the wheel pit, and thus avoid the losses due to churning the water by the wheel. Ordinarily, this will necessitate using another machine for driving the alternator in test while the pit is being drained, or else paralleling on the station bus. For reasons mentioned in the previous paragraph, the former alternative is the better, if another machine can be spared for the purpose. Again, it will be found in most cases that the flume gates are so leaky that the pit will be more or less flooded, even with the gates tightly closed, and steps will have to be taken to stop up the leaks as well as possible, in both head and regulating gates. Obviously, where this is necessary it will be impossible to start up the machine from its own wheel, and an auxiliary alternator will be necessary. The two generators can usually be started together, from rest, with normal field on each, provided the auxiliary is not speeded up so rapidly as to run away from the other. Some times they may start better with no field on the generator under test, running it as an induction motor at very low frequency. Vertical machines provided with Kingsbury or spring type thrust bearings have an extremely high static friction and cannot usually be "broken from rest" in this way. In such cases a crane or lever may be applied to the field to give it a start, after which the auxiliary generator will carry it up to speed as a synchronous motor without further trouble.

If, in addition to the friction, windage, and open circuit core losses, it is desired to find the stray load loss, this may be approximately determined by short circuiting the machine at the terminals with suitable current transformers, and measuring the short circuit stray load loss as outlined above for the open circuit core loss. The measured loss in this case will include the armature copper loss, which should be deducted to give the true stray load loss. The copper loss for a three-phase machine is $3/2\ I^2R$ and for a two-phase is $2\ I^2R$, where I is the armature current held during the period of deceleration and R is the total resistance of the armature circuit, including current transformers and leads, if any. The stray load loss may be determined for any load at which it is desired to calculate efficiency, by holding the armature current corresponding to that load during deceleration.

To obtain the efficiency of the machine, the total losses taken into account are as follows:

(1) No load core loss, determined as above.

(2) Stray load loss, determined as above

(3) Friction and windage loss, determined as above.

(4) I^2R loss in armature. R is the resistance between phases at generator terminals.

(5) I^2R loss in field. R is the resistance between collector rings, and I is determined for the load, voltage and power factor as outlined below.

(6) I^2R loss in rheostat.

NOTE: Items 5 and 6 can be combined by multiplying the excitation voltage, usually 125 or 250, by the field current.

If it is not convenient to take the required field current from actual operation it may be calculated approximately from the formula

$$C=\sqrt{a^2+b^2\pm 2\ ab\ sin\ \theta}$$

where a is the field amperes taken from the saturation curve corresponding to the voltage under consideration, b is the field current from the synchronous impedance curve corresponding to the armature current at the load at which the efficiency is being calculated, and θ is the angle whose cosine is the power-factor. Note that $sin\ \theta=\sqrt{1-(P.F.)^2}$, i. e., if power-factor is 0.8, $sin\ \theta=0.6$. For generators, use the positive sign if the power-factor is lagging and the negative if it leads.

In case it is impossible to obtain the moment of inertia Wr^2 for the machine, it will be necessary to take a "running light" reading. This consists in running the machine at no load under normal voltage, and reading the input carefully. This input will be composed of friction and windage losses and core loss, which may be separated by the deceleration method. Running light is a rather difficult test to take in a power house, because the necessary equipment is not usually available. It may be taken on a vertical generator equipped with a direct connected exciter, by running the exciter as a motor from some suitable source of power, and reading the input, as described later, or can be accomplished by running the generator as a synchronous motor and reading the input on wattmeters connected in the usual way for two wattmeters reading three-phase power. If this is done, the current transformers selected should be small enough to give a good reading on the wattmeters. The field excitation should be adjusted for unity power-factor, which will be indicated when the wattmeters read both positive and alike. The I^2R loss in the armature may be entirely neglected as it will probably be less than 0.2 per cent of the copper loss at full load.

Having obtained a good running light reading we may proceed to separate the losses by deceleration. If T_1 is the period of deceleration between speeds S_1 and S_2 with the field unexcited, and T_2 is the period with the field excited, to generate the voltage at which running light was taken, then kw. friction$=\frac{T_2}{T_1}\times Kw.$ running light, by which we may separate the core loss from the friction and windage.

Motor Core Loss

In taking "running light," as outlined above, if we can segregate another machine of similar voltage to devote to the machine in test, or in any way vary the supply voltage through a wide range, it will be unnecessary to resort to deceleration at all. With the machine running as a synchronous motor from a variable supply of voltage, and reading the input on two wattmeters connected to small current transformers, the voltage and field current may be varied together, holding unity power-factor, and readings of input taken at as many points as desired. It will not be possible to obtain an exact reading of windage and friction alone, as obviously it will be impossible to run without *some* voltage, but the curve can be carried low enough so that it can be extended to zero volts and the true friction and windage determined with tolerable accuracy.

Core Loss With Direct Connected Motor

Some vertical generators are equipped with direct connected exciters large enough to run as motors and supply the no load losses of the generator. In such a case it may be more convenient to get the core loss, friction, etc. by reading the input to this motor. The exciter *can* be run off the station bus, but it is preferable to use a separate source of power, and one whose potential may be varied at will, if such be available. If a variable resistance, such as a water rheostat can be obtained without too much trouble, this should be inserted in the armature circuit to dampen the fluctuations and make more accurate readings possible. The motor field should be separately excited, and held constant, speed being held by varying the voltage across the exciter armature. This voltage should be read by means of insulated brushes, to eliminate brush and brush contact drop.

After running two or three hours at normal speed with field unexcited, or until the input to the motor is constant, a careful reading of this input should be taken and this, less the I^2R loss, windage and core loss in the exciter armature, will give the friction and windage loss in the generator. The windage and core loss will probably have to be approximated, and a fair figure would be windage $\frac{1}{2}$ per cent and core loss $1\frac{1}{2}$ per cent of the rating of the exciter. In figuring the I^2R loss, the armature cannot usually be directly measured but the resistance can be found very closely in this way. There is generally about 4 per cent resistance drop in the armature at normal load, hence the armature resistance will be $R=0.04\frac{E}{I}$ where E and I are normal rated voltage and normal rated current of the exciter. All of these quantities entering into the exciter loss, although determined in a rather approximate fashion, are in reality very small compared to the generator losses being measured, hence any small error will not affect the net result to an appreciable extent.

With the friction constant, we may now proceed with the core loss curve; readings should be taken simultaneously of the armature volts and amperes and the field amperes of the exciter, speed, and the field volts and amperes and armature volts on the generator, at as many points as desired up to 125 per cent armature volts. Great care must be taken to see that the speed is exactly constant at the time of reading, as any accelerating or decelerating action will change the input. Plot the curve between armature volts as abscissae and kilowatts input as ordinates. In calculating the core loss, it should be remembered that the I^2R loss in the exciter changes for each new value of input current.

After obtaining the open circuit core loss, the stray load loss may be found in the same way by running the machine short circuited and reading the input to the exciter. The I^2R loss in the generator armature, current transformers and leads should be deducted, as noted above, for deceleration core loss. After getting the friction, windage, open circuit and short circuit losses, the efficiency can be calculated as before.

No Load, Normal Kv-a. Losses

If only a rough check on the efficiency is desired, the machine may be paralleled with the station bus, or with another machine, the gate closed and the field overexcited to take normal kv-a. If the power input is read on wattmeters, these will give approximately the full load armature losses, to which should be added the I^2R field loss for the proper excitation. This test should not be regarded as giving very accurate results, however, for even a good portable wattmeter is not accurate to closer than $\frac{1}{2}$ to $\frac{3}{4}$ per cent of the full scale deflection at such low power-factors, while an ordinary station meter is not much better than 2 or 3 per cent.

Regulation

By all means the best method of determining the regulation of an alternator is by watching its operation under actual load. If normal load at the given power-factor and voltage is thrown off and the speed and field excitation remain unchanged the no load voltage resulting will give the regulation directly. If, however, it is desirable to calculate the regulation, this may be approximately done from the saturation and synchronous impedance curves. Calculate the total field amperes required for full load at the given power-factor, as described above under "Efficiency," and from the saturation curve find the corresponding no load voltage. A more accurate and more complicated method is described in the Standardization Rules of the American Institute of Electrical Engineers.

Heat Runs

Heat runs are made, 1st, to determine whether the machine meets the manufacturer's guarantee, and 2nd, to determine whether or not it will carry its commercial load without undue heating. Under ordinary circumstances these two requirements are coincident, and both economy and convenience will dictate running under commercial load during heat runs. Sometimes, however, it may be impossible to get full load on the machine continuously or it may be desirable to determine the heating before the entire station is ready for service. At other times, the nature of the station load may be radically different from that for which the generator was designed as regards voltage or power-factor, which may make it desirable to determine the heating artificially. Probably the easiest and most satisfactory method of accomplishing this result is by a condenser heat run. The machine is paralleled with the station bus, or with another machine of at least equal capacity, and excited to take full kv-a. leading. The field will necessarily be overexcited during this test, and close watch should be maintained that it does not overheat. Take a careful reading of the field resistance and temperature before starting, and at intervals of half an hour during the run, read the field amperes and field volts by means of insulated brushes. Calculate the rise by resistance, and in case the field assumes a dangerous temperature, the run must be abandoned. Thermometers should be securely fastened to the armature core and coils by means of felt pads. In general, the Institute Rules should be followed very closely as regards location of thermometers, ambient temperature, etc. If felt pads are impracticable, ordinary putty will give very accurate results, if care is taken to apply sufficient putty to thoroughly insulate the bulb from the surrounding air, yet not so much as to restrict ventilation from the immediate vicinity and thus create an artificial hot spot. When the machine has reached a constant temperature, it may be shut down and thermometers quickly applied to the field coils, pole tips, armature core (inside) and other points inaccessible while the generator was running. Quick work is required to get accurate results as the surface starts to cool off rapidly after the load is removed.

If it is impossible or undesirable to run the machine as a condenser, open circuit and short circuit heat runs may be substituted. Run the machine on open circuit, with the field excited to generate 110 per cent of the normal voltage until constant temperatures are reached, then shut down and take off the heat run as before on the condenser run. The temperatures of the field coils, pole tips and armature core will be approximately what they would be under actual load. Then short circuit the armature through suitable current transformers, and make a heat run at 110 per cent of normal armature current on a maximum rated machine, or 125 per cent current on all others. This will give very nearly the heating of the coils under actual load.

A third method, and in some instances a better one than either of the foregoing, is to make an actual load run using a water resistance as the load. Plates or pipes, connected to the generator terminals may be located in the tail race or in a specially constructed tank, their size and distance apart depending upon the capacity and voltage of the machine being tested. A more detailed discussion of this form of artificial loading may be found in the October, 1915 number of the REVIEW, page 1001.

A straight resistance, however, will give very nearly a unity power-factor load, whereas the majority of generators are designed to carry a load at other than unity—quite often 80 per cent power-factor. If another idle machine is available, it may be paralleled with the one under test, then by reducing the excitation made to take wattless current so as to obtain a true kilowatt and wattless load.

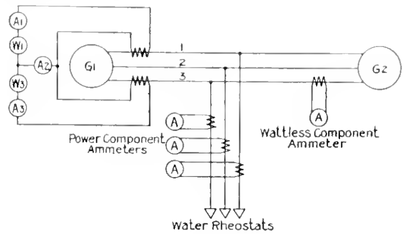


Fig. 1 Diagram of Connections for a Test Heat-run at a load of less than unity power-factor

In Fig. 1, G_1 is the generator under test and G_2 the floater taking the wattless current. Current transformers, wattmeters and ammeters should be inserted as shown, care being taken to keep the current in the three legs of the water rheostat balanced. For the sake of clearness, the potential transformer connections to the wattmeters have been omitted from the sketch. It will probably be found more convenient to adjust the power component of the load (the water rheostat) before paralleling the auxiliary generator. As a final check on the correctness of the adjustment, the current from the generator should be the square root of the sum of the squares of the power component and wattless component currents. If step-up transformers are not available, and the generator voltage is so low (below 2300) that it is necessary to use a tank and salt solution for resistance, the rheostat will have to be closely watched throughout the run. Unless the tank is of ample size, or plenty of cooling water is at hand, it may become very hot, with resultant boiling and flashing or burning of the terminals, which always causes the load to fluctuate. It is always better, if possible, to employ a high enough voltage so that the electrodes can be located in the tail race and avoid this trouble. After the run has become constant, it may be taken off and final temperatures read, as before.

In conclusion, it is quite impossible to lay down any set of strict rules for making tests in generating stations. The local conditions are so variable, and so many different factors enter, that it is impossible to forecast what line of procedure will be the best to adopt unless the local conditions existing at each particular installation are known. We have, however, endeavored to point out a few of the more general means employed, and it is hoped that some one of the various methods described will be found to suit the particular needs of the case at hand.

APPROXIMATE SOLUTION OF SHORT-CIRCUIT PROBLEMS

By E. G. Merrick

Power and Mining Engineering Department, General Electric Company

There are many short-circuit problems that are very hard to calculate; so this article is of particular value, as the author shows, by examples, the method of determining short-circuit values in various circuits with widely differing characteristics. The solutions are approximate, but are typical of actual practice, and are accompanied by results derived from actual test values.—Editor.

E. G. Merrick

The complicated interlinkage of electric and magnetic circuits in an alternator makes the theoretical analysis of short-circuit conditions an exceedingly difficult one. These conditions have been discussed at length by several authors* and will, therefore, be touched upon but briefly at this time. The main object of this article is to give the approximate solution of several typical short-circuit problems and also some results obtained from actual tests.

At the instant of short circuit, the armature current rises to many times its normal value, being limited only by the self-inductive reactance of the armature circuit. Gradually the field flux is reduced by the opposing armature flux and the armature current diminishes to a constant value, determined by the combined reactance, resistance and armature reactions, or what is termed "synchronous impedance"—giving the condition of sustained short circuit.

Fig. 1 is an oscillogram of a typical three-phase short circuit, the generator being short circuited at the terminals of the armature winding. Referring to the middle curve, the short circuit occurred when the phase voltage was near its maximum value, giving an approximately symmetrical relation of the current crests with respect to the zero axis; for the upper curve, the short circuit occurred when the phase voltage was near its zero value, giving an unsymmetrical current wave as the result. For both cases, the total amplitudes of the current waves at the instant of short circuit are the same and are equal to $I_0 = 2\sqrt{2}\,I$, where I is the effective value of the current. If we take into account the damping action of the field circuit, the total amplitude will be reduced approximately 10 per cent and the maximum possible value of the instantaneous current is, therefore, equal to

$$I_0 = \frac{1.8 \times \text{max. volts per leg}}{\text{impedance } (=\text{reactance})} = \frac{1.8 \text{ effective volts per phase} \times \sqrt{2}}{\sqrt{3} \times \text{reactance}}$$

(For a rational calculation of the damping effect, see "Short Circuits", Diamant, A.I.E.E., Sept., 1915.)

In calculating the instantaneous value of the short-circuit current which may occur under the worst possible conditions, one should, therefore, assume the case of an unsymmetrical current wave. For example, if the reactance of an alternator based on normal voltage and current is 10 per cent, and the short circuit occurs when the machine is operating at normal voltage, the maximum possible instantaneous current equals

$$\frac{100}{10} \times 1.8\ In \times \sqrt{2}; \quad \text{where } In =$$

effective value of rated full load current.

If any external impedance is included between the alternator and the point of short circuit, the internal and external impedances add directly to limit the flow of current.

* "Alternator Short Circuits" by Cassius M. Davis, General Electric Review, August, 1914. "Short-circuits" by N. S. Diamant, A.I.E.E., Sept., 1915

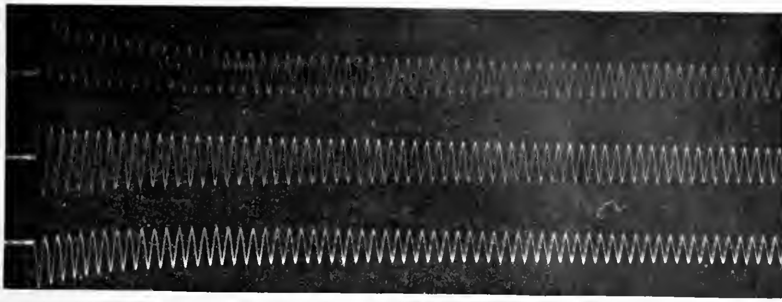


Fig. 1. Oscillogram of a Three-phase Short-circuit on a 10,000-kv-a., 6600-volt, 63-cycle generator

Fig. 2 shows the no load saturation and synchronous impedance curves of a 10,000-kv-a., three-phase, 11,000-volt, 25-cycle alternator. This machine was short circuited at its terminals when operating at no load and with a field excitation of 115 amperes which gave 6000 volts per phase. Fig. 3 is the oscillogram taken for this condition and indicates an average maximum possible instantaneous current for two of the phases of 11,150 amperes. From the given formula

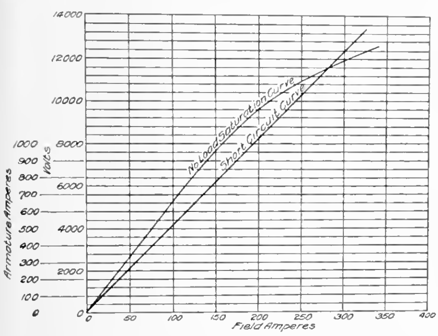


Fig. 2. The No-load Saturation and the Synchronous Impedance curves for a 10,000-kv-a., 11,000-volt, 25-cycle generator.

the impedance per leg equals

$$\frac{1.8\times 6000\times\sqrt{2}}{\sqrt{3}\times 11{,}150}=0.792 \text{ ohms}$$

The rated full load current of the generator is 525 amperes and the per cent reactance based on normal voltage and current is, therefore,

$$\frac{525\times 0.792\times\sqrt{3}}{11{,}000}=6.55 \text{ per cent.}$$

The alternator was then connected to an external circuit consisting of reactance coils, step-up transformer with a voltage ratio of 11,000 : 70,000 and transmission line; the total actual external impedance being equal to 16.4 per cent based on normal current and voltage. The total impedance was, therefore, equal to $16.45+6.55=23.0$ per cent. The short-circuit test for this case was made at no load with 190 amperes field current. As the impedance is practically constant with the usual range of excitation, a straight line saturation should be assumed, tangent to the lower portion of the magnetization curve; for the given excitation, we then have 10,000 volts low tension = 63,500 volts high tension. The per cent impedance based on the test voltage is, therefore,

$$\frac{23\times 70{,}000}{63{,}500}=25.3 \text{ per cent.}$$

The normal high tension current is 82.5 amperes per phase. The maximum possible instantaneous value of the current from the above equation equals

$$\frac{100}{25.3}\times 1.8\times 82.5\times\sqrt{2}=835 \text{ amperes.}$$

The oscillogram of Fig. 4, taken on this test, gives an average maximum possible value for the three phases of 863 amperes.

Sustained Short-circuit

The armature current has now reached a constant value which is determined by the combined effect of armature impedance and armature reaction; this quantity, which is termed "synchronous impedance" can be dealt with the same as armature impedance and can, therefore, be combined directly with any external impedance.

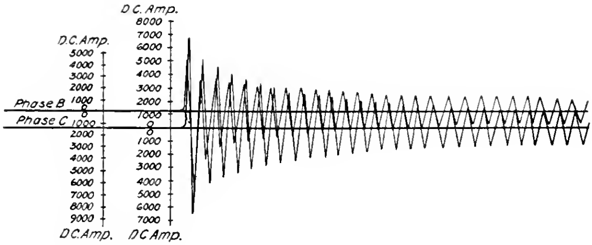


Fig. 3. Tracing of an Oscillogram of a Three-phase Short-circuit on a 10,000-kv-a., 11,000-volt, 25-cycle generator

Taking again the case of the 10,000-kv-a. alternator just mentioned; the synchronous impedance equals the no load voltage divided by the corresponding short circuit current for the same value of field current. As the resultant field flux is that corresponding to the voltage necessary to force the current

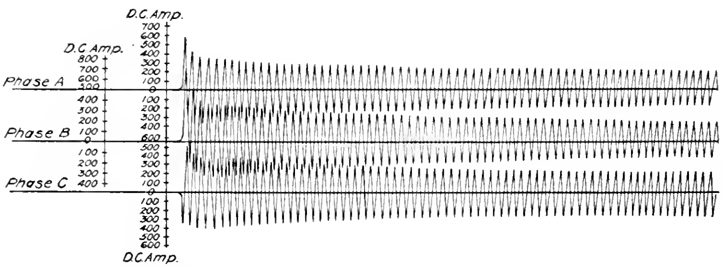


Fig 4 Tracing of an Oscillogram of a Three-phase Short-circuit on a 10,000-kv-a., 11,000-volt 25-cycle generator, including impedance of transformers, reactance coils and line

through the impedance of the circuit, there is no saturation of the magnetic paths within the usual limits of excitation, and the no load voltage corresponding to any value of field current should, therefore, be taken from the straight line portion of the saturation curve or a continuation of this straight line. From Fig. 2, the short circuit current corresponding to 275 amperes excitation = 1405 amperes or 2.68 × normal current; the synchronous impedance based on normal voltage is therefore $\frac{100}{2.68} = 37.4$ per cent.

With the same field excitation the sustained short circuit current was then measured with reactance coils, transformer and transmission line in the circuit; the external impedance based on normal voltage and current equals 16.2 per cent. As the excitation at no load for normal voltage is 211 amperes (straight line saturation), the corrected value of external impedance $= 16.2 \times \frac{211}{275} = 12.4$ per cent. The total impedance $= 37.4 + 12.4 = 49.8$ per cent.

Therefore the short circuit current $= \frac{100}{49.8} =$

$2.01 \times$ normal current.

The normal high tension current = 82.5 amperes, therefore, $2.01 \times 82.5 = 165$ amperes. The actual measured current was 160 amperes.

With an external impedance of 22.3 per cent based on normal voltage and current or $22.3 \times \frac{211}{275} = 17.1$ per cent based on excitation of 275 amperes, the total impedance equals $37.4 + 17.1 = 54.5$ per cent. or $\frac{100}{54.5} = 1.83 \times$ normal current, therefore $1.83 \times 82.5 = 151$ amperes. The observed value in this case was 145 amperes.

Actual and calculated data from other systems have given even closer comparisons; the ratio of external impedance to the synchronous impedance of the alternator was smaller, however, than for the examples given and the results are therefore less interesting.

In the above calculations of sustained short circuits, the per cent value of external impedance has been corrected, wherever necessary, in order that it may be on the same basis as the generator impedance. It is not always convenient to correct the external value. If this is not done, however, the generator impedance should be corrected to a fictitious value and the total result corrected by the same factor.

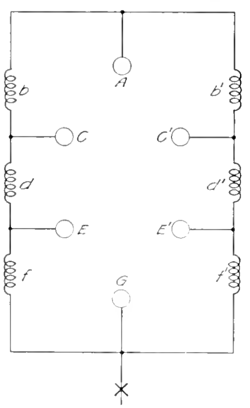


Fig. 5. A One-line Diagram of a Station Layout showing the generators connected to a ring bus

In case an automatic voltage regulator is used, it will endeavor to maintain normal voltage at the alternator terminals when the short circuit occurs; the exciter voltage will, therefore, increase to the maximum value which the exciter can give when connected across the generator field. The sustained short circuit in the generator circuit should, therefore, be based on this increased value of excitation.

Fig. 5 indicates diagrammatically a large generating station containing six 30,000-kv-a., 11,000-volt turbo-alternators, operating on a "ring" bus and with reactors between each two generators having a reactance of 10 per cent based on the normal current and voltage of one machine. Each generator is equipped with an automatic voltage regulator and the maximum excitation obtainable is $3.0 \times$ the excitation for normal voltage, no load (straight line saturation curve). The sustained short-circuit current with maximum excitation is $2.5 \times$ normal, or the synchronous impedance

$$= \frac{100}{2.5} = 40 \text{ per cent.}$$

The per cent bus reactance corrected for the increased excitation

$$= \frac{10}{3.0} = 3.33 \text{ per cent.}$$

For a short circuit occurring at "x," the total impedance of the station is obtained by combining the individual impedances as follows:

$$A + \begin{bmatrix} b \\ b' \end{bmatrix} = 40 + \frac{3.33}{2} = 41.67 \text{ per cent} \qquad (1)$$

$$(1) + \begin{bmatrix} C \\ C' \end{bmatrix} = \frac{1}{\frac{1}{41.67} + \frac{2}{40}} = 13.5 \text{ per cent.} \qquad (2)$$

$$(2) + \begin{bmatrix} d \\ d' \end{bmatrix} = 13.5 + \frac{3.33}{2} = 15.17 \text{ per cent.} \qquad (3)$$

$$(3) + \begin{bmatrix} E \\ E' \end{bmatrix} = \frac{1}{\frac{1}{15.17} + \frac{2}{40}} = 8.64 \text{ per cent.} \qquad (4)$$

$$(4) + \begin{bmatrix} f \\ f' \end{bmatrix} 8.64 + \frac{3.33}{2} = 10.31 \text{ per cent.} \qquad (5)$$

$$(5) + G = \frac{1}{\frac{1}{10.31} + \frac{1}{40}} = 8.2 \text{ per cent.}$$

$\frac{100}{8.2} = 12.2 \times$ normal current of one generator, i.e., the current corresponding to $12.2 \times 30{,}000 = 366{,}000$ kv-a.

As the current divides among the parallel circuits inversely as their impedances, we obtain the following results.

Generator	Current × Normal
A	1.79
$C(=C')$	1.88
$E(=E')$	2.08
G	2.5

Reactance	Current × Normal	Per Cent Volts Drop
$b(=b')$	0.89	8.9
$d(=d')$	2.77	27.7
$f(=f')$	4.85	48.5

Therefore the voltages of the different generators will be:

Generator A	9360 volts
Generator $C(=C')$	8380 volts
Generator $E(=E')$	5340 volts
Generator G	0.0 volts

On sustained short circuit, the individual generators will, therefore, operate approximately under the conditions of voltage and current as indicated.

The maximum possible value of current at the instant of short circuit is of interest mainly to the alternator designer, as the machines must be made sufficiently sturdy to withstand the stresses due to this value. From the standpoint of oil switch design, this maximum value is of less importance as there is always a certain time lag between the instant of short circuit and that at which the switch contacts open and the current at the latter instant has, therefore, decreased more or less depending on the type of relay used. With an instantaneous relay, the time lag for the relay, trip coil and switch may be approximately 1/4 second, whereas, a definite time relay can be set to operate after a time interval of several seconds.

Fig. 6 shows the decrease of the short-circuit current at different time intervals with constant field excitation. These results were obtained from oscillograph records of tests on different machines. The ordinate at any time t indicates the ratio of

$$\frac{\text{effective value of current at time "}t\text{"}}{\text{effective value of current at first crest}}$$

For symmetrical waves, the same curves would also show the ratio of instantaneous values of the current.

An analysis of many oscillograms of short circuits taken on both 25- and 60-cycle generators indicate that even when the current wave is unsymmetrical at the start, it becomes approximately symmetrical in from 0.2 to to 0.5 seconds; therefore, the current which the switch must rupture becomes a more definite quantity and has a fairly definite relation to the sustained short circuit current, providing the excitation remains constant.

An interesting comparison is obtained from curves No. 1 and No 3: Curve No. 1 is for a generator alone and curve No. 3 for the same generator with external impedance. The slow decay of current in the latter case emphasizes the objectionable feature of reactance coils in relation to instantaneous switch operation: namely, that although the instantaneous and sustained currents are reduced by the added reactance, yet the values of current for the two cases, at the instant of opening of the switch contacts, may possibly be approximately the same. As far as the switch is concerned no gain would have been made in such a case and a new element of danger would have been added on account of the possibility of high voltage discharge due to the reactive effect of the coil. Great care should, therefore, be exercised in determining the proper size of current limiting reactances to be used in any network.

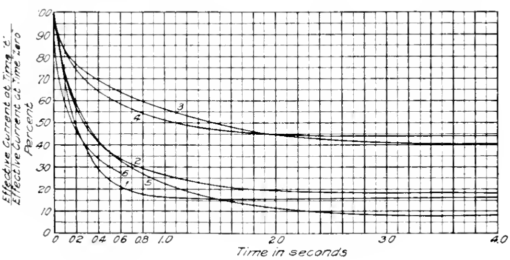


Fig. 6. Curves showing the Decay of Short-circuit current as a function of time

AN APPROXIMATE METHOD OF CALCULATING SHORT-CIRCUIT CURRENT IN AN ALTERNATING-CURRENT SYSTEM

By H. R. Wilson

Power and Mining Engineering Department, General Electric Company

The author of the following article points out first the importance of determining the short-circuit current values in an alternating-current system, and then differentiates between the instantaneous and the sustained values. From this point on, the article consists of a detailed diagrammatic and mathematical work-up of a typical set of calculations for reactance, current, etc., as applied to a representative large alternating-current system.—Editor.

H. R. Wilson

Today, the larger alternating-current systems have reached such a magnitude that analyses must be made of the current values that are created by short-circuits occurring at various points. These are necessary in order that the apparatus will most reliably meet the requirements caused by such short-circuits.

At the time a short-circuit occurs in the system, the maximum short-circuit current will be limited by the total effective impedance at that instant in the generators, transformers, and transmission lines to the fault. This value of impedance rapidly increases until the synchronous impedance of the generators is reached. We, therefore, have two limits to the value of the short-circuit current, viz., the *instantaneous* short-circuit current (dependent upon the *instantaneous* effective impedance of the system) and the *sustained* short-circuit current (dependent upon the *sustained* effective impedance of the system). Although resistance is a component of impedance, the total resistance of a system is of so small a value compared to the reactance that, for all practical purposes, the former may be neglected and all calculations be based on reactance only, instead of impedance.

The different combinations of generators, transformers, and lines so change the value of the short-circuit current that it is often found to be convenient and to facilitate calculations if the system is graphically represented as a diagram in which is included the reactance of each piece of apparatus; this reactance is to be expressed in per cent based on some nominal capacity, such as the capacity of the principal generating unit.

Since probably the most lucid form of an explanation of the practical method for calculating short-circuit factors is an example, a typical installation has been selected for this article and the calculations applied to it are worked out in detail in the following.

Consider a 60-cycle, three-phase system as shown by the one-line diagram in Fig. 1. The groundwork was laid down several years ago. As time went on, the system grew and considerable equipment was added. In accordance with the modern design tendency, the more recently installed apparatus has the higher reactance.

The *instantaneous* per cent reactance of each generator and each transformer, based on its rated capacity and the per cent of each based on an arbitrary value of 4000 kv-a. will be as in Table I.

TABLE I

Station No.		Per Cent Reactance Based on Rated Capacity	Per Cent Reactance Based on 4000 Kv-a.
1	4000 kv-a. generator	12.0	12.0
2	2300-kv-a. generator	12.0	22.6
3	6000-kv-a. transformer	6.0	4.0
4	1500-kv-a. transformer	11.4	30.4
5	1500-kv-a. transformer	11.6	31.0
6	6000-kv-a. transformer	7.3	4.9
6	2000-kv-a. generator	4.0	8.0
6	2250-kv-a. transformer	3.9	7.0
6	9375-kv-a. generator	22.0	9.4
7	4500-kv-a. transformer	5.5	4.9
8	1500-kv-a. transformer	11.7	31.2

The single-phase reactance in ohms per 1000 feet of a three-phase circuit is

$$\frac{2\pi f L}{1000} = \frac{\left[2\times\pi\times f\times\left(0.141\ log\frac{D}{d}+0.0576\right)\right]}{1000}$$

in which D = interaxial spacing of conductors and d = diameter of conductor.

The per cent reactance is

$$\frac{\text{kv-a.}\times\text{reactance ohms}}{(\text{kv.})^2\times 10}$$

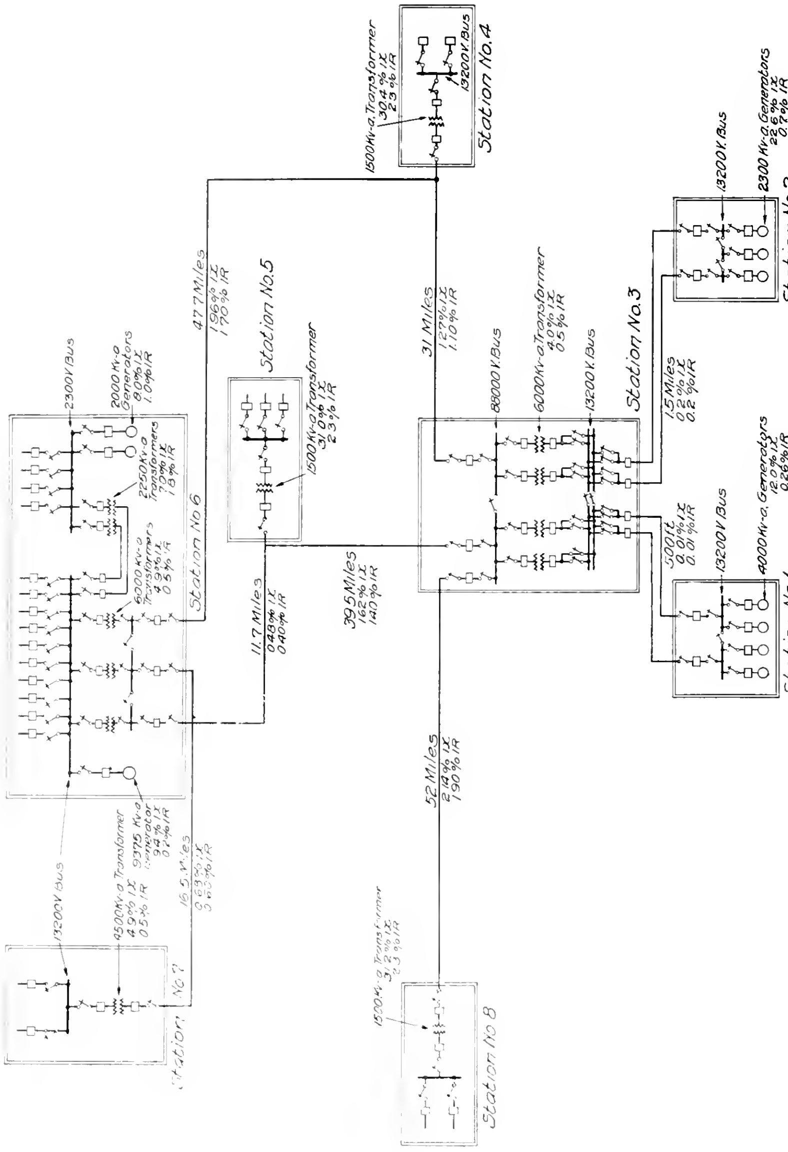


Fig. 1. One-line Diagram of an Extensive A-c. System

The lines from station No. 4 to station No. 3 and from station No. 2 to station No. 3 consist of 500,000 c.m. cable with three-foot spacing.

The reactance per 1000 feet is

$$\frac{[2\times\pi\times60\times(0.141\times1.64+0.0576)]}{1000}$$

$$=0.11 \text{ ohms.}$$

or, based on 4000 kv-a., is

$$\frac{4000\times0.11}{(13.2)^2\times10}$$

$$=0.025 \text{ per cent.}$$

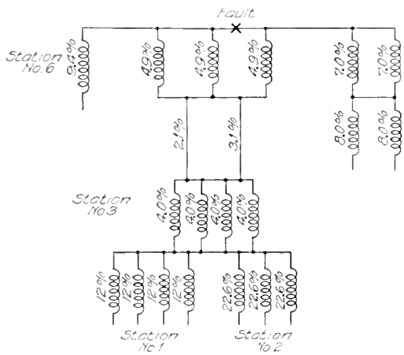


Fig. 2. A Diagrammatic Representation of Instantaneous Reactance when a fault occurs on the 13,200-volt bus of Station No. 6, Fig. 1

As these lines are of such short length, the reactance is comparatively small and will be neglected in the further calculations.

The lines for transmission at 88,000 volts consist of No. 0 conductor with 96-inch spacing.

The reactance of this conductor per mile is

$$\frac{5.28[2\times\pi\times60\times(0.141\times2.41+0.0576)]}{1000}$$

$$=0.8 \text{ ohms.}$$

or, based on 4000 kv-a., is

$$\frac{4000\times0.8}{(88)^2\times10}$$

$$=0.041 \text{ per cent.}$$

The several 88,000-volt lines will, therefore, have reactances as listed in Table II.

TABLE II

	Mile	Per Cent
Station No. 3 to station No. 4	31.0	1.27
Station No. 4 to station No. 6	47.7	1.96
Station No. 6 to station No. 7	16.5	0.68
Station No. 3 to station No. 5	39.5	1.62
Station No. 5 to station No. 6	11.7	1.48
Station No. 3 to station No. 8	52.0	2.14

Now, for a specific example of what will occur when a short-circuit takes place, consider a fault on the 13,200-volt bus of station No. 6—all the apparatus being in service and all switches closed. The instantaneous reactance to the fault may be diagrammatically expressed as in Fig. 2.

The total per cent reactance to the fault will be as follows:

Station No. 1: 4 generators in parallel

$$\frac{12.0 \text{ per cent}}{4}=3.0 \text{ per cent.}$$

Station No. 2: 3 generators in parallel

$$\frac{22.6 \text{ per cent}}{3}=7.5 \text{ per cent.}$$

Stations No. 1 and 2: In parallel

$$\frac{1}{\frac{1}{3.0}+\frac{1}{7.5}}=2.1 \text{ per cent}$$

Station No. 3: 4 transformers in parallel

$$\frac{4.0 \text{ per cent}}{4}=1.0 \text{ per cent.}$$

Two lines: In parallel

$$\frac{1}{\frac{1}{2.1}\times\frac{1}{3.2}}=1.2 \text{ per cent.}$$

Station No. 6: 3 transformers in parallel

$$\frac{4.9 \text{ per cent}}{3}=1.6 \text{ per cent.}$$

The total reactance from station No. 1 and No. 2 to the low-voltage bus of station No. 6 is

$$2.1+1.0+1.2+1.6=5.9 \text{ per cent.}$$

Station No. 6:

2 Generators in parallel

$$\frac{8.0 \text{ per cent}}{2}=4.0 \text{ per cent.}$$

2 Transformers in parallel

$$\frac{7.0 \text{ per cent}}{2}=3.5 \text{ per cent.}$$

Generators and transformers in series. . . $=7.5$ per cent.

1 generator 9.4 per cent.

Therefore, at station No. 6 there are in parallel 5.9, 7.5 and 9.4 per cent reactances which give

$$\frac{1}{\frac{1}{5.9}+\frac{1}{7.5}+\frac{1}{9.4}} = 2.4 \text{ per cent total reactance.}$$

The instantaneous current at the fault is equivalent to $\frac{100}{2.4} \times 4000 = 167{,}000$ kv-a. or 7300 amp.

The total resistance to the fault, determined by the same method as just described for total reactance, is

0.16 per cent.

and if the total reactance is 2.4 per cent the total impedance is

$$\sqrt{(2.4)^2+(0.16)^2} \text{ or } 2.405 \text{ per cent}$$

so, for all practical purposes, simply the reactance values need be used.

Calculations to determine the *sustained* short-circuit current will be sufficiently accurate if the synchronous reactance of the generators is added directly to the reactance of the remainder of the system.

The synchronous reactances of the generators in this system are as listed in Table III, it being assumed that all the generators are provided with voltage regulators which will increase the exciter voltage above normal voltage. Substituting these synchronous reactance values for the instantaneous values in the previous calculations, the sustained short-circuit current will be found to be equivalent to 91,000 kv-a., or 4000 amps.

TABLE III

Station No.		Per Cent Reactance, Based on Rated Capacity	Per Cent Reactance, Based on 4000 Kv-a.
1	4000-kv-a. generator	17.3	17.3
2	2300-kv-a. generator	18.5	32.2
6	2000-kv-a. generator	25.0	50.0
6	9375-kv-a. generator	51.0	21.8

The switch in this feeder would be required to rupture the instantaneous short-circuit current of 7300 amperes if it operated at the exact moment the fault occurred; but, as there is an element of lag in even the fastest moving automatic switch and as the short-circuit current decreases very rapidly, the current which the switch will break is more likely to be nearer to the sustained value, i.e., 4000 amps.

The reactance of the system when a fault occurs in the transformer at station No. 4 may be diagrammatically represented by Fig. 3, in which

x_1, reactance of line from station No. 3 to station No. 4, is 1.2 per cent.

x_2, total effective reactance of station Nos. 1, 2 and 3, is 3.1 per cent.

x_3, reactance of line from station No. 3 to station No. 6, is 2.1 per cent.

x_4, total effective reactance of station No. 6, is 5.8 per cent.

x_5, reactance of line from station No. 6 to station No. 4, is 1.9 per cent.

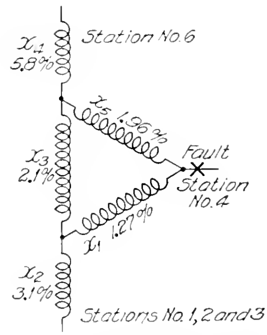


Fig. 3. A Diagrammatic Representation of Instantaneous Reactance when a Fault occurs on the High-tension Bus of Station No. 4, Fig. 1

By Kirchoff's law:

$$X_2 = \frac{K(x_1+x_2)+x_1\,x_2(x_4+x_5)}{K+x_1\,x_4}$$

$$= 4.3 \text{ per cent}$$

$$K = x_3\,x_4 + x_3\,x_5 + x_4\,x_5$$

$$= 27.7 \text{ per cent}$$

$$X_1 = \frac{X_2\,x_1}{x_2 - X_2}$$

$$= 4.5 \text{ per cent}$$

$$X_4 = \frac{X_1\,X_2\,x_4}{X_1\,(x_2+x_3)+X_2\,x_3}$$

$$= 7.8 \text{ per cent}$$

The total effective reactance to the fault

$$= \frac{1}{\frac{1}{X_4}+\frac{1}{X_2}}$$

$$= 2.77 \text{ per cent}$$

The instantaneous equivalent short-circuit current

$$= \frac{100}{2.77} \times 1000$$
$$= 145{,}000 \text{ kv-a. or } 950 \text{ amp.}$$

Substituting the synchronous reactance of the generators, the total effective reactance to the fault will be 3.17 per cent and the sustained short-circuit current will be 830 amperes.

Now, if a fault occurs on the feeder side of the transformer at station No. 4, the reactance of the transformer (30.4 per cent) will be added to the instantaneous reactance of 2.77 per cent, giving 33.17 per cent and the instantaneous equivalent short-circuit current will be equivalent to 121,000 kv-a. The inherent reactance of the transformer would limit the equivalent short-circuit current to the value of 13,200 kv-a., so that the transformer should be designed to withstand the strains due to practically full short-circuit current with sustained voltage, as the additional effective reactance in the system reduces the short-circuit current only 8 per cent.

Similar calculations will give the short-circuit current at the other stations and the requirements of the apparatus can thus be determined.

All these calculations have been made on the basis of all generators, transformers, and lines being in service, so if the apparatus is designed for such a condition it will meet the most severe requirement. On the other hand, some of the apparatus in a system of this capacity is considered as "spare" equipment, consequently, it is reasonable to eliminate this in the short-circuit current calculations; otherwise, the policy of designing to meet the condition of all apparatus in service will be liable at times to result in an excessive cost.

TESTING OF ELECTRICAL PORCELAIN

By E. E. F. Creighton and P. E. Hosegood

Consulting Engineering Department, General Electric Company

The authors, who are authorities on the subject, discuss the testing of porcelain for electrical purposes giving the methods evolved to meet actual service conditions, and they discuss numerous causes of failure. The theory, application and choice of oscillators are dealt with at length.—Editor.

It has now been more than a year since the publication of a long paper in the proceedings of the American Institute on the use of high frequency in the testing of electrical porcelain. A review, and further experiences, with these methods of testing, are given in the present article.

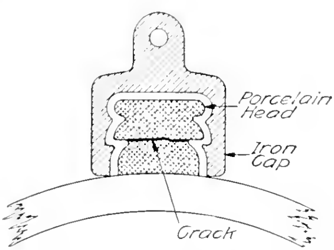


Fig. 1. Diagram showing how a porcelain head may be cracked by the longitudinal expansion of cap or pin

In one porcelain factory the high frequency method of testing has entirely supplanted the 60-cycle testing and there have been thousands of porcelain insulators tested. Nearly all the large manufacturers of porcelain insulators have an oscillator at their plants for use when so desired.

It is planned in the present article to review briefly the construction of the several types of oscillators, how to choose an oscillator for

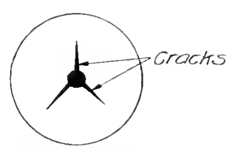


Fig. 2. Diagram showing radial cracks in porcelain caused by the radial expansion of pin

specific work, and the reasons for preferring the high frequency testing to the 60-cycle testing. It is also planned to give again a very brief review of the ceramic factors in the manufacture of a porcelain insulator.

The majority of failures of insulators on transmission lines have been due to two causes, namely cracks and porosity. A lesser percentage has failed due to lightning. Most of the actual failures take place in the summertime due to the fact that potentials derived either directly or indirectly from lightning are more likely to be above normal than in the winter-time. Many operators of transmission lines have not waited until the interruptions took place but have systematically gone over their circuits, replacing the insulators which were found to be evidently faulty.

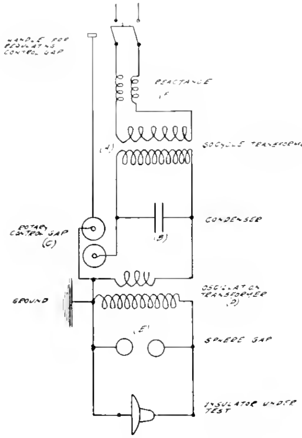


Fig. 3. Diagram of an Oscillator arrangement for testing Insulators

The cracked porcelain is due primarily to the unequal expansion of metal and porcelain, coming from the fact that the iron has a coefficient of expansion about twice as great as porcelain. This trouble does not show up during the early months of use of the porcelain because the Portland cement has not yet hardened sufficiently to transmit the strains. In the insulators examined, one cause was the placement of the metal cap directly on the porcelain skirt and also filling the space above the iron pin completely with cement. Expansion of the cap or pin then caused a horizontal crack in the porcelain head, as illustrated in Fig. 1. The longitudinal expansion of the pin is apparently less marked in its results than the expansion of the cap. In still other cases the radial expansion of the pin causes radial cracks in the porcelain, as illustrated in Fig. 2.

The most evident cause of this trouble has been overcome by spacing the cap from the porcelain at the time the cement is set and leaving an open space both at the top of the cap and the top of the pin. Further improvements have been made by doing away with the grooves in the porcelain and trusting to the grip of the roughened surfaces in one form or another. Whether this solves all the mechanical problems in relation to expansion and contraction is yet to be determined by experience. Intrinsically there is always a danger so long as materials of unequal expansion and contraction are used. If this metal and porcelain were to possess the same coefficient of expansion it is hardly conceivable that the differences in temperature of the two, even from a hail storm to warm sunshine, would cause enough difference in expansion to produce mechanical damage.

The other prolific cause of failure has been due to porous porcelain. Porosity in porcelain comes from a lack of vitrification. Vitrification depends upon two conditions: First, the amount of feldspar (the flux) which is mixed with the clays, and second, the temperature and time of firing. The less flux used the higher the temperature necessary to produce vitrification.

Porosity is an intrinsic fault in manufacture and such faulty porcelain is used only because of inadequate methods of electrical test or lack of tests. When the porcelain is very porous it will not withstand the electric stress at flash-over voltage. Such porcelain will absorb water rapidly within a few hours and will give a low reading on the megger.

For lesser degrees of porosity the 60-cycle test fails to cause a puncture. Subsequent absorption of water takes place very slowly, sometimes requiring days or even months to give a low megger reading. In actual practice the moisture absorbed by the porcelain insulator is derived from the excess moisture in the Portland cement used between the porcelain and hardware. The high frequency is especially valuable in factory testing for the detection of porous insulators. The high frequency has the advantage of producing a great deal of corona by a bombardment of the air in the pores and also by the applications of a momentary potential which is in excess of the normal spark potential. For example, on the suspension insulator which sparks over on 80 kv. at 60 cycles it is one of the regular tests to apply 120 kv. with the oscillator. This gives a superspark potential of 40 kv. above the normal spark potential. As an average, the oscillator will pick out about 8 per cent more faults in insulators than the regular 60-cycle tests

A third variety of fault in porcelain which is less frequently discovered by 60-cycle tests than by high frequency is a weakness in the skirt of the insulator. The high frequency, by bathing the entire surface of the insulator in visible corona, searches out every weak spot. The justification for the high frequency test lies in the fact that the stresses from lightning are of a similar high frequency nature.

The Theory of the Oscillator

The fundamental theory of the oscillator is shown by the connections in Fig. 3. Essentially the oscillator consists in charging up a suitable condenser to a voltage which will spark across a control gap. This discharge current flows through a few turns of an oscillation or coreless transformer. All the energy stored electrostatically in the condenser continues to oscillate until it is used up in heat. The natural frequency of this circuit gives the frequency of oscillation, which is usually of the order of 200,000 cycles to 400,000 cycles per second, depending upon the constants of the circuit. It should be noted, however, that this frequency is not continuously applied but only about once every half cycle of the generator wave. When

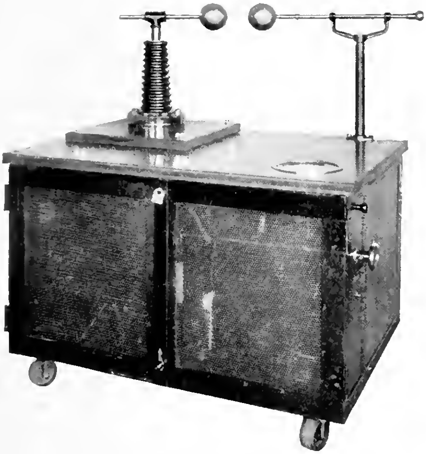


Fig. 4. A 125-kv. Oscillator having a maximum rating of 170 kv.

time is counted in terms of the duration of a single transient oscillation there is relatively a long interval between discharges.

Voltage measurements with the oscillating current are made the same as distances are measured with an inch-rule. Sphere gaps are used as the only available apparatus for indicating the potential and the gap length is laid off along an adjustable shank in terms of the equivalent 60-cycle voltage. Full control of the voltage is obtained by means of an adjustable control gap. Two turns of a screw

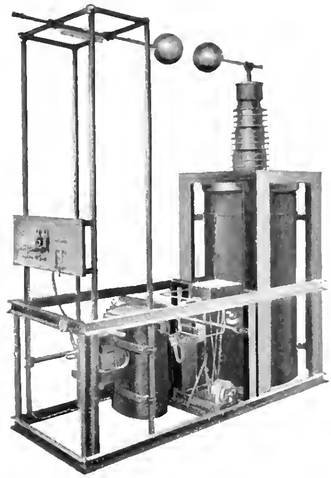


Fig. 5. A 250-kv. Oscillator

on the control gap will raise the voltage from a small value to the maximum value of the particular oscillator. Fig. 4 shows an oscillator rated at 125 kv. It has a maximum reading of 170 kv. and will test about ten suspension type insulators in parallel.

Fig. 5 shows the 250-kv. oscillator. Fig. 6 shows the 500-kv. oscillator with a maximum potential of 600 kv. The general appearance of the 250-kv. and the 500-kv. oscillators is the same, the differences are in the dimensions. With the 500-kv. oscillator the sphere for voltage measurement is 50 cm. in diameter. At 600 kv. the smaller sphere at the transformer end of the shank sends out corona streamers as long as one's arm, waving around in blank space. One is impressed with the possibility that a higher voltage would continue the discharge to an indefinite distance. Those who have heard Dr. Steinmetz's lectures will recall his explanation that certain lightning strokes do not jump through the intervening space but rather travel from one point to the next, building up an arc at the tip of the corona which produces the conducting path for the current to follow. This condition is very marked with the high frequency as a source since the charging current of the arc path maintains the path in a better condition of conductivity than either low frequencies or direct current.

A fourth type of oscillator of lighter weight and otherwise more suitable for transportation along the line to test the insulators in place is under development. A fifth type of oscillator producing over a million volts is being considered.

Application of the Oscillator

The oscillator is particularly applicable to the testing of non-inflammable materials like porcelain, glass, and some impregnated materials. As already stated, the high frequency produces a rich corona over the surface of the insulation. While this corona does not heat porcelain and glass to any great extent, due to the dissipation of the heat, it does, however, produce burning by its concentration on inflammable materials, like hard rubber for example. Hard rubber bushings have been tested with the oscillator but great care has to be exercised by short applications of potential to prevent damage by burning. It should be noted that materials damaged by the oscillator would be damaged also by high potential low frequencies although of course to a less extent. The oscillator has been used and is still being used for studying various types of insulation but this work is done under varying conditions of application according to the needs of each individual case.

The oscillator is not adapted to testing wet, porous porcelain. While it is much more effective in detecting and puncturing the dry, porous porcelain than the 60 cycles, the conditions are just reversed when the porcelain is allowed to soak up water. A moment's consideration of the conditions will make the reason for this evident. Water is a partial conductor and so long as it is conducting no concentrated puncture can take place in the porcelain. It is necessary to evaporate the water before the puncturing arc can form. An insulator having a low resistance of 300 megohms has an internal loss of only 16 watts when a flash-over voltage of about 80 kv. is applied. It is necessary to expend some energy (even thousands of joules, according to the distribution of the moisture) to evaporate the moisture and start an arc. The oscillator can produce a discharge of 5000 kw. but the discharge is of very brief duration. At flash-over voltage it can produce only the same I^2R loss in the wet porcelain as the 60-cycle voltage. It is applied, however, for such a short time that the total amount of energy is so small that it sometimes requires several minutes of test to drive out the moisture sufficiently to produce a puncture.

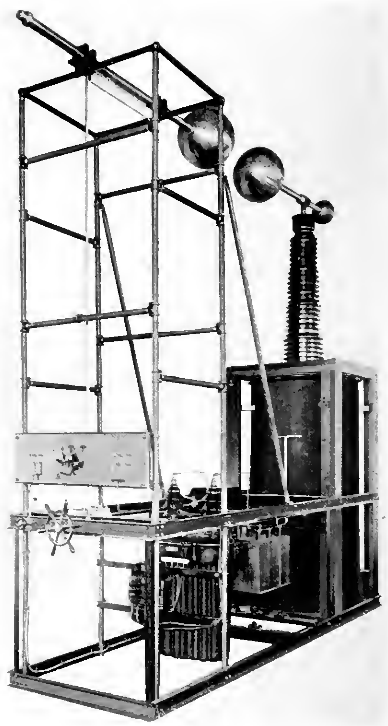


Fig. 6. A 500-kv. Oscillator having a maximum rating of 600 kv

As a rule the oscillator produces 120 wave trains per second. Each wave train has a natural frequency of 200,000 cycles per second. If a wave train lasted 100 cycles the potential would be applied for 0.0005 second and there would be an interval of practically 0.0080 seconds before the next wave train occurred, in other words, the period of no application of potential might be 16 times as long as the period of application.

Choice of the Oscillator

The 125-kv. oscillator shown in Fig. 4 covers most of the usual tests which practice demands. It will flash over all the types of suspension insulators and since the puncture value under oil of these insulators is usually far less than 160 kv., it can also be used for these tests of the insulator under oil. This size of oscillator is not quite large enough to produce a heavy discharge on the largest pin type insulators of the best designs. It is, however, capable of testing all the parts of a pin type insulator separately.

This oscillator is mounted on wheels and can be rolled around according to convenience. To those who have had to fuss with separate sine wave generators, exciters, rheostats, voltmeters, ratio calculations, etc., the simplicity of testing with the oscillator will make a special appeal. The simple connection to the 110-volt circuit, direct reading of voltage by sliding the sphere gap, and full control of the voltage by two turns of the control gap are convenient time-savers in testing. The higher voltage oscillators are necessary for testing strings of suspension insulators if such a test is desired. They are also used for testing large bushings. The two types are the same in form but differ in size. Discharges several feet long can be obtained from the 500-kv. oscillator in testing porcelain insulators. In a subsequent article the important elements in the manufacture of electrical porcelain will be briefly presented.

FACTORS DETERMINING THE SAFE SPARK-OVER VOLTAGE OF INSULATORS AND BUSHINGS FOR HIGH VOLTAGE TRANSMISSION LINES

By F. W. Peek, Jr.

Consulting Engineering Department, General Electric Company

The author discusses the various factors affecting the spark-over voltages of bushings and insulators under normal and abnormal conditions. A knowledge of the characteristics of bushings and insulators under all operating conditions is necessary in order that an intelligent selection may be made and the "factor of safety" determined. For instance, different designs of insulators with equal 60-cycle spark-over voltages may have entirely different lightning spark-over voltages. The characteristics are generally measured at sea level. As insulators or bushings are often used at high altitudes, it is important to be able to estimate the spark-over at various altitudes from the sea level values. Methods of making altitude corrections for dry bushings or insulators have already been given. The spark-over voltage during a rain storm is generally the determining one. The results of an investigation showing how the wet or rain spark-over voltage varies with altitude is for the first time given here.—Editor.


F. W. Peek. Jr.

An insulator or bushing for high voltage lines is generally so selected that the spark-over voltage at normal frequency is several times the normal operating voltage. It is usual to specify a minimum normal frequency spark-over voltage of a times the line to line operating voltage when the insulator is dry, and b times the line to line operating voltage when the insulator is wet. Since the wet condition is really the determining one, factor b is more important than factor a. Ratios a and b are often called "factors of safety."[1] This is a misnomer as they are ratios with the operating voltage and not with the lightning or surge voltages which really cause breakdown. These ratios should vary with the operating voltage, the probable lightning or surge voltage, and the lightning arrester setting, when there is protection.

Where there is good lightning protection, it is reasonable to make the ratio b lower than for the line insulator where there is no adequate protection. These ratios in terms of line voltage should be higher for the lower voltage bushings and insulators than for the higher voltage ones since they are all subjected to practically the same lightning voltages. This is especially true where the lines traverse practically the same sort of country. As the operating voltages increase, the probability of a great number of induced lightning voltages exceeding the operating

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[1] These arbitrary ratios are $\frac{\text{Insulator spark-over voltage}}{\text{Line to line voltage}} = a$ or b. Under normal conditions the actual voltage across the bushing for a three-phase line is $\frac{\text{Line to line voltage}}{\sqrt{3}}$. The ratio of spark-over voltage to normal voltage across the bushing is therefore always $1.73 \times a$ or $1.73 \times b$.

voltage decreases. It does not seem advisable ever to make the minimum ratio b lower than two, even for the very high voltages, as surge voltages due to internal disturbances may easily reach this value. It is not the object of this paper to assign arbitrary values to a and b, but to consider and give data on the various factors affecting the spark-over of insulators and bushings under normal and abnormal conditions. For example, measurements are generally made only at 60 cycles, at sea level. Insulators with equal 60-cycle spark-over voltages may have entirely different lightning spark-over voltages. The probability of spark-over failures would be less on the insulator with the higher lightning spark-over voltage. The wet spark-over voltage is generally the minimum one and, therefore, the determining factor. As this is measured at sea level, it is important to be able to estimate from the sea level value the wet spark-over voltage at the altitude at which the insulator is to be used.

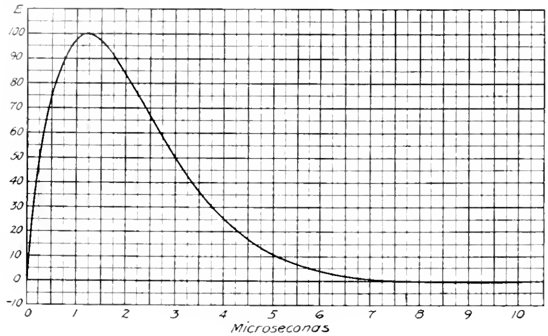


Fig. 1. A 200-kilocycle impulse wave

Lightning or Impulse Voltages of Steep Wave Front

Insulators of different design may have equal 60-cycle spark-over voltages but greatly different impulse or lightning spark-over voltages. This is because a definite, but very small time, is required for a spark to form

TABLE I

INSULATOR

No.	Type	60-Cycle Spark-over Kv.		Impulse Spark-over Kv. Single Half-cycle 200 Kilocycles Sine Wave		Impulse Ratio = Dry Imp. Voltage / Dry 60-cycle Voltage
		Dry	Wet	Dry	Wet	
1	Petticoat	100	67	142	140	1.42
2	Smooth	100	50	105	105	1.05

TABLE II

IMPULSE SPARK-OVER OF SUSPENSION INSULATORS WET AND DRY

Ins. No.	Type	60-Cycle Spark-over		100-Kilocycle Impulse Spark-over		500-Kilocycle Impulse Spark-over	
		Dry	Wet	Dry	Wet	Dry	Wet
A	Two-piece suspension with petticoats..	112	72	118	114	165	162
B	Two-piece suspension with petticoats... ..	116	70	128	125	172	168

which depends upon the bushing design and rapidity at which the voltage is applied. Higher voltages are required in the case of lightning, where the voltages are applied very rapidly and the time is, therefore, limited. Such rapidly applied voltages are said to have steep wave front. Spark-over does not occur when the 60-cycle spark-over voltage is reached by the rapidly increasing impulse voltage, but some time later when this voltage has reached a higher value. The theory of this, the complete data, the method of producing impulses, etc., is given fully elsewhere.[2] The ratio between the impulse spark-over voltage and the 60-cycle spark-over voltage has been termed the impulse ratio. The impulse ratio is very high for steep wave fronts and approaches unity for "low frequency" surges. For a given impulse, the impulse ratio is lower for smooth insulators than for insulators with properly designed petticoats or corrugations. An example of the variation of the impulse ratio for two different insulator designs is given in Table I.

It will be noted that although both insulators have the same 60-cycle spark-over voltage, the "lightning" spark-over voltage of insulator No. 1 is about 40 per cent higher than the "lightning" spark-over voltage of insulator No. 2. The impulse used was a single half-cycle of a 200-kilocycle wave as shown in Fig. 1. With a steeper impulse the difference would be greater.[3] Lightning would be less likely to cause spark-over of insulator No. 1. Rain does not greatly decrease the lightning spark-over voltage. Because of this the probability of failure due to steep wave front disturbances is greatly decreased. For "low frequency" surges the wet spark-over voltage approaches the 60-cycle wet spark-over voltage. The effect of steepness of wave front is shown in Table II.

Altitude Correction (Dry and Rain)

The spark-over voltage of an insulator or bushing decreases with the air density, or pressure and temperature. At high altitudes, where the barometric pressure is low, the spark-over voltage is much lower than at sea level. Generally the spark-over voltage decreases approximately with the air density. A curve of variation of air density with altitude is given in Fig. 2. These values of δ are in terms of unity at 76 cm. bar. (30 in.) and 25 deg. C.[4] Thus, from this curve the approximate spark-over voltage at 5,000 ft. altitude would be 82 per cent of the spark-over voltage at sea level (25 deg. C.). The method of making this investigation on the effect of altitude on the dry spark-over voltage of bushings and insulators, correction values for typical designs, etc., has already been given.[5]

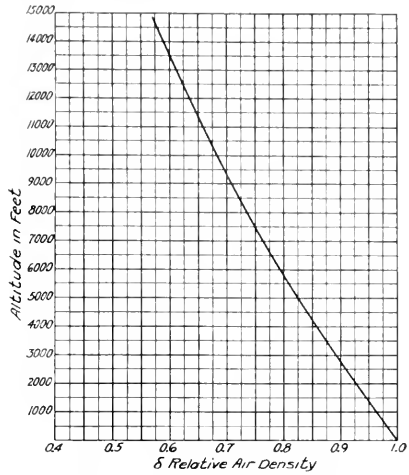


Fig. 2. Curve showing relative air density at various altitudes

As it is of more importance to know the correction for the wet or rain spark-over voltage an investigation of this has recently been made. The results are given here for the first time. The same apparatus was used as in the previous tests. The insulator or bushing was placed in the large wooden cask and the air exhausted. A rain nozzle was arranged in the cask and connected by hose to the city water supply. There was no difficulty in making the spark-over test at different pressures while the insulator was being sprayed. Impulse and 60-cycle spark-over voltages were taken. Table III gives a sample test sheet for Fig. 3.

[2] F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics." A.I.E.E., August, 1915.

[3] For method of test see F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics." Also, "Dielectric Phenomena in High Voltage Engineering," Page 108, Chap. IV Page 17, Chap. VII.

[4] $\delta = \frac{3.92\, b}{273 + t}$

t = temp. C. degrees.
b = barometric pressure in cm.

[5] F. W. Peek, Jr., "The Effect of Altitude on the Spark-over Voltage of Bushings, Leads and Insulators." A.I.E.E., Dec., 1914. Also, "Dielectric Phenomena in High Voltage Engineering" Chap. IV.

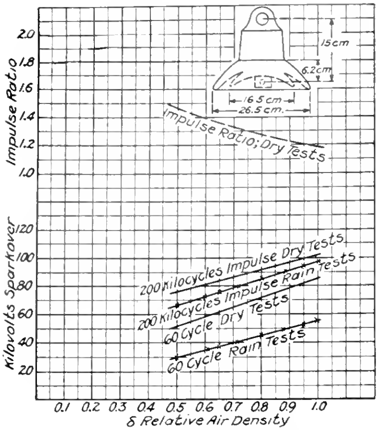


Fig. 3. Sixty-cycle and impluse spark-over curves for a suspension insulator. 200-kilocycle impulse wave (Fig. 1). Rain Tests 0.2 in. per min. at 45 deg.

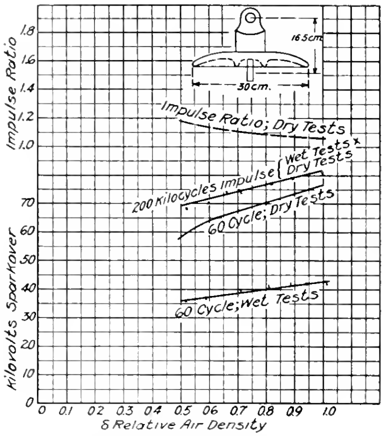


Fig. 4. Sixty-cycle and impulse spark-over curves for a suspension insulator. 200-kilocycle impulse wave (Fig. 1). Rain Tests 0.2 in. per min. at 45 deg.

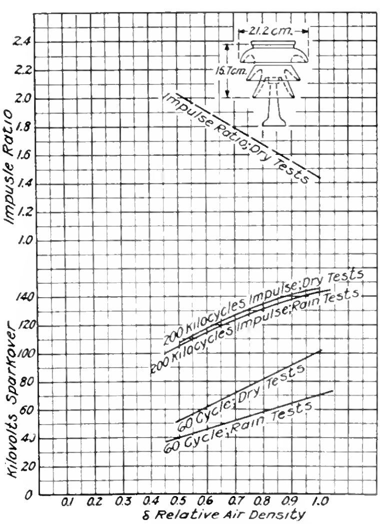


Fig. 5 Sixty-cycle and impulse spark-over curves for a pin insulator. 200-kilocycle impulse wave (Fig. 1 Rain Tests 0.2 in. per min. at 45 deg.

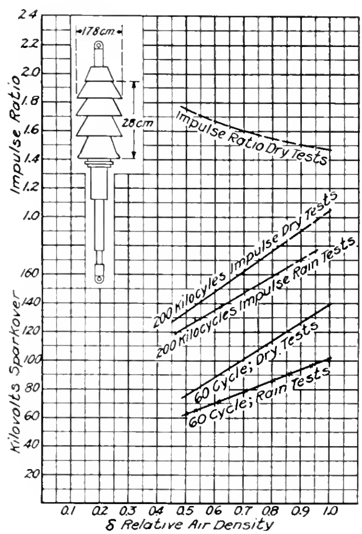


Fig. 6. Sixty-cycle and impulse spark-over curves for a transformer bushing. 200-kilocycle impulse wave (Fig. 1). Rain Tests 0.2 in. per min. at 45 deg.

TABLE III

SPARK-OVER VOLTAGE OF INSULATOR AT DIFFERENT AIR PRESSURES DURING RAIN

(Sample Data Sheet)

(See Fig. 3)

Rain Tests (0.2 in. per minute at 45 deg.)

Room Bar. cm.	Vacuum cm. (In the Cask)	Pressure cm. (In the Cask)	Temp. Cent. (In the Cask)	δ (In the Cask)	Kilovolts Spark-over (Effective)
60-cycle Spark-over ($\delta = 1.017$ in room)					
75.6	41.2	34.4	18.0	0.46	28
75.6	36.0	39.6	18.0	0.53	31
75.6	31.1	45.5	18.0	0.61	35
75.6	25.0	50.6	18.0	0.68	39
75.6	15.6	59.0	18.0	0.79	45
75.6	7.8	67.8	18.0	0.91	50
75.6	0.0	75.6	18.0	1.02	57
Impulse Spark-over 200 Kilo Cycles—Single Wave Fig. 1—Insulator Fig. 3 (Effective Kv.) ($\delta = 1.017$ in room)					
75.6	41.2	34.4	18.0	0.46	62
75.6	36.0	39.6	18.0	0.53	68
75.6	31.1	45.5	18.0	0.61	72
75.6	25.0	50.6	18.0	0.68	77
75.6	15.6	59.0	18.0	0.79	84
75.6	7.8	67.8	18.0	0.91	92
75.6	0.0	75.6	18.0	1.02	98

Figs. 3, 4, 5 and 6 give the wet and dry 60-cycle and impulse spark-over voltages for typical designs at various air densities. The voltages are in terms of effective values. Altitudes corresponding to δ may be found from Fig. 2. These tests show that the ratio between the 60-cycle dry and rain spark-over voltages remains approximately constant for different values of δ. Thus, from Fig. 2, the *wet* 60-cycle spark-over at 5000 ft. altitude is approximately δ times or 82 per cent of the *wet* 60-cycle spark-over voltage at sea level.

Figs. 3, 4, 5 and 6 show, also, that the steep wave front impulse spark-over voltage is not greatly lowered by rain. The impulse ratio increases with decreasing δ.

Dust, Salt, Etc.

Insulators and bushings are occasionally placed where they become coated with dust, salt, etc. When the coating becomes moist the spark-over voltage is very low. This is especially bad when the moisture is due to fog or condensation as the whole surface of the insulator then becomes coated. A higher "factor of safety" should be used for insulators so placed.

Puncture

It is not the purpose of this paper to discuss the cause of insulator failures by puncture. It may be well, however, to point out a few facts concerning such failures.

Many insulators fail by puncture. These failures are due to weakness which develops after the insulators are installed, and are not anticipated by high voltage tests in the factory. The chief causes of these failures are:

(1) Electrical puncture through cracks caused by uneven or excessive local mechanical stresses on the porcelain due to firing, flaws, expansion of metal parts, cement, or poor mechanical designs. These cracks develop gradually and it may be months before failure occurs. Such failures may be anticipated, to a considerable extent, by hot and cold tests and usually eliminated by correct design.

(2) Gradual absorption of moisture by porous porcelain is followed by electrical failure. The moisture is probably generally absorbed from the cement at the unglazed parts. Such troubles could be anticipated by absorption tests.

The puncture voltage should always be considerably higher than the spark-over voltage. This would lessen the probability of failure due to gradual weakening by the cumulative effect of lightning voltages.[6]

[6] F. W. Peek, Jr., "Dielectric Phenomena in High Voltage Engineering" Chap. VII.

IRON AND STEEL WIRE FOR TRANSMISSION CONDUCTORS

By T. A. Worcester

Power and Mining Engineering Department, General Electric Company

The author shows the relationship between the electrical characteristics of copper and iron wire, giving much useful data in the form of curves and tables. These data represent the results of tests made in the testing laboratory as well as those made under actual operating conditions. This article should be read in conjunction with the contribution that follows it by Mr. Ball. It has been difficult to obtain reliable data on this subject, but we hope to be able to publish some supplementary information in a future issue of the Review.—Editor.

T. A. Worcester

The relatively high cost of copper wire for transmission conductors has influenced many operating engineers to investigate the possibility of using iron or steel wire. In past years when the cost of copper was about one-half of what it is now the advantages of using iron or steel wire were hardly worth considering, except when the amount of current under consideration was so small that the size of copper wire which it would be necessary to use from an electrical standpoint would not have sufficient mechanical strength. Under present conditions, however, it is advisable to consider the possibilities of using iron wire for larger currents than would have formerly been considered practicable. The available data for calculating such conductors for 25 and 60 cycles is rather limited. It is the purpose of this article to present such data as is at hand without attempting to make deductions or derive formulæ.

For the calculation of voltage drop and energy loss in transmission circuits it is necessary to know the resistance, reactance and capacity of the wires. The constants for these quantities for copper wire are well established. For iron wire the constants are not so well established and it is difficult to evolve formulæ with which to calculate them owing to the great number of different kinds of wire and the variations due to permeability, eddy currents, hysteresis losses and skin effect. Iron wire is made in grades known as Best Best (B. B.) and Extra Best Best (E. B. B.) and steel wire in grades known as ordinary, Siemens Martin, High Strength and Extra High Strength. All of these grades have different permeability for any given current density and the permeability varies with the current. The eddy current and hysteresis losses and the skin effect are different for the different grades and likewise vary with the frequency. For very small wires, No. 12 to No. 14, the skin effect is small and may be neglected, but for larger sizes it must be taken into account.

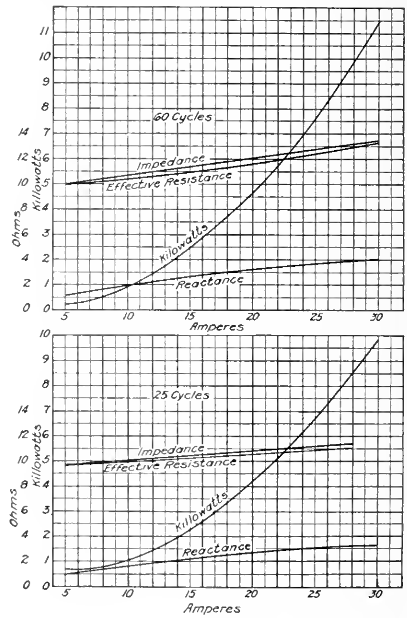


Fig. 1. Constants for one mile of ¼-in. galvanized stranded steel cable at 25 and 60 cycles. Direct-current resistance per mile of cable 9.72 ohms.

The impedance in an iron wire circuit is made up of two components—one the energy component, which is called the Effective Resistance, and the other the wattless component, called the Effective Reactance. The effective resistance when multiplied by the current squared gives the total energy loss in the circuit which includes not only the loss due to ohmic resistance, but also the hysteresis and eddy current losses. Likewise the effective reactance includes not only the external reactance of the wires due to their spacing, as in a copper circuit, but also the internal reactance due to the magnetic characteristic of the iron wire. Roughly speaking, when iron or steel wires are carrying the maximum permissible amount of current, their effective resistance for 60 cycles will range from $1\frac{1}{4}$ to 3 times the d-c. resistance and the effective reactance from 5 to 12 times the external reactance, i.e., times the reactance of the same size copper conductor. The smaller values in general are for the smaller diameter wires and for wires of low permeability (steel), while the larger values are for the larger

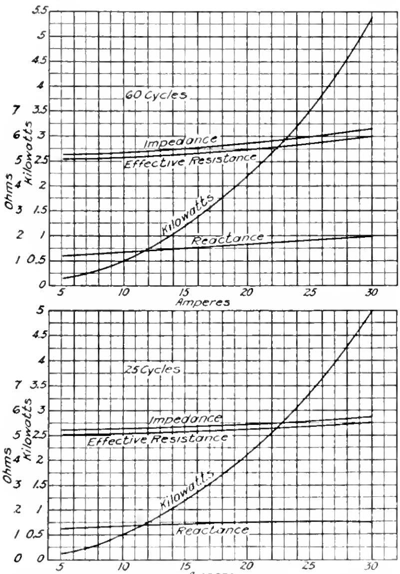


Fig. 2. Constants for one mile of 3/8-in. galvanized stranded steel cable at 25 and 60 cycles. Direct-current resistance per mile of cable 5.03 ohms.

diameter wires and those with high permeability (B.B. and E.B.B.).

The accompanying diagrams give the effective resistances, reactances and impedances for several different sizes and qualities of iron and steel wires. Figs. 1, 2 and 3 give the characteristics for 1/4-in., 3/8-in. and 1/2-in. stranded steel galvanized cable, ordinary grade. The tests were made by carrying the return current through a weatherproof insulated copper conductor which was taped to the steel conductor. This

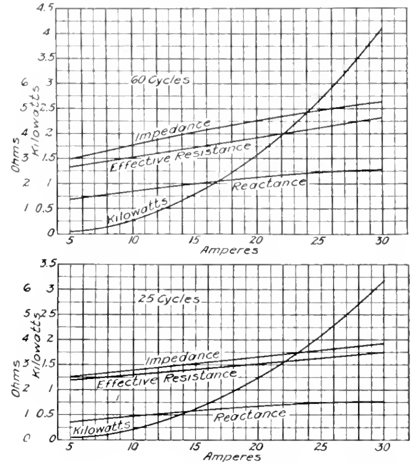


Fig. 3. Constants for one mile of 1/2-in galvanized stranded steel cable at 25 and 60 cycles. Direct-current resistance per mile of cable 2.42 ohms.

arrangement eliminated the external reactance. To use the constants for conductors spaced at a distance from one another it would, therefore, be necessary to add to the curve values the reactance due to the wire spacing and diameter which may be taken from copper wire tables. Figs. 4, 5 and 6 give data on No. 6 and No. 4 B.W.G. solid iron wire and on 3/8-in. 7-strand galvanized E.B.B. cable. In these latter figures the curves have been plotted from test data on lines in actual service and the effective reactance values include the external as well as the internal reactance. The wire spacings are indicated so that corrections may be made if desired. In making calculations the values of effective resistance and effective reactance should be used in the same manner as resistance and reactance constants for copper wire are used. In all cases the constants have been given per mile of wire and should be used in conjunction with volts to neutral in either single or polyphase circuits.

The heating of iron wire conductors is proportional to the kw. or I^2R loss, in which R is the effective resistance and not the resistance measured by direct current. One may estimate roughly what the heating will be in an iron wire by comparing it with a copper wire of the same size in which there is the same kw. loss. This method does not give strictly accurate results because of the difference in radiation from copper and iron surfaces. However, the error is too slight to be effective from a practical standpoint.

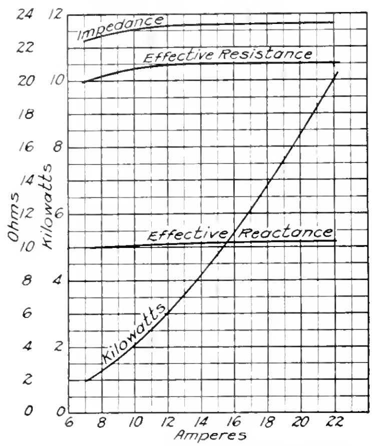


Fig. 4. Constants for one mile No. 6 B.W.G. solid BB galvanized iron wire at 60 cycles. Direct-current resistance per mile of wire 10.6 ohms. Tests made on three-phase circuit with wires at corners of 84-in. equilateral triangle.

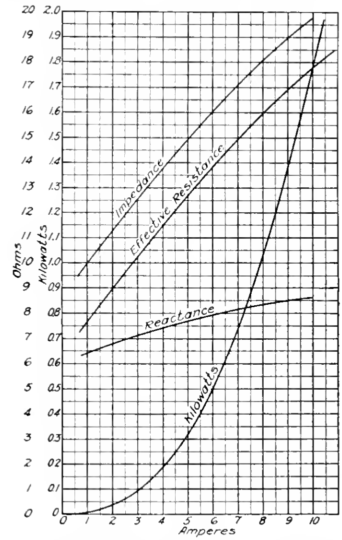


Fig. 5. Constants for one-mile of No. 4 B.W.G. solid EBB galvanized iron wire at 60 cycles. Direct-current resistance per mile of wire 5.97 ohms. Tests made on a three-phase circuit with wires in one plane on 42 in. centers.

TABLE 1

CHARACTERISTICS OF COPPER AND IRON WIRE

HARD DRAWN COPPER WIRE AND CABLE				WEIGHT PER MILE		GALVANIZED IRON WIRE AND CABLE					
						Size		B.B.		E.B.B.	
Size B.&S. and Circ. Mils.	Diameter Inches	Ultimate Strength in Lb.	Resistance per Mile 20 Deg. C.	Copper	Iron or Steel	Nominal Ins and B.W.G. Gauge	Actual Inches	Strength in Lb.	Resistance per Mile 20 Deg. C.	Strength in Lb.	Resistance per Mile 20 Deg. C.
*300000	0.630	15300	0.182	4831	4225	5/8	0.660	14000	1.17	12700	0.99
250000	0.690	12900	0.219	4026	3430	9/16	0.610	12000	1.37	10900	1.17
0000	0.430	10800	0.258	3405	2690	1/2	0.495	7900	2.08	7200	1.78
000	0.470	8600	0.326	2709	2190	7/16	0.440	6400	2.58	5800	2.21
0	0.375	5500	0.518	1700	1560	3/8	0.360	4200	3.93	3800	3.36
1	0.330	4300	0.653	1347	1110	5/16	0.327	3400	4.76	3100	4.07
2	0.291	3400	0.824	1072	875	9/32	0.285	2600	6.25	2400	5.36
* 4	0.261	2200	1.31	671	660	1/4 *	0.249	2000	8.20	1800	7.01
** 4	0.204	2000	1.31	678	573	No. 6**	0.203	1900	9.60	1700	8.21
5	0.182	1600	1.65	529	450	No. 7	0.180	1500	12.21	1300	10.44
6	0.162	1200	2.08	420	378	No. 8	0.165	1200	14.53	1100	12.42

* Stranded cable.
** Solid wire.

As an example of the method of approximating the temperature rise, assume a 3/8-in. E.B.B. iron wire cable carrying 48 amperes. From the curve, Fig. 6, note that the energy loss per mile of cable is 16.2 kw. Assume then that a 3/8-in. copper cable is carrying an amount of current sufficient to give an energy loss of 16.2 kw. Such a cable would have a resistance of 0.518 ohms per mile so that the current required to give 16.2 kw. loss would be $\sqrt{\frac{16{,}200}{0.518}}$ or 177 amperes. By referring to Table No. 3 opposite 175 amperes, it is noted that copper wire 0.373-in. diameter will have a temperature rise of 5 deg. and we conclude that the iron wire will have approximately the same temperature rise, since we have assumed the loss in the two wires to be the same. By a similar procedure using No. 6 B.W.G.

TABLE II

GALVANIZED STEEL CABLE

SIZE		ORDINARY GRADE		SIEMENS MARTIN		HIGH STRENGTH		EXTRA HIGH STRENGTH	
Nominal Inches and B.W.G. Gauge	Actual Inches	Strength in Lb.	Resistance per Mile 20 Deg. C.	Strength in Lb.	Resistance per Mile 20 Deg. C.	Strength in Lb.	Resistance per Mile 20 Deg. C.	Strength in Lb.	Resistance per Mile 20 Deg. C.
5/8 *	0.660	14000	1.31	19000	1.88	25000	1.92	42500	1.96
9/16	0.610	12000	1.62	15500	2.32	21000	2.37	34000	2.42
1/2	0.495	8500	2.45	11000	3.51	18000	3.58	27000	3.66
7/16	0.444	6500	3.05	9000	4.36	15000	4.45	22500	4.54
3/8	0.360	5000	4.63	6800	6.62	11500	6.76	17200	6.90
5/16	0.327	3800	5.62	4800	8.03	8100	8.20	12100	8.37
9/32	0.285	3100	7.34	4400	10.51	7300	10.73	10900	10.95
1/4 *	0.249	2300	9.72	3000	13.90	5100	14.2	7600	14.5
No. 6**	0.203	1800	11.3	2400	16.3	3900	16.6	5800	17.0
No. 7	0.180	1400	14.6	1900	20.8	3100	21.2	4600	21.6
No. 8	0.165	1200	17.2	1600	24.6	2600	25.1	3900	25.6

* Stranded cable.
** Solid wire.

TABLE III

HEATING EFFECT OF CURRENTS ON BRIGHT, BARE COPPER WIRE SUSPENDED OUT OF DOORS

(Blackened wires of approx. 3 per cent less diam. give the same heating)

Amperes	RISE IN TEMPERATURE IN DEGREES CENTIGRADE				Amperes	RISE IN TEMPERATURE IN DEGREES CENTIGRADE			
	5 Deg.	10 Deg.	20 Deg.	40 Deg.		5 Deg.	10 Deg.	20 Deg.	40 Deg.
	Diam. of Wires in Mils					Diam. of Wires in Mils			
1000		962	771	620	300	540	428	342	273
950		928	744	595	275	509	404	321	257
900		894	715	574	250	477	378	300	240
850		868	689	550	225	445	351	280	223
800		839	672	537	200	410	324	259	205
750		804	643	515	175	373	296	235	186
700	963	767	613	491	150	334	267	211	166
650	916	729	582	467	125	295	235	185	145
600	869	690	554	442	100	254	202	157	123
575	845	671	538	429	90	236	186	145	114
550	820	650	522	417	80	216	171	132	104
525	795	630	506	404	70	198	155	120	94
500	770	610	489	390	60	177	137	107	83
475	745	589	473	377	50	155	119	92	72
450	719	568	453	363	40	130	100	77	62
425	690	546	436	349	30	104	78	61	50
400	661	524	418	334	20	73	54	43	34
375	632	502	399	319	10	40	27	20	16
350	601	478	380	304					
325	571	453	362	289					

(0.203-in.) B.B. iron wire with 22 amperes it is observed that the loss per mile is 10 kw. With this same loss in a No. 4 B.&S. copper wire (0.204-in. diameter) the current would be 83.3 amperes. In Table No. 3 the nearest corresponding values are 90 amperes 0.186-in.

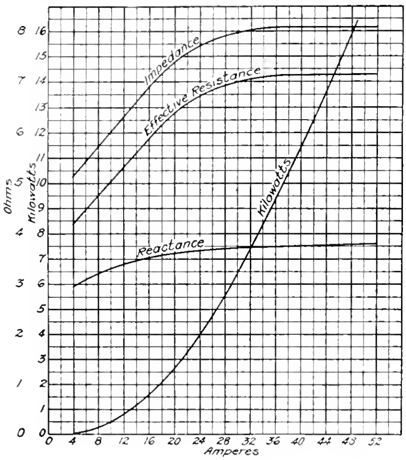


Fig. 6. Constants for one mile of $\frac{3}{8}$-in. galvanized stranded EBB iron cable at 60 cycles. Direct-current resistance per mile of cable 3.6 ohms. Tests made on a three-phase circuit with wires in one plane on 24 in centers.

diameter wire which gives a temperature rise of 10 deg. C.

With increase in temperature the resistance increases a little more rapidly than in the case of copper conductors, the temperature coefficient for iron wire ranging from 0.0046 to 0.006 per deg. C., these values being given by various authorities for different grades of wire. For an average value for commercial wire 0.005 may be used.

When considering the use of iron wire in place of copper it is desirable to take into account the life of the two when used as conductors. Copper wire except under unusual circumstances will not deteriorate to any great extent and will have a high scarp value after an indefinite number of years. On the other hand galvanized iron wire under average conditions will have a relatively short life. Galvanizing will last fairly well if exposed only to mild atmospheric conditions but if the wires are exposed to smoke, fumes from blast furnaces, smelting plants, chemical works and the like or are near the sea where salt is carried to them by fogs and wind, their life is materially lessened, the amount depending entirely on the severity of the conditions. An exhaustive study of the subject in connection with telephone and telegraph lines has lead to the following general conclusions:

Conditions of Installation	Useful Life
Near blast furnaces, smelters, chemical plants or on the sea coast	1 year
In large cities where soft coal is used or near the sea coast	3– 5 years
In inland towns where there is little smoke from soft coal	5–15 years
In inland country districts where there is little or no smoke	15–25 years

In the above, no attempt is made to classify the size or kind of wire. In general, it may be said that, after the galvanizing has once penetrated, the wires of the better grades E.B.B. and B.B. will show less deterioration than the steel wires. The ordinary grade of steel fence and guy wire shows rapid deterioration and should be avoided for transmission work.

While the curves and data given herewith do not by any means cover the entire range of iron and steel wire conductors, yet they serve to show the main characteristics of conductors of certain grades and sizes and by interpolation one may fairly well judge what to expect from other sizes.

SKIN EFFECT FACTORS FOR IRON WIRE

By John D. Ball

Consulting Engineering Department, General Electric Company

The use of steel wire has grown in importance with the increasing number of high-voltage low-power lines where the size of copper wire required for mechanical strength greatly exceeds the necessary conductivity. The present high cost of copper has also added to the attractiveness of steel wire installations. Tests on all sizes of wire at all frequencies are not available, but the present article gives formulæ for computing the effective resistance and a table derived therefrom for the standard sizes of iron wire at the ordinary frequencies and at the most interesting frequencies of surges where the increased resistance affords protection. Formulæ and tables are given whereby conductors may be selected whose effective resistance at various frequencies equals that of the standard wire sizes if no skin effect were present.—Editor.

John D. Ball

THE use of iron or steel wire has been often proposed for low power branch lines of high potential transmission systems, where the current is so small that the smallest suitable copper wire has more conductivity than economically necessary and the lower cost of the steel wire reduces the cost of the line. In such a case where the spans between supports are long from necessity or economy, the use of steel wire is especially prominent.

However, it is well known that in any wire the current density is not uniform throughout the conductor section, but decreases toward the center due to the higher e.m.f. of self inductance in the interior, which is due to the magnetic flux inside of the conductor. In iron wire the phenomena of forcing the current to the outer part of the conductor becomes sufficiently in evidence to require special attention as, owing to the high permeability of iron, the "screening" or "skin effect" is often sufficient to materially reduce the effective conducting area, which appreciably raises the effective resistance even at the commercial frequencies of 25 and 60 cycles.

The use of iron or steel wire has also been proposed repeatedly for lightning protective reactances, to get the benefit of the much higher effective resistances at high frequencies.

For the above reasons, it is of importance to know the approximate effective resistance of various sizes of steel wire at various frequencies.

Some tests have been made on existing installations and the results published, but the data are meager and refer only to a limited number of sizes of wire. As the skin effect may be readily calculated, it appears desirable to obtain therefrom tabulated information regarding the approximate effective resistance of the standard sizes of wire at the most interesting frequencies.

The following tables give these data.

Table I gives standard sizes of telegraph wire, the diameter, weight and resistance per 1000 ft. This table was calculated from Mr. Prescott's Western Union Telegraph Company tables, a temperature coefficient of 0.00458 was assumed.

In the following let

R_0 = the ohmic resistance

R = the effective resistance

TABLE I

E. B. B. TELEGRAPH WIRE

Size of Wire	Diameter		D-C. Resistance Ohms per 1000 Ft.		Weight Lb. per	
	Inches	Centimeters	25 Deg. C.	75 Deg. C.	1000 Ft.	Mile
4	0.238	0.605	1.18	1.42	150	790
5	0.220	0.559	1.38	1.66	128	675
6	0.203	0.515	1.62	1.95	108	570
7	0.180	0.457	2.06	2.48	85	450
8	0.165	0.419	2.45	2.96	72	380
9	0.148	0.376	3.05	3.68	58	305
10	0.134	0.340	3.72	4.48	47	250
11	0.120	0.305	4.65	5.58	38	200
12	0.109	0.277	5.62	6.77	31	165
14	0.083	0.211	9.68	11.66	18	96

l_0 = ½ the thickness of conductor in cm. (radius for circular conductors)
l_p = the effective depth of penetration
λ = the electrical conductivity
μ = the magnetic permeability
$c = \sqrt{0.4\,\pi\,10^{-9}\,\lambda\mu}$ and
f = frequency in cycles per second.

It has been shown that as a result of the unequal current distribution in the conductor, the effective resistance is increased from the ohmic resistance R_0 to the value

$$R = c\,l_0\,R_0 \qquad (1)$$

It has also been shown that.

$$l_p = \frac{l}{c} \text{ and} \qquad (2) \;\dagger$$

$$l_p = \frac{5030}{\sqrt{\lambda\mu f}} \qquad (3)$$

From (1) the resistance factor

$$\frac{R}{R_0} = c\,l_0 \qquad (4)$$

From (2) and (3)

$$c = \frac{\sqrt{\lambda\,\mu\,f}}{5030} \qquad (5)$$

† From "Transient Electric Phenomena and Oscillations," Steinmetz, 1909, pp. 376-377

therefore,

$$\text{The resistance factor } \frac{R}{R_0} = \frac{l_0\sqrt{\lambda\,\mu\,f}}{5030} \qquad (6)$$

For E.B.B. and B.B. wire, some tests have given an average resistivity value of 12.2 michrohms per cm.[3] or $\lambda = 82{,}000$. From Fig. 1 we may assume an average value of μ for unannealed wire of 500.

For steel wire the permeability is practically the same, but λ should be taken as 74,000. Letting $\mu = 500$ and $\lambda = 82{,}000$

$$\frac{R}{R_0} = \frac{l_0\sqrt{82{,}000 \times 500 \times f}}{5030}$$

$$= 1.275\, l_0\sqrt{f}$$

From this formula, Table II was calculated which therefore gives resistance factors or ratios which multiply the true ohmic resistance due to the unequal current distribution in the conductor for E.B.B. and B.B. grades of telegraph wires. By means of this table after the d-c. resistance is found, the effective a-c. resistance may be determined by multiplying the d-c. resistance by the factor which refers to the corresponding size of wire and frequency as given in the table.

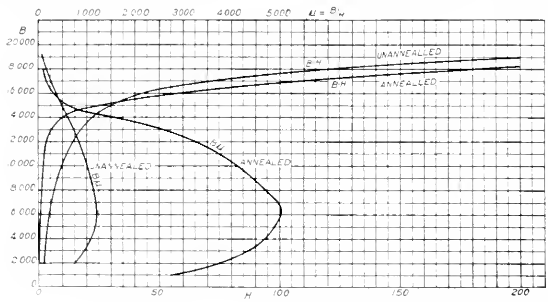


Fig. 1. Magnetization and Permeability Curves of Galvanized Iron Telegraph Wire

TABLE II

RESISTANCE FACTORS

Standard Size of Telegraph Wire

Size of Wire	25 Cycles	60 Cycles	2,000 Cycles	10,000 Cycles	50,000 Cycles	100,000 Cycles	1,000,000 Cycles
4	1.9	3.0	17	39	86	120	390
5	1.8	2.8	16	36	80	110	360
6	1.6	2.5	15	33	73	105	330
7	1.5	2.3	13	29	65	92	290
8	1.3	2.1	12	27	60	85	270
9	1.2	1.9	11	24	54	76	240
10	1.1	1.7	9.7	22	48	69	220
11	*	1.5	8.7	19	44	62	190
12	*	1.4	7.9	18	39	56	180
14	*	1.1	6.0	13	30	43	130

* As the effective penetration l_p here exceeds the radius l_0, the skin effect may be considered neglıgible.

Table II gives values for the following frequencies:

25 and 60 cycles, commercial frequencies.

2000 cycles, frequencies found in telephone and telegraph circuits.

10,000 cycles, low limit of frequency dangerous to transformers.

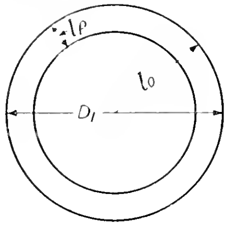


Fig. 2

50,000 cycles, average danger frequency.

100,000 cycles, upper limit of frequency dangerous to transformers.

1,000,000 cycles, steepness of wave fronts of nearby lightning discharges.

It must be remembered that Table II gives approximate values only and that the permeability varies with the magnetic induction. When the induction is known, closer results may be obtained by use of formula (6) and a typical curve, such as Fig. 1.

It is also to be noted that iron wire is not well standardized and inherently gives much variation. For steel wire even greater variation may be expected, due to the wide differences in the characteristics. If some test results are availabe on a definite grade of wire, the tables in this paper should be of value in obtaining comparative performances.

It is sometimes desirable to know the thickness of the equivalent conductor of large diameter, that is, a conductor whose effective conducting area is the same as the total area of a smaller wire having no appreciable skin effect. This may be found by calculating the effective depth of penetration from the Steinmetz formula (3) previously referred to,

$$l_p = \frac{5030}{\sqrt{\lambda \mu f}}$$

In Fig. 2 let:

D_1 be the diameter of the desired equivalent conductor. Obtaining therefrom the area of its angular ring, which we may assume is the effective conducting area.

$$A = \frac{2\pi l_0 + 2\pi (l_0 - l_p)}{2} \times l_p \qquad (7)$$

$$= 2\pi l_0 l_p - \pi l_p^2 \qquad (8)$$

equating this to the area of a small wire in which there is no appreciable skin effect and whose diameter is D.

$$\frac{\pi D^2}{4} = 2\pi l_0 l_p - \pi l_p^2 \qquad (9)$$

Then

$$l_0 = \frac{D^2 + 4\,l_p^2}{8\,l_p} \qquad (10)$$

as

$$D_1 = 2\,l_0,$$

$$D_1 = \frac{D^2 + 4\,l_p^2}{4\,l_p^2} \text{ or}$$

$$D_1 = \frac{D^2}{4\,l_p} + l_p \qquad (11)$$

At high frequencies for the sizes considered the addition of l_p becomes negligible and

$$D_1 = \frac{D^2}{4\,l_p} \qquad (12)$$

TABLE III

DIAMETERS OF EQUIVALENT CONDUCTORS OF UNEQUAL CURRENT DISTRIBUTION OF TELEGRAPH WIRE

Diameter in Cm. of Equivalent Conductors

Size of Wire	D-c.	25 Cycles	60 Cycles	2,000 Cycles	10,000 Cycles	50,000 Cycles	100,000 Cycles	1,000,000 Cycles
4	0.605	0.739	1.003	5.22	11.6	26.1	36.9	115
5	0.559	0.653	0.970	4.45	9.95	22.2	31.4	100
6	0.515	0.579	0.756	3.79	8.46	18.9	26.7	85
7	0.457	0.490	0.617	2.99	6.67	14.9	21.1	67
8	0.419	0.437	0.535	2.52	5.62	12.5	17.7	56
9	0.376	0.382	0.450	2.02	4.51	10.1	14.2	45
10	0.340	0.342	0.388	1.67	3.70	8.26	11.7	37
11	0.305	*	0.332	1.34	2.98	6.64	9.39	30
12	0.277	*	0.291	1.11	2.46	5.45	7.74	25
14	0.211	*	0.211	0.65	1.42	3.16	4.48	14

* See note for Table II.

For iron wire,
Letting $\lambda = 82{,}000$ and $\mu = 500$ as before,

$$l_p = \frac{5030}{\sqrt{82{,}000 \times 500 \times f}} = \frac{0.785}{\sqrt{f}}$$

and: (11) becomes

$$D_1 = \frac{D^2}{4 \times \frac{0.785}{\sqrt{f}}} + l_p = \frac{D^2 \sqrt{f}}{3.14} + l_p$$

and at high frequencies for above constants:

$$D_1 = \frac{D^2 \sqrt{f}}{3.14}$$

Table III was so calculated and gives diameter in cm. of conductors which should be used at the frequencies given in Table II, to carry the same current as the telegraph wire if there was no skin effect.

As an example of the use of Table III let us assume that d-c. resistance calculations show that a No. 8 wire (dia. 0.419 cm.) is the correct size if d-c. is used. Then to have the same resistance at 60 cycles we find by the table that it is necessary to have a wire of 0.535 cm. diameter (approximately No. 5). At 100,000 cycles from Table II we find that the effective resistance is 85 times as great, or by Table III to have the same effective resistance a conductor 17.7 cm. in diameter would be required.

For transmission lines unannealed wire should be used as it has lower permeability and in consequence less skin effect, which gives less effective resistance and in consequence less line losses. If high skin effect is desired as in choke coils etc. greater advantage may be gained by means of annealed wire.

In transmission lines the effective resistance varies with the current somewhat as the raising of the current increases the temperature and consequently the actual resistance by an amount which may be obtained by the use of the temperature coefficient. The effective a-c. resistance also changes with the current as with changing current we have changing permeability which gives varying depth of penetration. In this event it is to be expected that the effective resistance increases as the current increases up to the point where the current is of the value to give maximum permeability in the wire. Beyond this point, with increasing current the permeability is lowered and in consequence the depth of penetration becomes greater and the effective resistance less. The values of the permeability selected for these tables are taken as an average of the material for ordinary currents.

The reactance constants may be determined by similar means when required. The reactance is usually sufficiently large that when variations in permeability are considered the reactance effect of spacing conductors may be neglected for the distances ordinarily employed.

THE STEEL MILL AND THE CENTRAL STATION

By K. A Pauly

Power and Mining Engineering Department, General Electric Company

The author gives some data concerning the magnitude of the power load in steel mills. These figures are so large that they will astonish many of our readers. The nature of the load and the desirability of separate power plants for steel mills or the purchasing of power are discussed.—Editor.

K. A. Pauly

A FACT, not generally appreciated, is that the power requirements of the large and even the moderate mills exceed those of any other industrial field of motor application. For example, the main rolls of the rail mill at Gary are driven by six induction motors having a combined rated capacity of 24,000 h.p., with a maximum momentary capacity of approximately 80,000 h.p and the main rolls of the billet mill at the same works are driven by five motors with a combined capacity of 22,000 h.p. with a corresponding maximum momentary capacity. Then, too, we have the large reversing mills which are driven by motors from 2000 h.p. to 7000 h.p. taking peaks from 6000 to 20,000 h.p. momentarily. In addition to the power taken by the main rolls there are a very large number of smaller motors scattered about the plant for driving all manner of auxiliaries required for unloading the ore and transferring it to the blast furnaces, driving the blast furnace auxiliaries, and for transferring the iron and steel from the time it is drawn from the furnace until it is shipped as finished shapes.

The station load diagram of a steel plant is the result of a combination of load curves of almost every conceivable shape ranging from the extremely intermittent cycles of the large motors driving single stands of rolls and the small motors operating the screw downs, lifting tables, etc., to the more or less constant loads of the larger motors driving multi-stand mills, blast furnace pumps, gas washers, etc. The load factor of a central station supplying a steel mill obviously varies with the magnitude of the plant, although that for small plants is higher than might at first be expected owing to the fact that most small works do most of their rolling in multi-stand mills, roll smaller sections and take more passes to produce a given reduction. Further, the steel is of such length that it is looped in rolling and passes simultaneously through several stands of rolls, and in many mills several pieces are rolled at the same time thus producing a much more uniform load than obtains with the large single stand mill.

When power is purchased at a rate which is dependent upon the peak demand as well as the energy consumed or where power is supplied from a comparatively small central station means can frequently be provided for reducing the fluctuations in the load, but as the method of accomplishing this result depends upon a variety of local conditions the various methods will not be discussed here.

From the standpoint of the central station, steel mills can conveniently be divided into two groups. In the first are included those companies which operate their own blast furnaces and in the second group those which purchase their steel in the form of ingots, billets, or slabs, etc., for rolling, and fabricating works which purchase the rolled shapes. Although a few of those included in the first group do at present and probably will continue to purchase power to supplement that which is developed locally, the large majority of these companies have made and will continue to make all their own power as a by-product and many have a surplus to sell. The following figures taken from a paper read before the A.I.E.E. in 1909, will serve to indicate the immense amount of energy available as a by-product incident to the manufacture of steel.

As a result of the reduction of the iron ore in the blast furnace there is produced in the form of so-called waste gases approximately 150,000 cu. ft. of gas having an average thermal value of approximately 90 B.t.u. per cu. ft. Of this approximately 30 per cent is required for heating the hot blast stoves and approximately 25 per cent for driving the blast furnace blowing engines, gas washing machinery and auxiliaries used in connection with the blast furnaces and blowing engines, leaving 45 per cent or approximately 320 kw-hr. per ton of pig iron produced available for general power purposes. Also, many of the large steel plants are manufacturing the coke used in the blast furnaces which reduce the ore at the works and have available as a by-product of the coke ovens approximately 10,000 cu. ft. of gas having approximately 500 B.t.u. per cu. ft., of which approximately 50 per cent or approximately 130 kw-hr. per ton of coke produced is available for general power purposes elsewhere in the mill. As very nearly a ton of coke is required to produce a ton of pig iron in the blast furnace the by-product power available for general purposes from the blast furnace and coke oven gases is obviously approximately 450 kw-hr. per ton of pig iron. Also in many steel plants considerable additional power is being obtained from waste heat boilers used in connection with the open hearth furnaces. While the power from this source is small compared with that from the blast furnace and coke oven gases it is very considerable when compared with many industrial plants and has an appreciable effect in lowering the cost of producing power in the large modern steel works.

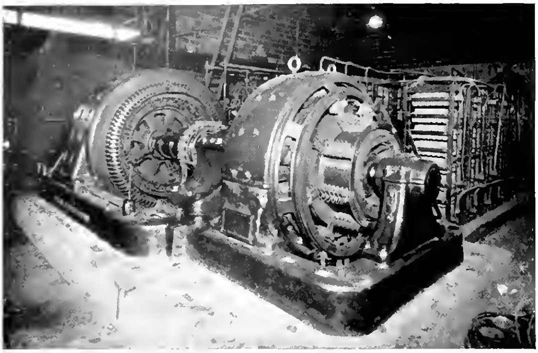


Fig. 1. 1400-h.p. Adjustable Speed Induction Rolling Mill Motor Rotary Converter System of Speed Control, Union Rolling Mills, Cleveland, Ohio

Fig. 2. Rotary Converter used for Controlling Speed: 1400-h.p. Motor, Union Rolling Mills, Cleveland, Ohio

A few figures taken from a paper entitled "Statistical Data on Electrical Application in the Iron and Steel Industry in the United States," read by Mr. R. Tschentscher, Electrical Engineer of the South Works of the Illinois Steel Company, before the Cleveland meeting of the Association of Iron and Steel Electrical Engineers, will serve to indicate the magnitude of the power plants of the modern steel mills. In this paper the author gives some authentic information concerning the power (electric) consumption of the steel plants of this country during 1913, including figures covering plants that generate and those that purchase all their power, as well as some which both generate and purchase power.

"The author wrote 85 companies engaged in the iron and steel industries, which companies operate approximately 200 plants. Of these companies 62 representing 170 plants reported. The figures given are for 1914.

Number of companies reporting	62
Number of companies generating electric power	59
Number of plants generating electric power	170
Number of power generating units	840
Kw. capacity generating units	394,466
Installed motor horse power	1,261,148
Number of motors in operation	45,512
Kw. load for illumination	33,863
Kw. load for metallurgical purposes	7,047
Kw. load for miscellaneous purposes	4,810
Kw-hr. generated and purchased in 1913	1,641,564,000
Kw-hr. generated in 1913	1,633,764,000
Average kw-hr. generated in 1913, per company	27,700,000
Average kw-hr. generated in 1913, per plant	9,610,000

The data obtained shows a power generating condition for 1913 varying from 100,000 kw-hr. in the smallest plant to 330,000,000 kw-hr. in the largest plant—electrically speaking. Three companies in 19 plants generated 683,000,000 kw-hr., this representing almost 42 per cent of the total generation. The electric power generation of the largest plant constituted 20 per cent of the total, and that of the next largest over 8 per cent of the total generation. Thus, the two largest plants—electrically—generated almost 30 per cent of the total electric power of the 170 plants from which reports were obtained. These two plants represent, no doubt, the highest development of electrical application in the iron and steel industry, and illustrate the magnitude to which such application may attain as other newer plants are established or the press of competition requires the existing older non-electrical iron and steel plants to substitute electrical drive for that now in existence, thus availing themselves of the economies incident thereto.

Mr. Tschentscher estimates that there are altogether from 225 to 250 separate plants engaged in the iron and steel industry and that the total kw-hr. consumption during 1913 would have reached 2,000,000,000, from which it follows that the average power consumption per plant was approximately 9,000,000 kw-hr.

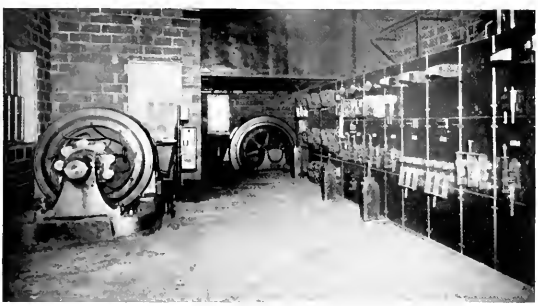


Fig. 3. 500-h.p. Adjustabe Speed Induction Rolling Mill Motor with Scherbius System of Control. Union Rolling Mills, Cleveland, Ohio

According to the U. S. Bureau of census 1260 companies operating the electric railways of the United States generated an average of approximately 4,800,000 kw-hr. per company, or slightly over one-half that generated per plant in the iron and steel industry. Since 1913, the year covered by these figures, there has been an enormous increase in the application of electric motors in all branches of the steel industry, and the present indications are that this development will continue for many years to come.

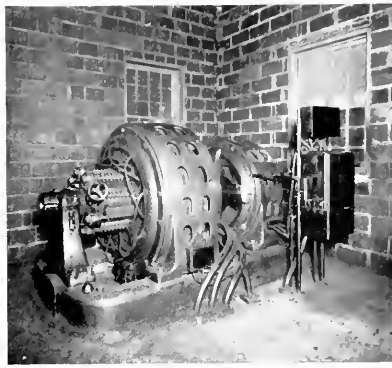


Fig. 4. Regulating Set for Controlling Speed 500-h.p. Motor in Fig. 3

It is apparent from these figures without considering any of the other factors affecting the power problem that there is little likelihood of public service central stations obtaining any considerable load from the larger steel companies. But there is a very considerable field for central station power in the smaller plants which purchase their steel in the form of ingots or billets and many of these plants are now purchasing a part or all of their electrical power.

Two of the most important considerations affecting the question of purchased power versus that generated locally are the relative costs per kw-hr. and the frequency. The question of price versus the cost of generating power is one which cannot be treated in generalities, each proposition being surrounded by very many special conditions which have an all-important bearing on the decision. However, the writer wishes to emphasize two points. First, that extreme care be taken to include all expenses properly chargeable against cost of power when, as is usually the case, the price of purchased power is being compared with an estimated cost of local generation. Second, that while the estimated cost of producing power locally may appear to compare favorably with or be even lower than the price quoted, the public service corporation is a manufacturer and seller of power, while for the steel mill the development of power is somewhat of a side issue, especially in small plants, and only one of the many factors incident to the manufacture of steel products. The whole effort of the public service company is devoted to improving the service, a large force of engineers being maintained for this purpose, and while theoretically this is possible with the steel mill also, practically it is never the case with small plants. Therefore, extreme care should be exercised before making a decision against purchased power based on an estimated cost of developing power locally, although this may appear to be justified by the figures.

There seems to be a feeling inbred into the minds of steel mill men that sixty cycle equipment is not at all suited to steel mill conditions. The foundation for this is doubtless to be found in the fact that all or practically all of the large steel works throughout the country have adopted 25-cycle as the frequency of their power systems. This prejudice is frequently a serious handicap to the public service power solicitor who is trying to interest the steel company in his goods which he can offer only at 60 cycles. Many of the constant speed auxiliaries about the mill are driven by induction motors and with 60 cycles more speeds are available than with 25 cycles, there being seven speeds from which to choose within the range of 500-r.p.m. and above with the former frequency and only three with the latter. Also most of the equipment such as motor generators, transformers, etc., are cheaper for 60 cycles and equally efficient and reliable. 25 cycles however, has considerable advantage over 60 cycles for supplying the slow speed, direct connected, main roll motors, the power-factor of such motors usually being higher for the same overload capacities and their costs less. The difficulty of operating gas engine-driven generators at 60 cycles has also been an important factor in bringing about the adoption of 25 cycles by the large steel plants. There is, however, no fundamental reason why motors cannot be designed for 60 cycles to meet the severe rolling mill requirements and any one of the large electrical manufacturers will readily guarantee such motors to develop the necessary overloads and to operate within any specified heating limits. The power-factor of the slow speed, 60-cycle machines is as previously stated lower than for 25-cycle units, but this defect can be neutralized by synchronous condensers. It is a fact, however, that most of the mills in the plants which fall in the second group are of the size and type which it is customary to drive either through gearing or rope transmission, thus permitting the use of motors of moderate speeds for which 60 cycles is at least as satisfactory, if not slightly preferable; so that in general it may be said that 25 cycles possesses little if any advantage over 60 cycles as a steel mill frequency for those plants which will consider purchasing their power.

As in the general treatment of all similar problems no definite recommendations can be made which will conform to all the special conditions which may surround any particular case. However, in summing up the writer feels safe in drawing the following conclusions from his experience in this field of application of electric power. First, that if for reasons other than the question of frequency, the power for supplying the plant is to be developed locally 25 cycles should be chosen as the operating frequency, except possibly in the case of some small plants referred to below. Second, that for plants falling in the second group, if reliable power can be purchased at a reasonable rate, which the writer believes is always the case, the mill frequency should be that of the available source of supply whether 25 or 60 cycles and the necessary power purchased, unless for reasons other than those having a direct bearing on the power problem, it is considered expedient to generate rather than purchase power. It is conceivable that it might be to the interest of the steel company to operate its own plant, although from power considerations alone this would seem unwise, and in such cases the adopted frequency should in general be the same as that of the local public service company so that in the event of a breakdown assistance can be obtained from the local company.

ELECTRIC FURNACE CONTROL

By John A. Seede

Power and Mining Engineering Department, General Electric Company

This article constitutes a brief review of the development of the control of electric arc furnaces. Among the problems that have had to be solved are the connections of the electric cables to the carbon electrodes, methods of suspending the electrodes, and most important of all, means of regulating the power input and consequently the temperature by movement of the electrodes and by changing the electrical characteristics of the furnace circuits. In the earlier furnaces the electrode control was effects through hand operated winches which required considerable attention from the operator. The Thury regulator, which was one of the first devices to be introduced for the automatic adjustment of the electrodes, effects the movement of the electrode through a series of small steps, while the latest regulators accomplish this adjustment in one continuous movement. The principal features of these later regulators and their points of superiority over previous types are outlined. —Editor.

John A. Seede

With the enormous increase in the use of electric furnaces for making various kinds of electric steel, and incidentally ferro alloys, a brief description of the unusual points of hand and automatic current and voltage control may be of value, or at least of interest. Some of these conditions are necessitated by metallurgical requirements which naturally come first, some by protection of electrical apparatus, and others by the power companies.

Some of these special features are: The use of transformers having somewhat more than normal inherent reactance, or separately controlled external reactances, to avoid disturbances to other power users when starting the furnace; the use of individual electrode control for automatically maintaining constant energy input to the furnace, the amount being variable according to condition of furnace and charge, with balanced power per phase; and the prevention of injury to product and equipment in case of power failure. As any furnace equipment is intended primarily for certain metallurgical operations it would be undesirable to require that the operative be a combination of melter, power station operator, and control specialist, and this fact is kept constantly in mind in designing these equipments, to secure maximum simplicity and strength consistent with the results to be obtained.

The first furnaces, for smelting experiments, employed and many still employ a simple frame with hand-operated winches, the electrode being suspended in the charge at the end of a chain or wire rope, and the electrode supports being separate from the furnace, permitting the simplest mechanical arrangements. The flexible connections were first made with cables soldered into the contact ring, but it was soon found that the heat from the open-top furnaces would melt the solder and break the circuit, causing shutdowns that ruined many experiments. Pinned and brazed terminals were tried with varying success, and finally perfection was attained in the welded terminal, the cable being continuous from end to end and failing only by destruction of the metal

As furnaces increased in capacity, and the closed type was developed, larger electrodes required different means of suspension, and it became necessary to guide the electrodes through the water-cooled roof openings to preserve the roof and the electrodes, and to prevent short circuits, especially in tilting furnaces where considerable side strain exists on electrodes when tilting. Mounting the electrode suspension on the furnace structure enables the furnace to be tilted without exposing the white hot electrodes to the open air, thus preventing rapid and unnecessary waste.

As long as the furnaces were operated single-phase and only one electrode was moved to regulate the power input, the hand device operated successfully and two or more electrodes could be handled by this means, although at great waste of labor.

Motor-operated winches were self-suggestive, and when this convenience was developed it was only one step more to the automatic system, which permits the operator to spend more time in watching the furnace and charge. Although this seems simple enough, it soon became evident that the apparatus must be designed to almost anticipate changes and be sensitive to changes before they occurred This requirement is due to movements of metal during the melting period, causing sudden and violent current changes, up and down, which may go from open circuit to nearly dead short circuit. Any disturbance of the metal due to boiling, raking, etc., will change the arc length, and the regulators must be designed to compensate for these changes, which function they perform very successfully.

The first and for some time the only successful apparatus available was the Thury regulator, imported from Switzerland. The principle of this regulator consists in moving the electrode to the new position by a series of small steps, as contrasted with the new method of control which makes this movement in one step and stops the electrode almost instantly when this point is reached. The Thury regulator consists of contact arms, one for each electrode, constantly oscillated by suitable mechanical connections to a countershaft that is belted to a small motor, and suitable switches for hand- or automatic-operation.

The contact arms are controlled by pawls, these in turn being operated by relays actuated by current or voltage, as required by the electrical characteristics. As the contact arm is moved to the right or left, the electrode motor connections are made and broken a number of times per minute, and the arc is lengthened or shortened by a series of small movements to the correct position. At full speed the electrode moves from 36 to 45 inches per minute.

Before the general use of interpolar motors and generators, the electrode speed setting was obtained by a potentiometer connection which would give the desired difference between power for raising and lowering; but this system uses power during operation and at standstill.

Fig. 1. Automatic Regulator Panel for three-electrode Arc Furnace (Front view); upper section—three contactor groups, each consisting of two upper contactors for raising and lowering electrode and one lower contactor for dynamic braking; middle section, three relays in glass case with corresponding dial switches below for different energy values; lower section, voltage relays for cutting out automatic control on failure of power supply.

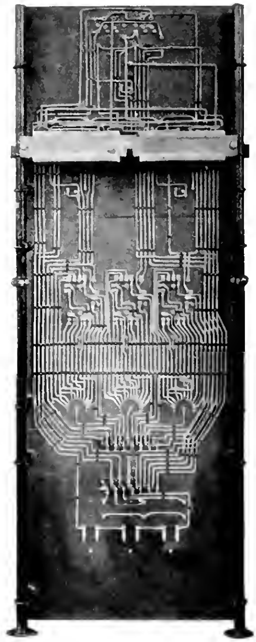


Fig 2 Automatic Regulator Panel for three-electrode Arc Furnace (Back view) showing simple method of wiring in three groups with controlling and braking rheostats mounted above

As more power is required to raise than to lower an electrode, there is more danger of overrunning when lowering than when raising, with consequent hunting. With the potentiometer arrangement the 250-volt circuit could be divided into two sections, one of 160 volts for raising and the other of 90 volts for lowering, or any other desired ratio. A more efficient method is to provide a different armature resistance for each motion and add a method of positively braking the moving parts. A convenient way of accomplishing this is to use a shunt motor with separate excitation and to short circuit the armature through a suitable resistance when it is not connected to the mains.

A different control has been developed, employing current relays in furnaces having three or more electrodes, or current and voltage relays when two electrodes are required, to control the contactors which operate the electrode motors that shorten and lengthen the arc, these contactors being mechanically interlocked with the dynamic braking contactor.

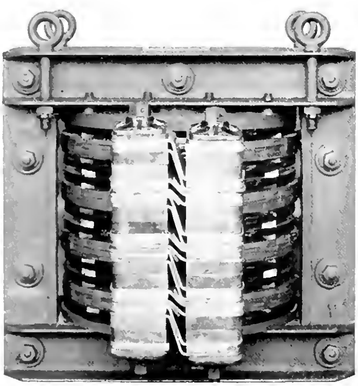


Fig. 3. Side view of external reactance showing coils and furnace circuit leads

By using an electrode speed of not more than 12 in. per minute, the electrode motor may be rotated until the current is raised or lowered in one movement to the desired point, when the relay will break the contactor control circuit and the electrode will be quickly stopped by the short circuiting of the electrode motor armature by the "off" contactor.

A condition that has occasioned some damage exists when the electrode circuit is broken without breaking the motor circuit, as may happen in systems having separately controlled alternating and direct-current circuits. To prevent this, voltage relays are provided that open the automatic control circuits and prevent the bath from becoming saturated with carbon, breaking the elec-

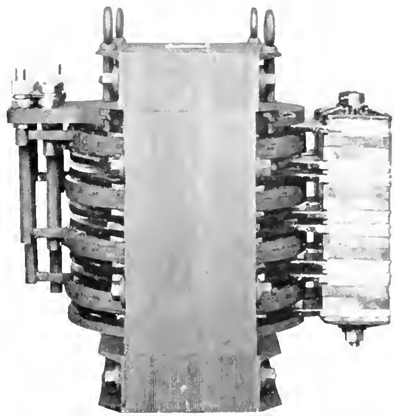


Fig. 4. End view of external reactance showing furnace circuit leads on one side and short circuiting leads on other side

trodes, the winches, or some other part of the equipment. Adjustable dashpots are provided to vary the damping action to suit local conditions. The stationary contacts of the relay are individually adjustable to control the ratio of average to maximum variations.

Taps from the relay windings are brought to dial switches that permit of regulating the power input within the limits of the equipment, which is normally 3 to 1. This method is superior to any method of variable resistance in shunt to relay windings, for in the latter method the current through the relay windings is always proportional to the electrode current (the relay and electrode being connected in series) where a poor contact can give varying resistance and poor calibration with the shunt arrangement.

In the operation of larger equipments, where normal operation means from 10,000 to 20,000 amps. at 100 volts, the proximity of large masses of cold magnetic metal causes a high reactance which results in a comparatively small amount of energy going into the furnace. This means longer time per heat, decreased capacity of equipment, higher labor and overhead charges per ton of metal, and a general idea that the apparatus is defective.

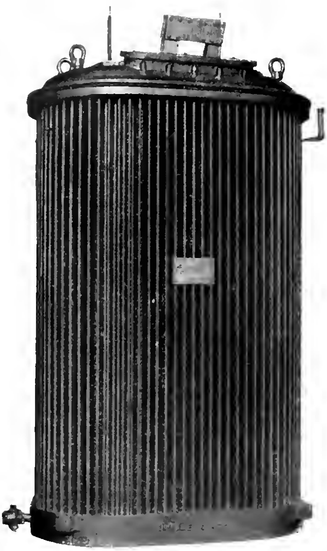


Fig. 5. Self-cooled 400-kv-a., 25-cycle, single-phase transformer for use on 13,200-volt circuit and delivering 4,000 amps. at 100 volts for furnace work

Several solutions of this difficulty are possible, such as:

1. Charging non-magnetic or hot metal.
2. Increasing number of electrodes.
3. Raising voltage.

1. This is not always possible. Furnaces for melting or preheating the charge occupy valuable space, require additional crews to operate them, and below a certain capacity it is an open question whether the increased plant complexity of cranes, ladles, etc., does not result in a higher cost over making the complete operation in the electric furnace.

2. This change also tends to increased complexity of equipment, difficulty of operation, and cost of roof up-keep. The electrical power equipment will be affected so little that it does not matter.

3. On account of necessarily heavy busbar construction, low voltage switching is not permissible, and as full kilovolt-amperes is not necessary for refining we can do switching on the high voltage side. This is a simple matter of delta-Y combinations. Where the quality of the scrap is favorable we can make our delta high voltage connections immediately and start melting with full kilovolt-amperes at 1.73 times normal volts, or other ratios that may be found to be desirable. If the scrap is very heavy, the furnace start can be made on the Y connection and operated this way until a good operating surface is developed under the electrode, when the switch is thrown over to the delta connection and left in this position until the longer arc begins to throw too much heat against the side walls and roof, when the Y connection is restored and operation continued at the same current and 57.7 per cent of normal kilovolt-amperes until the small amount of melting is completed and the

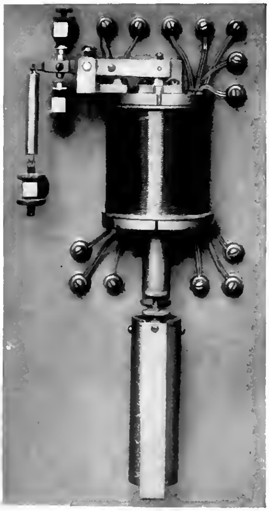


Fig. 6. Relay for automatic electrode control showing dampening device at bottom, taps for different current values and contacts at left for controlling electrode motor contactors

current reduced for the refining operations. This arrangement, with normal 3 to 1 current regulation, gives automatically a power regulation of 5.19 to 1, and to obtain equal overload current protection for our transformer with varying kilovolt-amperes, all that is necessary is to connect the overload relays to the secondary current transformers.

Within certain limits, this arrangement permits of increasing the power input during the slowest part of the process and when rapid working will cause least harm to metal and furnace, which is not the case after the metal is molten.

In operating arc furnaces, certain arrangements are sometimes recommended as regards insertion of external reactances and subsequent cutting out when conditions require such action. Assuming a 10 per cent reactance in a 6000-amp., 100-volt circuit, it is not always possible to locate the reactance close to the control panel on account of heavy wiring, and if the best arrangements are used the reactances will be installed with the transformers in a room separate from the furnace room. This means solenoid control, and a solenoid-operated 6000-amp. contact switch is not recommended for a number of operations per day if something better is available. Such apparatus is too heavy for frequent operations compared to standard contactors which are permitted by the new arrangement.

It is well known that if one winding of an ordinary transformer is short circuited, normal current can be passed through the other winding with a small percentage of the voltage normally existing across the winding. Advantage is taken of this phenomenon by adding a so-called short circuiting winding, so designed as to come within the current capacity of standard contactors. This permits of installing standard panels besides the reactances and short circuiting the reactances singly, in pairs, or in other combinations as may be desirable. Arrangements can be provided to automatically insert this reactance in case of failure of the arc, especially at starting, although the added complication may be objectionable.

Where it is thought advisable to change the furnace voltage during operation high voltage taps can be changed by oil switches, or if necessary to avoid breaking the continuity of heating, various methods of arranging solenoid or cam-operated switches can be employed as in certain kinds of resistance furnace work.

One arrangement advocated for single-phase furnaces is to use a reactance of approximately 30 per cent, which gives approximately constant energy input with wide variations of kilovolt-amperes and length of arc, and uses only hand operation.

The results of continued effort in exploiting electric furnace equipments must be gratifying to all interested in these applications, as it is clearly indicated that our manufacturers are becoming convinced of the value of these simple, reliable, and comparatively inexpensive outfits that give results that cannot be attained by any other means except at considerably higher cost. Obviously, there will always be a certain group whose mental make-up prevents their recognizing the value of new devices of demonstrated value, and while it is neither desirable nor necessary to claim that the electric furnace is a panacea for all metallurgical troubles, its great value in nearly every branch of metallurgy must be universally recognized.

It seems safe to state that the electric furnace, especially for the manufacture of high grade steel, is fast coming to the front rank, and the immediate future will see a continued expansion of furnace installations for all purposes.

SELECTION OF ELECTRICAL APPARATUS FOR CRANES

By R. H. McLain and J. A. Jackson

Power and Mining Engineering Department, General Electric Company

R. H. McLain

In the selection of electrical apparatus for crane drives, it is first necessary to consider the various classes of cranes. For reference later, these classes are enumerated below:

Class 1: Stand-by or service cranes which are used in emergencies, and at rare intervals. A typical example is the power house crane which is used during installation and thereafter only when repairs are made. The apparatus on such a crane should be simple and should be worked to the limit of its capacity. The control should be very accurate for placing large machines even when used by unskilled operators; as this kind of crane is so rarely used that there is no regularly trained operator for it.

Class 2: Machine shop and foundry cranes, which are always in service and moderately busy. The apparatus on them should be simple but not worked so nearly to the limit of its capacity as in Class 1. There is always a regular operator in attendance, and, therefore, the control apparatus does not necessarily have to be so accurate as in Class 1. In this same class belong loading cranes which serve storage yards where infrequent movement of the stock occurs.

Class 3: High duty cranes such as are used for moving material in steel mills and for loading material into cars with magnets from storage yards where stock is frequently moved. On these cranes rugged apparatus is required, and complications are warranted to some extent in order to secure long life of the apparatus. All apparatus should be very conservatively rated.

Class 4: Soaking pit and stripper cranes. On these cranes fire-resisting insulation is required on motors, and apparatus should be designed to be rugged, conservative in size and exceptionally safe in operation.

Class 5: Hot metal ladle cranes. These cranes should have fire-resisting insulation and should be extremely conservatively designed.

This article will not discuss various small jib cranes and others of this same kind which are operated by a man on the floor rather than by an operator who rides with the crane.

J. A. Jackson

General Selection of Electrical Equipment

To assist in selecting the general type and arrangement of electrical equipment, Table I on page 507, has been compiled, in which all the various features to be considered are pointed out.

Selection of Hoist Motors

$$\text{H.P.} = \frac{W \times S}{33{,}000 \times e} \qquad (1)$$

where H.P. = horse power to hoist at full speed. (*All* starting resistance short-circuited). (2)

W = weight of load on hook in pounds. (3)

S = speed of hook in feet per minute. (4)

e = necessary factor to allow for friction losses in the crane. (5)

The valve of e varies from 0.25 on slow speed (10 ft. per minute) cranes which use worm gears to 0.70 for high speed (75 ft. per minute) cranes which use good cut gears.

$$T = \frac{5250 \times \text{h.p.}}{\text{r.p.m.}} \qquad (6)$$

T = Torque on motor shaft required to hoist as in (1) expressed in pounds at one foot radius. (7)

$r.p.m.$ = speed of motor shaft in revolutions per minute with *all* resistance cut out of the circuit. (8)

$T_1 = T \times e^2$ if no friction brake is used for lowering. (9)

where

T_1 = braking torque in pounds at one foot radius required to lower the weight W. (10)

The torque to hoist or lower an empty hook is about 5 to 30 per cent of the torque required to hoist maximum rated load of the crane.

In addition to the work of hoisting (1) there is the work of accelerating. Most of this work is expended on the motor armature and brake wheel. An approximate rule is to assume that the horse power input to accelerate an armature and brake wheel to full speed in one second is equal to the 30-minute horse power rating of the motor for induction motors; (11)

and is equal to one-half the 30-minute horse power rating of the motor for series wound direct current motors. (12)

A more exact rule is to obtain from the motor manufacturers the weight and radius of gyration of the armature.

Then

Horse power input to start =

$$\frac{WR^2 \times r.p.m.^2}{1{,}612{,}800 \times t} \qquad (13)$$

where

W = weight of armature in pounds. (14)

R = radius of gyration in feet. (15)

$r.p.m.$ speed of motor shaft as in (8).

t = seconds used in acceleration. (16)

To select the proper size of motor for crane hoist determine (a) the maximum horse power to be delivered by the motor and (b) the usual horse power. The horse power value obtained by adding h.p. (1) to h.p. (13) for a maximum load and to h.p. (11) or (12) as the case may be, should always be less than the 5-minute rating of the motor if direct current is used; and less than the maximum pull-out horse power capacity, under minimum line voltage, of the motor if alternating current is used. By formula (1) the horse power delivered under usual operating conditions should be determined. This usual value of horse power determines the ordinary rating of the motor and it should be:

TABLE 1

A KEY TO ASSIST IN THE SELECTION OF ELECTRICAL EQUIPMENT FOR CRANES

- Electrical Equipment for Cranes
  - Motors
    - Enclosed or Open Insulation
    - Mechanical Strength and Ruggedness
    - Rating ....
      - A-C.
        - Wound Rotor or Squirrel Cage
        - Voltage
        - Frequency
        - No. of Phases
        - Heating Basis — 15 minute / 30 minute / 60 minute
        - Max. Torque
      - D-C.
        - Max. Torque
        - Series or Compound Wound
        - Voltage
        - Heating Basis — 15 minute / 30 minute / 60 minute
    - Accessibility for Repairs
  - Control Equipment
    - Controller
      - Drum
        - Straight
        - Reversible
        - Dynamic Braking
      - Magnetic
        - Straight
        - Reversible
        - Dynamic Braking
      - No. of points
      - Type of handle
      - No. of hand control points
      - No. of automatic control points
      - Plugging point — Hand controlled / Automatic
      - Creeping speed point
      - Space requirements
      - Type of handle on master
    - Rheostat
      - Heating
      - Starting Torque
      - Plugging
      - Creeping speed
    - Brakes
      - Series or Shunt Wound
      - Torque requirements
      - Ruggedness
      - Wearing qualities
  - Protective Equipment
    - Overload
    - No-voltage
    - Emergency conditions
    - Lock out on line switch
    - Individual motor switches
    - Overwind protection

For Class 1 cranes the 15-minute rating of the motor.
For Class 2 cranes the 15- or 30-minute rating of the motor.
For Class 3 cranes the 60- or 90-minute rating of the motor.
For Class 4 cranes the 60- or 90-minute rating of the motor.
For Class 5 cranes the 30-minute rating of the motor.

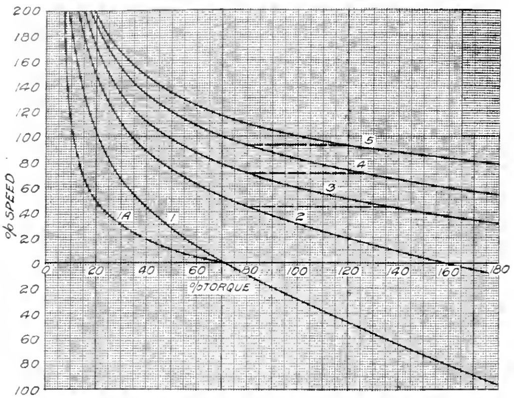


Fig. 1. Speed-Torque Curves of a D-C. Series Motor operated by a Straight Reversible Controller. Curve *1A* shows effect of connecting resistance in parallel as well as in series with the motor

On Class 5 it is customary to have two hoist motors, each of which alone can hoist the total load without exceeding its 30-minute rating. This excess capacity is warranted on account of the great value of the metal and the necessity of hoisting the load even if one motor is broken down.

When direct current is used the series wound motor is most suitable. When alternating current is used the wound rotor polyphase induction motor is most suitable, although for small (15 h.p. and less) cranes which require no reduced speed control a squirrel cage, high resistance rotor is suitable.

In order to make the same number of trips per day with an a-c. crane as with a d-c. crane, it is frequently necessary to gear the a-c. crane for a higher full load hoisting hook speed than would be used with d-c., and this means that the rating of the a-c. motor must be relatively greater than that of the d-c. motor. To explain let us assume that a round trip consists of hoisting full load 20 feet, lowering it 20 feet, hoisting an empty hook 20 feet and lowering it 20 feet. If a d-c. motor were used and geared for 40 feet per minute full load hoisting speed, it would hoist in 30 seconds, lower (see Fig. 2 where lowering speed is shown to be 190 per cent hoisting speed) in 16 seconds, hoist in about 15.5 seconds (see Fig. 2 where 20 per cent hoisting torque corresponds to 195 per cent speed), lower in 20.5 seconds—making a total of 82 seconds. An a-c. motor would have to be geared to hoist full load in about 20.5 $\left(=\frac{82}{4}\right)$ seconds in order to keep up with the d-c. motor, because the a-c. motor can never run above its synchronous speed. This means that the a-c. motor would have to be $\frac{30}{20.5}$ $(=1.46)$ times as large as the d-c. motor for the particular case illustrated. This ratio does not come as high as 1.46 for ordinary practical cases where there is a good deal of creeping speed work in the typical round trip of the crane hoist. However, in order to meet the requirements of an occasional extremely high load, an induction motor may have to be considerably larger than a d-c. motor, because a d-c. motor can exert more overload torque.

Example of Selection of Hoist Motors

Example:—

Take a crane which usually hoists 10,000 (W) lb. at 20 (S) feet per minute and which has gear efficiency (e) of 0.55. Take the extreme load to be 15,000 lb. For direct current substitute in (1).

$$\text{H.P.}=\frac{10{,}000\times 20}{33{,}000\times 0.55}=11 \text{ h.p.}$$

Let t line (16) be 2 seconds,

$$\text{Then h.p. (12)}=\frac{11}{2\times 2}=2.75.$$

When the motor has to hoist 15,000 lb. occasionally this will require approximately

$$\frac{15{,}000}{10{,}000}\times 11=16.5 \text{ h.p.}$$

Therefore, the usual horse power required will be 11 and on extreme loads $16.5+2.75=19.25$. Choose a motor which will start at 19.25 h.p. and whose 15, 30, 60 or 90 minute rating, according to class of crane, is 11 h.p.

For alternating current, first determine how much above 20 feet per minute the hoisting speed must be in order to make a typical round trip as quickly as a direct current motor will do it.

Assume $S=24$.
then from (4) we have

$$\text{H.P.}=\frac{10{,}000\times 24}{33{,}000\times 0.55}=13.2.$$

$$\text{H.P. (11)}=\frac{13.2}{2}=6.6$$

Maximum load demands

$$\frac{15{,}000}{10{,}000}\times 13.2=19.8.$$

Therefore, choose a motor whose 15, 30, 60 or 90 minute rating is 13.2 and which will start (19.8+6.6=)26.4 h.p. under minimum line voltage.

Selection of Bridge and Trolley Motors

$$\text{H.P.}=\frac{W\times f\times S}{33{,}000\times e} \qquad (17)$$

where

H.P. = horse power to propel when all starting resistance is short-circuited. (18)

S = speed of trolley in feet per minute (when fully accelerated). (19)

W = weight of trolley and load in pounds. (20)

f = factor of rolling friction. (21)

The value of f varies from 0.01 on good trolley tracks to 0.025 on poor and uneven bridge tracks,

and e = necessary factor to allow for gear losses. (22)

The value of e is about 0.90 for one reduction of gears, 0.85 for two, and 0.80 for three reductions of gears.

In addition to propelling there is the work of starting the armature, starting the trolley or bridge and sometimes of pulling external loads such as freight cars.

The value for armature starting will be as in (11) and (12) above.

The work of starting the trolley or bridge is determined by formula:

$$\text{H.P.}=\frac{\dfrac{W}{32.2}\times\dfrac{S^2}{60\times t}}{33{,}000\times e} \qquad (23)$$

Where S, W, e are as in (19), (20) and (22) and t = seconds used for accelerating. (24)

The work of pulling external cars is

$$\text{H.P.}=\frac{P\times S}{33{,}000\times e} \qquad (25)$$

Where S and e are as in (19) and (22) and P = rope pull in pounds required to drag the car. (26)

To select a proper bridge or trolley motor obtain the torque from (6) which corresponds to the H.P. values of (17), (11) or (12), (23)

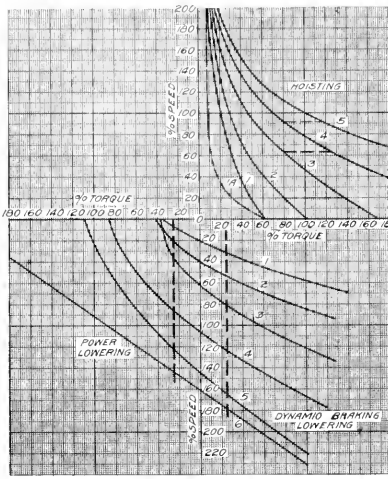


Fig. 2. Speed-Torque Curves of a D-C. Series Motor operated by a Dynamic Braking Controller. Curve *1A* shows effect of connecting resistance in parallel as well as in series with the motor

and (25) when maximum load is being handled. Add these torque values together and see that the motor chosen can exert this total torque for five minutes without damage. Then obtain the torque from (6) which corresponds to H.P. values (17) and (25) for usual load conditions. Add these torque values together and see that about 2.5 times this total corresponds to the 15-minute rating of the motor for Class 1 cranes, the 15- or 30-minute rating for Class 2, the 60- or 90-minute rating for Class 3, 60- or 90-minute for Class 4, and 30-minute rating for Class 5 cranes.

A shorter formula, which applies when the desired rate of acceleration is one foot per second and when no cars are to be pulled, is, for direct current series wound motors.

$$\text{H.P. rating}=\frac{W\times(f+0.0125)\times S}{33{,}000\times e} \qquad (27)$$

for alternating current wound rotor polyphase motors

$$\text{H.P. rating} = \frac{W \times (f + 0.0225) \times S}{33{,}000 \times e} \qquad (28)$$

Where S, W, f and e are as in (19), (20), (21) and (22).

Equation (27) is made to give a smaller horse power rating than equation (28) so as to take into account the series characteristics of a d-c. motor.

The horse power rating above given should be the 15-minute rating for Class 1 cranes, 15- or 30-minute for Class 2, 60- or 90-minute for Class 3, 60- or 90-minute for Class 4, 30-minute for Class 5.

Just as in hoist service a series wound direct current motor or a wound rotor polyphase induction motor is the most suitable type of motor.

A trolley with suspended maximum load usually weighs three times as much as a trolley without load. Hence, if, for example, 80 per cent of the rated motor torque is required to propel a loaded trolley, 26.6 per cent of the rated torque will be required to propel it with no load. Now, on Fig. 1, 80 per cent torque corresponds to 109 per cent speed and 26.6 per cent torque corresponds to 174 per cent speed. The average of 109 and 174 is 141.5. An induction motor would have to be geared $\frac{141.5}{109}$ (=1.30) higher than a series wound d-c. motor in order to make an average round trip in the same length of time. Therefore, for this reason alone, the rating of the induction motor in such a case will have to be 1.30 times the d-c. motor rating. In some cases a still further increase must be made in the size of the induction motor in order to meet the 5-minute test outlined in the first part of the paragraph above. An induction motor cannot take as much overload for a short period as a d-c. series motor.

The weight of a loaded crane is about 1.5 to 2 times the weight of a crane without load. By the same line of reasoning as used in the paragraph above, an induction motor for bridge service will have to be geared about 1.15 times as high as the d-c. motor. On bridge service the 5-minute maximum load test is much more important than on trolley service because a poor track or bad alignment of bridge is liable to cause the horse power in (17) to be excessively high in certain parts of a building. For these two reasons it is frequently advisable to use an induction motor whose rating is 1.33 to 1.50 times the rating of a d-c. motor.

Example of Bridge Motor

Example:—

Take a bridge whose data are as follows:
$S = 300$ in (19)
$W = 100{,}000$ in (20)
$f = 0.015$ for usual track and 0.025 for one bad spot (21)
$e = 0.90$
$t = 5$ in (24)

then from (17) we have

$$\text{H.P.} = \frac{100{,}000 \times 0.015 \times 300}{33{,}000 \times 0.90} = 15.1 \text{ h.p.}$$

to propel the usual load.

In (23) we have

$$\text{H.P.} = \frac{\frac{100{,}000}{32.2} \times \frac{90{,}000}{60 \times 5}}{33{,}000 \times 0.90} = 31.4$$

In (11) we have for alternating current motors about $\frac{30}{5} = 6$ h.p.

and in (12) we have for direct current motors about $\frac{30}{5 \times 2} = 3$ h.p.

For alternating current the motor must be able to stand 15.1+31.4+6 or 52.5 h.p. for 5 minutes and its rating must be 15.1×2.5 or 37.8 h.p. or more.

For direct current, the motor must be able to stand for five minutes a torque =

$$\frac{15.1 + 31.4 + 3}{15.1}$$

or 3.3 times the torque which the motor delivers at 15.1 h.p., and its rating will be about 2.5 times this torque. Such a motor would be found, by reference to its speed torque curve, to be rated about 28 h.p.

The extreme test which this motor must meet occurs when the crane must be started on a bad spot in the track where $f = 0.025$. The propelling H.P. at this point will be

$$\text{H.P.} = \frac{100{,}000 \times 0.025 \times 300}{33{,}000 \times 0.90} = 25.2 \text{ h.p.}$$

The torque required for acceleration will then be $\frac{25.2 + 31.4 + 3}{15.1} = 3.95$ times the torque which the motor delivers at 15.1 h.p. The motor must be able to do this occasionally without breaking down.

D-C. Hoist Motor Control

In the choice of control for hoist motors, the principal factors to be considered are whether to use manual or magnetic, straight reversible or dynamic braking, and the capacity and ohmic values of the rheostat.

The choice of manual or magnetic control depends primarily on the size of the motors and the severity of the service, although in many cases, magnetic control is used to prevent careless operators from abusing the equipment where, with a reasonably careful operator, manual control would be satisfactory. Reliability and reduced maintenance charges result from the use of magnetic control while the operator's work is lighter on account of the small weight and easy operation of the master controllers.

A knowledge of the speed torque curves of the motor when controlled by a straight reversible controller and by a dynamic braking controller is valuable in deciding which type to use. Fig. 1 gives the speed torque curves of a straight reversible controller while Fig. 2 gives similar curves for a dynamic braking controller.

These curves show the torque and corresponding speeds of a series motor when connected directly to the line and also when connected to the line through a controller with definite values of resistance in series. The dynamic braking curves (lower curves of Fig. 2), and curves 1A of Figs. 1 and 2 show the speed torque relations with definite values of resistance both in series and in parallel with the motor.

It will be seen from the above curves that, in the hoisting direction, both controllers give the same characteristics. The principal features to be obtained when hoisting are: 1st, low torque on the first point; 2nd, slow speeds with light loads, and 3rd, current peaks which the motor will safely stand. The controllers shown on the curves give from 60 to 70 per cent torque on the first point at standstill, and the horizontal dotted lines show the peaks obtained when accelerating a load requiring 80 per cent torque.

In lowering with the straight reversible controller the same speed torque curves are used as in hoisting, the speed and torque of course being reversed as the motor is working against the friction of the mechanical load brake. This friction is, at best, far from constant and hence it is difficult to obtain definite slow speeds in the lowering direction.

With the dynamic braking controller the speed of lowering depends on the weight of the load and the electrical resistance, in the dynamic braking circuit. The load, in any one case, being constant, the speed can be controlled to a nicety by varying the resistance in the braking circuit. In the controller shown in the curves (Fig. 2) the circuits are so arranged that both power and braking are obtained on each lowering curve depending on which the load demands. For instance, on point 1 lowering, 35 per cent torque tending to drive the hook down is applied at standstill. Should the controller be left on this point and the load be heavy enough to over-haul the motor, it would accelerate on curve 1, until the power torque passes through zero and changes to dynamic braking torque. Acceleration continues until the braking torque equals that due to the pull of the load at which time acceleration ceases and the load travels down at the speed reached. For instance, if a load exerting a full equivalent to 25 per cent braking torque is being lowered, the speed will become constant at 31 per cent on the first point, at 53 per cent on the second point, etc., and will reach a speed of 179 per cent on the last point. If a light hook is being lowered it will not overhaul the motor and power torque, probably 25 per cent, will be required to drive it down against the friction of the crane. The vertical dotted line through 25 per cent power torque shows the speeds obtained on each point. From this it can be seen that for every torque value there is a fixed positive speed on each curve. With proper operation the solenoid brake is called upon to stop the load only from the speeds obtained on curve No. 1 thus making its duty light.

An additional refinement of control in the hoisting direction can be obtained by shunting the motor with a rheostat on the first point of either straight reversible or dynamic braking control. This changes the speed torque curve from No. 1 to No. 1A (see Figs. 1 and 2) which gives slower and more stable speeds than curve No. 1. This refinement is referred to in line (j) page 512.

With straight reversible control a mechanical load brake and a one-half torque solenoid operated brake are necessary for lowering, while with dynamic braking the mechanical load brake is omitted and a solenoid brake capable of retarding twice the actual full load lowering torque ($2 \times T_1$ in (10) page 506) is required. Thus, with straight reversible control safe lowering depends entirely on two mechanical friction devices, each of which will prevent a runaway if the other fails, but which will not actully stop the load. Both brakes, however, are subjected to wear and tear each time the crane stops which detracts from their reliability and tends to increase maintenance charges. With dynamic braking, mechanical friction is depended upon only to stop and hold the load after being brought to a slow speed by electric braking. This makes the duty on the solenoid brake light and reduces wear and tear to a minimum.

An additional increase in the reliability of dynamic braking control can be obtained by using a double trolley in the dynamic braking circuit; and also by using two solenoid brakes, one on the motor shaft and one on the back shaft—each capable of holding from 1.25 to 1.5 times the actual full load lowering torque.

On very important cranes handling dangerous material such as hot metal cranes, a fly ball governor can be added which will set the brakes if the speed becomes dangerous.

For convenience of selection it has been found expedient to divide rheostats into two classes as regards heat dissipating capacity. One may be called a *standard duty rheostat* the other a *heavy duty rheostat* the latter being of twice the capacity of the former. The ohmic resistances of these two classes are, of course, identical for a given horse power and controller.

Summarizing the above, we have the following types of control from which to select:

(a) Manual
(b) Magnetic
(c) Straight reversible with one mechanical load brake and one solenoid brake.
(d) Dynamic braking with one solenoid brake.
(e) Dynamic braking with two solenoid brakes.
(f) Dynamic braking with two solenoid brakes and fly ball speed limit.
(g) Standard duty rheostats.
(h) Heavy duty rheostats.
(j) Creeping speed resistance in parallel with motor.
(k) No creeping speed resistance.

Table II shows the control which the writers believe is best adapted to the various classes of cranes given in the first part of this article.

TABLE II

Crane Class	Hook Speed in R.P.M.	H.P. of Motor	Control to consist of
1	15 or less	100 or less	(a), (c), (g) and (k)
1	Above 15	100 or less	(a), (d), (g) and (k)
1	All speeds	Above 100	(b), (d), (g) and (k)
2	20 or less	50 to 75 or less	(a), (c), (g) and (k)
2	Over 20	50 to 75 or less	(a), (d) or (e), (g) and (k)‡
2	All speeds	50 to 75 or more	(b), (d) or (e), (g) and (k)‡
3	All speeds	15 or less	(a), (c), (h) and (k)
3	All speeds	Over 15	(b), (d) or (e), (h) and (j) or (k)
4	All speeds	All h.p.'s	(b), (d) or (e), (h), and (j) or (k)
5	All speeds	100 or less †	(a),* (e) or (f), (g) and (k)
5	All speeds	Above 100	(b), (e) or (f), (g) and (k)

* With manual control a double-throw contactor should be added, the upper contacts of which close the line while the lower contacts close by gravity to provide dynamic braking if power fails while hoisting.
† Magnetic control is advisable above 50 h.p. unless the operator is thoroughly careful and reliable.
‡ (j) may be required on some foundry cranes.

D-C. Bridge and Trolley Control

As neither dynamic braking or solenoid brakes are used to any extent on the bridge and trolley motions, the control narrows down to straight reversible, either manual or magnetic. Refined speed control is not usually required but as plugging is used for stopping the trolley and often the bridge as well, the rheostat must have sufficient resistance to limit the plugging torque to a safe value. An inspection of curve Fig. 1 which is applicable to motors up to about 25 h.p. shows that if, when running at 100 per cent speed on curve 5, the controller be plugged to curve 1, the torque will be about 184 per cent tending to stop the motor. For larger motors the torque on the first point at standstill should be about 50 per cent.

For manual control on bridge and trolley motions, the current peaks which the motor will stand determine the minimum number of control points. The first point should provide a high resistance for plugging and is not considered an accelerating point.

For magnetic control, the number of automatic accelerating points is also determined by the current peaks which the motor will stand while the number of hand controlled steps which should be used depend on—first, the condition of the track, whether wet, dry, dirty or oily; second, windage, on outside cranes; third, the delicacy of control required for the work; fourth, external loads to be dragged around, such as cars, etc.; fifth, variable grade on track and tight places; sixth, final free running speed.

It is difficult to make hard and fast recommendations for all of the above conditions, but as a kind of guide is can be stated that one step hand control should not be used except where all of the above conditions are most favorable and where the final free running speed is not over 75 feet per minute. Two steps of hand control will cover the same conditions as one step of hand control, except that a free running speed as high as 300 feet per minute could be used.

Where all of the conditions are severe; it becomes necessary to use three or more hand controlled steps; first hand controlled step to give a light torque for moving the crane when unloaded; second hand controlled step to give more torque, just barely sufficient to start the crane with the heaviest suspended load; third step of hand control to give a torque just inside the slipping point of the wheels on a wet track; fourth step of hand control to give a torque just inside of that required to slip the wheels with a good dry track; fifth step of hand control to accelerate it to full speed.

Unless the first point contains sufficient resistance to limit the current to a safe value when plugging from full speed, an additional point must be added to obtain this resistance. A foot brake is often used on the bridge motion and this removes, to some extent, the necessity for a plugging point. The capacity of the rheostats for bridge and trolley motors should be the same as that of the hoist motor.

A-C. Hoist Motion Control

Dynamic braking has not been developed commercially for this motion of a crane as yet, and hence the ordinary practice at the present time is to use either a manual or a magnetic controller, a mechanical load brake and a solenoid brake which is set to retard with 50 per cent of the rated motor torque. Manual controllers are generally used for horse powers up to 100 unless the service is so severe as to cause undue expense for maintenance, in which case it is advisable to use magnetic control above 50 h.p.

The number of steps or points on the controller, the amount of torque which should be given on the first step of the controller, the weight of the rheostat, and the advisability of using a permanent resistance in series with the rotor circuits are all matters which come up for consideration in the selection of control.

In order to obtain refined speed control with alternating current crane motors, it is necessary to work the motor not above 35 or 40 per cent of its maximum break-down torque. It is necessary to have a sufficient number of controller steps so that the change in speed or torque from one step to another will not be too violent. It is necessary to have good smooth running gears on the crane, a smooth operating, reliable mechanical load brake, and a smooth setting, quick operating solenoid brake. It is also necessary to provide sufficiently low torque on the first step of the controller so as not to jerk a light load too violently.

Fig. 3 shows the speed torque curves of an eight-point controller which gives 50 per cent starting torque. Fig. 4 shows the same kind of curves for a twelve-point controller, giving 25 per cent starting torque. A careful examination of these curves will show that the controller in Fig. 4 will give far smoother results than in Fig. 3, and for certain classes of duty the characteristics shown in Fig. 4 are necessary. It is possible to get as delicate control from that shown in Fig. 4 with a crane geared for 40 feet per minute, as it is from Fig. 3 with a crane geared for 20 feet per minute, and it is possible to handle a much lighter load by that shown in Fig. 4 than by Fig. 3 without undue shock at starting. Fig. 5 shows an eight-point controller which is used in connection with sufficient permanent external rotor resistance to give not over 85 per cent full speed on full load torque. This controller is also laid out to give 25 per cent torque at standstill. Fig. 5 will give about as refined speed control on a crane geared for 30 feet per minute as will Fig. 4 on a crane geared for 40 feet per minute.

If an induction motor is thrown directly on the line with its slip rings short-circuited by the controller, it will exert only about 50 to 75 per cent of its maximum starting torque and will take about six times its full load current from the line. Such a speed-torque curve is 8 of Fig. 3. If the proper resistance is in the rotor circuit when the motor is connected to the line, maximum starting torque will be exerted as in curve 8 of Fig. 5, and only about three times full load current will be taken from the line. It is all right to turn the

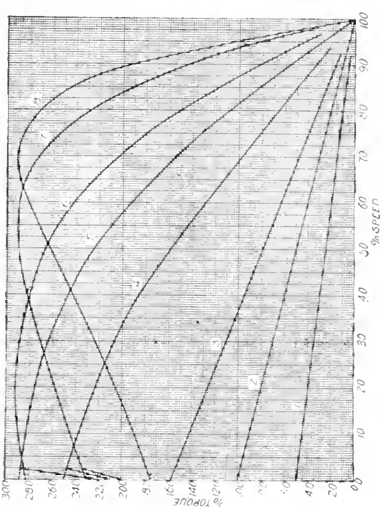


Fig. 3. Speed-Torque Curves of a Wound-Rotor Induction Motor operated by an 8-Point Controller; 50 per cent starting torque on first point

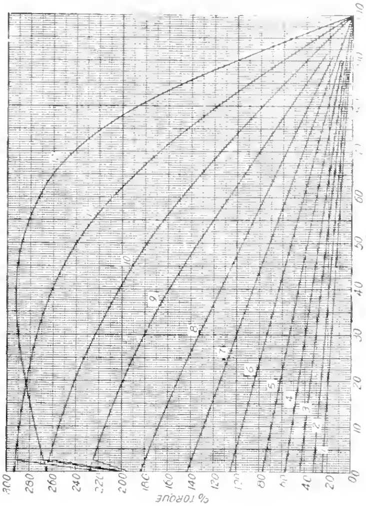


Fig. 4. Speed-Torque Curves of a Wound-Rotor Induction Motor operated by a 12-point Controller; 25 per cent starting torque on first point

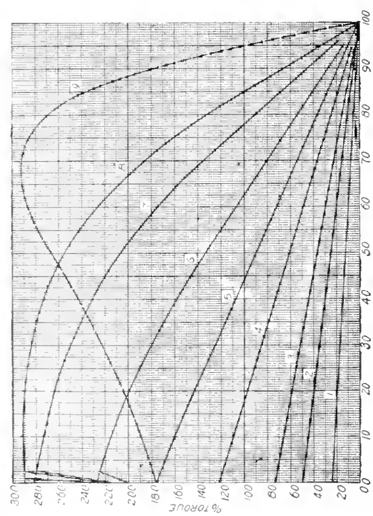


Fig. 5. Speed-Torque Curves of a Wound-Rotor Induction Motor operated by an 8-point Controller; 25 per cent starting torque on first point, permanent external rotor resistance

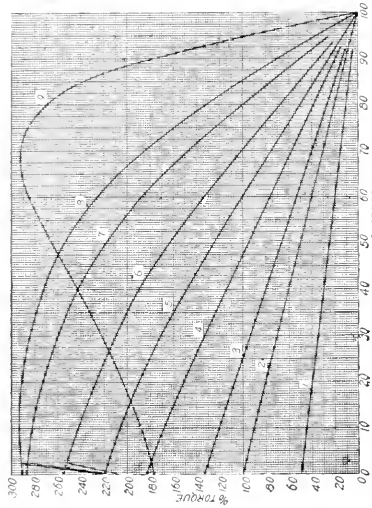


Fig. 6. Speed-Torque Curves of a Wound-Rotor Induction Motor operated by an 8-point Controller; 50 per cent starting torque on first point, permanent external rotor resistance

controller of Fig. 3 to step or curve 8 after the motor has attained 60 per cent speed or more, but until that speed is reached, the motor is working disadvantageously if on this curve.

The above explains the advantage of having a permanent rheostat in the rotor circuit so that the motor will always start efficiently no matter how quickly the controller is turned on. A careless, ignorant or hurried operator is quite liable to damage a motor and controller like that of Fig. 3 by operating it too rapidly. A careful operator, of course, need not damage the motor even when the permanent rheostat is not used.

A further advantage of this expedient will be seen by examining Fig. 5 which, as above pointed out, enables an eight-point controller to compare more favorably, as to refinement of control, with the twelve-point controller in Fig. 3 than would be the case if this permanent resistance were not used.

A direct comparison between Fig. 3 and Fig. 6 will show 2 eight-point controllers, each of which gives 50 per cent torque at starting. In Fig. 6 a permanent resistance is used, and it is never possible to get more than 85 per cent of full speed when full torque is being hoisted whereas in Fig. 3, 95 per cent of full speed could be obtained. However, there is practically no difference in speed when a 20 per cent load is being hoisted. The speed control of Fig. 6 is somewhat more refined than Fig. 3, and the danger of too quick a start is entirely removed. The efficiency of starting by Fig. 6 is greater than the efficiency by Fig. 3 if the operator is prone to turn on power too rapidly. Therefore, if the controller is to be used principally for starting as in the case of trolley and bridge motion, and if the load is fairly light after the motor is up to speed, Fig. 6 is really more efficient than Fig. 3. On the other hand, if starting is a small part of the work of the motor and if heavy loads are to be hoisted more frequently than light loads, Fig. 3 will be more efficient than Fig. 6.

Referring to classifications of cranes, in the first part of this article, Class 1 usually takes a controller which gives 25 per cent torque at starting and which has either eleven or twelve points on the controller, or which has eight points on the controller with a permanent resistance in series. A light duty rheostat is generally sufficient.

Class 2 cranes usually require 50 per cent torque at standstill and an eight-point controller for 30 H.P. or less, and eleven or more

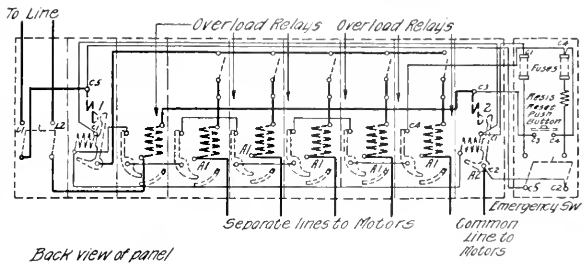


Fig. 7. Wiring Diagram of a Complete D-C. Protective Panel for a five Motor Crane

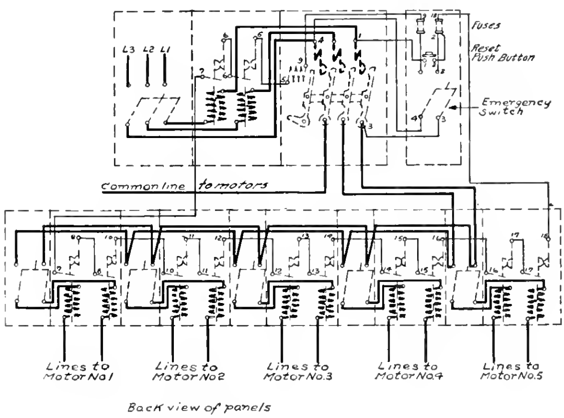


Fig. 8. Wiring Diagram of a Complete A-C. Protective Panel for a five Motor Crane

points for motors above 30 H.P. A light duty rheostat is usually sufficient.

Class 3 crane would require magnetic control very frequently for motors above 30 H.P.; and in almost all cases, if manual control is used, a permanent resistance should be used in series with the rotor to prevent the operator from abusing the motor. Heavy duty resistance would be required. For this class of crane an exceptionally rugged mechanical load brake and solenoid brake are required, and the solenoid brake should have a retarding torque equal to that of the rated motor torque.

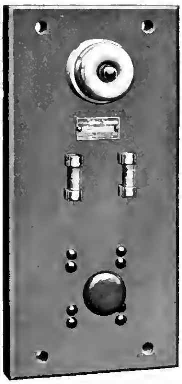


Fig. 9. Panel containing Emergency Control Switch, fuses and reset push button. Front view showing particularly the insulated knob for operating the switch

Cranes of Classes 4 and 5 are very similar to Classes 3 and 2 respectively.

A-C. Trolley and Bridge Motion Control

Many of the problems in bridge and trolley motion control are similar to those in hoist motion control. However, as a rule the requirements for refined speed control are not stringent.—50 per cent torque on the first point of the controller is usually sufficiently low. An eight-point controller up to 30 H.P. and eleven-point controller above 30 H.P. give sufficient refinement. It is on the trolley and bridge motion more than anywhere else that the most advantages and the least disadvantages of using a permanent rotor resistance appear. Rheostats as a rule should be as heavy on trolley and bridge service as they are on hoist service.

The trolley motion is stopped by means of plugging the motor, and the bridge motion is usually stopped by means of a foot brake or by plugging the motor. No solenoid brakes are required on this service unless they are used in connection with limit switches to stop the motion of the crane at each end of travel, or to stop the motion of the crane when power fails. The retarding torque of such solenoid brakes should be somewhere between 25 and 50 per cent of the rated motor torque. If the solenoid brake exerts too powerful a torque, the shock of stopping by means of it will be objectionable.

Fig. 10. Back View of Panel Shown in Fig. 9

Protective Features

Indications at the present time are that the users and manufacturers of cranes have not agreed as to the best method of obtaining crane protection and there seems to be no uniformity of the few existing laws pertaining to this subject. Hence, rather than discuss the merits and demerits of the various systems of protection in use, this article will outline one arrangement of protective equipment for a complete crane.

Regardless of whether magnetic or drum control is used, the protective equipment should be concentrated in the operator's cab, and an emergency switch for opening the main line circuit breaker should be mounted in a prominent place directly in front of the operator and within easy reach. This emergency switch must be so designed that no matter how carelessly operated an electric shock cannot be obtained from it.

Complete overload protection should be afforded even though one line becomes accidently grounded, and to accomplish this there must be a circuit breaker contactor and an overload relay in each side of the incoming power supply.

No voltage protection should be afforded which means that the circuit breaker contactors should drop out on failure of power, but must not come back in on return of power until a push button is pushed by the operator.

Fig. 7 shows a protective panel wiring diagram for a five-motor d-c. crane and, Fig. 8 shows similar connections for an a-c. crane. The line switch disconnects all electrical equipment on the crane from the source of power. It should be provided with a "lockout clip" enabling it to be locked open with several padlocks at one time. In this way several workmen can be assured of protection while making repairs as each one can have his own lock and key and until the last lock is removed the switch cannot be closed. Two single-pole line contactor circuit breakers insure both sides of the line being broken as their operating coils are connected in multiple, and are then connected in series with all the overload relays. A common overload relay is placed in one side of the line while each motor has its own individual overload relay in the other side of the line. This arrangement gives full protection regardless of grounded circuits with a minimum number of relays. The relays are reset by gravity after an overload occurs. Their contacts are all connected in series and are wired to the operating coils of the circuit breaker contactors. This control circuit is wired to the line side of one circuit breaker contactor and to the motor side of the other contactor, hence when the contactors open they remain open after the relay resets by gravity since the contactors break their own control circuit. A reset push button, wired across the circuit breaker contactor, must be pushed by the operator to reset the panel after either an overload or a loss of voltage. Each motor has its own line switch so that it can be disconnected in case of trouble, allowing the rest of the motors on the crane to be operated. Further, motor disconnecting switches facilitate the location of grounds, short-circuits, etc. The double-pole emergency control switch is of the "back-of-board" mounted type and is operated by an insulated knob on the front of the panel (see Figs. 9 and 10), the knob being pushed in to open the switch. This arrangement keeps all live parts of the switch out of the operator's way. This switch is double-pole so as to prevent grounds or partial grounds from holding the circuit breaker contactors in after the emergency switch is opened.

On large important cranes with full magnetic control, the protective panel control circuit can, by the addition of a small relay for each motor, be wired up in such a way that it will be necessary for the operator to bring all his controllers to the off position before he can reset the circuit breakers after an overload or a failure of power. This refinement is, however, hardly necessary on anything but an important crane handling expensive or dangerous material.

THE ALABAMA POWER COMPANY'S SYSTEM AND ITS OPERATION*

By H. H. Dewey

Power and Mining Engineering Department, General Electric Company

and W. E. Mitchell

Operating Manager, Alabama Power Company

The information contained in the following article is descriptive of a modern high-tension system in which an unusual effort has been made in the layout and operation to assure practically continuous service to its customers. After the lines had been in service somewhat over a year, an insulation-resistance test was made of the individual high-tension insulators; a detailed description of the method used and a discussion of the subsequent report are included. In furtherance of the policy to attain and maintain a high standard of continuity of service a study of relays and an application of them was made in the system. The article describes in detail how by this means lines in trouble are cut off, without interrupting service on other lines, quickly enough to prevent appreciable damage to conductors and insulators. A description of the routine and emergency operation and maintenance of the system, together with a discussion of the make-up of the operating force, concludes the article.—Editor.

H. H. Dewey

It is quite the regular thing when speaking of any particular division of the electrical field to note the wonderful progress made in the last decade. It is quite remarkable that it is nearly always true; certainly it is of the high-tension systems which have made the development of great water-powers possible. Fifteen years ago, a 50-mile transmission line at 50 kilovolts was thought to be the ultimate possible; to-day, there is in successful operation a 250-mile transmission line at 150 kilovolts and a net-work of 110-kv. transmission lines tying in six or seven systems covering four states and extending over a distance of 1000 miles.

The complexity of the operating problems has increased almost in proportion to the upward jumps in voltage and the extension of lines and systems. With the larger territory covered and greater number of customers served, a very much higher quality of service has been demanded.

What constitutes genuinely good service, varies greatly, depending as it does on the type of load served. Where the load is practically all industrial, several short interruptions a week might be suffered and yet the service called good; whereas if a large city lighting or street-car service were interrupted only once a week, the service would be called very bad.

It is the intent of the Alabama Power Company to give to all its customers the type of service that would be satisfactory to a large city railway and light load. The whole system was laid out from the beginning with the idea of continuity of service foremost in mind. The experience gained in the past ten years was of advantage in building this very large system. To insure continuity of service, apparatus and workmanship must be of the best, good engineering judgment must be used in the design, and most careful attention and study must be given to all local conditions.

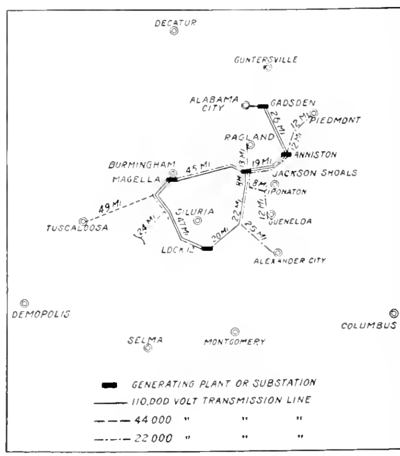


Fig. 1. Map showing the Lines of the Alabama Power Company and the Territory Served

The present territory served by the lines of the Alabama Power Company is shown by Fig. 1. The main power plant, which is one of the most modern in the country, is located

* This paper is based on one presented by the authors at the annual convention of the Southeastern Section of the N.E.L.A. Grove Park Inn, Ashville, N. C., September, 1915.

at Lock 12 on the Coosa River about 50 miles from Birmingham and has installed four 13,500-kv-a. vertical generators with room to add two more. Fig. 2 is a general view of the Lock 12 Dam and Power House. Current is generated at 6600 volts, 60 cycles and is stepped up to 110 kilovolts for transmission. Three high-tension lines leave the station, two going direct to Birmingham over a double-circuit steel-tower line and the other going to Sylacauga, Talladega, Jackson Shoals and then across to Birmingham. At Gadsden, on the northern end of the system, there is a modern steam plant in which are installed two 6250-kv-a. turbine-generators. Fig. 3 shows a view of the Gadsden Steam Plant. The substation in connection with this plant transforms the current generated here to either 22 kv. or 110 kv. A double-circuit transmission line on steel towers connects this station with Anniston and Jackson Shoals, and thus with the balance of the system.

The Anniston Substation and Switching Station consists of a double 110-kv. bus with disconnecting switches arranged to tie either line incoming or outgoing to either bus. It is used as a section station for the 110-kv. line as well as a step-down substation for distribution at 22 kv. in the vicinity of Anniston. There is installed one 6000-kv-a. bank of transformers for stepping down from 110 kv. to 22 kv. Fig. 4 shows a general view of this substation.

Jackson Shoals is an important station for it ties in the lines from the North, the South, and the West. The substation here has a capacity of 6000 kv-a. and steps down from 110 kv. to 22 kv. Fig. 5 shows a general view of this substation.

Located at Magella, three and a half miles from the center of Birmingham, is the largest substation. This supplies the demands of Birmingham and the surrounding industrial district. This substation is served by three high-tension lines and has a capacity of 40,500 kv-a. at present, with room for extension to 67,000 kv-a. Fig. 6 shows a general view of this substation.

Fig. 3. The Gadsden Steam Turbine Generator Station

The present load on the system is 25,000 kw. maximum, with a load-factor of 75 per cent. Except at low water periods the load can be carried on two units at Lock 12 and the steam plant at Gadsden is kept as a stand-by only, three boilers being kept up to pressure. This arrangement provides sufficient steam to pick up the Gadsden load at

Fig. 2. Lock 12 Dam and Power House, the Principal Generating Station

short notice, should both circuits of the 110-kv. line from Jackson Shoals to Gadsden break down at the same time due to lightning or other cause.

The method of operating the system at present takes into account the distribution of

Fig. 4. A General View of the Anniston Substation and Switching Station

Fig. 5. A General View of the Jackson Shoals Substation

the load and means are provided for more than one source of power to all customers wherever possible. The four main substations are each fed from two high-tension lines, one of which is sufficient to carry the load for a long time to come with a reasonable loss and regulation.

The distribution system at 22 kv. parallels the high-tension system to a considerable extent; and, with the present substation loads, it can be depended upon to carry the load out of Jackson Shoals or Anniston even though the high-tension lines at these stations be out of service, the load being carried from Magella.

The Magella or Birmingham Substation is normally fed from a double-circuit 110-kv. tower line direct from Lock 12, but it can be fed by way of Jackson Shoals in case of trouble on both circuits of the Lock 12—Magella line.

It will be seen that with the present load a very extensive break-down of lines and apparatus would be necessary to cut off service for any considerable length of time.

The section of country through which the lines pass is subjected to severe lightning storms throughout the summer, and the first season's experience showed a considerable amount of trouble from this source. Storms come up suddenly on some part of the system nearly every day during June and July, and frequently severe storms cover practically the whole system. At times these storms pass over without damage to the lines but at others many flashovers or punctures are likely to occur.

During the first season a considerable number of insulators were broken, chiefly on the high-tension lines; and the resulting cost of maintaining lines and the hazard to continuous service was such that a careful study was made of the situation with the view of eliminating as many of the breakdowns as possible and furthermore when a breakdown did occur to keep the resulting damage to a minimum.

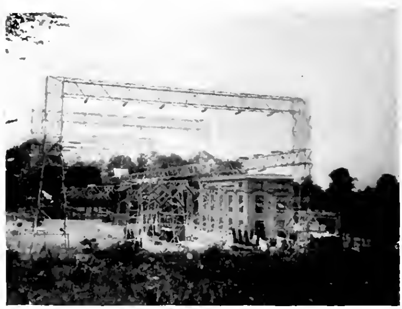


Fig. 6. A General View of the Magella Substation

On examination of the insulators broken during the lightning season of 1914 it was difficult to determine in most cases whether the primary cause was puncture or arc-over. Many times the porcelain would be entirely broken away from the metal cap. Although the cap might show a clean hole burned through it, there was a possibility that the heat of the arc had broken away the porcelain causing a crack to run up under the cap and the burning of the cap followed. Occasionally, there were clean punctures where the porcelain was not broken, as well as broken porcelain without apparent puncture. Thus it was concluded reasonable to suppose that both types of breakdown occurred to some extent. Where puncturing of insulators occurred, it was judged that the cause was defective porcelain; but where clean arc-overs occurred it was concluded that there must be disturbances of a higher voltage equivalent than the insulator string was designed to withstand. A weeding out of the defective insulators should take care of punctures; but if clean arc-overs were occurring it would be necessary to increase the arcing voltage per string, in other words, to add extra disks. Fig. 7 shows a partial string of suspension insulators taken from the Lock 12—Birmingham line during the 1914 lightning season. It is evident that an arc-over rather than a puncture caused the breaking of the porcelain. Fig. 8 shows a complete string of strain insulators taken from the Lock 12—Jackson Shoals line. This string is so badly damaged that it is impossible to tell whether they punctured first or whether the porcelain all broke away from the heat of an arc-over and puncture followed.

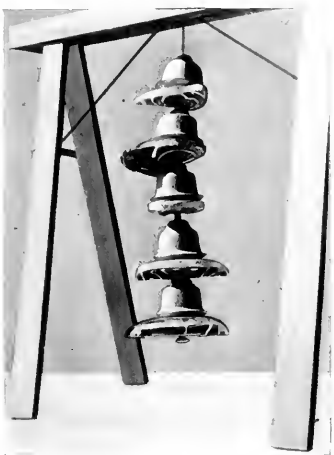


Fig. 7. A Partial String of Insulators Broken by Arc-over During the 1914 Lightning Season

After thoroughly canvassing the situation it was decided to go over the lines adding an extra disk on all strings (making seven disks in suspension instead of six, and eight disks in strain instead of seven) and at the same time replacing all insulators that showed low resistance by megger test. The following description of the method of meggering nearly 300 miles of 110-kv. transmission line, adding one extra disk and replacing defective ones, together with the results obtained, will be of interest. Fig. 9 shows the type of tower used by the Alabama Power Company.

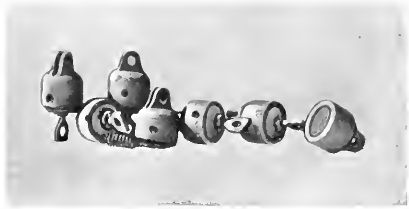


Fig. 8. The Remains of a String of Insulators after a Very Destructive Breakdown

TESTS OF SUSPENSION TYPE INSULATORS

General

There were 60,000 suspension type insulators in service on the high-tension lines, some lines being operated at 110 kv. using six suspension units and the remainder at 22 kv. with two suspension units. It was the purpose of this series of tests to eliminate all weak insulator units. In conjunction with this work, one additional unit was placed on each string.

Organization

The field staff required for this work consisted of one foreman, one megger man, seven linemen, three ground men, two double-team and one single-team wagons with drivers, and one cook. This allowed three working crews made up as follows:

(1) Megger man and two linemen.

(2) Two linemen, ground man and one double team.

(3) Three linemen, two groundmen, and one double team. These were accompanied by the cook and camp mess arrangement.

Grounding

Considerable attention had to be given to grounding in order to protect the men from "static." Because all the lines tested were on double-circuit towers induced voltages were not easily overcome. For this purpose

Fig. 9. The Type of Transmission Line Tower Used

Johnson sticks and grounding clamps fitted with $\frac{3}{16}$ in. flexible steel wire were found to be more satisfactory than the usual grounding chains with heavy coils of rope attached.

The camp foreman reported each morning to the switching chief and requested that the proper line be tagged out to him; and at the end of the day's work this foreman gave the clearing report. After having received orders from the switching chief in the morning, the men grounded out that portion of the line which was to be worked that day. No one was permitted to work outside these grounds. In case work was completed up to the head ground, a third ground was put on the line, the back ground not being disturbed until all crews were clear. After the testing work was over the grounds were taken off, the last one to be taken off being prearranged so that all crews reported off at this point before the ground was taken down. Additional grounds were used during the lightning period to protect the men and instruments, the ground being used by each man on the wire on which he was working. Also, no man was allowed to work on a tower without using a belt and safety.

Meggering

After grounding the line the work proceeded as follows: In the first crew, consisting of the megger man and two linemen, one lineman took the testing fork and operated it. As shown by Fig. 10, this tool consisted of two prongs properly spaced to touch the metal parts of a single insulator unit. The prongs were insulated from one another and held rigidly to an impregnated wooden rod. Weatherproof insulated wire connected the prongs to the megger. In cases where additional grounding was desired, the second lineman climbed the tower and attached the hand ground as shown in Fig. 11. Usually one lineman took a tower, thus allowing the men more time between "hikes." The lineman, on signal from the megger man, placed his fork on each insulator. Faulty insulators were noted by the megger man, and after all had been tested the lineman filled out tags as instructed and pasted them on each defective unit. The purpose of the tags was to

Fig. 10. The Method of Measuring Insulator Resistance with a Testing Fork and Megger

notify the following crew that the insulator was defective and to later identify each unit.

Tag Notation

The tags were numbered so as to show what line, tower, circuit, wire, and part of the string from which it was taken, also to record the megger reading. The following abbreviations were used:

Lock 12—Gadsden Line	G
Jackson Shoals—Magella Line	M
Jackson Shoals Substation	J S
Anniston Substation	Ann
Gadsden Substation	G S
Magella Substation	No Mark
Lock 12—Magella Line	No Mark
Lock 12 Substation	X

Letters "A" and "B" designated the circuits. A tag would appear as follows: G, 290, B, 1, 1, 25. Its significance would be as follows:

The amount of work that was done in a ten-hour day varied from 15 to 35 towers of single-circuit line. This was an average of three miles per day. The factors governing the work accomplished in a day were the topography of the country and the number of defective units per tower. However, more important than any of these factors is the delay due to grounding and clearing the line. This item is more important by far than any of the others, particularly where the lines are available for only a short part of a light day.

G	290	B	1	1	25
Lock 12—Gadsden Line	Tower No. 290	"B" Circuit	Wire No. 1	Insulator No. 1	Megger Reading 25

Wire No. 1 was the bottom wire, No. 2 the middle, and No. 3 the top. Insulator No. 1 was next to the crossarm. To distinguish between the two strings per wire on a strain tower, the sign (+) was placed in front of the insulator number to signify the string forward and (−) to denote the back string.

Hanging Insulators

The second crew replaced defective insulators and added one additional unit to the suspension strings. With them was a double team and driver whose duty was to distribute material. The equipment required for the crew consisted of a set of four-inch double-sheave blocks and a hand line.

The third crew's duty was to take care of the grounding, to change defective insulators, and to put an additional unit on strain strings. On account of the long jumps between strain towers and the advantage gained by pulling all strain towers from the ground, using 6-inch blocks, a wagon was needed by this crew. The further duty of the wagon was to collect all defective insulators.

Fig. 12 gives a view showing the use of the turnbuckle to catch off strains. This method does away with considerable equipment and is faster for repair work, say on one wire, but where several pulls have to be made on one tower the blocks to ground are desirable.

The second and third crews could readily be adjusted to keep them working at the same rate. It was found on this work that where the ratio of suspension to strain towers was approximately 8 to 1 the above crews were properly proportioned.

This part of the work was speeded up when possible by the use of horses and especially reliable men were always employed.

Fig. 11. The Method of Attaching a Hand Ground when Necessary for Testing Purposes

Results of Tests

Table I gives the overall results on the system.

TABLE I

	Number of Insulators Tested	Number Defective	Per Cent Defective
Suspension	37,898	1706	4.5
Strain	14,640	1596	10.9
Total	52,538	3302	6.3

The per cent of defective insulators on the entire system was 6.3. This figure varied for a day's work from 32.0 per cent as a maximum to zero per cent as a minimum. These variations occurred in districts using each type of insulator, the most severe condition being

Fig. 12. View Showing the Use of a Turnbuckle to Apply a Strain

encountered in hilly and wooded country. On towers having 110 kilovolts on one side and 22 kilovolts on the other the variation in percentage defective was found to be parallel, although the low-voltage line with two suspension units has a higher overall percentage defective.

In general, increasing the mechanical tension on an insulator increases its depreciation. This factor, together with the increased exposure of a strain insulator compared to a suspension unit, caused the percentage defective of strain insulators to be 10.9 per cent or more than twice as much as for the suspension unit the depreciation of which is 4.5 per cent. On one 26-mile division a very exceptional insulator condition was found. The suspension units tested 0.8 per cent defective; the strain units were 22.6 per cent defective. On this line with three strain units a smaller power wire was used, thus reducing the weight on all insulators; however, there are several long spans held up by strings that tested out particularly well. The relation of percentage defective to mechanical strain is very evident from the following result obtained from the tests:

Type of Construction	Per Cent Defective	Tension
Suspension	4.4	260 lb.
Strain	12.2	1400 lb.

The stringing tension was 1400 lb. and 260 lb. is the weight of a standard span of 2/0 copper.

Three sections of line comprising some 150 towers were taken for the following comparison:

A = Towers that carry less than one-half the weight of the wire in the adjacent spans, due to being in low ground.

B = Towers that carry more than one-half the weight of the wire in the adjacent spans.

Location of Tower	Per Cent Defective Suspension	Per Cent Defective Strain
On Crest	3.22	7.93
In Trough	2.52	6.95

The comparatively good results obtained on this division may, in part, be attributed to the smaller wire used on this line.

Defective Insulators

The insulators are required by specification to have a dark brown glaze. The variation in this color is due largely to the amount of heat applied to the insulator during the glazing process. An insulator with a light reddish hue denotes under-glazed porcelain. Defective units are generally of this type, and the testers when climbing a tower use this feature in forecasting the number of defective units. Another type of defective unit is the over-glazed one, with numerous pin-head blisters under the glazed surface. There were also frequent cases of cracks in the porcelain which occurred in the baking process and were not noticed before glazing and shipping. Insulators with none of the above faults were often found to have small air holes in the cement around the pin, from which issued thin charred filaments.

In the tests, all units giving a megger reading below 500 megohms were eliminated; in bad weather this limit was reduced to 300 and 400 megohms. Very few insulators tested between these values and 2000, the limit of the megger. The most of them were above 2000. The scarcity of units testing between the 300–400–500 limit and 2000 indicated that deterioration of an individual insulator proceeds at a rapid rate when once started. The number of defective insulators per string, as given in Table II, affords a good study of the future performance of the lines.

The results of the megger test gave no very definite information as to the cause of the apparent deterioration of the insulators, unless the difference in defective insulators on strain and suspension towers could be considered a clue. The results obtained in this respect check with those that have been found elsewhere but still leave the question open as to whether the difference in mechanical strain or in exposed surface to moisture accounts for the greater deterioration of insulators in strain.

Recognizing the improbability of being able to eliminate all insulator punctures and flash-overs by weeding out those units that the megger showed to be bad and by adding an extra disk, and believing that the probability of flash-over was greater than that of the puncture of an entire string, it was reasonable to suppose that if the line or section of line carrying an arcing insulator could be dropped within a very short time after the arc-over occurred much of the damage due to the heat of the arc could be eliminated. It was also desirable to cut out a line that was in trouble before the resulting disturbance to the system would cause a customer's synchronous apparatus to drop out of step and trip the overload relays. A very extensive study was therefore made of a method to equip the system with relays so as to cut off a line in trouble in the shortest possible time and where two lines were available to leave the other line to carry the load without interruption to service.

Frequently, insulators were found on which spill-overs had occurred, burning off the glaze, and in four instances the horns on the clamp had been melted, also the top of the cross-arm. However, in all such cases, the insulator megger reading was satisfactory.

Table III shows the distribution of defective units in various parts of the strings.

Operation of Relays

During the summer of 1914 the system was operated with the neutral ungrounded, and though an arc-over or puncture of a single string of insulators would not cause a short-circuit on the line the electrostatic unbalance resulting from a single ground would cause heavy surges. Arcing grounds of this character and the attendent high-frequency surges resulted in the other two phases being stressed much beyond normal and other breakdowns were liable to follow. Under such conditions the charging current of the system, which is ordinarily a considerable amount, would be greatly increased. The generating station normally operates with a leading power-factor when all lines are connected and consequently with low field voltage. The automatic voltage regulators and exciters were somewhat sluggish when working at the low exciter voltage necessary under normal conditions, and when this extra charging current due to the arcing ground was thrown on there would be a considerable rise in voltage which still further increased the disturbance.

TABLE II

Defective Units per String	Suspension		Strain	
	No. of Strings	Per Cent Defective	No. of Strings	Per Cent Defective
1	826	14.4	403	24.8
2	199	3.5	204	12.5
3	65	1.1	76	4.7
4	21	0.4	43	2.6
5	2	0.03	22	1.3
6	0	0.0	7	0.4
7	0	0.0	4	0.3
Total Defective Units	1513		1391	
Total Units Tested	5724		1632	

TABLE III

Wire	Top							Middle							Bottom						
Insulator	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Susp. insulators found defective	91	62	60	54	73	73		96	92	100	100	93	73		96	89	89	79	92	82	
Ave. per string				72							92							87			
Strain insulators found defective	71	57	54	76	59	54	63	58	70	66	68	68	71	65	81	80	59	65	66	67	51
Ave. per string				59						66.5								68			

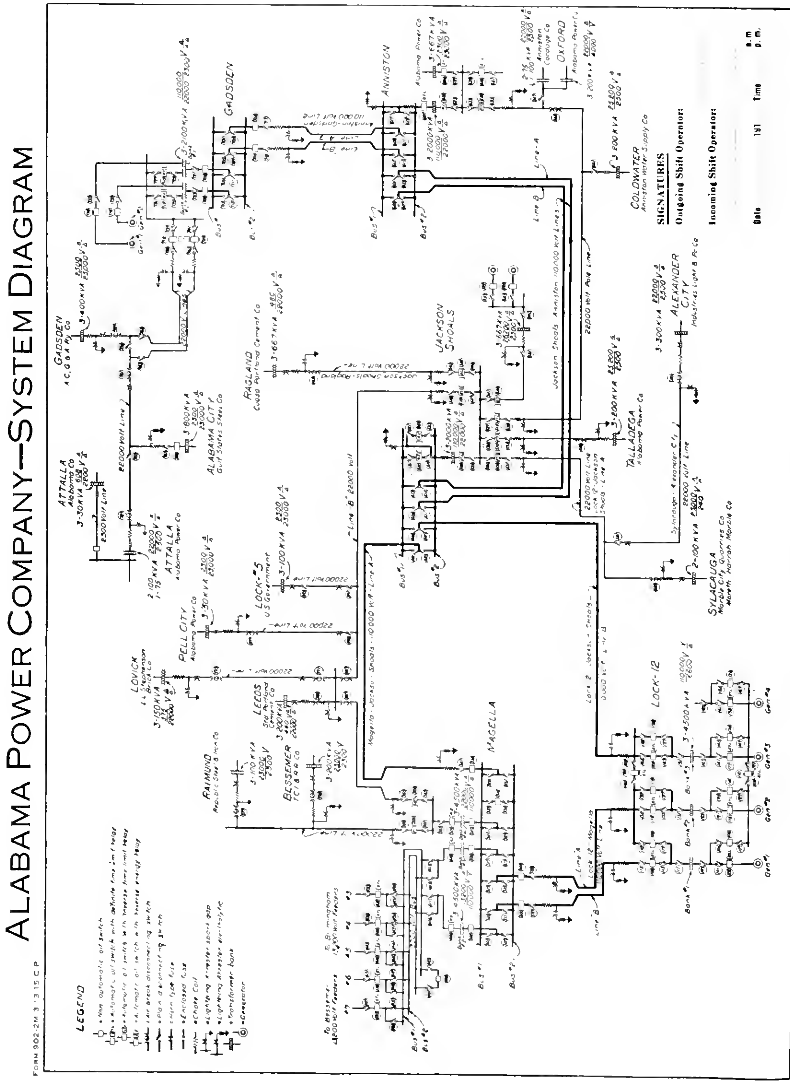


Fig. 13. A One-line Diagram of the System

There was usually a considerable rise in current due to this type of ground but it varied so widely in amount with different lengths of line in service and depended on whether the lines were parallelled on the high-tension side and also with the nature and amount of the load that it was impossible to make use of it for tripping relays selectively. It was therefore decided to ground the neutral of the high-tension transformers at Lock 12 and to make every accidental ground a short-circuit from phase to neutral in order to obtain a definite and known condition with which to work when relaying the system and to eliminate the stresses on the other two phases in case of a ground on one.

The transformers were grounded without resistance, partly to save the cost of a reliable resistance and partly to obtain on short-circuit a sufficient amount of current to operate the relays satisfactorily from bushing type current transformers.

No trouble was anticipated nor has any been experienced from excess magnetic stresses in the generators or transformers when short circuited without a limiting resistance or reactance other than that inherent in the machines themselves. No trouble with automatic oil switches when tripping the circuit under these conditions has been encountered.

The result enabled a close predetermination to be made of the amount of current and direction of its flow when a line was grounded at a given point with various arrangements of circuits and numbers of generators in operation. This rendered possible an arrangement using selective relays.

Fig. 13 is a diagram of connections for the greater part of the system. It will be noted that there are many possible methods of operating the various lines and the scheme of connections will be changed from time to time to suit conditions as they arise.

The present system of connections under normal conditions has all three lines from Lock 12 in service and in parallel on the high-tension bus. The two lines to Magella are kept separate on the high-tension side at Magella, the "A" line feeding No. 1 bus and one bank of transformers as a unit with the line, and the "B" line the other bus and other bank of 13,200-volt transformers. These two banks of transformers are parallelled on the low-tension side.

Each of these two outgoing lines from Lock 12 is provided with definite time-limit overload relays set for 2 seconds time and current equivalent to about 30,000-kv-a. at 110-kv. Bushing type current transformers operate the relays.

At Magella the low-tension side of each of these two transformer banks is provided with only instantaneous reverse-power relays

Fig. 14. A View of the Magella Substation and Cooling Pond

The company feeds the city of Birmingham, through the Birmingham Railway, Light & Power Company, at 13,200 volts from this station and consequently the maintenance of continuous service is necessary.

The action of this part of the relay system when trouble occurs on one line cuts off the low-tension side of the transformer bank at Magella on a reversal of power which flows toward the fault and cuts off the line at Lock 12 on overload an instant later, should the fault remain. This leaves the other line carrying the Birmingham load through one bank of transformers. This condition may overload the transformers but it is not serious. As no generating capacity is lost by this move the other line and transformers will take the load with only a drop in voltage. Should the voltage of the line on which the fault occurred not rise to normal when it is charged, the line will be cut out of service and the transformer bank at Magella cut in parallel with the one already in service.

Line "A" from Magella to Jackson Shoals, Anniston and Gadsden is tied to the same bus at Magella as the Lock 12—Magella "A" line. The Lock 12—Jackson Shoals, Anniston and Gadsden "B" line and the "A" line from Magella thus form a double feed for Jackson Shoals and the North. These lines are normally kept separated at Jackson Shoals and Anniston, the "A" line being tied to No. 1 bus and the "B" line to No. 2 bus in each station.

At Gadsden the high-tension lines are kept separate and are operated as a unit with each of the two transformer banks. This station is ordinarily operated as a substation and the two banks are tied together on the 22-kv. bus. The 22-kv. switches are provided with

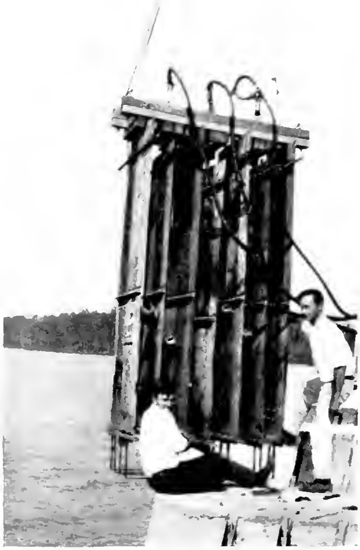


Fig. 15. The Water Rheostat Electrodes used when Testing the Generators of the Lock 12 Station

reverse-power relays set to trip at a definite amount of current feeding back into the high-tension line. These relays are instantaneous in time setting.

Should trouble occur on the "A" line, say near Jackson Shoals, there would be two paths to the fault, one direct from Lock 12 to Magella and on to the breakdown and one over the "B" line to Gadsden down through No. 2 bank of transformers and back through No. 1 bank of transformers, thus tripping the low-tension switch on reverse power and leaving the "B" line to carry the load.

At Magella the 13,200-volt switch on the transformer bank fed from the "A" line would then trip unless, as sometimes happens, the arc breaks as soon as the Gadsden switch opens. Before the Gadsden switch opens, practically the only power available to trip the Magella switch on reverse power is what may pump back from synchronous apparatus on the Magella bus. It will make no difference in the clearing of the line in trouble whether Gadsden or Magella clears first or both at the same time. Lock 12 should clear last on account of its two-second relay setting.

This arrangement then will clear out the whole "A" line from Lock 12 to Gadsden but will leave the other line feeding each station.

When operating normally, the No. 4 bank of transformers at Magella, stepping down from 110 kv. to 22 kv., is tied to the No. 2 bus at Magella and is fed from the Lock 12—Magella "B" line. Jackson Shoals is normally fed from the Lock 12—Gadsden "B" line, being tied to the No. 2 bus at Jackson Shoals. Anniston is fed normally from the Magella—Anniston "A" line and is also tied in with Jackson Shoals over the 22-kv. line which parallels the 110-kv. line between these stations.

The switch which controls the step-down transformers at both Jackson Shoals and Anniston is equipped with reverse-power relays to trip on power feeding back into the high-tension lines. The 22-kv. switch on the No. 4 bank of transformers at Magella is equipped with reverse-power relays to trip on power feeding back into the high-tension line.

It will be seen then that in case of trouble on the Lock 12—Magella "B" line that the No. 4 bank of transformers will open on the low-tension side, leaving the 22-kv. customers out of Magella to be carried from Jackson Shoals over the 22-kv. line. In case of trouble on the Lock 12—Gadsden 110-kv. "B" line, Jackson Shoals should trip off on reverse power, getting its feed from Magella over the 22-kv. "B" line and from Anniston over the 22-kv. line.

Should the Lock 12—Magella—Gadsden "A" line trip out, Anniston would be cut loose by reverse-power relays getting their feed over the 22-kv. line from Jackson Shoals.

Should both the Lock 12—Gadsden "B" line and the Lock 12—Magella—Gadsden "A" line go out at the same time, both Jackson Shoals and Anniston will trip clear by the reverse-power relays receiving their feed from Magella over the 22-kv. lines.

The use now made of the 22-kv. lines as an auxiliary feed will not be possible when the load has grown to its ultimate proportions, on account of the transmission distance. At present the two 1000-kv-a. generators in

Jackson Shoals Station are operated in connection with an automatic voltage regulator and are of material assistance when stations have to be fed over the 22-kv. line. This station does not have a sufficient supply of water to operate during the summer months to any great extent, but both machines are ordinarily kept running as synchronous condensers to hold a constant voltage at this station.

The system of connections and arrangement of relays to keep a continuous supply of power on the buses of the main substations looks complicated at first, but it is not particularly when consideration is given to the fact that there is practically no way the relays can go wrong other than by burning out or getting out of order mechanically. A very close watch is kept on all relays to avoid such an occurrence and as a result none has failed to operate due to these causes.

The feeder relays out of all the main substations are expected to take care of trouble on their own feeders without affecting the remainder of the system. There is enough differential current between the feeder relays and the main station overload relay that in no case has use been made of selective-time limit relays. A short-circuit on none of the feeders will give enough current to trip out the main line switch, unless it is at the switch itself.

As a rule, all individual feeder switches are set for as high a current value as possible, yet still trip for a short-circuit on the high-tension side of the transformers at the far end. Where a feeder switch controls only one customer, the relays are set for a very short time—less than one second—the idea being that the short-circuit will be a breakdown or arc-over on insulators and should be dropped as quickly as possible to avoid extensive damage to the line or apparatus. Should a feeder trip out, it will be charged again immediately. If it trips out again it will be tried a third time and then held out, the line patrolled, and repairs made as quickly as possible.

Where a switch controls a feeder with branch lines taken off to different customers, the relays are given a short time setting sufficient to allow fuses on the branch lines to clear ahead of the switch, so as to avoid a shut-down for all customers on the line.

Considerable attention has been given to the size of fuses on such circuits, the current in a short-circuit being calculated and a fuse used that will blow on short-circuit ahead of the main switch.

In this connection, the short-circuit current on all parts of the system has been calculated with the system operating under normal conditions. These values have been checked wherever possible and practice has shown the calculations to be very close. The short-circuit value of the main generators is taken from the synchronous impedance values, as the time element of relays and switches is such as to be workable only after the instantaneous values have died down practically to the continuous values. In using the synchronous impedance values of the generators account is taken of the probable field current at the end of a definite period after short-circuit occurs, since the generators have their fields controlled by automatic voltage regulators which naturally increase the field strength under short-circuit conditions. There is of course some error in predicting how fast the regulators will work and the field build up under varying circumstances, but very good working data can be obtained from a few experiments with a generator exciter and regulator under varying conditions. The impedance of the lines and transformers is quite definite and is easily calculated within sufficiently close limits. No allowance need be made for partial short-circuits or high-resistance short-circuits as a rule, for the resistance of an arc is comparatively low and nearly any short-circuit can be treated as a "dead" short-circuit with but little error. A short-circuit occurring on a wood pole owing to broken insulators, however, may be not taken care of by the usual relaying and fusing for short-circuits and it will be necessary to depend upon the operators judgment to cut off the line before the pole is burned down.

In actual operation much attention is given to noting unusual occurrences especially at times of trouble. Special meters have been installed in many parts of the system and during storms and at times of other unusual conditions the operators are instructed to watch these meters. Thus they obtain an estimate of what they should read under ordinary load conditions and they are becoming quite expert in diagnosing cases of trouble as to their probable location and nature.

All switching of lines other than local feeders is done at the order of the system operator or his assistant. Whenever any unusual occurrence is noted by any station, it is reported to the system operator who directs the procedure in hunting the cause.

The system operator keeps a record of all the main circuits that are in operation at the time, showing when switches are opened or closed, by whose order, and for what purpose. This record is of great assistance in checking the operation of automatic switches after trouble has occurred, as when lines or apparatus are out of service it naturally affects the operation of certain automatic features.

The system operator in taking apparatus out of service takes into account the effect this will have on the automatic features and makes plans accordingly. Often times other sections of line or other apparatus than that on which work is being done is taken out of service if it does not give added insurance of continuous service or it would cause possible confusion in locating trouble quickly.

All customers feeders are taken care of by the substation operators direct and all switching is recorded on blanks similar to those used by the system operators, so that at all times the position of any switch on the system can be checked.

To facilitate handling switching orders by telephone, all switches are numbered and the system operator gives the number of the switch to be opened or closed or tagged for men at work. He keeps a record of all operations on blanks as well as on the operator's board.

From January 1st to August 1st there were on the high-tension lines 24 cases of trouble which caused the switches controlling these lines to trip. Of these 24 cases there was only one which developed a sufficient number of broken insulators in a string to make necessary the holding out of a line for immediate repairs. On this occasion a string of strain insulators on the top wire broke apart, allowing the top conductor to sag close to the middle conductor. After the switch tripped, the line was charged all right but the switch tripped out twice later so the line was held out for repairs. In only four other cases were there any broken insulators and then not more than one or two disks in a string. The lines are always charged in one-half minute from the Lock 12 station and in no case have they failed to come up all right.

During the period named the Magella bus has been dead twice. On these two occasions both lines between Lock 12 and Magella tripped out at the same time at Lock 12. The Jackson Shoals bus has been dead six times, the Anniston bus four times, and the Gadsden bus five times.

Some of these cases of interruption during high-tension line trouble have been due to the fact that one or more lines were out of service at the time the trouble took place and other cases occurred due to wrong adjustment of relays.

The Gadsden interruptions were due to wrong action of the reverse-power relays. Single-phase relays were originally installed but it was found that with an arc-over of a single string of insulators, causing a phase-to-neutral short-circuit at Lock 12, there would be a reversal of power in one phase that would cause the wrong relay to operate. Two phases would be in the right direction for selective operation but with one reversed with respect to the other two the result was that both switches would trip, thus causing an interruption.

Extensive tests were made to determine the cause of this reversal and to learn under what conditions it would occur with the result that it was found that with a phase-to-neutral short-circuit when feeding back through an ungrounded-neutral bank of transformers it would occur at all times irrespective of the electrical constants of the circuit. With a phase-to-phase short-circuit on two legs there would be such a reversal if the far end of the line was open-circuited. If the far end of the line was connected to a transformer bank, there would be less distortion of the voltage triangle and no reversal of one phase with respect to the other two would take place.

It was decided that in all cases where reverse-power relays were to be used to act selectively at a substation that is fed by two lines it would be necessary to use three-phase reverse power relays, unless there is a sufficient amount of synchronous apparatus fed from the substation to pump back into a short-circuit on one line and thus give a differential action between the two relays.

Three-phase relays were installed at Gadsden and these have eliminated both switches tripping out for trouble on one line only. It has been practically decided to use three-phase relays for reverse power in all cases in the future for this type has all the advantages of the single-phase type and lacks many of the disadvantages of the latter.

Three-phase relay connections are similar to wattmeter connections and the relays can be placed in a watthour meter case; thus they line up with the watthour meters on the switchboard. Single-phase relays must either be wound for 57 volts and connected in star or wound for 95 volts and have half-voltage taps brought out of the potential transformers in order to have the potential in phase with the current under normal working conditions. In adding reverse-power relays to existing installations, these features involve complications since few potential transformers have half-voltage taps. Additional potential circuits necessarily have to be installed. With three-phase relays none of these complications arise.

Telephones

Telephone communication between stations is of the greatest importance in maintaining service and consequently the protection of telephone lines and apparatus has been given much thought.

The telephone lines are run on separate wood poles located on the same right of way as the main transmission lines with but a few branch lines on the same poles as the 22-kv. feeders. This arrangement gives only a small amount of trouble from induction under ordinary circumstances; although the 1914 lightning season gave some trouble during storms, chiefly amounting to burning out ringer coils and occasional telephone transformers and draining coils as well as blowing a considerable number of fuses, thereby causing short interruptions to the telephone service.

The draining coils used in 1914 were built by the telephone manufacturers and were evidently too small for the purpose.

Before the 1915 lightning season commenced the telephone equipment was carefully gone over and some protective features added that have worked thoroughly satisfactory.

The telephone protection equipment as it enters the station consists of the following apparatus in the order named:

(1) Lightning arrester; Home-made from old multi-gap lightning arrester knurled studs.

(2) General Electric Company fused disconnecting switch; Standard telephone switch.

(3) $1\frac{1}{2}$-kw. transformer 1100/2200–110/220 volts, used as drainage coil.

(4) General Electric Company standard 1:1 telephone Transformer. Across line side of telephone transformer is installed a General Electric vacuum-gap lightning arrester to protect telephone transformers in case of line becoming grounded.

With this equipment service has been maintained without the loss of any drainage coils or telephone transformers and but two ringer coils. In no case has a telephone line been out of service longer than a few minutes due to trouble in the station.

In one case a 22-kv. feeder circuit burned off and dropped across the telephone line without damage to the telephones or equipment, the lightning arresters taking care of the surge until the circuit was opened.

The operators are able to use the telephone with good results during severe lightning storms, very seldom having met with serious interference from the noise of discharges or other causes.

Operating Personnel

In addition to the purely engineering features of this system, as with others, there is still another element that will have a very marked effect on the operation. This is the operating staff. If they are not carefully trained there is grave danger of the whole elaborate system failing.

The selection of the best qualified men and the training of them to see, understand, and act quickly and correctly in an emergency is really a more difficult task than selecting good apparatus. There is a tendency amongst capitalists to think that after several million dollars have been spent building a large system it ought to be capable of being run by only a very small staff of low-salaried men. This is a mistake. High-grade men are required if service is to be maintained and apparatus properly protected.

The organization for handling the operating department is as follows: The Operating Manager is in entire charge of all the operating. The chief storekeeper, engineering department, superintendent of construction, and superintendent of operation report directly to him. The various plant superintendents report direct to the Superintendent of Operation, as do the maintenance foreman and line supervisor. In handling the routine operation, of course, all operators in the various stations receive their orders from the operator in charge of the shift at the Magella Substation, who acts as system operator during his shift. When the system has become more extensive, there will be a chief operator at Magella on day duty but on call at any hour. Two twelve-hour shifts are worked in all the stations.

Most of the operators are men who had worked on the construction of the plants, as it has been found practically impossible to secure operators who are already trained. Also, it has been found better to take an untrained man and train him for the work of this particular system than to take an old operator from another system, because of having to make the latter man unlearn many things which may have been good where he came from but which do not fit in this system.

The temperamental requirements of a good operator are very different from those of a good construction man. The good operator must never tire of doing the same thing in the same way, nor weary from the monotony of having everything running smoothly day after day. The switchboard operator's life is, if anything, somewhat tiresome, yet he must never "go to sleep on the job," he must always be alert and be instantly ready to act in any emergency. College men seldom make good operators, although when one does take to it he usually surpasses the practical man because his theoretical knowledge helps him to work out problems more quickly and correctly.

After an applicant has been accepted he is put to work as an assistant in one of the stations. A few months later he is moved to another station and so on. At the end of a year he is familiar with practically the whole system and can assume a regular operator's duties at one of the smaller substations or those of a regular assistant at Lock 12 or Magella. The men are questioned at intervals to test their familiarity with the system and the operating rules. No standard rules have yet been issued on account of the newness of the system, but from time to time bulletins and notices embodying rules found to be necessary are sent out by the Operating Manager. Rules are made as general as possible and outline methods of handling troubles rather than trying to specify to an operator just what switches to throw. The aim is to teach the men to think for themselves and to interpret and diagnose their troubles from the indications given them by meters, ground detectors, arresters, etc.

Great emphasis is laid on safety-first principles and most rigid instructions are given regarding the grounding of all lines and apparatus before starting work on them. A lungmotor is installed in every station for use in resuscitating men from shock or drowning. Demonstrations of and drills in its use are made regularly. First-aid kits are kept in each station and the men instructed in their use.

Operators at practically all the stations are provided with cottages, steel lockers, shower baths, and modern toilets are installed at each station. A doctor makes regular visits to the various plants and examines the men. Recently 75 employees were inoculated against typhoid at the Company's expense. An extensive study has been given to the prevention of malaria. Blood tests are made and any persons showing positive specimens are immediately treated according to the latest method of the federal health authorities. Large sums of money have been spent in screening and draining to prevent both malaria and typhoid, which are the two diseases most to be feared.

In operating a large transmission system, the maintenance of lines and apparatus is of great importance. In order to operate the system as a whole at maximum efficiency it is necessary that the condition of all the parts should be known at all times and that trouble with lines or apparatus should be anticipated wherever possible.

The transmission line and private telephone line maintenance is in direct charge of the Line Supervisor. Line patrolmen are stationed at different parts of the system and report directly to the line supervisor on all matters relating to line repairs.

All high-tension lines and the greater part of the distribution lines of the Company are patrolled weekly and any defects are noted and corrected at the earliest possible moment.

In order to keep a record of the time at which lines are patrolled and also of the patrolman's location for emergency work, the system operator keeps a daily record of all patrolmen's activities on patrolmen's location blanks furnished for the purpose. All patrolmen report each morning giving their location, plans for the day, and how they can be reached by telephone. When starting on patrol, they report regularly from telephone booths stationed about 5 miles apart along the main lines. If not on patrol, the men report regularly twice a day for instructions. Should they change their location at any time during the day, they report this change and the quickest method of reaching them by telephone. The system operator keeps a record of the location of the Line Supervisor as well as the patrolmen.

For emergency patrol, in case of transmission line or telephone line trouble, the patrolmen work under direct order of the System Operator. Should trouble be found, the patrolman reports immediately to the System Operator giving as much detail as possible of the nature of the trouble and his plans for repairs together with the length of time he estimates will be required for completing the work. Should he need material or assistance other than that which he can obtain locally, he states his requirements. The System Operator immediately reports the trouble, with all data obtained from the patrolman, to the Line Supervisor together with the importance of the line to service and the necessity of immediate repairs. Should the work require extra men or a greater degree of skill than is possessed by the patrolman the Line Supervisor either goes to the location of trouble himself or sends such help as is needed. Repair material such as conductor, splicing sleeves, insulators, etc., together with tools and appliances for making repairs, are stored at various points on the system.

The Line Supervisor looks after the distribution of the necessary material, makes general plans for the taking care of trouble, and sees that the patrolmen are properly instructed as to their duties. He sees that all patrolmen are familiar with methods of transportation, including all train schedules on their sections, and where they can obtain teams or automobiles, etc., in order that as little time as possible may be lost in hunting or repairing trouble.

The Company is experimenting with the use of motorcycles by patrolmen in hunting trouble on lines that parallel roadways. These machines are very useful in hunting telephone trouble especially as the lines can be sectionalized and tested at all telephone booths and the trouble quickly located within a five-mile section. It is expected that by their use additional patrolmen can also be thrown into a given section of line for hunting and repairing a breakdown, thus saving the time of waiting for trains. The motorcycles are equipped with side cars or tool boxes and a considerable amount of repair material, etc., can be carried. They also have tandem attachments that will carry an extra man to assist in making repairs.

The maintenance of apparatus on the system is looked after by the Chief of Maintenance, who acts as Chief Inspector of apparatus as well. It is his duty to see that all apparatus is kept at all times in good working condition and to make all necessary repairs or adjustments to equipment in service. He looks after all transformers and oil switches, making regular tests of the oil for dielectric strength and seeing that it is filtered when necessary. He adjusts all relays, sees that they are kept in working order, and makes regular tests to determine their condition. He sets all lightning arrester horn-gaps and sees that the arrester is in proper condition. He makes all repairs to apparatus that are of a difficult nature and such as cannot properly be done by the regular operating force. He takes care of all construction work such as can properly be charged to the Operating Department, keeping a small force for maintenance and picking up such help as is necessary from time to time. The work of the Chief of Maintenance as Chief Inspector is most important as will be readily understood for on his efficiency in locating possible sources of trouble and in making repairs at the proper time depends to a great extent the quality of service furnished the customers.

Fig. 16. A Panoramic View of the Magella Substation and Outdoor Equipment

PORTABLE MACHINERY FOR PACKAGE FREIGHT HANDLING

By R. H. Rogers

Power and Mining Engineering Department, General Electric Company

The author after telling of the almost insurmountable difficulties attending the handling of package freight by machinery classifies the different types of machines now used for this purpose. He discusses the field of operation for each different type of machine and shows its use and limitations. A great deal of data are given concerning the capacities of the different types of machines. Auxiliary apparatus is being designed to meet the requirements of each equipment when its use in a particular field becomes sufficiently extensive to warrant it.—Editor.

R. H. Rogers

THE handling of package freight in railway terminals, piers and warehouses is one of the most variable propositions that can be imagined. The packages run from a spice box to an auto truck with bundles of pipe and stacks of tank plates by way of shapes. The number of like packages in a given movement may range from one to one hundred and twenty-five thousand and the starting and ending points of the movements will be found to shift freely and in a most disconcerting manner all over the area that can be affected.

Fig. 1. "Two Horse Power" Tramp Crane Discharging Lighter to Wagons, South St., New York (present practice).

Fig. 2. Hand Trucking Coffee

Packages are moved in every possible combination between ships, lighters, cars of many types, vehicles, sheds, open spaces and warehouses high or low. To cope with these trying conditions the "gang" with hand trucks has been almost universally used because such an organization is as flexible as the service is exacting.

To do this work to any great extent by machinery requires types of machines approaching the versatility of the man and hand truck for it has been proven over and over again that traffic practices cannot be changed to any great extent to fit the rigidness of ordinary machine practice. There are so many commercial considerations running parallel with and threaded through freight movements that the most unexpected complications arise whenever more than the most superficial changes are attempted.

Portable machinery is being used successfully on various phases of package freight work, though success in one place does not mean that the same machine will be successful on apparently similar work in another place. Besides having to be suited to the physical conditions of location and to the work carried on, machinery has to be acceptable to the labor and immediate management else it will surely fail.

By portable machinery is meant devices that may be moved about, self propelled or otherwise handled, and with or without rails.

Fig. 3. Battery Truck Crane Carrying 1800 lb. Tobacco Casks 1000 ft. Car to Ship's Side

Fig. 4. Moving 1800 lb. Tobacco Casks 1000 ft. Cars to Ship's Side

Track devices include cranes and vehicles. Trackless devices include cranes, conveyors, hoists and vehicles. Floating devices include cranes.

The most popular of the rail machines is the locomotive crane. Electric motors are used on the ordinary types of locomotive cranes to a considerable extent and have proven to be well adapted to certain classes of work. The most marked advantage of this type lies in intermittent work, as the electric crane is always ready to begin operations at a moment's notice at any time of the day or night without in the meantime having to carry banked fires or requiring any time for getting up steam. The operator is not required to have any knowledge of care and maintenance of a steam plant and does not have to devote any of his time to firing. The number of motors applied may be anywhere from one to five, but the usual practice is to use one large series wound railway type or mill type motor, transmitting the power to the various movements through the usual arrangement of gearing and clutches.

Where work is being done in a thickly populated locality the absence of smoke and steam is an advantage. A wood covered third rail is usually laid alongside the track on which the locomotive crane is to work, current being collected by a slip shoe. On some cranes it is the practice to dispense with the steam boiler and run a pipe line from a stationary boiler plant to the crane. This requires the service of a couple of steam fitters whenever the crane is moved along the track beyond certain very narrow limits and at a cost and delay that makes a very marked advantage for the electric means of transmitting power. The maintenance on an elec-

Fig. 5. Storage Battery Crane and Tractor. Hoisting Capacity 4000 lbs. Drawbar Pull 2500 lb.

Fig 6. Tractor and Trailer Handling Coffee. Pier to Warehouse

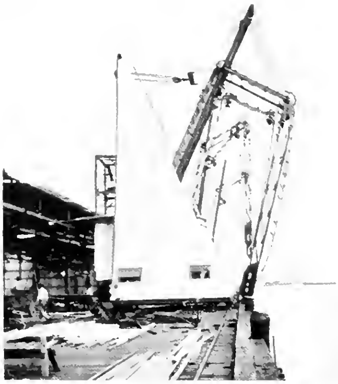


Fig. 7. Conveyor Cranes for Fruit Steamers

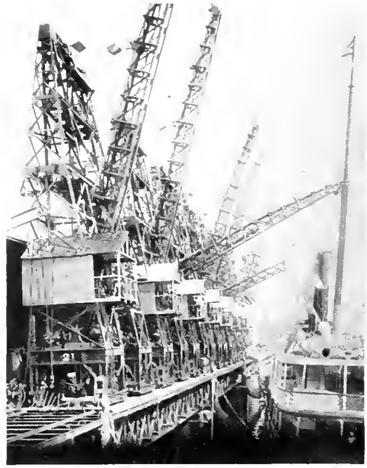


Fig. 8. Trolley Boom Cranes on Balboa Docks

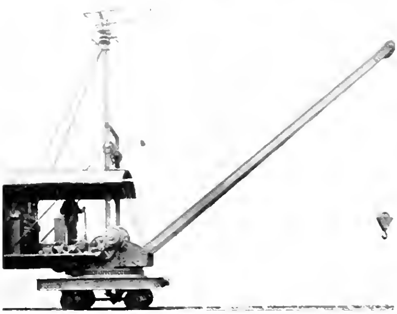


Fig. 9 Electric Locomotive Crane. Low Upkeep, Readiness to Serve and Operator's Attention Undivided.

Fig. 10. Floating Cranes Alongside Ships. New York Harbor

Fig. 11. Gantry Crane in Railroad Yard

Fig. 12. 15-h.p. "Tramp Crane" Discharging Barge to Trailers in Tow of Storage Battery Tractor

trically operated crane is very much less than that of a steam crane, as there is no boiler maintenance and no fire, water or gas (with all their destructive tendencies) to contend with.

Motor capacities for locomotive cranes run from 35 h.p. to 200 h.p. the size being determined largely by the duty cycle expected. Where it is necessary to use a-c. energy, wound rotors with resistances are specified.

Bridge cranes are so little used in package freight handling that they will be omitted. Gantry cranes are common in railroad yards for serving gondola and flat cars, drays and temporary storage piles. A common span is 50 ft. and capacities run from 25 to 100 tons. There are usually four motors used, viz., main hoist, auxiliary hoist, bridge motion and trolley motion. They are equipped both a-c. (wound rotors) and d-c. (series wound). Drum controllers are used in both cases. Modifications and combinations of the above are found in roof cranes, half gantry cranes and gantry locomotive cranes, the latter being popular in foreign ports. A special type is the conveyor cranes such as are used for discharging and loading fruit steamers. These machines use a single 15-h.p. squirrel-cage motor which runs the endless conveyor, adjusts the articulated leg and moves the whole structure along the pier to the proper hatch. This machine conveys bananas from the hold to the wharf near the cars at the rate of 42 bunches per minute.

The cranes at Balboa, Panama Canal, for package freight handling represent still

Fig. 13. Hand Trucking Live Turtles

another type in which loads are trolleyed along an adjustable structural steel boom between two towers that stand on tracks on the wharf apron. The inshore end of the boom projects within the shed where the loads are deposited or picked up. When ships are being moved or when not in use the boom is luffed to a nearly vertical position out of the way. Three motors with drum controllers are used for these cranes—two of 115 h.p. and one of 25 h.p. capacity.

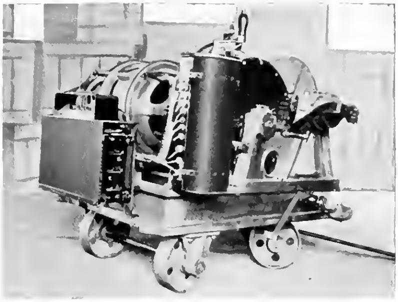


Fig. 14. 15-h.p. Portable Dock Winch, 1 Ton Capacity at 200 ft. per Minute

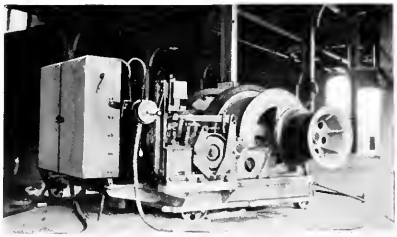


Fig. 15. Portable Master Controller Applied to 2-motor, 2-drum High Capacity Dock Winch

Trackless machines include conveyors, hoists, cranes and vehicles. The conveyors are of two types, articulated horizontal conveyors and single unit stackers. The continuous conveyors can be used on inclines and the end sections are capable of considerable angular adjustment to suit receiving and discharging conditions. They are quickly reversed, can be moved bodily short distances or when disjointed are easily moved to distant points or stowed closely when not being used. For a capacity of 60 tons per hour at 100 ft. per minute there is required a 5 h.p. motor every 50 ft. if inclines of 20 per cent are to be worked. This motor may be compound wound d-c. or squirrel-cage a-c.

either totally enclosed or covered with a close fitting metal shield to keep out cement, chaff, lint, etc. Drum controllers are much more satisfactory than any other form of starter for these machines. Fixed conveyors without end extensions are very much inferior to the portable type for reasons outlined in the first part of this article and illustrated by Fig. 16 showing the hand loading of a steamer within a few feet of a fixed conveyor.

Stackers are motor driven conveyors capable of working at an angle up to 60 deg., and are made in lengths up to 40 ft., requiring a 5-h.p. motor to operate. Their weight is not great and being mounted on ball bearing caster wheels no hardship is involved in the frequent moves required to suit the growing or shrinking piles—the machine being reversible and frequently used to lower material.

Fig. 16. Loading Steamer with Rice Alongside of Stationary Conveyor (under shed at left

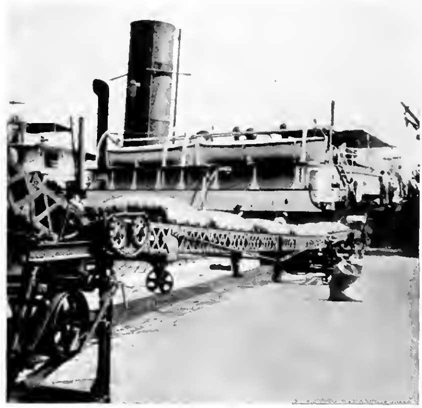


Fig. 17. Portable Conveyor Carrying 60 Tons of Coffee per Hour from Ship's Deck to Storage Piles

The use of a relatively small number of portable dock hoists rather than a large number of fixed ones is becoming common. They are made in single drum and double drum types with gypsy heads and one and two motor drives. The control may be by drum controllers mounted on the machine or by magnetic control where the panel is mounted on the machine, and the master controller is carried by the operator who has a range of 100 ft. radius or more if necessary. Both a-c. and d-c. motors equipped with solenoid brakes are used where the control is remote. In some cases the motor runs continuously and the drum is handled by a friction clutch and foot brake. The small size illustrated in Fig. 14 is equipped with a 15-h.p. motor and has a capacity of one ton at 200 ft. per minute.

Trackless cranes are of two types—"battery" and "cable," i. e., one is operated from a storage battery and is self-propelling while the other takes energy from a service station through a long cable and is not self-propelling. The battery truck crane is built in one and two ton sizes and is very useful in gondola and flat car work especially when a short haul is required. The cost of taking cast iron water pipes (1600 lb. units) from a gondola car to alongside a ship 60 ft. distant has been reduced to one-fourth the cost of hand methods reinforced by trucks, skids, block and fall, etc.

Portable cranes taking energy by cable are called "tramp cranes" and are used for serving unrigged craft supplying service akin to the ship's cargo, booms and winches. They are also used for gondola and flat car work. The tramp crane illustrated in Fig. 12 discharged many sugar barges (elevating 25 ft.) at the average rate of 48 tons per hour with a 15-h.p. squirrel-cage motor.

Vehicles used as freight handling machines are of two types—tractors with trailers and electric freight trucks. Both use storage batteries, the first towing its loads on a plurality of trailers and the latter carrying loads on its own deck. Tractors are heavily built and carry large capacity batteries so as to have a high tractive effect for starting and grade climbing. Trailers are provided in liberal numbers so the tractor always finds loads to tow and empties to return. Being on the go all the time, one man, one battery and one motor keep roughly 400 sq. feet of carrying deck busy, viz., 9 trailers 4 ft. by 12 ft. Rather long hauls are most favorable for this method. Cotton has been moved one-half mile at the continued rate of 30 tons per hour over rough roads with frequent short grades by a tractor having a 2½-h.p. automobile type motor and a 44 cell, 185-amp. hour battery. To economize power the trailers should have roller bearings and liberal springs.

The industrial trucks, electric warehouse trucks or electric stevedores as they are called are usually rated at 2 tons capacity and have 24-volt batteries and motors. These trucks are among the most easily applied portable machines and where distances are great or grades steep they can usually be used to advantage. Packages that can be put on and taken off by not more than two men are most advantageous as the self loading and self unloading feature of the hand truck make it hard to displace on packages of 300 lb. or over. Men very readily learn to "navigate" these miniature trucks as is proven by the fact that a complete change-over from hand trucks to electric trucks in a 25 man gang was effected in 20 minutes, not one of the men having had any experience with such machines. The care of batteries has been very much simplified and battery charging equipments are reliable and easily understood.

Floating machinery is represented by the numerous lighter derricks or cranes in harbors. These run to 150 tons capacity for freight handling and the most active size is about 75 tons capacity. Some have a large carrying capacity on deck; one in Montreal harbor can carry 600 tons. They serve admirably on long waterfronts, often competing with fixed cranes which are frequently in the wrong place. The "Pelican" in New Orleans harbor frequently discharges ship loads of great marble blocks directly to flat cars, the cars being shifted almost continuously to provide empty spaces within reach of the boom.

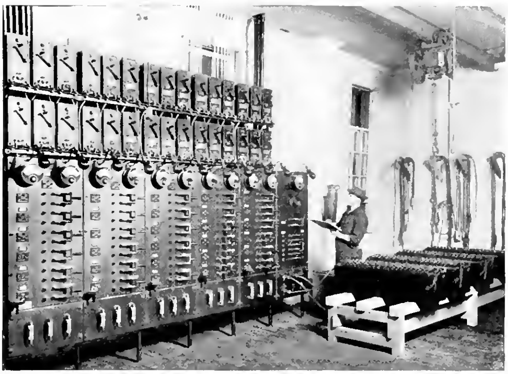


Fig. 18. Thirty Circuit Battery Charging Equipment on Pier

The spreading use of portable machinery is developing auxiliary apparatus to meet peculiar requirements. Two and three wire cables suitable for exposure to weather and the wear and tear incident to much dragging over wharves as well as to horses' hoofs and wagon tires are available for even very large motor equipments at 220 volts.

Rugged cable connectors for use at the service stations, between sections and at the machines, are not so readily obtained but will be developed as the need grows. Service stations consisting of a fireproof cabinet, containing fuses, switch, meter, cable connectors and fitted with a conduit for bringing in the feed wires are so inexpensive that they should be installed liberally for it is much easier to bring a machine to the job, if current is conveniently available, than it is to bring the job to the machine. In fact, the work will be done by hand if the machine is not readily put in operation there.

Storage battery machines have a distinct advantage on short jobs by being self propelled and being able to work anywhere on short notice. Their disadvantages lie in the capital investment in batteries and battery charging apparatus, in the room taken up and expense of attendants.

All these machines make a desirable load for central stations and the great field in which they have hardly found a foothold could be canvassed energetically by central station men to their advantage. Prospective users of such machinery are frequently so out of touch with electrical progress that they do not know how easily machinery can be substituted for hand work or how little extra wiring is necessary to make such machinery available.

Fig. 19. Electric Freight Trucks Plying between Drays and Steamer's Deck

THE CEDARS RAPIDS HYDRO-ELECTRIC DEVELOPMENT

By R. C. Muir

Power and Mining Engineering Department, General Electric Company

This article gives a most useful description of a 160,000-horse power hydro-electric development. The historical notes concerning the title to the property makes interesting reading. The article is very complete, but is not burdened with uninteresting details. After dealing with the station and equipment under numerous headings the author gives some very valuable data relative to costs and in conclusion summarizes the equipment data for ready reference.—Editor.

R. C. Muir

The map, Fig. 1, shows the location of Cedars Rapids and the following geographical and historical sketch, taken from a descriptive pamphlet published by the Cedars Rapids Manufacturing and Power Company, relates how the building of a 160,000-horse power hydro-electric plant at Cedars Rapids came to pass.

Geographical

"Along a seventy-five mile stretch of plateau, through which the St. Lawrence River pierces the range of mountains forming the Laurentians on the north and the Adirondacks on the south, the natural slopes in the topography take the form, in the river, of cascades and rapids.

"About thirty miles west of Montreal, between Lake St. Francis and Lake St. Louis (merely expansions of the river) the Cedars Rapids lie, forming a thirty-two foot fall in the water level.

Historical

"The Cedars Rapids Manufacturing and Power Company was organized by Act of the Parliament of Canada, 4 Ed. VII, ch. 65, with ample powers for the development of water-power at Cedars Rapids; the expropriation of land involved, and the construction of transmission lines.

"The first record of any water-power at Cedars Rapids is derived from an old deed referring to a mill which had been erected some time previous, probably about 1850. This mill utilized but a fraction of the waterfall and was merely a grist mill. To this was added, some time later, a small woolen carding mill, which was built on the Cedars Point, and this latter mill was operated for a number of years.

"As far back as 1669 the French Government reserved to the Crown all navigable rivers and their banks, and by reason of this the owners of land along the St. Lawrence River, unless they were specially permitted to do so, had no right in the water-powers adjacent and bordering on their land. In passing it is interesting to note that the builders of this original water-power obtained no rights from the Government.

"For some time during the early French regime, Montreal was the western limit of settlement in this Province, but eventually grants of adjacent lands were given to various nobles, and in 1702 a grant was made to Pierre Jacques Marie de Joibert, Seigneur of Soulanges, of a strip of land twelve miles in length and five miles in width, extending along the north side of the St. Lawrence River and including the land adjacent to the Cascades, Cedars and Coteau Rapids. Much of this land was later alienated in part, but a considerable portion remained in the hands of the heirs of the original seigneur. It is from this grant that the title of the property at Cedars is derived.

"For many years the development of the rapids in the St. Lawrence River had been discussed, and plans had been made, based on different types of development.

"Upon the lands being acquired, the proposed plan of works was submitted to the Dominion Government for approval. This was obtained, and thereupon an Order-in-Council, dated the 6th day of January, 1906, was passed, authorizing the Company to take from the flow of the St. Lawrence River an amount of water equivalent to 56,000 cubic feet per second, which is sufficient to develop, with the available head of 30 feet, a total amount of 160,000 horse power.

"As the scheme of development assumed definite proportions it became evident to the Dominion Government that care must be taken that the proposed scheme did not in any way interfere with the navigation of the St. Lawrence River, and that any grants made would not conflict with the provisions of the Treaty made with the United States whereby a diversion of water from the St. Lawrence River should have the consent of the International Waterways Commission.

"Upon the submission of the proposal to this Commission an exhaustive investigation was made which resulted in the Commission expressing its approval, under date of the the joint interests of the Shawinigan Water and Power Company and the Montreal Light, Heat and Power Company.

"Soon after the control of the Cedars Company passed into these hands, contracts were made with the Aluminum Company of America and the Montreal Light, Heat and Power Company for large amounts of power, which ensured the success of the Company from a financial standpoint, and work was immediately started in the field and carried on with great vigor."

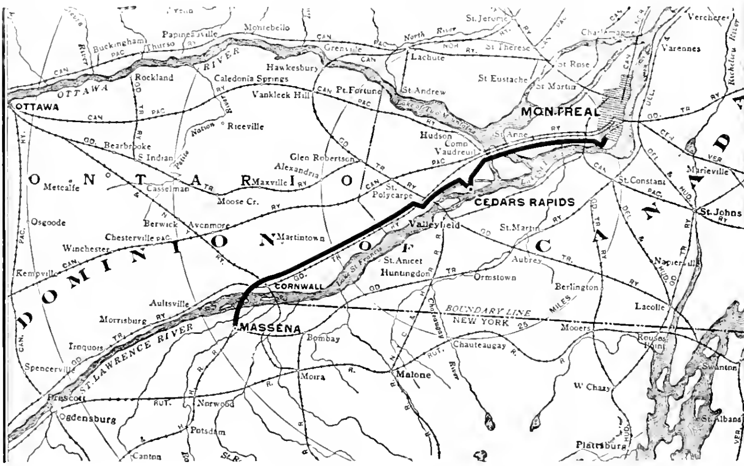


Fig. 1. Map Showing Territory Served by Cedars Rapids Development

19th of April, 1909. The Dominion Government was then in a position to amplify the previous Order-in-Council and an agreement was entered into on the 28th of May, 1909, authorizing the Company to proceed with the construction of the works.

"Although the St. Lawrence River is an International River the water rights involved at this point are vested in the Province of Quebec, and it was therefore necessary to obtain a lease from the Provincial Government, which was entered into on the 2nd day of August, 1910.

"Because of its magnitude and the fact that the greater proportion of the development would necessarily have to be completed before any power whatever could be obtained, this potential value to Canada stood undeveloped until the control became vested in

January 1st, 1915, was the time set for completion of the first development of 100,000 horse power and considering no work was done until June, 1912, this time was very short indeed.

The Cedars Company put down the cofferdams during the balance of the year of 1912, and partly unwatered the site. The contract for the excavation and embankment was then let to Fraser, Brace & Company, of New York, in the early part of 1913, and the work was pushed rapidly forward from that time until completion, November 1st, 1914. By January 1st, 1915, the complete plant was ready to deliver power and did deliver power throughout the year in sufficient quantities to build up a substantial surplus, a most unusual record for a hydro-electric company in the first year of operation.

River Flow

The ratio of maximum to minimum flow of the St. Lawrence River for the years that records have been kept is three to one. The variation in water level is very slight and since the tailrace and headrace rise and fall together, the effective head on the plant is nearly uniform. The maximum variation of head at the power house for the year 1913 was from 30.2 ft. to 31.2 ft. In this respect operating conditions are ideal.

Power House

The present power house structure, Fig. 5, is approximately 700 ft. long, 130 ft. wide and 121.5 ft. high—57.5 ft. of which is substructure and 61 ft. superstructure. The ultimate length will be approximately 1200 ft.

The scroll cases, pits, inlets and tailrace for the water wheels are all found in the substructure, as will be noted from cross section. The superstructure is of reinforced concrete supported by a steel skeleton. The concrete in the superstructure was made up in slabs at a convenient location some distance from the power house, and assembled on the steel frame later. This method of construction proved very satisfactory and assisted greatly in the speed of construction.

It was not considered advisable to place the step up transformers and high tension busses and switches in the power house and, therefore, a separate building, called the transformer house, was constructed. Fig. 20 shows the transformer house to the left of the power house and Fig. 5 shows a cross section.

The construction is of reinforced concrete units throughout, the units being made up nearby, the same as was done for the superstructure of the power house.

The separate transformer house affords several advantages, such as convenient and

Fig. 2. Birdseye View of Cedars Rapids Development

Scheme of Development

The scheme of development is clearly shown in Fig. 2. The headrace, or canal is approximately two miles long and an average of 900 ft. wide, the northerly bank of the river forming one side and an artificial embankment built up in the river channel and extending from an island at the head of the rapids to the power house site at the foot of the rapids, forming the other side. The power house itself forms the dam at the end of the canal. The excavation of the canal involved the removal of 1,730,000 cubic yards of earth and 650,000 cubic yards of stone.

Cross sections through the embankment built up in the river channel and through the power house are shown in Figs. 3 and 4 respectively.

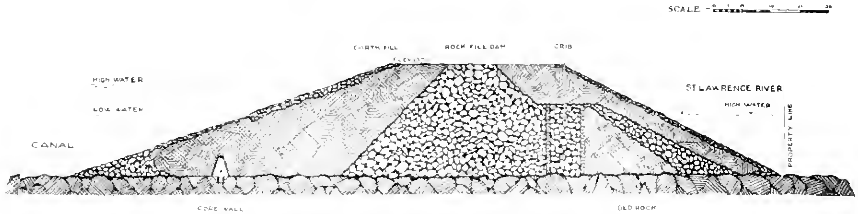


Fig. 3. Cross Section of Embankment built in River Channel

economical arrangement of busses, oil switches, transformers and outgoing lines, ample space for oil storage without involving expensive construction and isolation of transformers and oil from generating apparatus.

Apparatus

By referring to the apparatus data sheet given herewith and the one line wiring diagram, Fig. 6, the reader can readily follow the description covering the characteristics and arrangement of the various apparatus installed in the power house and transformer house.

Hydraulic Equipment

Racks and Gates

All details in connection with the turbine auxiliaries have been worked out very carefully and with due consideration to operating conditions and ease of inspection.

The racks are made in an upper and a lower section, located in slots in the concrete so that they can be lifted by the gate house crane. On account of the great depth—32 feet—it is impossible to clean the rack bars at the bottom in the usual manner with rakes; therefore, an emergency gate is provided just

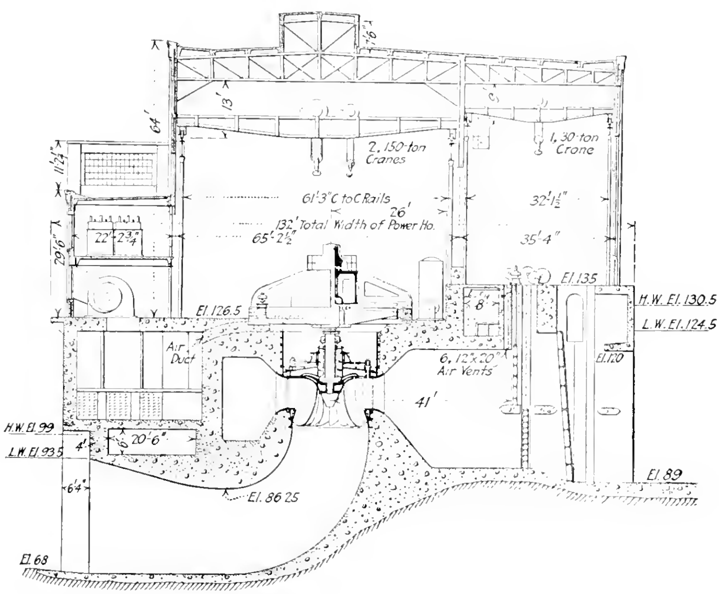
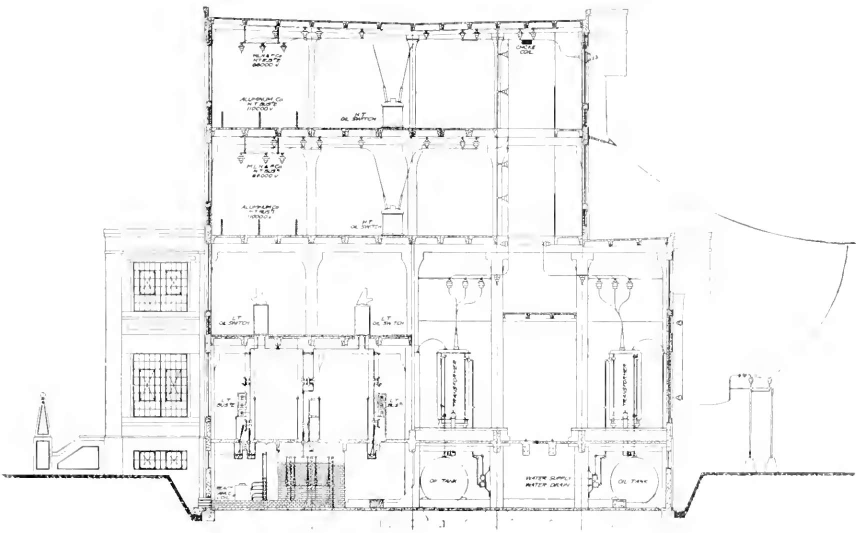


Fig. 4. Cross Section of Power House

inside of the curtain wall whereby the water passage containing the racks and head gates can be drained and any necessary cleaning or repairing can be easily accomplished.

The head gates are located at the very entrance to the wheel chamber and for convenience of operation, upper and lower gates are provided. The intake, Fig. 7, is divided into three chambers, each approximately 13 feet wide by 27 feet high, so that six head gates are necessary for each unit. The upper gates are controlled by motor driven screw hoists and the lower gates are lifted by motor driven drum hoists and closed by their own weights. Fig. 8 is a photograph of the gate house. The temporary water rheostat used for testing purposes will be noted in the intake of one of the turbines.



SECTION THROUGH TRANSFORMER HOUSE

Fig. 5. Cross Section of Transformer House

Main Turbines

In the design of the main turbine units the manufacturers went one step farther than heretofore in the design of single runner vertical wheels.

The wheels are rated 10,800-h.p. at 30 ft. head, 55.6 revolutions per minute. This speed corresponds to a frequency of 63 cycles per second, which is the frequency of the Montreal Light, Heat and Power Company's system. Most of the units supply energy for Massena, however, and operate at 53-r.p.m., which corresponds to a frequency of 60 cycles per second.

The runners are of cast iron, built in halves. The maximum diameter is 17 ft. 8 in. and the total weight of the runner is 160,000 lb. The shaft is a single forging and carries the rotating parts of both generator and turbine. A Kingsbury thrust bearing, supported by massive brackets located on top of the generator, carries the entire weight of the rotating element, 550,000 lb. A babbit guide bearing just below the thrust bearing and a lignum vitae water lubricated bearing just above the wheel hold the shaft in line.

The water inlet to the turbine is controlled by wicket gates which are connected to a rigid cast steel operating ring and this, in turn, is connected at two diametrically opposite points to regulating cylinders or engines.

With the Kingsbury bearing it is advisable to bring the generator to rest as quickly as possible after the gates are closed and for this reason six air operated friction brakes are installed. These brakes are mounted on

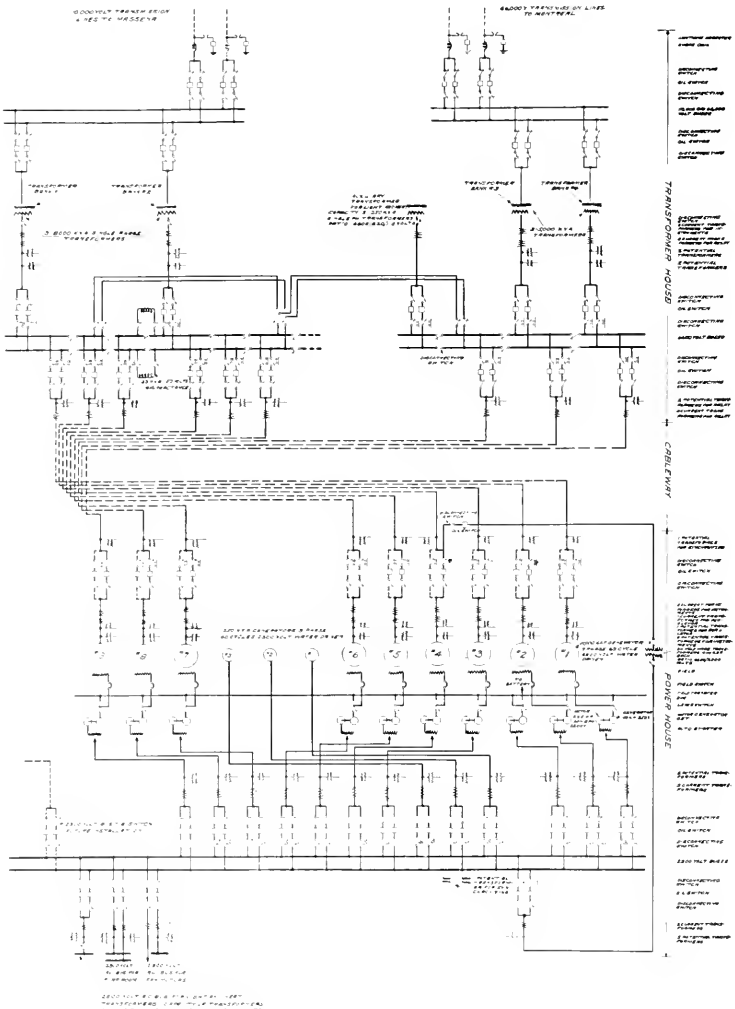


Fig. 6 One Line Wiring Diagram of Generating Room and Transformer House

the generator foundation plates and act on the lower field rim of the generator.

Governors

The governors are located on the generator floor, driven by countershafts geared directly to the main shafts. Water is used as the control medium and is pumped at 200 lb. pressure directly into the mains connected to the controlling cylinders. Some trouble was experienced at first due to oxidation in the working parts of the governor and piping system. This was taken care of satisfactorily by treating the water with potassium bichromate, using approximately 1 lb. to 1500 gallons. Fig. 9 shows the pump pit containing the governor pumps and the oil pumps. The control cylinders discharge into a copper lined concrete tank extending the full length of the power house on the up stream side, and the governor pumps draw from this tank.

Oiling System

The gravity oil system is used. From tanks located near the roof, the oil flows by gravity through the thrust bearings and guide bearings of the various units to the sump in the pump pit.

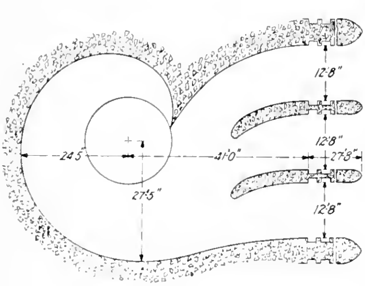


Fig. 7. Plan of Water Intake to Turbine

From here the small vertical pumps, shown in the cut, pump the oil back to the tanks near the roof. It is interesting to note that approximately 21,000 gallons of oil are required for this system.

Auxiliary Units

The three auxiliary turbines are rated 1500-h.p. at 30 ft. head, 150 revolutions per minute. The details of design, as regards auxiliaries and the turbine, are as nearly like the larger units as possible, considering the difference in size.

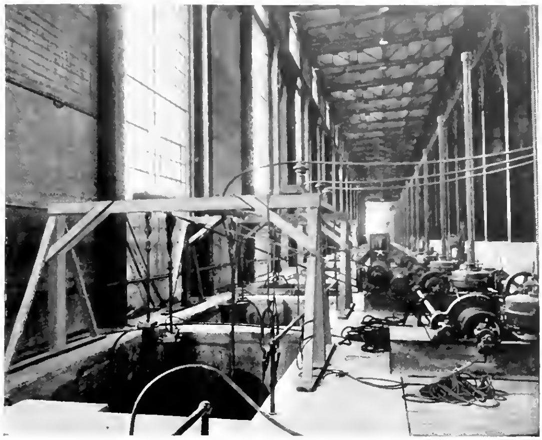


Fig. 8. Interior of Gate-House. Temporary Water Rheostats Installed for Testing are Shown in Foreground

Main Generators

One look into the power house interior, Fig. 10, is sufficient to satisfy the visitor that the design of the main generators is unique. Every effort was made to keep the overall height down and as a result the final accepted design saved approximately seven feet in the height of the power house over the design at first proposed. Part of the saving was made by placing the thrust bearing on top of the unit and part was due to the exceptionally low height of the armature frame. Fig. 11 illustrates this feature of design.

The generators are rated 10,000-kv-a., 0.75 power-factor, 3-phase, 6600 volts, 136 poles, 53-r.p.m., or 55.6-r.p.m.

The outside diameter is 37 ft. 4 in. and the diameter at the air gap is 31 ft. 11 in. The height of the generator frame is only 33 inches. The rotor weighs 213,000 lb. and has a WR^2 of 31,000,000 lb. at 1 ft. radius. The stator weighs 146,000 lb.

The collector rings are placed below the field and a screen immediately above the

Fig. 9. Pump Pit Containing Governor Pumps and Oil Pumps

rings provides protection to the operator when inspecting the brushes.

The characteristics of these generators may be interesting:

	Efficiency				Regulation
	1¼ Load	Full Load	¾ Load	½ Load	Full Load
1.0 Power-Factor	96.4	96.1	95.4	93.5	14 per cent
.9 Power-Factor	95.8	95.5	94.6	92.8	24 per cent
.75 Power-Factor	95	94.5	93.7	91.7	27 per cent

An allowance of 50-kw. has been made in the efficiency to cover windage and friction.

The temperature rise is guaranteed not to exceed 45 deg. C. under continuous operation at full load. The generators are equipped with six temperature coils located in the slots between top and bottom armature coils at equal distances around the generator. These coils are connected to temperature indicating instruments mounted on the switchboard, so that the operators are kept posted at all times regarding the actual temperature of the armature winding.

Auxiliary Generators

It will be noted from Fig. 12 that the three auxiliary generators are of the same general type as the main generators. These generators are rated 1250-kv-a., 0.8 power-factor, 3-phase, 60 cycles, 2300 volts, 48 poles, 150 r.p.m. and have 18-kw., 220-volt direct connected exciters mounted directly above the Kingsbury bearings. The auxiliary generators furnish energy for the motor generator exciter sets, governor pump motors, oil pump motors, fan motors and for general motor and lighting service around the power house.

There are several good reasons why auxiliary generators were installed, some of which are: the operation is more convenient, especially in starting up the plant, only one main unit is affected in case of exciter trouble; the cost of cables and switches is a minimum; and all auxiliary machinery is a-c. driven, which brings the first cost down and at the same time makes it possible to take power from the large units in emergency conditions.

Exciters and Voltage Regulators

Individual 150-kw., 220-volt motor driven exciters with K-8 voltage regulators are pro-

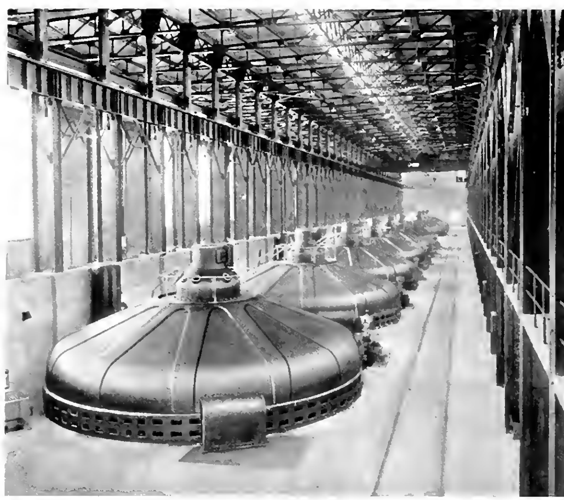


Fig. 10. View of Generater Room

vided for each main generator. This arrangement affords the best and simplest method of obtaining automatic voltage regulation. Regulating rheostats are provided so that the main generator voltage can be varied approximately 15 per cent without changing the adjustment of the regulators. Cross currents between generators operating in parallel are prevented by a current winding on the a-c. control magnet of the regulator, the phase of the current winding being 90 deg. from the current in the potential winding. In other words, if the potential winding is connected to the potential transformer across phases 1 and 3, the current winding is taken from the current transformer in phase 2.

The exciters are connected to the main generator fields by remote controlled solenoid operated circuit breakers. The main generator field rheostats are motor operated and the exciter field rheostats and auxiliary generator field rheostats are solenoid operated. Fig. 13 shows the rheostat panel and one of the 150-kw. exciter sets.

Ventilation

The engineers in charge were familiar with the difficulties experienced in other plants in obtaining effective ventilation on large slow speed generators; therefore, an effective ventilating scheme was carefully worked out. Fig. 14 shows a plan and sectional elevation of the ventilating system and Fig. 15 is a photograph of one of the motor driven fans. From the latter it will be noted that the sheet iron room surrounding the fans can be opened to the power house so that in the winter time the air is simply circulated within the generator room, assisting greatly in keeping the room warm.

Each generator requires a maximum of 35,000 cu. ft. of air per minute, at $\frac{1}{2}$ oz. pressure, just enough to insure positive circulation. Two of the blower sets have sufficient capacity to supply the required amount of air for six generators, the extra blower being a spare.

Each blower is driven by a 60-h.p. motor, so that only 120-h.p. is required under the

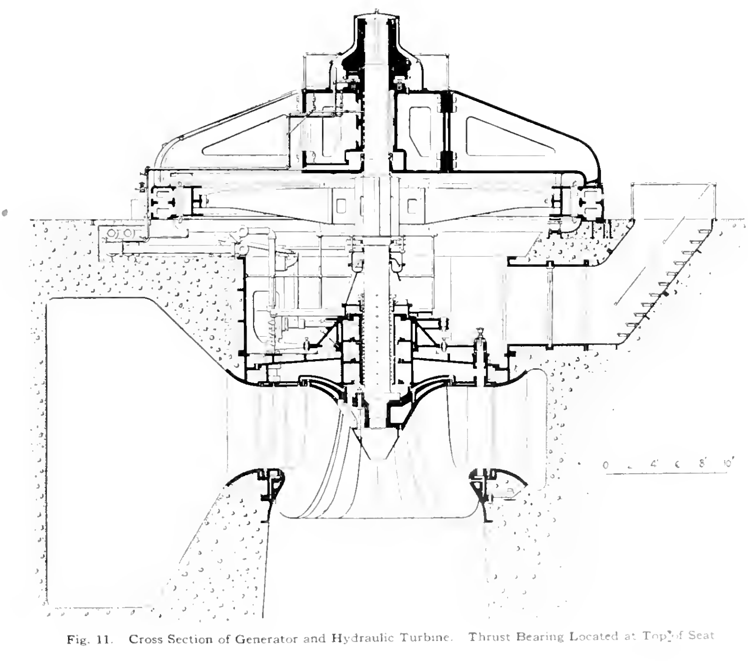


Fig. 11. Cross Section of Generator and Hydraulic Turbine. Thrust Bearing Located at Top of Seat

worst conditions for a generator capacity of 60,000 kv-a.

Switchboards

Fig. 16 shows the main control and instrument board at the left and the auxiliary generator, exciter and 2300-volt control board at the right, both in the power house. Fig. 17 shows the control desk and instrument board for the transformers and outgoing lines in the transformer house, and on the right hand side the auxiliary board for storage battery, lighting circuits, heating circuits, etc., can be seen. The main control board in the power house controls the main generator circuits up to the 6600-volt duplicate busbars in the transformer house. At present three switches are installed in each generator circuit, one in the power house and one for each bus in the transformer house. The switches are non-automatic on overload, but the switches in the transformer house are equipped with reverse power relays so that in case of a short circuit in any generator or cable between the power house and transformer house, that generator is isolated from the balance of the system. The last equipment supplied is arranged so that the power house switch and generator field switch will trip out at the same time as the switch in the transformer house.

The step up transformer switches, or low tension outgoing line switches, are equipped with a combination of inverse time limit and definite time limit relays and the high tension switches are equipped with inverse time limit switches set very high. These latter relays may be disconnected, depending entirely on the low tension switches.

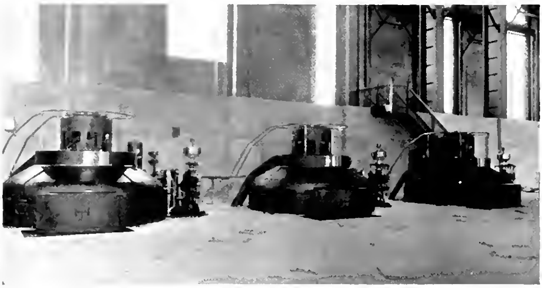


Fig. 12. Three Auxiliary Generators, Each of 1250-kv-a., 150-r.p.m.

The cross section of the transformer house shown in Fig. 5 shows the arrangement of the busses, oil switches, transformers and outgoing lines in the transformer house. Fig. 18 is a photograph of the H-6 oil switches on the second floor and shows the ample room provided for inspection.

The switches, busses and cables used in connection with this installation are designed with a large factor of safety. The 6600-volt switches are rated 15,000 volts and the 2300-volt switches are rated 7500 volts, while the 6600-volt cables are suitable for 13,200-volt operation and the 2300-volt cables are suitable for 4400-volt operation.

Some of the features of the switchboard and switch gear equipment are:

Testing studs are provided for check purposes.

All rheostats and switches are remote controlled.

Rheostat and field switch panel are located opposite the main generators.

Fig. 13. One Generator Field Rheostat Panel and Exciter

The oil switches are electrically interlocked.

The center disconnecting switches are provided with signal lamps mounted on the control board in view of the operator.

Duplicate synchroscopes are provided on both 6600-volt and 2300-volt boards.

The synchronizing of all main generators is done with switches in the power house so as to protect system against improper handling of main units.

The graphic meters on step up transformers are synchronized.

Temperature indicators are provided on the main generator panels.

Signal System

The generator room is so long that an effective signal system is necessary.

There are located on each instrument panel and opposite each generator, signal boxes containing six compartments lettered—START, STOP, etc., together with signal switches. In order to call the floor man's attention to signals from the control room, a large indicator is mounted on one of the columns in the generator room and mounted near this indicator is an air whistle, to call attention to the fact that a signal is being given. The large indicator contains twenty-four compartments, eighteen for the main units and six for the exciter units. In the control room is mounted an enunciator with twenty-four drops, lettered similarly to the main indicator, by which the floor man can obtain the attention of the switchboard operator. The system is very effective but not complicated.

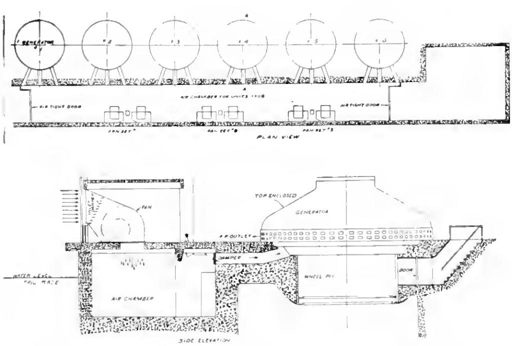


Fig. 14. Plan and Cross Sectional Views of Ventilating System for Generators

Storage Battery

A motor generator set, with an auxiliary storage battery and control panel, is installed in the transformer house and provides energy for the switch control circuits in both the transformer and power house. The battery is also large enough for emergency lighting service, the capacity being 75 amperes for eight hours, 125 amperes for four hours and 315 amperes for one hour.

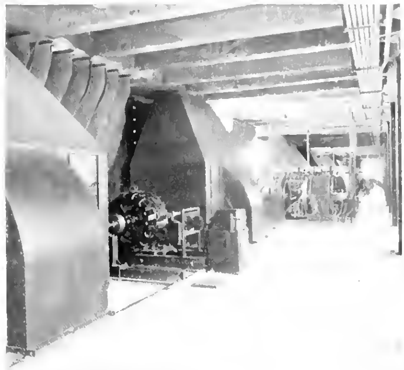


Fig. 15. Motor Operated Fans for Generator Ventilation

Reactors

Four per cent reactors, based on the capacity of one generator, are installed between every group of three generators. The generators themselves have 21 per cent reactance. With this protection, assuming all eighteen generators are operating in parallel, the maximum possible instantaneous short circuit current will not exceed thirty-four and one-half times the capacity of one unit.

Lighting System

The lighting system is designed to give even illumination without shadows, particularly in the important parts of the building. The plane of illumination was taken at 3 ft. above the floor level and the following intensities were adopted.

Power house—generator room and gate house—3 ft. candles, control room—$3\frac{1}{2}$ ft. candles.

Transformer house—control room—3 ft. candles; switch and bus room—$1\frac{1}{2}$ ft. candles; transformer chambers—1 ft. candle.

The amount of energy used for power house illumination per sq. ft. in the generator room and gate house is 0.63 watts and this gives perfect illumination for operating conditions.

Tungsten lights with steel dome reflectors were adopted, the 500-watt size being used in the power house and smaller sizes in the transformer house.

Fig. 16. Main Control and Instrument Switchboard

Heating System

Electric heating figured out to be the least expensive and most convenient. The heater units are of 10-kw. and 15-kw. capacity and are distributed throughout the buildings in suitable locations. The transformer house requires a maximum of 500-kw. for heating purposes and the power house requires a maximum of 2100-kw. for heating purposes, 1100-kw. of which is supplied by the generator losses.

Costs

The present development of 100,000-h.p. represents an investment of approximately $10,000,000.00, of which $2,000,000.00 is common to the whole development.

The detailed costs on the hydraulic development are not as yet available.

The costs of the electrical development, including engineering supervision and interest during construction, are as follows:

	Per kw.
Generators, exciters and blower equipment	$10.04
Switchboards and H. T. switch gear	2.18
Switch cells and bus structures	.26
Control cables and conduits	.54
Main cables and ducts in P. H. and T. H.	.23
Feeder cables, ducts and trestle	1.40
Auxiliary power cables and conduits	.28
Auxiliary transformers	.22
Auxiliary switchboards	.37
Storage battery installation	.11
Lighting system	.19
Heating system	.19
Miscellaneous	.24
	$16.25

The total cost of the transformer house, including crane, turntable, transfer truck, etc., was $3.02 per kw.; the cost per cu. ft. was 9 8/10 cents; the cost per sq. ft. of floor 25 1/10 cents; number of sq. ft. of floor per kw. 1.2.

Cost of Operation

The operating staff consists of the operating superintendent, Mr. W. G. Hullett, and twenty-four men operating three shifts, or eight men per shift. Thus far the entire plant has operated very smoothly and indications are that it will continue to do so.

The operating costs for the first year are remarkably low—less than $50,000.00, including rentals, general expenses and taxes. The ratio of operating expense to gross revenue for the first years is 7 per cent.

Conclusion

It has been impossible in this short description to outline the numerous problems and the various phases thereof that had to be considered during the construction of this unique plant.

Fig. 17. Control Desk and Instrument Board in Transformer House for Transformers on Outgoing Lines; and in back-ground, Auxiliary Board for Battery, Lighting, Heating, etc.

If the reader should visit Cedars Rapids, however, he would probably be surprised at the simplicity of everything—the scheme of development, the power house, the arrangement of the apparatus, and even the operation itself, and then he would realize how well these problems have been worked out. All of these features are of the utmost importance, since every unnecessary dollar put into a large hydro-electric development increases the burden which that plant must bear, and every dollar saved in the operation increases the net earnings by just that amount.

The entire success of the undertaking is due to the efforts and ability of the engineers in charge—Mr. Julian C. Smith, Hydraulic Engineer; Mr. R. M. Wilson, Electrical Engineer; their assistants Mr. W. D. Bergman, Mr. Alex. Wilson and Mr. G. P. Hawley; and the consulting engineers, Mr. Henry Holgate and Mr. R. S. Kelsch.

The writer is indebted to Mr. R. M. Wilson and Mr. A. Gall for the photographs and much of the data given in this article and desires to express his appreciation of their generous assistance.

In all probability many readers of this article will be particularly interested in the apparatus installed, so the following summary of the electrical apparatus has been prepared for their convenience, providing a ready means of reference without searching through the entire text to learn about the details of apparatus.

Fig. 18. High Tension Oil Switches, Located on Second Floor of Transformer House

CEDARS RAPIDS MANUFACTURING AND POWER COMPANY HYDRO-ELECTRIC GENERATING STATION

Present Capacity—100,000-h.p. Ultimate Capacity—160,000-h.p.

Main Generating Units

Present number—10. Ultimate number—18.

Rating water turbine—10800-h.p., 30-ft. head—53-r.p.m., or 55.6-r.p.m.

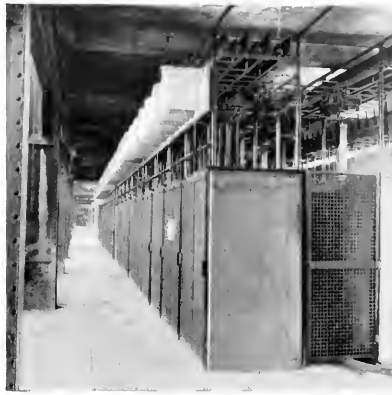


Fig. 19. High Tension Bus Compartment

Rating generator—10000-kv-a., 3-phase, 60-cycle, 6600 volts, 136 poles, 53-r.p.m., 60-cycle, 55.6-r.p.m., 63-cycle.

Type—Vertical—Kingsbury thrust bearings.

Auxiliary Generating Units

Present number—3. Ultimate number—6.

Rating water turbine—1500-h.p., 30-ft. head, 150-r.p.m.

Rating generator—1250-kv-a., 3-phase, 60-cycle, 2300 volts, 48 pole, 150-r.p.m.

Type—Vertical—Kingsburg thrust bearings.

Exciters

Main generators—One 150-kw., 220-volt exciter driven by 200-h.p., 2300-volt induction motor for each generator. Motor driven from auxiliary generators.

Auxiliary generators—Direct connected—18-kw., 220-volt exciter for each generator.

Transformers

Step up for Massena.

Number, 7 single-phase. Two 24000-kv-a. banks and one spare.

Rating—8000-kv-a., 6600 volts low tension, 110,000 volts high tension. Connections delta delta.

Step up for Montreal.

Number, 4 single-phase. One 15000-kv-a. bank and one spare.

Rating—5000-kv-a., 6600 volts low tension, 66000 volts high tension, connections delta delta.

Auxiliary

Power House.

One 3000-kv-a. bank, 6600 volts primary, 2300 volts secondary.

One 1500-kv-a. bank, 2300 volts primary, 220 110 volts secondary.

Transformer House.

One 750-kv-a. bank, 6600 volts primary, 220 110 volts secondary.

Batteries

One in transformer house. Capacity—75 amperes 8 hours, 220 volts.

Switchboard

Main generator control board in power house. Bench type. See Fig. 16.

Auxiliary generator and exciter control board. Vertical type—Location, see Fig. 16.

Outgoing line control panels in transformer house. Desk type with vertical meter and relay board behind. See Fig. 17.

Main generator oil switches—Type H-6—1200-ampere—15000 volts. Reverse power relays on switches in transformer house.

Outgoing low tension switches—Massena—Type H-6—3000-ampere—15000 volts. Definite time limit relays.

Outgoing low tension switches—Montreal—Type H-6—2000-ampere—15000 volts. Definite time limit relays.

Auxiliary transformer and low voltage feeder switches—Type H-6—300-ampere and 1200-ampere—15000 volts. Inverse time limit relays.

Outgoing line high voltage switches—GA—Reactance type.

Auxiliary generator, motor generator, exciters and 2300-volt feeder switches—Type K-12—7500 volts in cells.

Field switches—double pole—800-ampere—air break—solenoid operated.

Reactors

4 per cent. based on capacity of one generator—875-amperes. One three-phase unit located between every three generators.

Governor Pumps

Four 200-h.p. motors driving six stage centrifugal pumps—1100 gallons per minute—250 lb. pressure.

Oil Pumps

Three vertical induction motor driven pumps, each 200 gallons per minute, or of sufficient capacity for 9 main units and 3 exciter units.

Fans

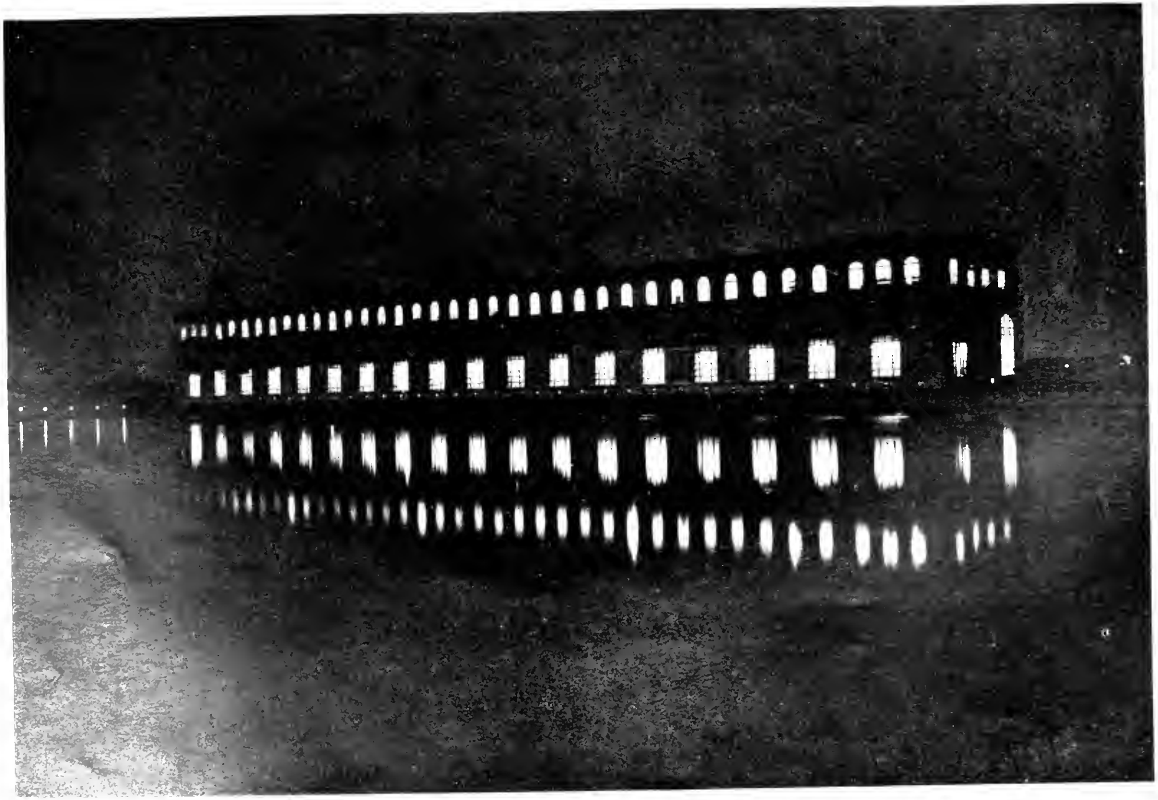
Five—52500 cu. ft. per minute—½ oz. pressure—driven by 60-h.p., 2200-volt induction motors.

Lightning Arresters

Two—110,000-volt aluminum cell type.

Two— 66,000-volt aluminum cell type.

Fig. 20. View of Cedars Rapids Power House and Transformers from Up-stream Side



The Power House at Keokuk, on the Mississippi River, by Night

An interesting view of one of the world's notable hydro-electric stations

CROWN MINES HOIST INSTALLATION

By F. L. Stone

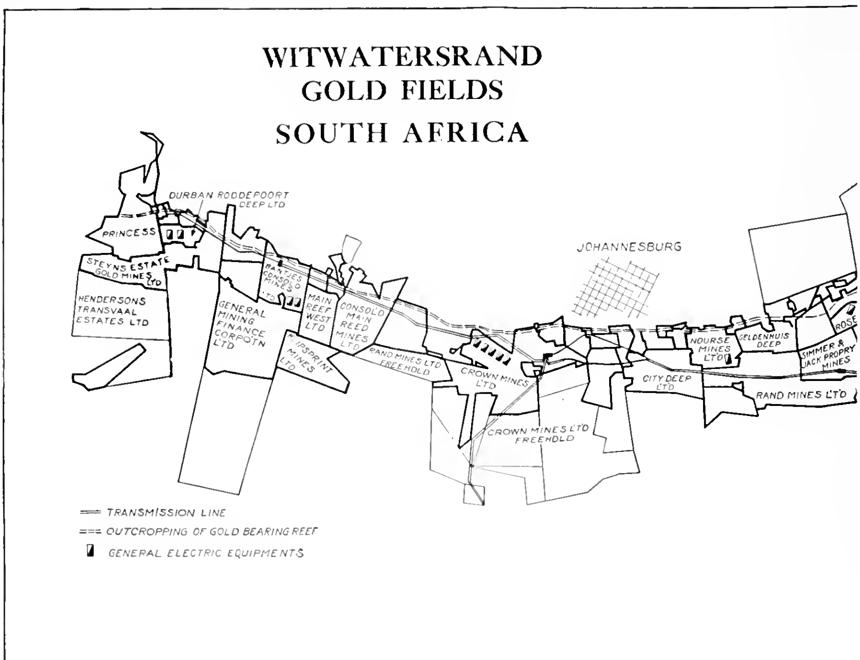
Power and Mining Engineering Department, General Electric Company

The author gives an interesting description of the physical characteristics of the Crown mines on the Rand and shows why electrical equipment was not used at an earlier date. The last part of the article is devoted to a description of the large electrical equipments furnished in the last few years.—Editor.

F. L. Stone

The Crown Mines are located in about the center of the principal gold field in South Africa. The gold-bearing reef extends east and west, a few miles south of Johannesburgh and has a total length of approximately fifty miles. The reef outcrops almost continuously throughout the entire distance, and pitches south at angles varying from 30 degrees to nearly vertical.

No mining of any importance was carried on in this locality until about thirty years ago when the value of the deposits became known. Up to this time and for quite a number of years following the principal mining was naturally carried on along the outcrop. Later, however, when the geology of the country was better understood, other properties were opened south of the outcrop and vertical shafts sunk until they intersected the gold bearing strata. Cross tunnels were driven at various points in the shaft both above and below the vein, until they intersected it, and thus the ore could be brought to the shaft from many levels.



The general indications seem to be that the main body or vein somewhere reaches a basin, though this has never been proven. Very thin outcrops, however, have been found many miles further south. They are so lean, however, that mining has only been attempted in one or two places. On the other hand, a very good body of ore has been found well to the north of the original outcrop. It is very limited in its area, however, paralleling the main reef for a very short distance. Its existence has proved a constant source of argument among geologists for many years. As the wonderful possibilities of the Rand became appreciated engineers of marked ability devoted their attention to the recovering of the ore. A system of mining was evolved which looked well into the future. It is very questionable if even at this time the real value of this tremendous body of gold bearing ore was appreciated.

Originally all of the winding engines were steam-driven. Later some comparatively small isolated electric plants were put down and the winders were electrified. This in some instances did not show the saving hoped

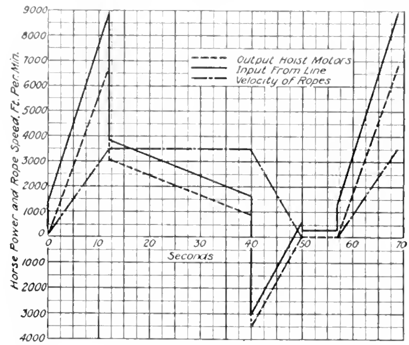
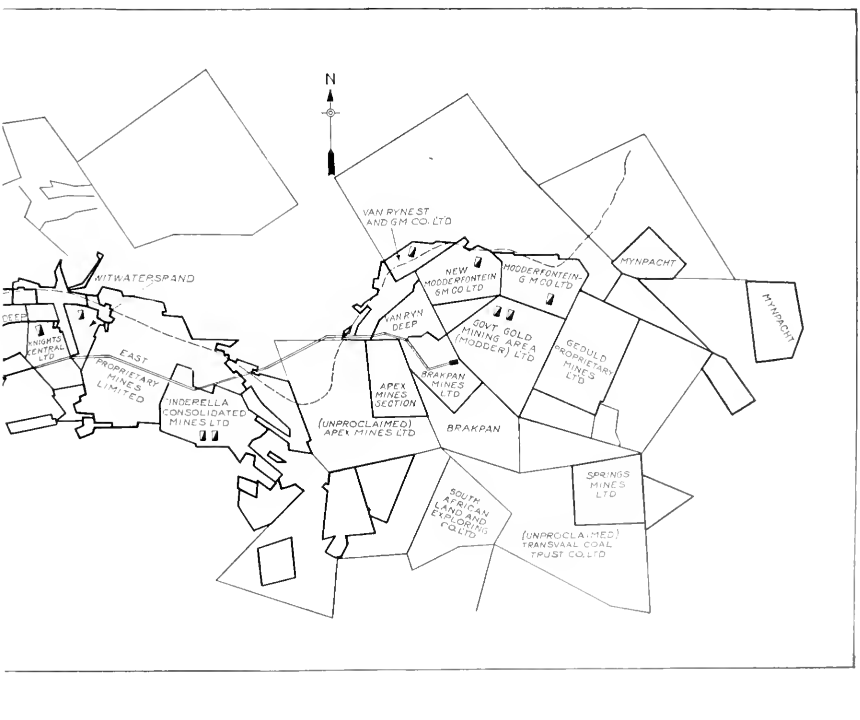


Fig. 2. Duty Cycle when Winding from the 2260-ft. Level



for due to the poor load factor of the small plants. It was not until the Victoria Falls Power Company erected its plants and ran its power lines the entire length of the Rand that electrification was really well started.

In connection with the Victoria Falls Power Company it might be well to explain that this plant is entirely steam-driven and not as the name would seem to indicate a hydro-electric installation. The company originally contemplated the harnessing of the great Victoria Falls some 600 or 700 miles north of Johannesburgh, but the difficulties which would have been encountered in carrying a high tension transmission line for such an extreme distance through an absolute wilderness led to the abandonment of this scheme. The company decided to put down a large steam plant in close proximity to the gold mine field This was done, and today the Victoria Falls Power Company has in operation at its various plants a capacity of approximately 220,000 kw. all available for mining purposes.

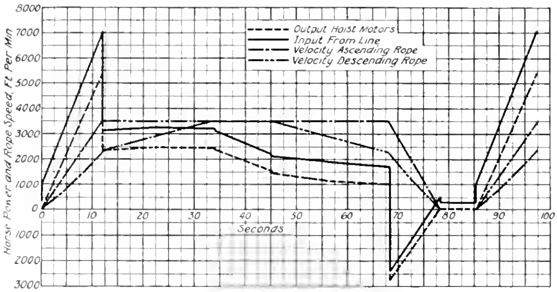


Fig. 3. Duty Cycle when Winding from the 3540-ft. Level

As soon as a constant source of power was assured the electrification of the mines was taken up most energetically. Electrical manufacturers in Europe and this country were flooded with inquiries for all classes of apparatus. The bulk of the early business was divided between the German and English markets. In recent years, however, the worth and sterling quality of apparatus manufactured by the General Electric Company became appreciated and today America is receiving its share of the South African mining business.

The map shown by Fig. 1 will give a very fair idea of the amount of business that has come to this country from the South African mines in hoisting appliances alone. The location of each of the hoisting equipments built in Schenectady is plainly marked on this map.

The power transmission lines may be seen on the map running from one end of the reef

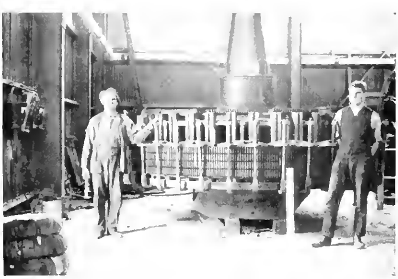


Fig. 4 Armature Core Construction of Hoist Motor

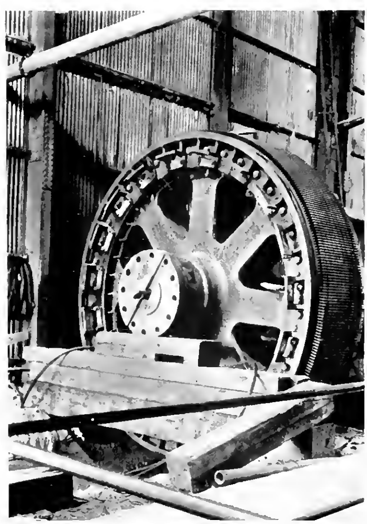


Fig. 5. The Armature Core Assembled

to the other. In some instances parallel circuits are run. There are two principal generating stations, the prime movers being steam turbines. The outcrop of the reef is shown as a broken line along the northern end of the properties.

In September, 1912, specifications were issued by the engineers of the Rand Mines Limited for a hoisting equipment for their own Crown Mines, South Rand shaft. The principal data submitted was as follows:

Depth of shaft	3540 ft.
Inclination of shaft to horizontal	90 deg.
Weight of ore per trip	16,000 lb.
Weight of skip	8700 lb.
Size of rope	2 in.
Weight of rope per side	22,300 lb.
Type of drum	Double cylindro-conical
Diameter of rope centers at small end of drums	12 ft.
Diameter of rope centers at cylindrical end of drums	20 ft. 8 in.
Number of turns of rope on cone	25 turns.

Fig. 6. Drawing on the Commutator of the Hoist Motor

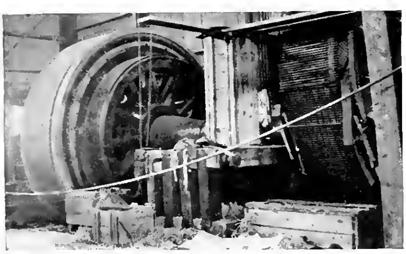


Fig 7. Motor Armature Assembled

Number of turns of rope on cylinder, 1st layer	21 turns.
Number of turns of rope on cylinder, 2nd layer	14 turns.
Maximum rope speed, ft. per minute	3500 ft.
Maximum r.p.m. of drums	53.5 r.p.m.
WR^2 of revolving parts of hoist (less motors)	15,810,000 lb. ft.
Time for acceleration	12 sec.
Time for retardation (assumed)	10 sec.
Rest period	7 sec.

Fig. 8. Motor Magnet Frame Assembled

The equipment was to consist of two direct connected motors for driving the hoist and motor-generator set made up of an induction motor and two direct current generators, all the direct current machines being wound for 550 volts, both the motors and generators being operated in series. The motor speeds were to be controlled by varying the voltage of the generators which were to be separately excited. Duty cycles were made up showing the operation of the hoist when lifting from the deepest level and also when lifting from intermediate levels. Fig. 2 shows the input from the line to the induction motor, the output of the hoist motors and the rope speed when hoisting from the 2260-ft. level; while Fig. 3 shows the operation of the hoist when lifting from the 3540-ft. level. It is interesting to note that while hoisting from the upper levels as shown in Fig. 2 the rope never leaves the cylindrical portion of the drums; on the other hand, while lifting from deeper levels the conical effect of the drum is used. It was found

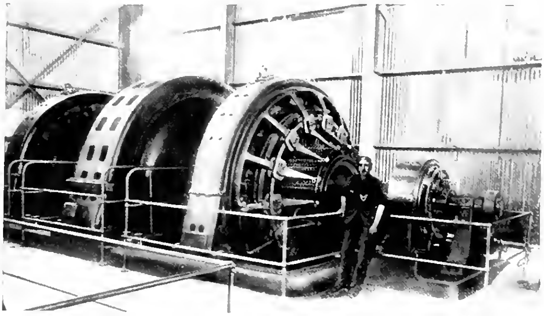


Fig. 9. Three-unit Motor Generator Set

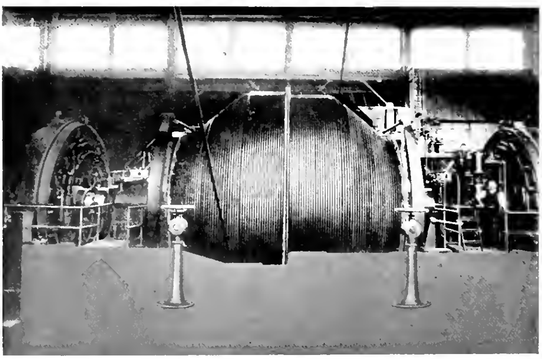


Fig 10. Side View of the Complete Hoist

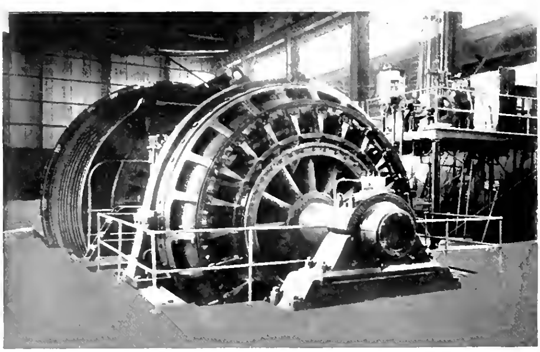


Fig. 11 End View of the Hoist

that the heating of the apparatus when winding from the higher levels was considerably in excess of that developed when winding from the deeper levels. To meet the duty cycles the following apparatus was supplied:

Two 22-pole, 2000-h.p., 53.5-r.p.m., 550-volt, shunt wound motors.

One 4-unit, motor-generator set consisting of:

One 16-pole, 5000-h.p., 375-r.p.m., 2000-volt induction motor

Two 14-pole, 1650-kw, 375-r.p.m., 550-volt, shunt wound generators

and

One 60-kw. compound wound exciter together with the necessary control apparatus.

On account of the size of the motors it was found that they would have to be shipped completely disassembled and built up on the scene of operation. The cast steel spiders of the armatures of the motors being the largest individual parts.

Fig. 4 shows the building up of the armature laminations for one of the direct-current hoist motors, Fig. 5, the armature core assembled, and Fig. 6 the commutator shell being drawn on the shaft, while Fig. 7 illustrates the completely assembled armature. Fig. 8 shows the magnet frame of one of the hoist motors ready to put in place. Fig. 9 illustrates the completely assembled motor generator set some time after operation had begun. Figs. 10 and 11 will give an excellent idea of the general arrangement of the motors and drums.

This equipment has been in operation for over a year and no delays or troubles of any kind have been experienced. In fact an order has been awarded for an almost exact duplicate equipment for the New Modderfontein mines.

CONTINUITY OF SERVICE

By Jas. R. Werth

Lighting Department, General Electric Company

The author first discusses some methods of preventing interruptions of service, especially emphasizing the importance of current limiting reactances for this purpose. Other interruption-preventing devices are also dealt with. The seriousness of even short interruptions of power supply are shown by citing the loss in various industries incident to such delays. The author also tells of several interesting schemes devised to insure continuity of service in different practical instances.—Editor.

Jas. R. Werth

THE investment of capital to secure continuity of service in a large central station is essential under modern conditions where electric energy is employed in so many individual and domestic activities; as we have arrived at its stage where it is, practically speaking, indispensable in our every day lives.

One must expect accidents and breakdowns of individual generators, substation units, switches, feeders and distributing transformers; but a careful study of any system should indicate many ways in which the troubles may be localized and limited to that part or section of the system where it originated.

One of the successful methods of reducing the number of interruptions to service and of localizing the trouble when interruptions do occur has been found in the use of current limiting reactances. In the case of a central station of 10,000 kw. capacity which experienced 76 partial shut-downs in a year and after installing current limiting reactances, reduced the number of interruptions per year to 17, it would seem that the commercial desirability of the installation was established beyond a reasonable doubt. Current limiting reactors are high-grade protective devices, and, in approximating their probable value in dollars, the matter has to be looked upon largely from the standpoint of insurance, since their function is to decrease the risk of interruptions of service and of damage to apparatus, cables, busbars, switches, etc., caused by short-circuits or surges of current.

For example, assuming the case of a 100,000 kw. generating station with three-phase, 13,200-volt, 5000-kv-a. feeders rated about 200 amperes, the cost of suitable feeder reactors for such a system would probably be in the neighborhood of $900 per three-phase feeder. This is about 40 per cent less than the cost of the double-throw, motor-operated oil switch necessary to connect the feeder selectively to the main generating bus, or to the auxiliary bus. The price is about 50 per cent less than 1000 ft. of the underground leaded cable that will be used on such a feeder, which would probably be three-conductor, 250,000 c.m. paper covered; so that from the viewpoint of comparative costs, the reactance is not an expensive piece of apparatus. The advantages resulting from reducing the rush of currents into short-circuits are many and varied. For example, reactances may be installed in the generator leads. In this case, the function is to protect the generator winding and the station bus from the severe strains and the resulting distortions which may be caused when a short-circuit occurs on the generator bus, and the current surges from the generator into the bus. This location of the reactors is equally useful when the short-circuit occurs internally, that is, in the windings of the generator.

Bus sectionalizing reactances may be installed in order to segregate, or to partially isolate, a section of the bus where three or four generators are used to feed one section. Such an installation is obviously of value in localizing a short-circuit by confining its effect largely to that section of the bus where it occurs.

Feeder reactances also have this function of localizing trouble and, in addition to this, when a short-circuit occurs on the feeder, they are capable of consuming the entire voltage drop, thereby preventing an undue fall of potential on the generator busbars. The value of this in maintaining continuity of service is obvious, because, if the voltage on the station generator bus drops suddenly, due to a short circuit, the result may be that the synchronous apparatus on the far end of all the various feeders connected to the bus will fall out of step and valuable time will be lost before the machines can be again started.

The building of current limiting reactances is, at first glance, apparently such a simple matter that there is great danger that the inexperienced may attempt to construct them without realizing all the various points, which must be considered for a satisfactory design, and which can be learned only after years of designing, building and use.

It is most essential that current limiting reactances should be of very rugged construction. Any attempt to build them by laying cable loosely within the slots of some insulating material is apt to result disastrously, due to the reactance breaking down mechanically and electrically at the time of short-circuit. This is because the current rush causes very great mechanical strains, and a correspondingly high induced voltage both between turns and between layers.

In summing up, the main point to be observed is that ruggedness of design with the resulting ability to resist distortion at the time of short circuit is the absolutely essential requirement of this device. A reactance of low first cost and of fragile construction (like a life insurance policy with a mushroom company) is apt to prove a very costly investment in the final analysis.

The superintendent of distribution of a 200,000-kw. central station expressed himself in regard to interruptions of service as follows:

"We seriously object to any apparatus being placed in a station or connected to a station that may cause an interruption or a total shut down. An operating company cannot afford to have a total shut-down at any time and they attempt to maintain the voltage uniformly on their busbars. If a uniform voltage can be maintained at the station busbars, it is reasonable to suppose that satisfactory service will be supplied to its various substations. We do not figure on any interruptions to service due to cable burn-outs. In order to protect ourselves from this, we supply current to each substation from more than one cable, and place on this cable a set of reactances to limit the current flow in order that the voltage may be maintained on the station bus, which, in turn, will maintain uniform voltage on feeders other than the one that may have been damaged. During the past year, we have had approximately 5 cable burn-outs, none of which seriously affected the service supply from a substation."

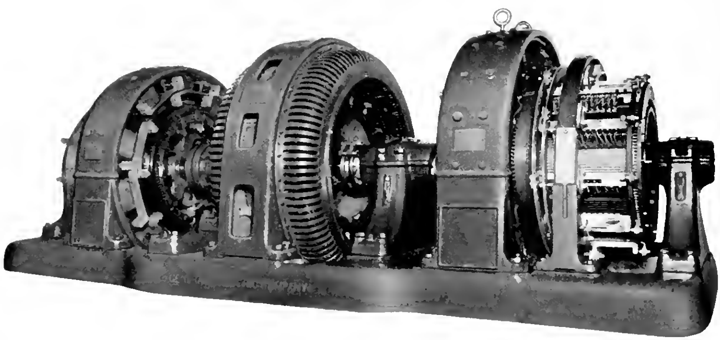


Fig. 1 Three-unit Synchronous Motor Generator Set

The induction meter type overload relay shown in Fig. 2 fills a long-felt need for a device to secure selective tripping of oil switches through varying conditions of operation. In other words in case of a short-circuit on one of several feeders going out from a generator bus, an equipment of accurate overload relays such as are shown in Fig. 2, will insure the oil switch controlling the defective feeder tripping open, and the oil switches controlling the remaining feeders staying closed.

A central station in the Middle West generates hydro-electric power at a considerable distance from its center of distribution, at which point they use large synchronous motor-generators to convert a part of the power from a-c. to d-c. for their Edison system. Synchronous motor-generators are used rather than a more efficient rotary converter equipment in order to operate them at 0.7 power-factor leading and, thereby, supply leading or magnetizing current to the a-c. system to keep up its power-factor.

Instead of buying a standard two-unit motor-generator, however, the consulting engineers of this station purchased a three-unit set with a 0.7 power-factor motor in the middle, direct connected to a 1500-kw. 250-volt 3-wire generator at each end. The generators normally operated in multiple with each other feeding the Edison 3-wire system. The couplings are so located, as may be seen from the photograph, that in case of serious trouble with one generator, the damaged machine may be uncoupled, and the remaining generator and the motor operate as a 2-unit set supplying the 250/125-volt feeders.

It should be noted that this is an entirely different arrangement for the old scheme of operating two generators each wound for 125 volts in series with each other.

Incidentally, this engineer secured not only a marked improvement as regards continuity of service, but, also, paid less and achieved a higher efficiency than he could have secured with any other arrangement of motor-generator sets.

He even carried this scheme of operation to his railway substation, using there a 3-unit set with a synchronous motor and two 600-volt generators operating in multiple to deliver current to his 600-volt railway feeders.

A central station selling current from its 600-volt rotary converter substation to a street railway faced the complaint that for about an hour during the peak-load period, the voltage at the car motor terminals was too low, due to excessive line drop in the d-c. feeders and trolley circuit at that time. The rotary converter transformer was equipped with the usual taps which would permit the rotary to be operated at a higher direct current voltage than normal, but, obviously, the transformer connection could not be "broken" from the normal voltage tap and then "made" to the low voltage tap as the peak load came on without interrupting the service.

This problem was solved by closing the oil switch leading to the high voltage tap before opening the switch leading from the normal voltage tap, and preventing the included section of the transformer from being short circuited (during the period of time when both switches were closed) by judicious use of current limiting reactances with iron cores, thereby securing both good voltage regulation and continuity of service with a minimum of expense.

Water-cooled transformers have sometimes been put out of commission owing to the failure of the supply of cooling water. The

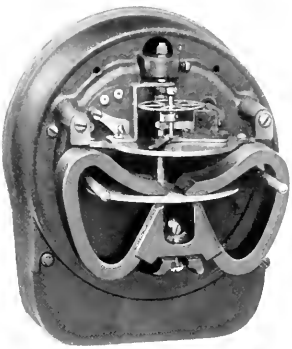


Fig. 2. New Induction Meter Type Overload Relay

water-cooled transformer shown in Fig. 14, page 445 of this issue, by means of its radiator tank for conducting away the heat can be operated at half load without water (or as a self-cooled unit), so that one of the causes of interruption to continuity service can be eliminated by its use.

The superintendent of the Electrical Department of a large steel works was asked, "What is the minimum length of time a steel plant could permit a complete failure of its electric power supply without causing losses other than production?" He replied, "It is not production losses which are to be weighed in such a case, but the liability of serious accidents to equipment and fatal accidents to employees.

For instance, at all our metal mixers we not only provide extra feeders from various sources wherever possible, but do away with all overload devices; this to absolutely prevent failure of power and a consequent spilling of metal—troubles now being experienced through the country.

Another instance, not as serious as the foregoing, is the liability of charging and drawing machines being burned up on account of becoming inoperative while in the heated zone. Other cases are the cobbling of steel in rolling mills, danger of putting plant in darkness. All of these irregularities strictly prohibit the entire loss of power for even the slightest interval of time around a steel mill.

At our plant, as far as I can remember, we suffered total loss of power in only one instance, and we had considerable trouble when starting up, as practically all motors on the plant were in a waiting attitude for starting simultaneously, which of course, overloaded all feeder lines."

The losses to the ultimate consumer may be entirely out of proportion to the length of time of the interruption of his power supply.

For example, a half-minute shut-down in a paper manufacturing plant will probably mean a delay of an hour or more, owing to the paper web breaking and to the laborious job of cleaning the wire screen conveyer belt which carries the stock. Or else, in the case of a cement mill, a half-hour interruption may cause the revolving kiln to become so hot in one place, (due to the fact that that particular spot is not rotated away from the position of greatest heat), that the kiln will either be warped, or else, if means are taken to cool it, the loss of the heat will run up to a figure several times the amount of the power bill for the entire day.

In case of a foundry, it is absolutely necessary that the blowers of the blast furnace be capable of rendering continuous service. If the power service be suddenly interrupted at a critical time, the result may be that the cupola will have to be completely destroyed, in order to remove the suddenly congealed iron.

Many mechanical manufacturing plants operate twenty-four hours per day seven days out of a week, and the question of continuity of service will generally be the deciding factor as to whether they operate a power plant of their own, or whether they purchase central station power.

A SMALL TURBINE FOR DIRECT CONNECTION OR GEARING

THE TYPE L

By Richard H. Rice

Turbine Engineering Department, General Electric Company, Lynn, Mass.

The author gives a concise description of a new small turbine unit telling its uses and describing some of the principal features of design. Some of the most notable features are shown in the illustrations and the variation of efficiency with power is given in the form of a curve.—Editor.

Richard H. Rice

A recent addition to the line of Curtis turbines is a small unit, known as the Type L turbine, that has been developed for driving a-c. and d-c. generators through gearing, and for various mechanical applications, such as the operation of pumps, either by direct coupling or through gearing. When coupled direct the speed of the driven shaft will be that of the turbine, viz., 1200 to 3600-r.p.m., while if geared, the gear ratio will be chosen to give best results. The customary speed for d-c. generators and 60-cycle alternators for use with this turbine is 1200-r.p.m., which requires a gear ratio of 3:1.

The experience that was availed of in the production of this turbine began in 1903, and was gained through the design, construction, test and commercial operation of several thousand units of similar rating. This experience was supplemented by an exhaustive study of the constructional features and economical performance of all turbines in commercial use, so far as any information (of which a considerable mass was in hand) was available.

All possible simplification has been embodied in this turbine, as this feature makes for reliability and ease of operation, and entails less attention in service; further, it helps in dismantling for repair or renewal and decreases first cost. Care has been taken, of course, to insure that no loss of effectiveness has resulted from this simplification.

The study which has been given to this design has resulted to a marked degree in an effective use of material. The effort was made to dispose the material in such a manner as best to resist the stresses involved in operation. As a single example may be mentioned the fluting or radial corrugations of the front head and diaphragm. This construction provides great stiffness to resist the steam pressure, with a minimum of material. Different designs which have been made indicate the real advantage of the construction. In this same manner every detail of the construction has been scrutinized. The resulting whole is an assemblage of parts, each of which is the survival of the fittest.

The performances of many turbines that are in commercial service, and have been for a sufficient length of time to furnish valuable experience, have been such as to indicate the full success of the design.

The characteristics which were sought were:

Inherent efficiency (i.e., good water rate)
Flexibility as to water rate for a given output
Adaptability to the varying conditions of installation
Reliability under favorable and unfavorable conditions
Pleasing appearance
Economy of manufacture.

Fig. 1. Inlet Side Second Stage Diaphragm Type "L" Curtis Steam Turbine

In considering the question of efficiency it must be realized that, design for design, efficiency depends intimately upon cost. For a certain cost it is only possible to obtain a certain efficiency. If a better efficiency be desired, another stage or stages must be added, and the cost will be correspondingly increased. This design possesses great flexibility in efficiency, which means that the number of stages can be readily varied, and the correct number to meet specific conditions chosen almost at will.

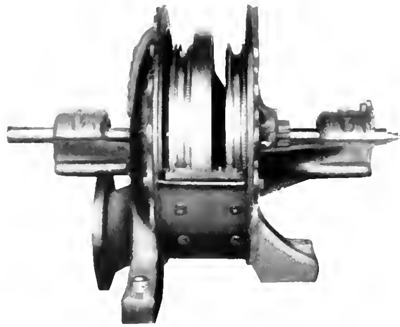


Fig. 2. Two Stage Type "L" Curtis Steam Turbine with Upper Half of Wheel Casing Removed

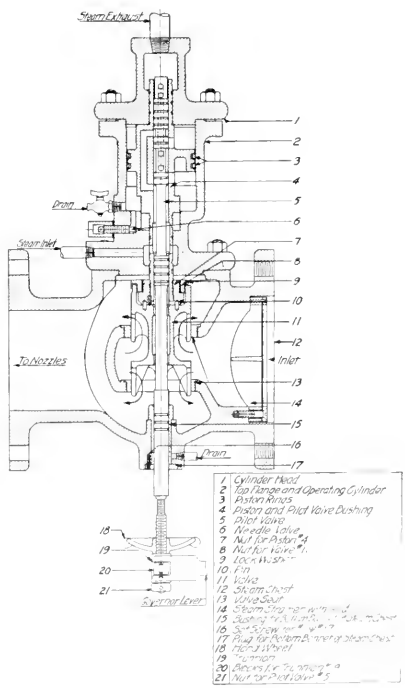


Fig. 3. Assembly of Valve Gear Pilot Valve Type Type "L" Curtis Steam Turbine

The Type L turbines are suitable for rated outputs varying from 50-kw. to 300-kw. and 20-h.p. to 400-h.p.

In general, three water rates are available for a given output, speed, and steam conditions, with corresponding costs.

The conditions met with in practice as regards speed, steam pressure, superheat, output, etc., are so widely different that no specific figures can be given in this place. It is sufficient to say that the exhaustive comparisons previously spoken of indicate that, considering cost and water rate together, the characteristics of these units are excellent.

A word as to the methods of governing may be interesting. For ordinary purposes the speed control is effected by a powerful shaft governor acting through a bellcrank that is coupled directly to the main throttling valve stem. This method suffices amply for ordinary service and for throttling valves of moderate dimensions. Where the throttling valve is larger, on account of low steam pressure or large output, or where the governing must be such as to maintain the speed very accurately, a steam relay is used. With this device the governor no longer connects to the main throttling valve, but instead actuates a pilot valve. This pilot valve controls the flow of steam to and from a piston which is rigidly connected to the main throttling valve, the regulation being such that movements of the pilot valve originating in the shaft governor are followed accurately by movements of the piston and main throttling valve. The advantage of this arrangement is that steam at boiler pressure, acting on the piston, is available to move and control the main valve, while the force needed to be exerted by the governor is negligible.

With this simple and effective device regulation of speed to any practical degree of fineness is readily obtainable.

It is possible in certain special cases to so arrange the governor that operation at either of two definite speeds may be had by a slight adjustment.

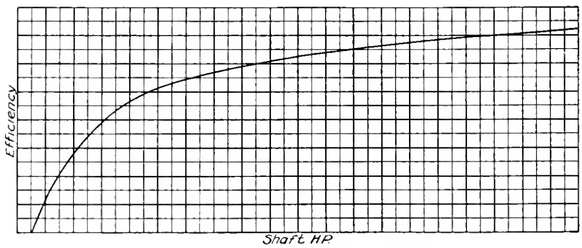


Fig. 4. Variation of Efficiency with Power. Type "L" Turbines

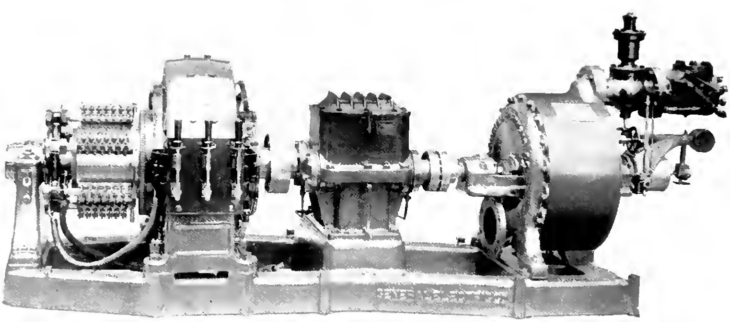


Fig. 5. Small Curtis Steam Turbine Geared to Direct Current Generator

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

THE EFFECT OF RAIN, MOISTURE, DUST, ETC. ON THE SPARK-OVER VOLTAGE OF GAPS

It is often of use in design to know approximately the effect, on the spark-over voltage, of foreign material on various electrode surfaces, for instance, the effect on the sphere gap spark-over voltage of moisture on the sphere surfaces. Data will be given here for three typical forms of electrodes; the sphere, parallel wires and points. We have given most of this data before but, as it appears that this is not generally realized, it seems well to review it here.[1]

Spheres

Table I gives the effects of various foreign materials on the spark-over voltage of 12.5 cm. spheres at 5 and 10 cm. spacings.

TABLE I

Condition of Sphere Surface 12.5 Cm. Spheres 60 Cycles	5 CM. GAP		10 CM. GAP	
	Kv. Arc Over	Per Cent of Normal	Kv. Arc Over	Per Cent of Normal
Polished Spheres	91	100	151	100
Surface Oxidized by Weather and by HNO_3	91	100	151	100
Thin Coating of Oil	91	100	151	100
Thin Coating of Dry Dust	89	98	148	98
Excessive Pitting (craters 0.4 m.m. deep and beads about 0.25 m.m. in height)	82	90	114	75
Heavy Coating of Oil and Sand	80	87	115	76
Thin Coating of Ice	80	87	115	76
Coating of Copper Chloride Crystals about 1.25 m.m. thick	80	87	118	78
Thick Coating of Rough Ice	73	81	100	67
Rain 0.2-in. ppt. per min. (Polished Spheres)	39	42	58	39
Rain 0.2-in. ppt. per min. (Pitted Spheres)	39	42	58	39

With surfaces wet the effect may be almost as much as that due to rain. The spark-over voltage is determined by the amount of moisture on the electrode surface and not by the drops in the air. Conducting dust may have an effect similar to moisture.

It may be pointed out incidentally that an examination of the table shows that no trouble, due to surface conditions, need be experienced in making voltage measurements with the sphere gap if ordinary precautions are taken. Although oxidation causes no appreciable error, it is desirable to keep the surfaces fairly well polished to prevent the collection of foreign materials. Dry dust does not cause a large decrease in spark-over voltage. Occasionally, due to lint from the wiping cloth, the first spark-over is low, but the foreign material is immediately blown or burned away and successive spark-overs are of normal value. The excessive pitting, listed previously, does not occur in making measurements, but was intentionally caused by drawing out arcs at low voltage and very high current. The greatest possible cause of error is from free moisture on the *electrode surface* due to condensed steam, spray, moist dust, etc. The cause of the low spark-over voltage when the electrodes are coated with moisture is quite apparent; if the wet electrodes are viewed in the dark, just before spark-over occurs conducting sprays and brushes are seen to be blown from the surfaces, giving very much the appearance of an illuminated atomizer.

Wires

Ordinary weathering on transmission line wires may reduce the corona-starting voltage to 90 per cent of that for the polished state. The spark-over voltage is less affected. Moisture, or rain, on the wire surfaces may lower the visual corona and spark-over voltage to 50 per cent of the dry surface value. During rain the decrease in voltage is not governed as much by the drops in the air as by the amount of moisture on the electrode surfaces. Oil on the wire surfaces does not greatly lower the corona voltage but may considerably lower the spark-over voltage. Ice may affect the corona voltage almost as much as water.

Points

Points, as would be expected, are not greatly affected by foreign material, rain, etc., as the stress at the point is already at a maximum.

This data is not given for correction in spark gap measurements as there is no excuse for so placing a measuring gap that such corrections are necessary. It is given for use in estimating the spark-over voltage of certain apparatus subjected to weather, etc. For this reason the three common types of fields are discussed.

F. W. P., Jr.

[1] F. W. Peek, Jr., "Dielectric Phenomena in High Voltage Engineering."—Chaps. III and IV.
F. W. Peek, Jr., A.I.E.E., June, 1911; June, 1912; August, 1915.

GENERAL ELECTRIC REVIEW

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VOL. XIX, No. 7 — JULY, 1916

CONTENTS

BERNARD E. SUNNY

President of the Central Group of Bell Telephone Companies

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

It is with great pleasure that we publish in this issue an article by Dr. W. R. Whitney on Research Organization. We have constantly urged the importance of this work in our columns and have made a continual practice of publishing the results achieved by industrial research, as we have always recognized that the future industrial prosperity of the country must be largely dependent upon the work of research organizations.

The substance of the article under consideration outlines the scope of the Newlands Bill, at present under consideration by Congress, and reviews the work along similar lines being undertaken by other English-speaking countries.

The history of this article is not without interest. It was originally prepared for the June REVIEW, but as our last impression was a special issue, it was reserved for the July number, but in the meanwhile copies of it were sent to the Committee of One Hundred of the American Society for the Advancement of Science, the Editors of the principal Chemical, Physical and Metallurgical Journals, and to about one hundred other prominent gentlemen interested in science and manufacture, as well as to each member of the Naval Consulting Board. The latter body unanimously approved of the Bill. In addition to this gratifying approval, answers have already been received from over sixty, of which only seven have been anything but enthusiastically favorable.

The criticisms have been directed against three points; the inadvisability of making numerous small grants instead of using the total sum for the establishment of a single large laboratory; the fact that many of the grants will fall into the hands of institutions which have not heretofore produced research work and so be wasted; the designation as "Engineering" or "Mechanic Arts" experiment stations which is construed by some to overlook chemical investigation.

Although the absence of special reference to chemistry among the "Mechanic Arts" might raise the question as to its possible exclusion, we believe common experience has shown that in most undertakings in material research, physical and chemical researches are such inevitable factors that the mention would be superfluous.

In regard to the waste of inexperienced men, it should be pointed out that in the nature of research not every separate investigation is a "paying proposition" however well accredited and efficient the laboratory in which it is carried out. But, the aggregate has always "paid." Again, why not give the unknown man a chance? He may surprise you yet.

Of the work of the agricultural experiment stations, which represent an exactly parallel method of applying money, an Englishman, M. C. Cooke has written: "I note with great gratification the immense development of this branch of study (plant diseases) on your side, which puts us to shame. Your experiment stations are fine institutions. . . . I care not who does the work, only I am delighted to see it is being done, and between ourselves, to realize that it is being done by an English-speaking race and not by Germans or Frenchmen."

The scattering of the benefits of the act among the individual states is perhaps the greatest advantage of the bill and has been so regarded in many of the replies. We believe that it can be demonstrated by the experiment of the Newlands Bill that there are and have long been in many colleges groups of men who could and would do good research work if they were permitted or encouraged. They might and probably would collect about them in a few years post-graduates and men doing advance work, which would then warrant greater expenditures. We think the scheme of distributing this small amount to the different land grant colleges is one of the best and quickest ways of discovering the possibilities; and if this scheme were organized under the Department of the Interior, so as to coöperate with other departments as planned, no scheme we can think of would be better.

If the amount of money represented by the Newlands Bill proposal were centered in a single organization, it would not, to our mind, serve the purpose half as well. In the first place, it would not discover the men in the various colleges who are now in a position to do advanced scientific work. It would cut out local interests and possible state appropriations, and would not take advantage of the enormous amount of available apparatus in the colleges.

This experiment station scheme should contribute a good foundation for scientific coöperation throughout the country.

RESEARCH ORGANIZATION

By W. R. Whitney

Director Research Laboratory, General Electric Company

We have constantly emphasized the importance of industrial research work in the Review; the present article will show how widespread the recognition of this work is becoming. The substance of the Newland's bill before Cengress is given, and the author reviews the official activities as regards research work in the most important English speaking countries. We recommend this article to our readers as being worthy of careful consideration.—Editor.

When the war is over it will probably be found that there has been established in many countries a much more methodical and extended interest in, and support of, research than existed before. While it was Germany that set the example for half a century, there was a tendency in America to follow her example even before the war. The American Association for the Advancement of Science had, in 1914, appointed a Committee of One Hundred to promote coöperation between the industries and universities. Scientific journals frequently published articles upon the subject, but the advance was slow. The awakening which the war produced has led to vigorously renewed activity, and a partial summary of the efforts already made among the English speaking nations may be interesting. This is the more fitting at this time because of the U. S. Senate Bill 4874, recently introduced into Congress by Senator Newlands, of which the substance is as follows:

"That in order to aid in acquiring and diffusing among the people of the United States useful and practical information on subjects connected with engineering and the other branches of the mechanic arts, and to promote the scientific investigation and experiment respecting the principles and applications of the mechanic arts, there shall be established under the direction of the land grant college in each State or Territory. . . . . a department to be known and designated as an "engineering" or a "mechanic arts experiment station."

"That it shall be the object and duty of said experiment stations to conduct original researches, to verify experiments and to compile data in engineering and in the other branches of the mechanic arts as applied to the interests of the people of the United States, and particularly of such as are engaged in the industries; also to conduct researches, investigations and experiments in connection with the production, transportation, extraction and manufacture of substances utilized in the application of engineering and of other branches of the mechanic arts to industrial pursuits; . . . .

"That bulletins giving results of investigations or reports of progress shall be published. . . . . .

"That, for the purpose of paying the necessary expenses . . . . . . the sum of fifteen thousand dollars per annum is hereby appropriated to each State and Territory, ...

"That in order to secure, as far as practicable, uniformity of methods and economical expenditure of funds in work of said stations, the supervision of the proposed experiment stations shall rest with the Secretary of the Interior."

In other words this Bill proposes to so supplement and extend the research bureaus of the United States government that all branches of industry shall have the same advantages that agriculture already enjoys. It gives recognition to the fact that, as the basis of all industrial progress and substantial prosperity, scientific research is as much a governmental function as is education, of which it is indeed merely the creative phase.

In Great Britain the Board of Education is putting forth a "Scheme for the organization and development of scientific and industrial research." It "is designed to establish a permanent organization for the production of industrial and scientific research," and particulars were given in a report issued on July 26, 1915. [Journal of the Society of Chemical Industry *34*, 783 (July 31, 1915).]

The scheme provides for the establishment of:

(a) A Committee of the Privy Council responsible for the expenditure of any new moneys provided by Parliament for scientific and industrial research;

(b) A small Advisory Council responsible to the Committee of Council and composed mainly of eminent scientific men and men actually engaged in industries dependent upon scientific research.

The Committee of Council will consist of the Lord President, the Chancellor of the Exchequer, the Secretary for Scotland, the President of the Board of Trade, the President of the Board of Education (who will be Vice-President of the Committee), the Chief Secretary for Ireland, together with such other Ministers and individual members of the Council as it may be thought desirable to add.

. . . .

The first members of the Council will be: Rayleigh, Beilby, Duddell, Hopkinson, M'Clelland, Meldola, Threlfall, with M'Cormick, as administrative chairman.

The present scheme is designed to establish a permanent organization for the promotion of industrial and scientific research.

It is in no way intended that it should replace or interfere with the arrangements which have been or may be made by the War Office or Admiralty or Ministry of Munitions to obtain scientific advice and investigation in connection with the provision of munitions of war. It is, of course, obvious that at the present moment it is essential that the War Office, the Admiralty, and the Ministry of Munitions should continue to make their own direct arrangements with scientific men and institutions with the least possible delay.

It is clearly desirable that the scheme should operate over the kingdom as a whole with as little regard as possible to the Tweed and the Irish Channel. The research done should be for the kingdom as a whole, and there should be complete liberty to utilize the most effective institutions and investigators available, irrespective of their location in England, Wales, Scotland, or Ireland. There must therefore be a single fund for the assistance of research, under a single responsible body.

It is obvious that the organization and development of research is a matter which greatly affects the public educational systems of the kingdom. A great part of all research will necessarily be done in universities and colleges which are already aided by the State, and the supply and training of a sufficient number of young persons competent to undertake research can only be secured through the public system of education.

The primary functions of the Advisory Council will be to advise the Committee of Council on

(i) Proposals for instituting specific researches.

(ii) Proposals for establishing or developing special institutions or departments of existing institutions for the scientific study of problems affecting particular industries and trades.

(iii) The establishment and award of Research Studentships and Fellowships.

The Advisory Council will also be available, if requested, to advise the several Education Departments as to the steps which should be taken for increasing the supply of workers competent to undertake scientific research.

Arrangements will be made by which the Council will keep in close touch with all Government Departments concerned with or interested in scientific research and by which the Council will have regard to the research work which is being done or may be done by the National Physical Laboratory.

It is essential that the Advisory Council should act in intimate co-operation with the Royal Society and the existing scientific or professional associations, societies, and institutes, as well as with the universities, technical institutions, and other institutions in which research is or can be efficiently conducted.

It is proposed to ask the Royal Society and the principal scientific and professional associations, societies, and institutes to undertake the function of initiating proposals for the consideration of the Advisory Council, and a regular procedure for inviting and collecting proposals will be established. The Advisory Council will also be at liberty to receive proposals from individuals and themselves to initiate proposals.

It is contemplated that the Advisory Council will work largely through sub-committees reinforced by suitable experts in the particular branch of science or industry concerned. On these sub-committees it would be desirable as far as possible to enlist the services of persons actually engaged in scientific trades and manufactures dependent on science.

The Advisory Council will proceed to frame a scheme or programme for their own guidance in recommending proposals for research and for the guidance of the Committee of Council in allocating such State funds as may be available. This scheme will naturally be designed to operate over some years in advance, and in framing it the Council must necessarily have due regard to the relative urgency of the problems requiring solution, the supply of trained researchers available for particular pieces of research, and the material facilities in the form of laboratories and equipment which are available or can be provided for specific researches.

Office accommodation and staff will be provided for the Committee and Council by the Board of Education.

This is Great Britain's first step toward a general correlation of her industries with science, the necessity for which has been made overwhelmingly apparent by recent experiences.

In accordance with the tendency of the times the Commonwealth of Australia has initiated a similar movement, and an Advisory Committee appointed to formulate proposals to the Government in regard to the establishment of a "Commonwealth Bureau of Science and Industry" has already reported. [Nature *97*, 38-40 (March 9, 1916)].

"The proposals of the Committee are on lines somewhat similar to those of the British Government's scheme for the organization and development of scientific and industrial research. Primary as well as secondary industries are included, and particular notice may be directed to the recommendations as to the governing body of the proposed institute, by which, as consistently advocated in our columns, the balance of power is placed in the hands of men of science."

. . . .

The Committee, in formulating the following scheme, has been greatly impressed with the magnitude and the possibilities of the proposals made by the Prime Minister, and is strongly of opinion that the time has arrived for initiating the extensive scheme of scientific research work in connection with industry which he has outlined.

The Committee is convinced that the results of properly conducted investigations into many of the subjects referred to in his address will amply repay considerable expenditure and fully justify a bold and comprehensive policy being adopted. Not only will the results be a greatly increased productivity and output in many directions—in both primary and secondary industries—but the stimulus generally given to scientific research in relation to our industries will exert a powerful influence on our educational institutions and bring them and the industrial community to realize the commercial value of science more fully than hitherto. In fact, the initiation of the scheme will, in the opinion of the Committee, go far to inaugurate a new era in the economic and industrial life of the Commonwealth.

The proposals which follow will provide for the formation of a Commonwealth Institute of Science and Industry under the control of directors of the highest business and scientific attainment, acting with the advice and cooperation of a council representing science and the primary and secondary industries of Australia.

Recommendations

(1) There should be established under Act of Parliament a Commonwealth Institute of Science and Industry.

(2) The functions of the institute should be:

(i) To consider and initiate scientific researches in connection with, or for, the promotion of primary or secondary industries in the Commonwealth.

(ii) The collection of industrial scientific information and the formation of a bureau for its dissemination amongst those engaged in industry.

(iii) The establishment of national laboratories.

(iv) The general control and administration of such laboratories when established.

(v) To promote the immediate utilization of existing institutions, whether Federal or State, for the purposes of industrial scientific research.

(vi) To make recommendations from time to time for the establishment or development of special institutions or departments of existing institutions for the scientific study of problems affecting particular industries and trades.

(vii) The establishment and award of industrial research studentships and fellowships, to include either traveling fellowships or fellowships attached to particular institutions.

(viii) To direct attention to any new industries which might be profitably established in the Commonwealth.

(ix) To keep in close touch with, and seek the aid of, all Commonwealth and State Government Departments, learned and professional societies, and private enterprises concerned with, or interested in, scientific industrial research.

(x) The co-ordination and direction of scientific investigation and of research and experimental work with a view to the prevention of undesirable over-lapping of effort.

(xi) To advise the several authorities as to the steps which should be taken for increasing the supply of workers competent to undertake scientific research.

(xii) To recommend grants by the Commonwealth Government in aid of pure scientific research in existing institutions.

(xiii) To seek from time to time the co-operation of the educational authorities and scientific societies in the States with a view of advancing the teaching of science in schools, technical colleges, and universities, where its teaching is determined upon by those authorities.

(xiv) To report annually and from time to time to Parliament.

(3) The committee gave careful attention to the relation between the proposed institute and the existing Commonwealth Laboratory. It was recognized that the daily routine of Customs, naval and military stores, and other departments requires the performance of a great deal of important scientific work, particularly chemical analysis of material, and that the laboratories in which such routine scientific work is carried out must necessarily remain under department control, though they might with advantage be co-ordinated and their equipment increased. On the other hand, as the work of the proposed institute develops there will be an increased scope for work in national laboratories devoted to special branches of research and experimental investigation which are not otherwise provided for. Such laboratories and their scientific staffs should, in the Committee's opinion, be kept distinct and placed under the control of the institute.

In the future it will be necessary to undertake experimental work in connection with the growth of our naval and military defence, the testing of materials with regard to the physical reasons underlying deterioration and change of structure due to mechanical and heat treatment, and as to failure in operation under varying conditions, the testing and trying out of processes in connection with the metallurgical industry and biological and geological problems.

The highly specialized intricate work of standardizing electrical instruments and other scientific apparatus for use as substandards by different Government departments and other institutions in which research work may be carried on would also naturally fall within the functions of the institute.

A convincing reason for drawing a line of distinction between laboratories primarily for scientific research and laboratories primarily for the necessary routine work of departmental testing is that any attempt to combine the two would lead to confusion and hamper and weaken both branches of activity, and would tend to drown the research work for which the institute is being created.

It cannot be too strongly insisted that the qualifications of a staff for "researching" are different in character from those of a staff which is to carry out scientific routine testing.

The Committee therefore recommends that:

(a) The control of the present Commonwealth laboratories be not disturbed, but that they be co-ordinated, their staff increased, and their equipment improved.

(b) Any new national laboratories which may be created for special purposes of research and experimental inquiry, including a physical laboratory for testing and standardizing purposes, should be controlled by the institute.

(4) With regard to the constitution of the institute the Committee passed the following resolutions:

(i) "That an Advisory Council consisting of nine members representing science and the principal primary and secondary industries be appointed who shall advise and co-operate with the directors in framing the policy and in the administration of the institute."

(ii) "That the members be appointed by the Governor-General in Council."

(iii) "That for the purposes of controlling and administering the institute and of collecting and determining on the researches to be undertaken and directing their elucidation, three highly qualified salaried directors, of whom one should be chairman of the directors, shall be appointed by the Governor-General in Council. The directors shall seek the advice and cooperation of the Council and shall be ex-officio members thereof."

(iv) "That of the three directors one should be an expert business and financial man with ability in organization; the other two should be chosen mainly on account of scientific attainments and wide experience."

(v) "The tenure of the directors shall be fixed by the Act."

(vi) "That the scientific staff should be appointed by the Governor-General in Council on the recommendation of the directors."

(5) The Committee further resolved as follows:

(i) "That all discoveries, inventions, improvements, processes, and machines made by workers directly employed by the institute should be vested in trustees appointed by it as its sole property, and should be made available, under proper conditions and on payment of gratuities or otherwise, for public advantage."

(ii) "That the council of the institute should be empowered to recommend to the Government the payment of bonuses to successful discoverers or inventors working under the auspices of the institute."

(iii) "That the institute should be empowered to charge fees for special investigations subject to regulations approved by the Governor-General in Council."

(6) Though these matters are not directly connected with the proposed institute the Committee passed two further resolutions:

(i) "That steps should be taken with a view to co-ordinating the work of our technical colleges and trade schools throughout Australia, so that a supply of scientifically taught craftsmen will be available to support the expansion of industry that it is hoped will result from the operations of the Institute of Science and Industry."

(ii) "That with a view to promoting our export trade in Australian products it is desirable that serious attention be given to the study of modern languages, including Oriental languages, for commercial purposes."

(7) The Committee realizes that the establishment of the institute will necessarily involve some delay, but being impressed with the urgent need for work of the character proposed the Committee resolved as follows:

(i) "That until the institute is established an Advisory Council be appointed by the Governor-General in Council particularly to carry out the objects expressed in resolutions 2 (i) and (ii), viz.: To consider and initiate scientific researches in connection with, or for, the promotion of primary or secondary industries in the Commonwealth, and (ii) the collection of industrial scientific information and the formation of a bureau for its dissemination amongst those engaged in industry."

(ii) "That the Federal and State Munitions Committees, heads of the Commonwealth and State scientific departments, and bodies representative of Commonwealth manufacture, commerce, agriculture, mining, and engineering, the universities and technical colleges, and private enterprises, be invited to suggest branches of industrial scientific research in which investigation would be of immediate practical use to producers and manufacturers."

(iii) "That the Advisory Council be appointed forthwith, and that when appointed it immediately take steps to initiate research work into the most pressing matters needing investigation, and seek the cooperation of existing institutions and utilize the resources of staff and equipment at our disposal at the present time."

. . . .

. . . .

The Committee, however, suggests that ......most valuable work could be done in collecting data, and, in effect, making a preliminary census both as to present discoveries, and the staff and apparatus available in Australia. Such work is an indispensable first step in all research.

"In addition to this there is ample scope for practical work during the interval in vigorously prosecuting the dissemination of known information as to processes, etc., amongst our producers and manufacturers."

. . . .

Canada also appears to be following the general trend. Recently the "Royal Canadian Institute has inaugurated a bureau of scientific and industrial research, based upon the system in operation at the Mellon Institute." [Science, *43*, 455 (March 31, 1916).] Details are not available, however.

Representatives of the movement for governmental organization of research in all three of these countries have already inspected the various research organizations of America within the past few months to see what is being done.

At a discussion on "University and Industry" held on April 7th at the Chemists' Club in New York, Dr. Takamine stated that the Japanese government has just appropriated $1,000,000, for a laboratory for physical and chemical research, and that the Emperor has contributed an additional $500,000.

In the United States, scattered efforts toward a general coordination of industry and science have not been lacking. Preeminent among these has been Mellon Institute, of the University of Pittsburgh.

"This Institute [Journal of Industrial and Engineering Chemistry, 7, 343-7 (April, 1915)] represents an alliance between industry and learning, the possibilities of which may be said to be without limit.

"The alliance takes the form of what is known as "The Industrial Fellowship System." According to this system, an individual or a company having a problem requiring solution may become the donor of a fellowship by contributing to the Institute a definite sum of money, for a period of not less than one year. This money is used to pay the salary of the man or men selected to carry out the investigation desired, and the Institute furnishes such facilities as are necessary for the conduct of the work. The results obtained belong exclusively to the donor of the fellowship."

The idea of this system of practical cooperation between science and industry was formulated by Robert Kennedy Duncan, the late Director of the Mellon Institute, in 1906, while attending the Sixth International Congress of Applied Chemistry in Rome.

. . . .

"In 1911, Dr. Duncan was called to the University of Pittsburgh to inaugurate the system in the Department of Industrial Research, and the working of the fellowships began in a temporary building erected at a cost of about $10,000. In March, 1913, Messrs. Andrew William Mellon and Richard Beatty Mellon, impressed by the practical value of the system, both to industry and to learning, established it on a permanent basis through the gift of over half a million dollars. While the Institute is an integral part of the University of Pittsburgh and works in close sympathetic accord with it, it possesses an endowment of its own and is under its own management. The present annual expenditure for salaries and maintenance is over $150,000.

"The Company obtains from the Institute such research laboratory facilities as but few industrial concerns possess. Even more important, it obtains complete library facilities, which are so valuable for research work."

There is a scarcity of men gifted with the genius for research, and it requires much experience in selecting suitable men and in training them to the desirable degree of efficiency, after having determined the special qualities required. Important qualifications in industrial researchers are keeness, creative power, and confidence; these are often unconsidered by manufacturers who, in endeavoring to select a research chemist, are likely to regard every chemist as a qualified scientific scout. The men who are best trained for a particular problem are carefully chosen by the Institute and these work under the supervision of a staff experienced in handling industrial research problems. The Company thus secures at a comparatively small cost ideal conditions for working out industrial problems which would cost any single company probably from $60,000 to $70,000 each year to duplicate in a laboratory which it might establish in connection with its own factory.

. . . .

"There is about university work, as differentialted from the factory, freedom from interference, correct judgments concerning progress, and an atmosphere sympathetic to research.

"All these advantages, laboratory, library, consultative and inspirational, together with the supervision and administration of these Fellowships, the Institute offers gratuitously to any company having important problems offering a reasonable chance of solution, and it undertakes, as well, to surround the researches with the necessary secrecy."

. . . .

The University, under the agreement, fulfils its function in increasing the sum of knowledge; the fact that it is useful knowledge does not make it any less valuable. Furthermore, the right, after a reasonable time, to publish such knowledge is assured to the University. The University also obtains a highly trained staff of specialists as a faculty for a School of Chemistry and Chemical Engineering. Then, too, the University undoubtedly feels the stimulating influence of having in its midst a large body of trained investigators engaged in research work.

"At the present time (March 1, 1916) [Science *43*, 453, (March 31, 1916)] there are thirty-six fellowships and two additional ones have recently been arranged for, to begin later in the year. Sixty-three industrial fellows are engaged on the fellowships now in operation. The growth of the institute has about reached the stage where we shall be obliged to decline further industrial investigations for the present, since our laboratories are almost filled up to capacity.

. . . . . . "The experience of the industrial research institutions now in operation, which is certain to be drawn upon heavily in the movement to make the research work of the country national in both scope and effort, should be readily available for use by their prospective allies. Their entrance into this field should be warmly welcomed. No greater good fortune could come to the Mellon Institute, for example, than a division of labors with a number of similarly well-founded establishments." . . . . . .

Still in the tentative stage is the progress of the Committee of One Hundred on Research. The Pacific Coast Subcommittee has recently expressed its prospective policy in the following terms: [Science *43*, 457 (March 31, 1916).]

"1. The relation of advances in pure and applied knowledge to intellectual and economic progress and to good government should be made clear to individuals and to communities at every opportunity.

2. The publication of timely and accurate popular articles making known to the people the results of research should be encouraged.

3. The committee should be informed concerning researches now in progress in the Pacific region. This information need not be carried to extreme detail.

4. The committee should lend assistance to investigators who are handicapped in any way. In special cases it may be possible to assist with grants of money from the American Association, or from other sources."

. . . .

Among the subjects which have given this committee concern is the responsibility of scientists in the United States for the progress of research during and immediately following the European war. Will the impoverishment of governments curtail the support of science in Europe, or will the demonstrated efficiency of scientific methods induce the governments to maintain scientific research at a sacrifice of something else? Whatever the outcome may be, the obligations of American men and women of science to push forward the boundaries of knowledge are certain to be increased.

Within the universities themselves, there seems also to be a growing recognition of the responsibility and privilege of producing new knowledge which has been well expressed by Professor Wilson [Science *42*, 630 (November 5, 1915)] of Columbia University.

"We have heard of late an intimation that the universities have not been so much leaders of progress as "depositories of stationary thought." Well, depositories of stationary thought the universities indubitably have been, like the monasteries that they succeeded as centers of learning; and they have thus served as the guardians of a treasure that is beyond all price. But this is only half the truth; for it has long been one of our most cherished ideals that universities should also be the natural homes of original discovery and productive scholarship. The real universities—and I believe that our own is one of them—have demonstrated by their example that the atmosphere which these things create make teaching live and move."

SINGLE-PHASE ALTERNATING CURRENT MOTORS

By W. C. K. Altes
Induction Motor Department, General Electric Company
and N. Currie, Jr.
Assistant Engineer, Motor Engineering Department, Pittsfield

In our February and March issues, we published articles covering the polyphase series brush-shifting motors and in the present article we deal, from a practical standpoint, with the most interesting features of the single-phase constant-speed motor and also with those for variable speed which are provided with brush-shifting devices. In subsequent issues, we hope to have further articles covering the theoretical side of the motors described in this issue.—Editor.

When electric light and power companies began to extend their lines beyond the densely populated districts, largely through the construction of single-phase lines connected to three-phase distribution points, the necessity for reliable small single-phase power motors became apparent. At first, the demands were met by using three-phase induction motors started by resistance-reactance starters, i.e.,—the split-phase induction motor. It soon became apparent that single-phase motors were required for general application which could exert more torque at starting. This result was obtained by adding a clutch pulley to the single-phase induction motor or by building it with a clutch armature, but even this improvement failed to give the desired results in many cases, due not only to unsatisfactory torque characteristics but also due to the large current drawn from the line at starting which resulted in disturbances to the lighting circuits.

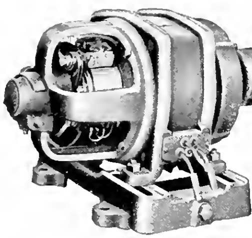


Fig. 1. A Standard Type RI, 2-horse power, 1800-r.p.m., 110/220-volt, Single-phase, Constant-speed Motor

It was not until the commutator had been added to the single-phase motor that single-phase motors were produced which overcame these objections and met practically every demand of general service. At first, the efforts were concentrated on the successful development of the constant-speed single-phase motor which has, broadly speaking, the same field of application as the direct-current shunt motor and the constant-speed polyphase motor. Since this problem has been solved, the growing use of the constant-speed motor has increased the demand for a variable-speed motor and this has resulted in the development of the single-phase commutator brush-shifting motor and the further development of the single-phase repulsion motors with resistance control for crane and hoist service.

In this series of articles, the various types of single-phase power motors developed by the General Electric Company will be dealt with.

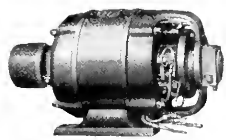


Fig. 2. A Standard Type RI, one-half-horse power, 1800-r.p.m., 110/220-volt, Single-phase, Constant-speed Motor

CONSTANT-SPEED SINGLE-PHASE MOTORS

So far the largest demand has been for a constant-speed motor for general purposes having a small variation in speed between no-load and full-load. A standard line of Type RI motors has, therefore, been developed ranging from 1/4 h.p. to 20 h.p. at 1200 and 1800 r.p.m., 60 cycles and from 1/4 h.p. to 5 h.p. at 1500 r.p.m., 25 cycles, with the possibility of furnishing a wide range of ratings, speeds and frequencies. Figs. 1 and 2 show two ratings of these motors in their latest improved construction known as Form C. The motors are simple in construction and operation, and easy to install;

they develop high-starting torque with low-starting current.

Construction

The mechanical construction of the motor is rugged and simple, consisting of the usual laminated field, two bearing brackets, wound armature with commutator and brush rigging, and as shown in Fig. 3 is free from all centrifugal switches, clutches and short-circuiting devices.

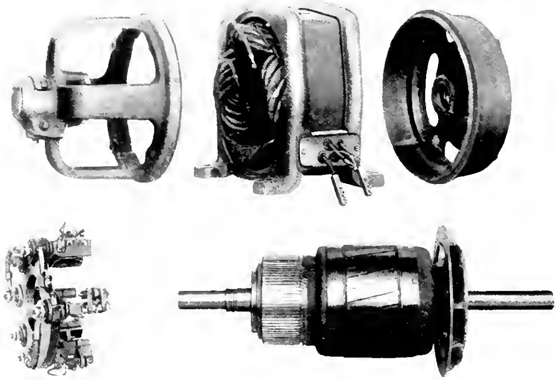


Fig. 3. The Parts of the Motor shown in Fig. 1

The stator is of the well known riveted frame construction, having exposed laminations for greatest efficiency of radiation. It has a lap wound single-phase winding and in addition a small auxiliary winding, called the compensating winding, consisting of a few coils wound with a small pitch and located in the center of the poles. The stator winding is wound so that it can be connected externally in series or in parallel for 110 or 220 volts.

The armature is substantially a d-c. armature, short circuited along one axis by a set of brushes called the energy brushes, and excited along an axis at right angles to the energy circuit by the compensating winding described above.

The brush rigging is sturdy and compact. A split yoke clamped to the bearing housing carries the insulating retainers and the cast brass brush-holders. A high grade brush is provided, giving high polish and long life both to the commutator and brush.

The bearing heads are provided with bearings of liberal size and with housings of liberal oil capacity. The oil wells are equipped with covers, dust caps, oil fillers and oil drain plugs.

To insure uniform and safe working temperatures throughout the motor and to permit the use of the minimum amount of active material, the motor has been equipped with an effective ventilating system. A fan mounted on the armature draws the air through the field at the back of the coils and through the armature and commutator, this air being discharged through openings in the pulley end bracket.

Characteristics

The RI motor develops at starting 250 per cent of the normal rated torque, drawing from the line approximately 18 amperes per horse power at 220 volts. Fig. 4 gives the torque speed and torque current curves of this motor and shows that the initial torque decreases but slowly as the motor comes up to speed, insuring rapid acceleration and a minimum of line disturbance during the starting period.

A comparison of its torque and current characteristics with those of the single-phase and polyphase induction motors, see Figs. 5 and 6, show it to be far superior to the former and to compare favorably with the latter. The high torque values from start to 50 per cent speed are desirable and necessary to take care of excessive line drop which is liable to occur on the small single-phase line extensions on which these motors are usually installed. The value of the type of "compensated" motor over the induction motor is shown by the low full load current readings in Fig. 6.

Fig. 7 shows the performance characteristics of this type of motor. As it is of the compensated type, the power-factor of the motor is approximately unity and retains a high value throughout the whole range of normal operation. The efficiency is also well sustained throughout the working range from half-load to load and a quarter. The regulation is 8 to 12 per cent which compares favorably with the d-c. shunt motor of equivalent size.

Applications

Of the large variety of applications, a few may be enumerated as follows:

Household and Store Appliances

Coffee grinders	Blowers
Meat choppers	Ice machines
Vacuum cleaners	Mixing machines
Pumps	Ice cream freezers

Industrial Applications

Laundry machines	Printing press
Lathes	Linotype
Boring and mill machines	Folding machine
Drill press	Bending machine
Slotter	Brick machine
Shaper	Can making machine
Riveting machine	Bottle washer
Gear cutter	Bottle corker
Moulding machine	Bottle labeler
Planer	Grinder
Band saw	Buffer
Buzz saw	Cloth cutter
Jig saw	Feed pump
Farm machinery	Tool grinder
Shoe machinery	

Apparatus geared or direct connected to the driving motor and designed to be driven

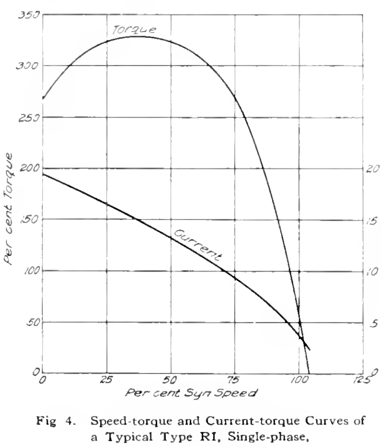


Fig 4. Speed-torque and Current-torque Curves of a Typical Type RI, Single-phase, Constant-speed Motor

at definite speeds by 60-cycle motors may be driven at approximately normal speed by odd frequency motors having special windings without mechanical changes. Examples of apparatus of this kind are: vacuum cleaners, pumps and meat grinders.

VARIABLE-SPEED MOTOR

Brush-Shifting Motors (Type BSS)

After the constant-speed commutator motor had once been brought to its present high degree of perfection for constant speed work, it became a simple problem to develop the single-phase variable-speed brush-shifting motor, known as the Type BSS, which has

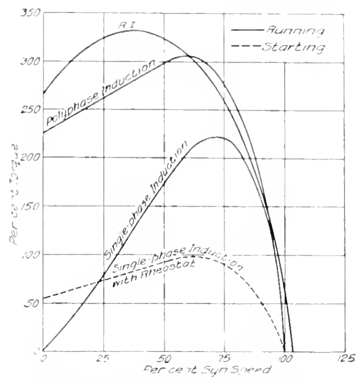


Fig 5. Speed-torque Curves for Comparison of Single-phase and Polyphase Motors

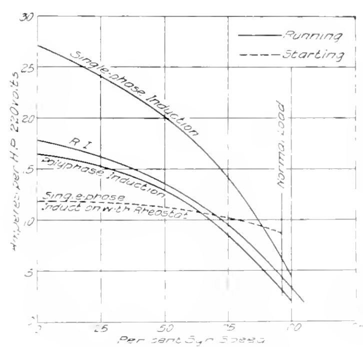


Fig. 6. Speed-current Curves for Comparison of Single-phase and Polyphase Motors

not only as good torque-speed characteristics as the polpyhase induction motor with secondary resistance control, but also the advantage of operating with a better efficiency than the induction motor at reduced speed.

Abroad, the repulsion motor with speed regulation obtained by shifting the brushes has been extensively used. This motor is not suitable for belting unless provided with a centrifugal switch which disconnects the motor from the line when the speed exceeds a certain amount. In the Type BSS motor, this no-load speed is limited without the use of the centrifugal switch by the introduction of a transformer in series with the line, the secondary of which is connected to the brush circuit with its axis at right angles to the short-circuited energy brushes. The saturation in the iron of this transformer limits the no-load speed to a definite safe value. Since the primary of this transformer is connected in series with the line, depending on the brush shift, a part or all of the torque producing flux is excited by the armature, thus making it possible to operate this motor at nearly unity power-factor at full load and full speed.

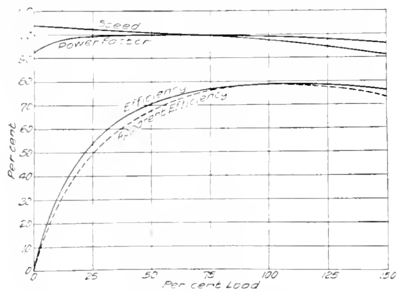


Fig. 7. Performance Curves of a Type RI, 5-horse power, 1800-r.p.m., 60-cycle, Single-phase, Constant-Speed Motor

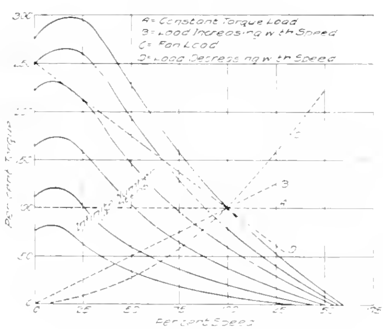


Fig. 8. Speed-torque Curves for a Single-phase Variable-speed, Brush-shifting Motor

The speed torque characteristics of motors of this type are shown in Fig. 8. Efficiency and power-factor characteristics for regulation with full and half torque have been plotted for different values of speed in Fig. 9. The starting characteristics are shown in Fig. 10. The motor can be started up with the brushes in any position, but it is recommended that it be started with the controller in the low speed position, in order to draw a minimum amount of starting current from the line.

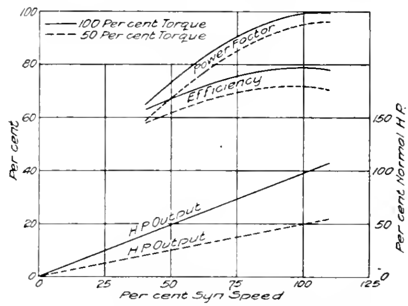


Fig. 9. Performance Curves for a Single-phase, Variable-speed, Brush-shifting Motor

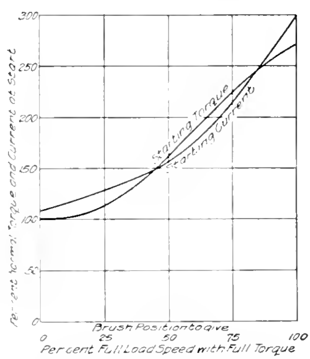


Fig. 10. Starting Curves for a Single-Phase, Variable-speed, Brush-shifting Motor

This motor is particularly advantageous for printing press drives. On small presses, the brushes are shifted by a foot controller, connected by rods to the rocker shaft located on the motor which in turn is connected to the brush yoke. Fig. 11 shows a BSS motor driving a job press and controlled by this foot controller. To start the motor and to disconnect it from the line, a double-pole switch is used. This equipment may be further supplemented, as illustrated in Fig. 12, by a spring base and friction pulley for friction drive to the flywheel of small job presses.

The brushes can also be shifted by means of a hand controller, as shown in Fig. 13. This controller serves at the same time as a line switch, disconnecting the motor from the line when the brushes are shifted beyond the lowest speed running position. For controlling the speed at the motor itself, a handle with sector can be provided for attachment to the motor.

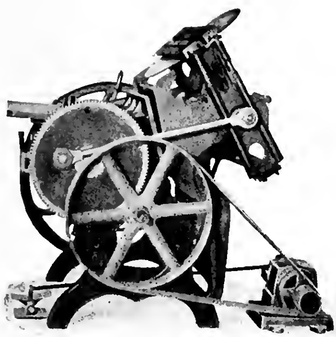


Fig. 11. A Single-phase, Variable-speed, Brush-shifting Motor with Foot Control Driving a Job Press

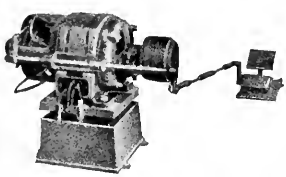


Fig. 12. A Single-phase, Variable-speed, Brush-shifting Motor Mounted on a Spring Base for Driving a Job Press Flywheel through Friction

There are a large number of such drives where the application of the efficient variable-speed motor, having practically an infinite number of speed steps can result in considerable increase in production. For instance, there are a number of manufacturing processes always carried on at a comparatively low speed so that they will run smoothly when atmospheric or other conditions are at their worst. This efficient variable-speed motor will make it possible to take advantage of better conditions. Operating engineers are

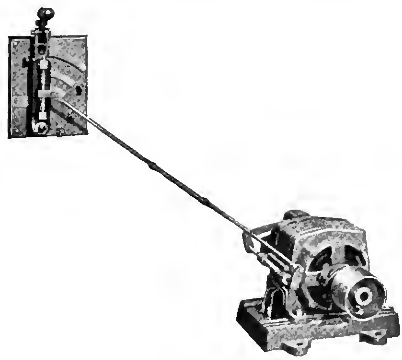


Fig. 13. A Single-phase, Variable-speed, Brush-shifting Motor with Hand Control.

realizing the possibilities of such a motor and are rapidly extending its use.

Crane and Hoist Motor (Type RIC)

There is also being developed a variable-speed motor for crane service having the same characteristics as the d-c. series motor, and controlled in the same way by means of a drum controller which reverses the field winding and changes the resistance of the primary circuit. Fig. 14 gives the torque-speed and torque-current curves for different values of resistance connected in series with a motor of this type rated as RIC 4-pole, 7½-h.p., 1200-r.p.m., Form G, 220 volts. As this is a 60-cycle motor, the windings have been designed in such a way that the full-load speed (1200-r.p.m.) equals approximately two-thirds of the synchronous speed which is 1800-r.p.m. A reactance connected across the brushes limits the no-load speed to about twice the full-load speed, and it thus becomes possible to run the motor fast with light loads, an advantage which cannot be obtained with the slip-ring induction motor. This method of proportioning the windings also secures satisfactory commutation over the entire speed range. The commutator has moreover been much more liberally proportioned than it has on standard motors in order to be able to operate this motor at crawling speeds. The simplification of the control and the reduction in the number of trolley wires, in many cases, will compensate for the increased cost of the single-phase commutator motor.

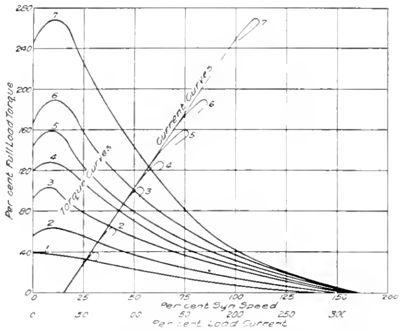


Fig. 14. Torque-speed and Torque-current Curves for Different Values of Resistance in Series with a 7½-horse power, 1200-r.p.m., 220-volt Crane and Hoist Motor

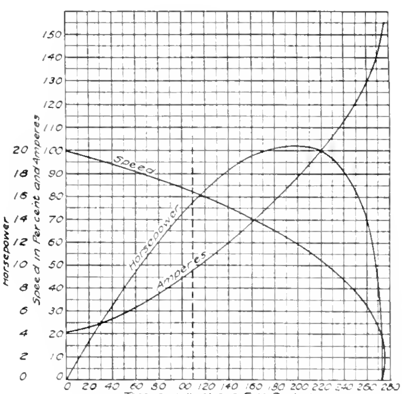


Fig. 16. Performance Curves of a Polyphase Reversible Motor.

CONSTANT-SPEED REVERSIBLE MOTORS

A large field of application for the constant-speed reversible motor is created by dumb-waiters, freight and low-speed passenger elevators and other applications of this character. The polyphase motor with high resistance squirrel-cage has been employed to a large extent in this field. As these applications require motors of small size, simplicity of control is of the greatest importance in order to not make both the first cost and the cost of maintenance prohibitive. The polyphase squirrel-cage motor is very satisfactory in this respect as it requires only a double-throw triple-pole switch for starting and reversing.

A single-phase motor which can be controlled by a similar switch and which gives similar characteristics can be secured from a standard constant speed, Type RI, Form C motor by making certain re-arrangements of

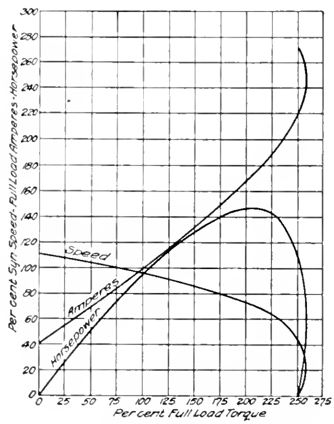


Fig. 15. Performance Curves of a Single-phase Reversible Motor.

the connections to the brush yoke and to the main field. In some cases to secure higher torque, it is necessary to supply a small reactance coil for the secondary circuit.

The similarity in characteristics between the single-phase and polyphase reversible motors may be seen by comparing Fig. 15, showing the former, and Fig. 16, showing the latter.

Fig. 17 shows a standard RI, Form C motor reconnected and supplied with the auxiliary terminal board and leads which it is proposed to furnish for these motors. The change can then be readily made on a stock motor.

CONSTANT-SPEED FAN MOTORS

In order to meet the demand for direct connected blower motors of relatively low-speed which will develop even under a condition of excessive line drop a high value of torque at starting with minimum current

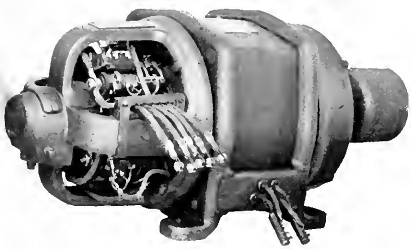


Fig. 17. A Type R1 Reversible Motor.

which resemble the ordinary constant-speed motor, previously described, but have specially designed windings. These motors have no compensating winding to limit the no-load speed, the fan being mounted on the armature shaft so that the motor never runs free.

In order not to handicap the design by too large a number of poles, the windings have been adjusted in such a way that the motors operate below synchronous speed. Fig. 18 shows an 8-pole 60-cycle motor direct-connected to a Ventura fan which operates normally at 440 r.p.m. Fig. 19 shows an 8-pole 60-cycle motor direct-connected to a Davidson fan, normally running at 400 r.p.m. These motors may be equipped with series resistances to secure reduced fan speeds when desired.

For belt-driven blowers, standard constant speed motors, having limited no-load speed,

Fig. 18. An 8-pole, 60-cycle, 440-r.p.m., Constant-speed Motor Direct-connected to a Ventura Fan.

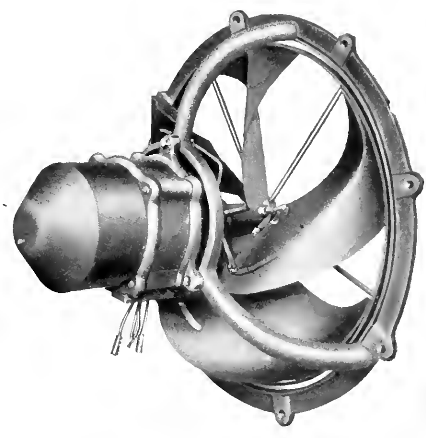


Fig. 19. An 8-pole, 60-cycle, 400-r.p.m., Constant-speed Motor Direct-connected to a Davidson Fan.

and which can be thrown on the line without an auxiliary starting device, such as is required by the single-phase induction motor previously used for this purpose, there has recently been developed for this service a line of totally-enclosed single-phase motors

are recommended as heretofore, in order to prevent the motor from running away in case the belt should drop off. Furthermore, in that case a motor of relatively high speed can generally be used with corresponding reduction in motor cost.

LIGHTNING

By F. W. Peek, Jr.

Consulting Engineering Department, General Electric Company

This article is the result of an extensive investigation of the time interval between the application of high voltages and the formation of insulator and gap arc-overs, or the failure of insulation. It is probably the first time that the time lag of gaps and the formation of corona, etc., has been accurately measured or studied with impulses of known wave shape and duration. It was found that the electrode shape, etc., makes a vast difference in this time interval, which is measured in microseconds. Many apparently inexplicable and peculiar arc-overs and insulator and insulation failures, due to surges and lightning, are readily explained when the time lag is considered. The subject is of great importance.—Editor.

Many peculiar and apparently inexplicable failures occur in insulation, line insulators, etc., due to lightning or surges. Lightning, for instance, may pass a needle gap set at a very low voltage, and strike across a higher voltage gap at the busbars or over a line insulator, etc. It requires small but finite time for a spark to form, depending upon the spacing, shape of the conductors, etc.; most of such phenomena are caused by voltages of steep wave front, or of extremely short duration, where the time to form a spark is limited. Steep wave front means that the surge, or lightning impulse voltage, is applied across the apparatus at a very rapid rate. Some of the phenomena about to be described were produced by voltages starting at zero and increasing at the rate of 1000 kilovolts per microsecond.*

* Microsecond = one millionth of a second. 1000 kilovolts per microsecond = 1,000,000,000 kilovolts per second.

For complete description of tests, method of producing impulses, laws of impulse spark-over, etc., see "The Effect of Transient Voltages on Dielectrics" by F. W. Peek, Jr., A.I.E.E., August, 1915.

A brief description of some of the effects produced by impulse voltages and the probable mechanism of breakdown for common conductors will first be given.

Spark-over, or failure of insulation, means a tearing apart or change in the atomic or molecular structure. In air, for example, it is supposed that there are always a certain comparatively small number of "particles of electricity" called ions. The negative ions or electrons have a mass of about 1/1800 of that of the hydrogen atom, and are attracted toward a positive, or repelled from a negative, electrode or conductor. The velocity at which they travel increases with increasing voltage, or dielectric field intensity. When their velocity becomes great enough in their mean free path new ions are produced by collision with atoms or molecules. The neutral atoms become separated into positive and negative parts by the collision. The number of ions then rapidly increases until "ionic saturation" along some path, which is

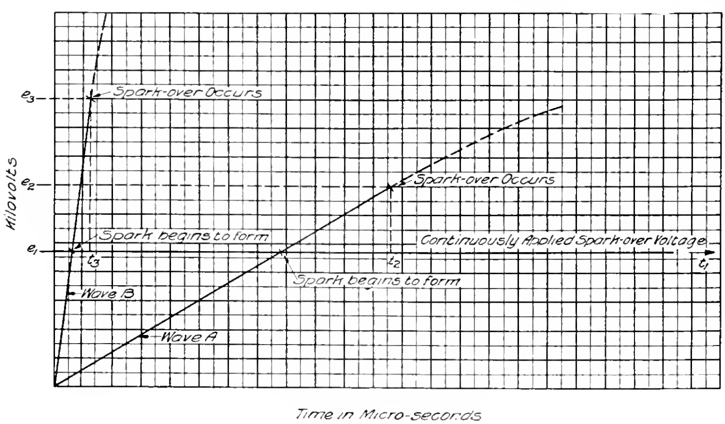


Fig. 1 Diagramatic Illustration of Why the "Lightning" or Impulse Spark-over Voltage is Higher than the Continuously Applied

spark-over, finally results.† The field intensity, or the voltage gradient, at which this action *starts*, is always definite and, at ordinary atmospheric pressure, is 30 kv/cm.‡ Any such process requires energy and, therefore, time, since the power is never infinite. Briefly, and regardless of any theory of ionization, the process of tearing the air apart along some path or of building up a spark or corona *always starts* at a definite gradient or, for a given pair of electrodes, when a given definite voltage is reached. After the process starts, a certain time must elapse before spark-over can take place and during this time the impulse voltage must rise to some higher value.

Referring to Fig. 1, the spark-over voltage of a given needle gap is e_1, and always practically constant, if the time of application is not limited. Spark-over may take place after the continuously applied voltage, e_1, has been on for some time t_1. If a voltage increasing at a rapid rate as represented by A, in Fig. 1, is applied, spark-over will not take place when the continuously applied spark-over voltage, e_1, is reached, as the time t_1 is required at this voltage. The spark will begin to form when the voltage reaches the value e_1, however. The voltage will, therefore, rise above e_1, and spark-over will take place after the time, t_2, has elapsed and the voltage has risen to e_2. When the voltage is applied at a more rapid rate along wave B, the spark as before will begin to form when voltage e_1 is reached. The voltage will con-

† Corona is spark from conductor to space.
‡ This short and general discussion of ionization by collision is not intended to be strictly technical.

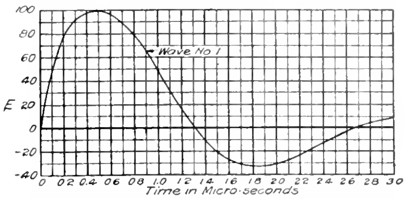


Fig. 3. Approximate Single Half Sine Wave Impulse (Only first half of the Wave need be considered as the voltage is comparatively low after the first crest)

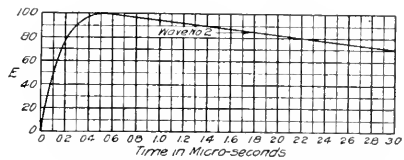


Fig. 4 Impulse with Steep Front, but of Comparatively Long Duration

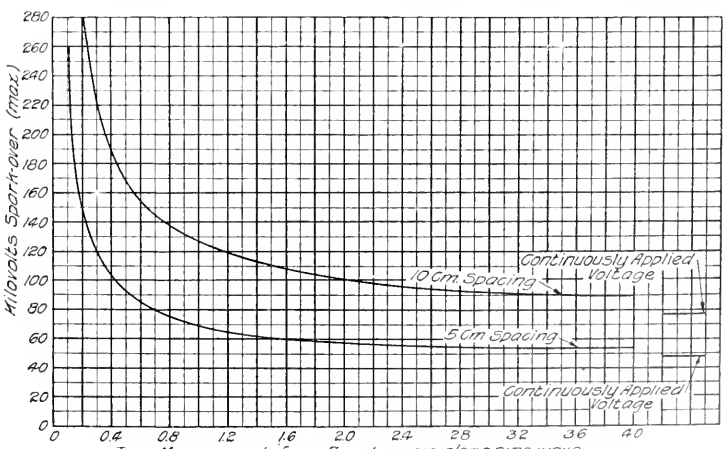


Fig. 2. Time and Voltage to Spark Over Needle Gaps (Sine Wave Impulse)

tinue to rise and reach the value e_3, during the time t_3, before spark-over occurs Thus, on account of the time lag, when voltage is applied at a very rapid rate, as by an impulse, spark-over does not occur when the continuously applied breakdown voltage is reached. The voltage "over shoots" this value during the time that rupture is taking place. The excess in voltage is greater, and the time lag less, the greater the rate of application. The time lag for any given gap or insulation has thus not a fixed value but depends on the wave shape of the impulse or rate of application of the voltage. In making a study of such phenomena it is necessary to use certain definite wave shapes. Fig. 2. shows the impulse voltage-time characteristics for needle gaps. The impulses used in this test were single half-cycles of sine waves. Note that the impulse spark-over voltage is not greatly above the continuously applied or 60-cycle voltage when the time is over 5 microseconds; that is, when the time of application is comparatively long there may be a considerable variation of this time without an appreciable increase in the spark-over voltage. The continuously applied (60-cycle or d-c. where heating does not occur) spark-over voltage is the lowest voltage at which spark-over can take place.

Figs. 3 and 4 show actual wave shapes used in these tests.§ Fig. 3 is equivalent to a single half-cycle of a sine wave; Fig. 4 rises to a maximum at the same rate as Fig. 3 but has a flat top or is of much longer duration. Of the two waves shown in Figs. 3 and 4 the voltage required to spark-over a given gap should be higher for the one of shorter duration or for wave Fig. 3. This is shown from actual test in Fig. 5. For a 10 cm. gap between needles wave No. 1 must have a maximum value of 180 kv. before spark-over can result; with wave No. 2 spark-over results at 104 kv. The spark-over at 60 cycles is 75 kv. The time that wave No. 1 is above the continuously applied breakdown voltage is 0.95 microseconds, wave No. 2, 2.70 microseconds. The impulse and continuously applied needle gap spark-over curves are given in Fig. 6. An examination of Fig. 6 shows that the impulse spark-over

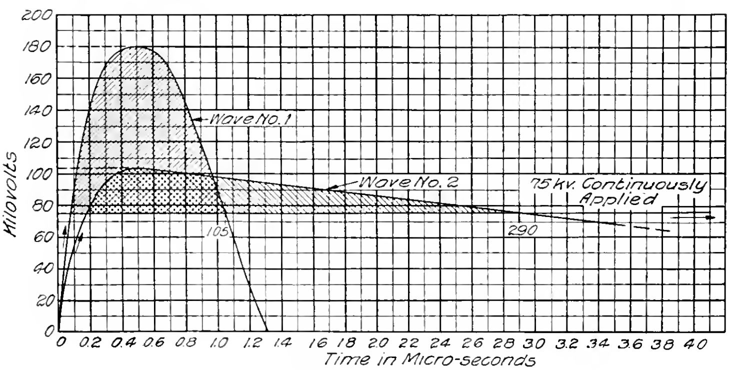


Fig. 5. Continuously Applied and Impulse Voltages to Just Cause Spark-over of a 10 cm. Gap Between Needles

voltage of needles is always higher than the continuously applied spark-over voltage. For instance, with wave No. 1 the impulse spark-over voltage for a 10 cm. gap is 180 kv., or 2.4 times the 60-cycle or continuously applied voltage. The ratio of the impulse spark-over voltage to the continuously applied voltage has been termed the impulse ratio.

The time to spark over a gap varies with the spacing and shape of the electrodes. For a given 60-cycle voltage setting the time required to form a spark is greatest for gaps between points and least for gaps between well rounded surfaces. For spheres, the time lag is so small that discharge takes place before the impulse voltage can rise appreciably above the continuously applied or 60-cycle spark-over voltage. This is shown in Fig. 7 where the drawn curve is the 60-cycle

§ For full description see "The Effect of Transient Voltages on Dielectric" by F. W. Peek, Jr., A.I.E.E., August, 1915.

curve while the impulse spark-over voltages for waves No. 1 and No. 2 are represented by crosses and circles. The reason will appear later.

Place a sphere gap and a needle gap in multiple as shown in Fig. 8. Set each of these gaps to spark over at 75 kv., 60 cycles.

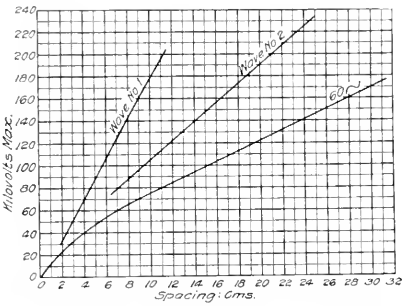


Fig. 6. Needle Gap Spark-over Curves for 60 Cycles and for Impulse Waves Nos. 1 and 2, shown in Figs. 3 and 4

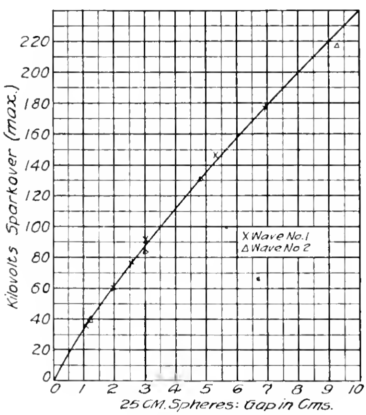
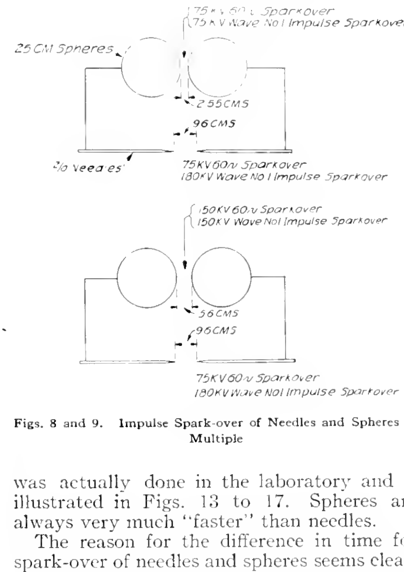


Fig. 7. Sphere Gap Spark-over Curves for 60 Cycles and for Impulse Waves Nos. 1 and 2, shown in Figs. 3 and 4. (Drawn curve, 60 cycles—points, waves Nos. 1 and 2.)

The impulse spark-over with No. 1 wave is 180 kv. for the needles and 75 kv. for the spheres. If an impulse is applied it will always spark over the spheres. The sphere gap spacing may now be increased to 150 kv. 60 cycles spark-over, or double the 60-cycle spark-over voltage of the needle gap, as shown in Fig. 9. An impulse of wave No. 1 will spark over the spheres when the voltage reaches 150 kv., as 180 kv. is required to spark over the needles. If wave No. 2 is used the needles will spark over when the maximum of the wave is 104 kv. as given in Fig. 6, curve 2. Thus, when wave No. 1 is applied to this combination the sphere will always spark over. When wave No. 2 is applied the needles will spark over before the voltage reaches the sphere gap setting of 150 kv. A spark may thus be made to strike over either gap at will by a change in wave shape, the steep waves passing between the sphere and the slanting waves between the needles. This



Figs. 8 and 9. Impulse Spark-over of Needles and Spheres in Multiple

was actually done in the laboratory and is illustrated in Figs. 13 to 17. Spheres are always very much "faster" than needles.

The reason for the difference in time for spark-over of needles and spheres seems clear. The relative spacings for a needle gap and a sphere gap set at the same 60-cycle or continuously applied break-down voltage is shown in Fig. 8. The needle spacing is much greater than the sphere spacing. Before the needle gap can spark-over, brushes or "spheres" of corona must first form about the points and finally spark-over takes place along line 1–2 as illustrated in Fig. 10 The energy must be supplied through this air as it is ionized. The capacity between the points changes as the corona forms. This capacity must be gradually charged through the corona resistance before different sections are brought up to the breakdown voltage gradient. A vast amount of air must be torn apart or brought to ionic saturation. This may be readily observed by gradually applying voltage to the needles in the dark. The sphere spark-over requires

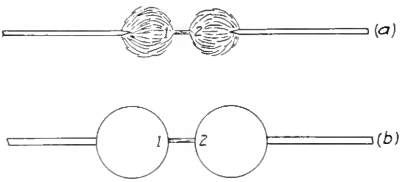


Fig. 10. Diagram Illustrating Spark Formation on Spheres and on Points

breakdown of only the very small, short tube 1–2 shown in Fig. 10. The stress is practically uniform over this tube and breakdown takes place all along this tube at practically the same time. The relative settings of needles and spheres for a 140 kilovolt (max.) impulse spark-over voltage at various impulses are shown in Fig. 11. The sphere spark-over voltage is 140-kv. at 5.6 cm. spacing and is the same for 60 cycles and for impulses. The 60-cycle spacing of the needles for 140-kv. (max.) is 25 cm.; this spacing must be decreased to 15.5 cm. (100-kv.—60-cycle) before a 100-kilocycle impulse will spark-over the needles; at 900 kilocycles the setting for 140-kv. spark-over is only 5.8 cm. (54-kv.—60 cycles).

Assume now that a needle gap and a sphere gap are placed in multiple as in Figs. 8 and 9; that the 60-cycle setting of the needle gap is 100 kv. the sphere gap 200 kv. If a voltage is applied, increasing as shown in Fig. 11, spark-over will not take place at the needle gap when the voltage reaches 100 kv. but the spark will just begin to form; the voltage will continue to rise to 200 kv. and t_s microseconds later, the spheres will discharge after the voltage has increased to 200+kv. The needles cannot discharge unless the spheres are disconnected. If the spheres are disconnected discharge will then take place across the needles in the time, t_n, at 220 kv. If 60-cycle is applied and gradually increased spark-over will occur across the needles when 100 kv. is reached. If a needle gap and a sphere gap are set at the same continuously applied or 60-cycle voltage and placed in multiple an applied lightning impulse will always strike across the spheres.

In practice, lightning often discharges across a large space between busbars, line insulators, etc., in preference to point gaps which have a much lower 60-cycle setting. The explanation above makes the reason for this quite apparent. The lag at the points allows the impulse voltage to rise above their 60-cycle setting to a value sufficient to spark over the well rounded surface of the busbars where the lag is very small. The practical importance of utilizing these phenomena in design is readily seen. It is desirable so to design protective gaps that discharge takes place in minimum time, and so to design bushings, insulators, etc., that the time for the spark to form is maximum.

This is well illustrated in Figs. 13 to 17. In Fig. 13 an insulator is placed across the line and is "protected" by spheres and points, in multiple with the line, set at lower 60 cycle spark-over voltages are:

60-cycle Spark-over Voltages (kilovolts max.) *Fig. 13.*

Insulator 120 Spheres 77 Points 77

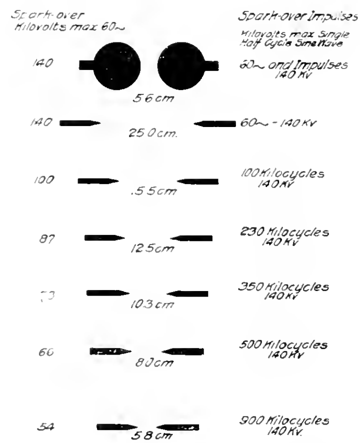


Fig. 11. Settings of Needle and 12.5 cm. Sphere Gaps for Equal Impulse Spark-over Voltages of Various Wave Fronts Impulse Voltage Setting 140 kv. max. Waves single half sine 100 kilocycles and 900 kilocycles

The spheres and points are set at equal 60-cycle spark-over voltages. A steep impulse with a 420 kilovolt maximum is applied. The spheres spark over and protect the insulator and the points. The 60-cycle setting of the spheres is then increased in Fig. 14, while the needles are unchanged. The 60-cycle spark-over voltages are now:

60-cycle Spark-over Voltages (kilovolts max.) *Fig. 14.*

Insulator 120 Spheres 137 Points 77

The spheres still protect the insulator and points, although their 60-cycle spark-over voltage is higher than that of the insulator or points. In Fig. 15 the spheres are removed; the points are unchanged. The 60-cycle spark-over voltages are thus:

60-cycle Spark-over Voltages (kilovolts max.) *Fig. 15.*

Insulator 120 Points 77

The points fail to protect and the insulator sparks over. Corona may now be observed on the points. The *impulse spark-over voltages* of the insulator, spheres and points with 60-cycle settings as in Fig. 13 are:

Impulse Spark-over Voltages (kilovolts max.) *Fig. 13.*

Insulator 140 Spheres 77 Points 200

It is obvious, therefore, that the points can never protect the insulator against the steep impulse used in the above tests. In Figs. 16 and 17 the 60-cycle spark-over voltages are:

60-cycle Spark-over Voltages (kilovolts max.) *Figs. 16 and 17.*

Spheres 250 Horns 140

In Fig. 15 a steep impulse voltage sparks over the spheres although they are set at 1.8 times the 60-cycle spark-over voltage of the horns; in Fig. 16 a slanting wave sparks over the horns. A spark may thus be made to strike at will over either gap by changing the wave front of the applied voltage.

Lightning travels along a transmission line at the rate of 3×10^8 meters per second. Thus, a wave one kilometer in length passes a given point in 3.3×10^{-6} seconds or in 3.3 microseconds. By referring to Fig. 2 it can be seen that a wave of the above length might easily pass by a needle gap before discharge could take place.

Line insulators and bushings may have equal 60-cycle spark-over voltages, but vastly

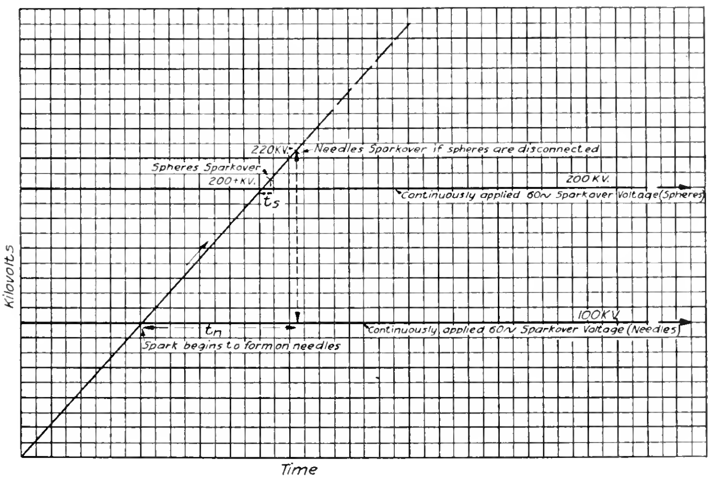


Fig. 12. Diagram illustrating why an impulse may strike across a sphere gap even when the sphere gap is set at double 60-cycle voltage of a needle gap in multiple; how an impulse may be made to strike over either the sphere gap or needle gap at will by a change in the wave front of the applied voltage

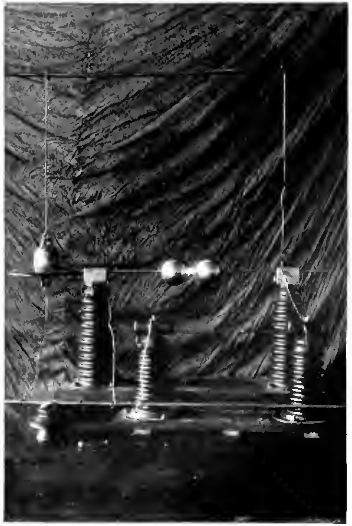


Fig. 13. Relative Protective Value of Spheres and Points

60-cycle spark-over voltage setting in kilovolts maximum.

Insulator	Spheres	Points
120	77	77

The spheres protect by discharging the impulse. The points have the same *60-cycle* voltage setting but do not discharge.

Fig. 14. Relative Protective Value of Spheres and Points

60-cycle spark-over voltage setting in kilovolts maximum.

Insulator	Spheres	Points
120	137	77

Although the sphere *60-cycle* spark-over voltage setting is, in this case, higher than that of either the insulator or the points, the spheres protect because the sphere "lightning" spark-over voltages is the lowest of the three.

Fig. 15. Relative Protective Value of Spheres and Points

60-cycle spark-over voltage settings in kilovolts maximum.

Insulator	Spheres	Points
120	—	77

The points do not protect because of their very high "lightning" spark-over voltage.

The spark-overs shown are due to a succession of steep wave point impulses applied to the line.

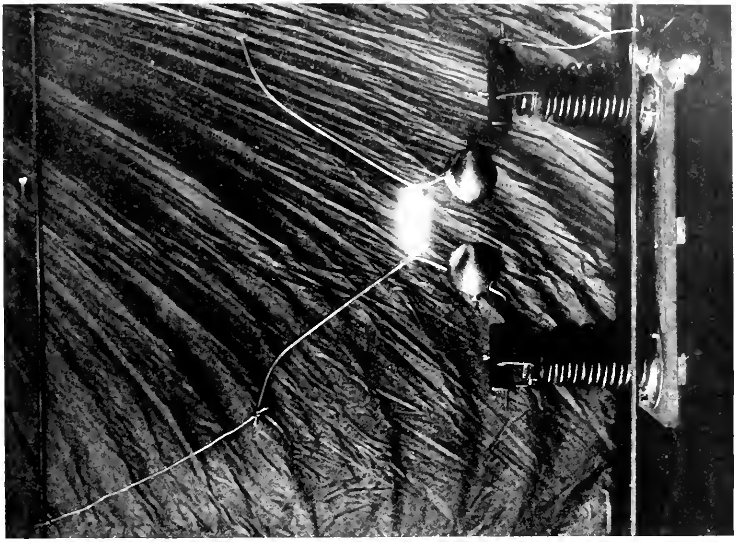


Fig. 17. Sphere and Horn Gaps having a Slanting Wave front Voltage Applied

Spheres 250 Horn 1[illegible]

Fig. 16. Sphere and Horn Gaps having a Steep Wave front Voltage Applied

Horn 140

different impulse or lightning spark-over voltages. As an example,

Insulator	60-Cycle Spark-over	Impulse Spark-over (Single Half-cycle 200 Kc. Wave)
No. 1	90	92
No. 2	90	130

Insulator No. 1 is smooth, insulator No. 2 has proper corrugations. The lag of No. 1 is very small, and No. 2 very large. Lightning impulses would readily pass by No. 2 and strike over No. 1. Insulator No. 1 would be difficult to protect from spark-over. Moisture from rain reduces the 60-cycle spark-over voltage of insulators from 20 to 50 per cent. The steep wave front impulse spark-over voltage is not greatly affected by rain. Line insulators may thus be weakened by rain or moisture for 60-cycle voltages, but retain their normal factor of safety for lightning voltages. Impulse sparks generally closely follow a surface.

The start of corona about a wire is spark from the conductor to space, over a small distance. The dielectric field over this small distance is fairly uniform for large wires. The lag is thus very small. Corona formation should be, for this reason, of some protective value on transmission lines. Considerable energy might be dissipated in this way by the kilometer wave mentioned. It is of interest to note that corona which is produced by voltages lasting only a few microseconds is readily seen.

Liquid insulations, compared to air, have a very great time lag. Transil oil is, therefore, an extremely good insulation for transient voltages.

Impulse voltages much higher than the low frequency operating voltages are generally required to rupture solid insulations. The effect of such over-voltages is cumulative. Each one, which is not in itself sufficient to cause complete breakdown, contributes to final rupture. Failures often occur, due to this cumulative effect, at *apparently* low voltages. Absorbed moisture greatly lowers the strength of insulation at 60-cycle voltages. Absorbed moisture has, as a rule, very little effect on the impulse strength. Different types of insulations of equal 60-cycle breakdown strength may have greatly different impulse strength. Dry or brittle insulations are generally badly shattered by over-voltages of steep wave front.

Many of the effects described above are those produced by impulses *corresponding in duration to single half-cycle of sine* waves of 20 to 1000 kilo-cycles. For surges of long duration the effects approach those produced by 60-cycle voltages. These effects must not be confused with those produced by continuously applied high frequency or undamped oscillations where burning occurs.*

* For comparative tests, etc., see "Electrical Characteristics of Solid Insulations" by F. W. Peek, Jr., G. E REVIEW, November, 1915.
"The Effect of Transient Voltages on Dielectrics" by F. W. Peek, Jr., A.I.E.E., August, 1915

VENTILATION AS A FACTOR IN THE ECONOMICAL DESIGN OF ELECTRICAL MACHINERY

PART II

BY EDGAR KNOWLTON

ALTERNATING CURRENT ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY

The first part of this article appeared in the May issue of the REVIEW and dealt with the flow of heat through materials and surfaces. The present section is the concluding installment and covers the methods of circulating air through machines and the selection of the proper form for this purpose.—EDITOR.

Appliances for Passing Air Through Electrical Machines

The ventilation of nearly all classes of electrical machines may be improved by fans, and means for directing the air to the parts where it will be the most useful. For the purpose of this article a fan may be defined as any part which is placed on the rotating member for the sole object of producing a movement of air. There are several types of fans and unless the type selected is suitable for the purpose the results will be disappointing, and the designer may conclude that further attempts are useless, whereas a proper selection of fan would produce a remarkable improvement. Before studying types of fans it will be necessary to consider the motion of air.

Air in Motion

When air in motion is having no energy supplied to it the direction of flow is from a

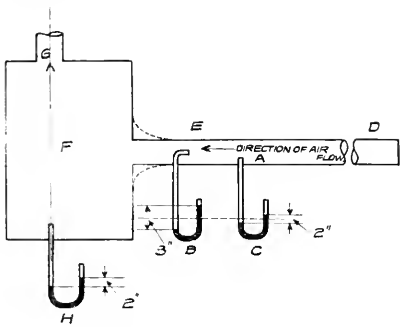


Fig. 5. Diagram of a Method for Measuring the Flow of Air in a Duct

place of higher to a place of lower pressure. Conversely, to produce a flow of air a difference in pressure is necessary. The pressure of air is usually measured by the difference in level of two columns of water, and is expressed in inches of water. In Fig. 5 let air be flowing in the air duct A at a velocity of 4000 feet per minute. If a U tube B is connected to an opening whose plane is at right angles, and a tube C is connected to an opening whose plane is parallel to the direction of air flow, the former will show the greater pressure. If the air was at rest and at any pressure above or below the atmosphere both tubes would read the same, therefore, the difference in the pressures of the two tubes must be due to the motion of the air. The greater the velocity of the air the greater will be this difference. In the Fig. 5:

The tube B measures Impact Head (Ih) or Pressure.

The tube C measures Static Head (Sh) or Pressure.

$Ih - Sh =$ Velocity Head (Vh) or Pressure.

If $Vm =$ the velocity of air in feet per minute, and $Vs =$ the velocity of air in feet per second.

$$(4) \qquad V_m = 4000 \sqrt{Vh}$$

$$(5) \qquad V_s = 67 \sqrt{Vh}$$

If two other tubes similar to B and C were placed at point D, it would be found that both would give a higher reading than the corresponding tubes at E and that the difference between the two impact heads was equal to the difference between the two static heads. This difference of head between similar pressures is due to the internal friction of the air and to its friction against the walls of the pipe between the points D and E.

If the air duct connects to a chamber F having an outflow pipe G, and if the size of the chamber F is so large that the velocity of the air in it is practically zero, the pressure measured by U tube H will be the same as measured by U tube C. This means that a pressure equal to the velocity head has been entirely lost, the kinetic energy of the moving air being changed to heat because of its being suddenly brought to rest. If the duct A was joined to chamber F by a cone or bell shaped nozzle as shown by the dotted lines, part of the velocity head would be converted into static head and the static pressure in F would be greater than the static, but less than the impact, pressure measured on tubes C and B, at a short distance from the chamber F. An important point to remember is that a gradual decrease in velocity head allows part

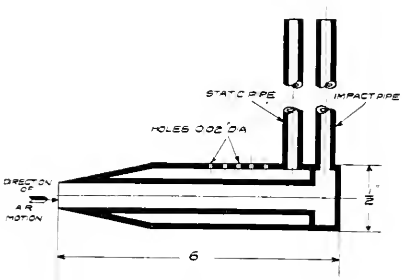


Fig. 6. Section of a Pitot Tube for Measuring Static and Impact Pressures

of this decrease to be converted into static head, whereas a sudden decrease in velocity head causes all of the difference in the two velocity heads to be lost. Any sudden change in velocity or direction of flow produces a loss that is dependent on the velocity head of the air, and the abruptness with which the change is made. The greater the ratio

$$\frac{\text{Velocity Head}}{\text{Impact Head}} \text{ i.e. } \frac{\text{Velocity Head}}{\text{Static}+\text{Velocity Head}}$$

the greater is this loss; therefore, for air passages having many abrupt changes in cross section or direction the static head should be a large percentage of the impact head. If there are few changes of the nature mentioned the static head may be a small percentage of the impact head. Examples of alternating current generators requiring these different methods of ventilation will be described later.

Air Velocity Measuring Instruments

For accurate results considerable refinement is necessary in the method of air velocity measurement described in the last section. In practice the two tubes which are inserted in the air duct, Fig. 5, are combined into one instrument called a pitot tube, see Fig. 6. Rubber tubes are used to connect the impact and static pipes to the U tubes. By connecting the static pipe to one leg, and the impact pipe to the other leg of the U tube the difference between the two, i.e. the velocity head may be measured directly. The pitot tube should be in the center of the cross section of the air duct and their axes should be parallel. This position should give the maximum impact and the minimum static reading and this may be used as a check on the correctness of the position. If the conditions of test are right the velocity of air will generally be greatest at the center of the cross section of the air duct. Various authorities state that the velocity pressure measured at the center of an air duct of circular cross section should be multiplied by 0.81 to give the average velocity pressure. If $Vh\ l$ = velocity head so determined, formulæ (4) and (5) become:

(6) $$V_m = 3600\ \sqrt{Vh\ l}$$

(7) $$V_s = 60\ \sqrt{Vh\ l}$$

If there is any doubt regarding the absence of eddy currents in the air or if the duct is rectangular a sufficient number of readings should be taken in various positions in the cross section of the duct to insure that the average velocity pressure has been obtained. If the variations in pressure are great they should be averaged by their square roots. Usually this is unnecessary. Air tight connections between pitot and U tubes are essential and neglect of this precaution is a common source of error in air velocity measurements.

The velocity of air may also be measured at the end of a pipe which should preferably be not less than three diameters long. The metal

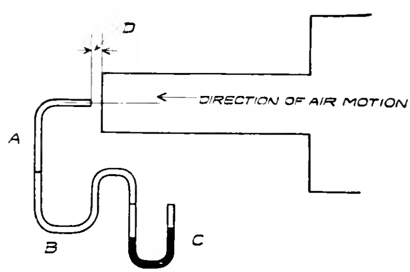


Fig. 7. Diagram of a Method for Measuring Air Flow at the End of an Air Duct

tube A, Fig. 7, is held with one leg parallel to the air flow. The end of this leg should be beveled from the outside so that a sharp edge is presented to the air, while the other leg is connected by the rubber tube B to the tube C. The static pressure just outside the end of the air duct is 0 and the pressure measured is due only to the velocity of the air. The end of tube A may be held in the center of the cross section, in which case formulæ (6) and (7) should be used, or it may be held in a number of positions and the average pressure

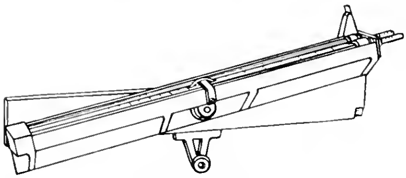


Fig. 8. Sketch of an Inclined U-Tube for Measuring Small Pressures

used in formulæ (4) and (5). The end of tube A should not be held inside of the end of the air duct but a short distance D should be maintained. This distance may be from 10 to 25 per cent of the air duct diameter without affecting the reading. The exact distance within these limits is not important and the tube may be held in a position parallel to the air flow by hand with sufficient accuracy. When the velocity of the air is low it is difficult to obtain an accurate reading on the usual U tube, and a draft gauge may be used. This consists of a U tube having one leg vertical and the other inclined at a small angle from the horizontal so that a vertical depression in one leg is multiplied by the other leg; for instance a depression of .02 inch vertically may cause a movement of liquid of 0.1 inch in the inclined leg. Another modification is to incline the whole U tube as shown in Fig. 8. The angle of the tube may then be adjusted to suit the pressures being measured. Gasoline is a satisfactory liquid when employed in draft guages and inclined U tubes, since it keeps the inside of the tube clean, has a very definite meniscus, and practically no capillary attraction for the glass. Account should be taken of the specific gravity of gasoline, which at present is about 60.

Anemometers are instruments having rotating vanes driving a pointer on a dial. The dial is marked to give the velocity of the air in feet per minute when the instrument has been held in the air current for one minute. The difficulties of calibrating, exact timing, varying friction and changes in the angle of the driving vanes, give very inaccurate results. It may be useful for comparison when two or more tests are made at short intervals and care is taken to eliminate the errors mentioned. There are other more accurate methods of air measurements than have been described but their use is not warranted for the purposes mentioned in this article.

Types of Fans

In Fig. 9, A, B and C,

W = peripheral speed of fan.

R = relative velocity of air along the blade of the fan. Note that this does not refer to the actual velocity or direction of motion in *space*.

V = actual velocity of air in *space*.

All of these speeds are in feet per second.

Subscript 1 refers to entrance conditions.

Subscript 2 refers to exit conditions.

Experiment has shown that just before entering a properly designed fan the air moves in a radial direction. Since abrupt changes in the direction of motion of air should be avoided, the inner angle of the blades should be such that this radial motion is continued for a short distance after entering the fan, as in Fig. 9 (B) and (C), not as in (A). The use of a blade like the latter is justified only when the peripheral speed is low and the ratio of inside

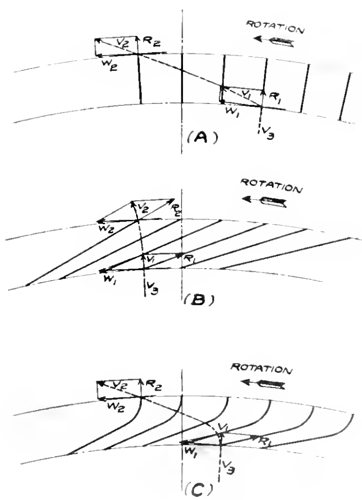


Fig. 9. Diagram of Three Types of Fan Blade Shapes

diameter to outside diameter is 0.5 or less. The radial velocity V_1, (B and C) may be determined from the volume of air and the internal peripheral area of the fan, and the value of W_1 is known from the diameter and speed. V_1 is the resultant of W_1 and R_1 and

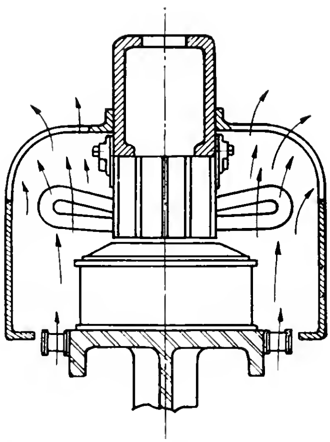


Fig. 10. Section of a Type of Alternator Which Requires a Fan of Low Static Pressure

knowing the magnitudes and directions of the first two the latter quantity may be obtained by completing the parallelogram of velocities as shown in the figure. Since in (A) and (C), Fig. 9, the outer ends of the blades are radial the relative movement of air R_2 just as it leaves the blade will be radial. The actual velocity and direction of the air in space is V_2 the resultant of R_2 and W_2. The path of the air through the fan is approximately shown by the dotted lines. Note the gradual change in direction in (B) and (C) as compared with the abrupt change in (A). Also refer to Table III and compare the velocity V_3 just before entrance with the velocity V_1 just after entrance in the three designs A, B and C. Because of the more sudden change in direction and velocity the fan A will generally have a lower efficiency than fans B and C. This is especially true if V_1 is several times V_3 as is the case in fan A where the ratio is 86/24.

The energy put into the air by the fan may be divided into three parts:

(a) Centrifugal Head (Ch), produced by the centrifugal force of the air contained in the fan at any instant.

(8) $Ch = \frac{W_2^2 - W_1^2}{4500}$, inches of water

(b) Reaction Head (Rh), produced by the decrease in relative velocity of the air from the entrance to the exit of the air passages between the blades.

(9) $Rh = \frac{R_1^2 - R_2^2}{4500}$, inches of water.

The sum of these two quantities is the static head developed by the fan above the pressure at the entrance. The entrance pressure is below the atmospheric pressure by the amount due to the velocity of air just before entering the fan (V_3). Note that in fans B and C, Table III, $V_3 = V_1$ but in Fan A, $V_3 = R_1$

Therefore for a general rule the velocity head at the entrance should be

(10) $Vh_1 = \frac{V_3^2}{4500}$

This must be subtracted from the sum of the centrifugal and reaction heads to obtain the static head above atmospheric pressure, hence

(11) $Sh = \frac{W_2^2 - W_1^2 - R_1^2 - R_2^2 - V_3^2}{4500}$,

inches of water

In fans of this type the actual static head is about 50 per cent of the theoretical static head and

(12) $Sha = \frac{W_2^2 - W_1^2 + R_1^2 - R_2^2 - V_3^2}{9000}$,

inches of water

(c) The velocity head of the air as it leaves the fan is

(13) $Vh = \frac{V_2^2}{4500}$

The sum of (12) and (13), the impact head above the atmospheric pressure is,

(14)
$$Ih = \frac{W_2^2 - W_1^2 + R_1^2 - R_2^2 - V_3^2}{9000} + \frac{V_2^2}{4500}$$
$$Ih = \frac{W_2^2 - W_1^2 + R_1^2 - R_2^2 + 2V_2^2 - V_3^2}{9000},$$

inches of water

In order that a comparison of three common types of fans may be made, consider the pressures produced by the fans A, B and C, Fig. 9. Table III gives the values of the various factors of design and lines 14 to 19, inclusive, show the pressures produced. The static pressure, line 17, is the sum of centrifugal and reaction heads, lines 14 and 15, minus the entrance velocity head, line 16. The impact head, line 19, is the sum of static and velocities heads, lines 17 and 18.

The duty to be performed by a fan depends a great deal on the proportions and construction of the machine to be ventilated. For any case design *C* will circulate more air than design *A*, but there are conditions where the difference between the two is of lesser importance than in other cases. Such a case is shown in Fig. 10, where the fan is not completely incased and discharges through the ends of the armature winding. In such a design very little air passes through the armature air ducts and the heat in the core portion is largely transmitted to the ends where the cooling is very effective. Heat may even flow from the armature teeth to the copper in the slots and thence axially to the armature winding ends outside of the core. Under these conditions the fan operates against a very low resistance and the direction of motion of the air is but little changed before it becomes effective in cooling. In making the calculations of Table III a volume of 300 cu. ft. per second was assumed for all fans, but if they were working against a very low resistance air circuit as in Fig. 10 the quantities would be approximately proportional to the $\sqrt{\text{Impact Heads}}$, for instance:

Fan *A* would pass approx. 250 cu. ft. per sec.
Fan *B* would pass approx. 190 cu. ft. per sec.
Fan *C* would pass approx. 300 cu. ft. per sec.

In Fig. 11 is shown a design having a long axial length of armature core. To transmit the heat from the longitudinal center line to the ends as was done in Fig. 10 would require too great a temperature drop and the armature copper at the center line would be dangerously hot. It is therefore necessary to pass a considerable quantity of air through the armature ducts. The ends of the windings and the fans are enclosed by shields which are practically air tight. As stated in the section "Air in Motion," when discharging air into such a chamber the velocity head of the air is lost and the pressure available for forcing the air axially between poles and radially through the armature ducts is the static head. From line 17 Table III the static heads are for:

Fan *A*, 0.094 inch.
Fan *B*, 0.597 inch
Fan *C*, 0.847 inch

The differences in pressure are so great that it is hardly allowable to compare the volumes passed by the fans, without knowing the pressure-volume curves of each fan, but the values would be approximately:

Fan *A*, 100 cu. ft. per sec.
Fan *B*, 250 cu. ft. per sec.
Fan *C* 300 cu. ft. per sec.

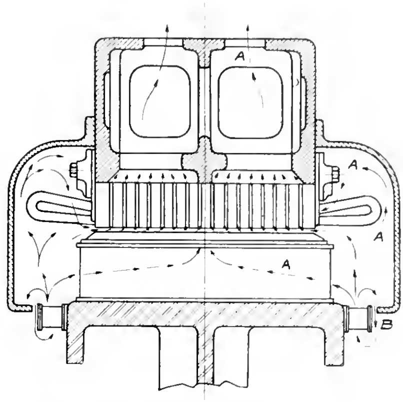


Fig. 11 Section of a Type of Alternator Which Requires a Fan of High Static Pressure

Referring to Fig. 11, assume that the fan shown is the one in Column C, Table III. The difference in static pressure between the exit and entrance of the fan is 0.86 inch and between the exit of the fan and the atmosphere is 0.847 inch. If the passage *B* between the fan and the shield has the same resistance as the passage *A* between the poles, through the air ducts and through the frame, one-half the air discharged by the fan will re-enter it via passage *B*, leaving one-half to go via passage *A*. The passage *A* has a considerable resistance due to the many turns, changes in the area of air passages, and the small size of the air ducts. It is therefore very important that the clearance between the fans and shields be reduced to the smallest practicable amount, otherwise so large a quantity of air will be short circuited that the pressure will be reduced and the quantity of air through passage *A* will be insufficient. The passage *B* is analogous to a short circuit of greater or less resistance across the terminals of a generator, while path *A* corresponds to the external circuit.

Axial Fans

This fan is defined as one in which the air passes axially through the fan as in the familiar fan motor. In such fans the pressure is produced by the reaction effect of the blades. If the blades of fans *A*, *B* in Fig. 9. were changed in position so that they "scooped" the air axially through the fans the static heads produced would be the same as given in line 15, Table III. Axial fans working against an appreciable pressure should have a guard to prevent leakage around their outer periphery. These fans have sometimes been applied without guards and the benefit derived was due to their discharging air in a radial rather than in an axial direction. This is the usual result when blades are set at an angle at each pole with the object of driving the air in between the poles of a revolving field alternator. Flat radial blades without shrouds or casings are sometimes attached along side the poles of a revolving field salient pole alternator, as shown in Fig. 12. On the left hand side the blades are shown attached to the rotor rim while on the right hand side they are attached to the end rings of a squirrel-cage winding. The use of such blades is allowable on rotors of small diameters where the mounting of more efficient fans is impossible. Also they may be used on machines of large diameters whose capacity is limited by other factors than ventilation and only a slight increase in the quantity of air is required. The use of a stationary baffler to prevent re-entrance of air to the blades would doubtless be an improvement in many cases.

Fan Characteristics

In many ways the characteristics of fans resemble those of electrical generators. For instance:

	Fan	Generator
Item 1.	Pressure corresponds to	Voltage
Item 2.	Cu. ft. per min. corresponds to	Amperes
Item 3.	Space between blades corresponds to	Arm. conductors or internal circuit
Item 4.	Path from exit of fan to atmosphere thence to entrance corresponds to	External circuit
Item 5.	Pressure Vol. curve corresponds to	Field characteristic curve.

Item 1

The exit of the fan may be likened to the positive and the inlet to the negative terminal of a continuous current generator. This comparison emphasizes the fact mentioned in the previous section, that a circuit of low resistance placed between the terminals is objectional in a fan as well as in a generator.

TABLE III

COMPARISON OF FAN DESIGNS

1.	Design	A	B	C
2.	Speed r.p.m.	100	100	100
3.	Cu. ft. air per sec.	300	300	300
4.	Outside diameter, inches	200	200	200
5.	Inside diameter, inches	188	188	188
6.	Axial length, inches	3	3	3
7.	W_1	82.2	82.2	82.2
8.	W_2	87.5	87.5	87.5
9.	R_1	24.4	85.8	85.8
10.	R_2	23.0	52.5	23.0
11.	V_1	85.8	24.4	24.4
12.	V_2	90.5	46.5	90.5
13.	V_3	24.4	24.4	24.4
14.	Centrifugal head $(W_2^2 - W_1^2) \div 9000$	0.1	0.1	0.1
15.	Reaction head $(R_1^2 - R_2^2) \div 9000$	0.007	0.51	0.76
16.	Entrance vel. head $V_3^2 \div 4500$	0.013	0.013	0.013
17.	Static head above atmosphere	0.094	0.597	0.847
18.	Exit vel. head $= V_2^2 \div 4500$	1.82	0.48	1.82
19.	Impact head	1.914	1.077	2.667
20.	kw. to drive with 300 cu. ft. per sec.	4.3	3.6	7.5
21.	Cu. ft. of air delivered to Fig. 10	250	190	300
22.	Cu. ft. of air delivered to Fig. 11	100	250	300

Item 2

The product of Items 1, 2 and a constant, gives the energy output for both fan and generator.

Items 3 and 4

The length, area of cross section, and shape of the space between the blades determine the internal resistance of the fan similarly as the length and area of cross section of the armature conductor fixes the internal resistance of the armature. In a generator the effect of increasing the area of the cross section of the armature conductors depends on the relative resistance of the internal and external circuits. If the resistance of the external circuit is many times the resistance of the internal, a large increase in the cross section of the armature conductors will have an inappreciable effect on the current flowing. Similarly a fan ventilating an enclosed machine, Fig. 11, will have its capacity but slightly increased if the axial width of the blades is made considerably greater. When a fan ventilates an open machine, as in Fig. 10, the external resistance is more nearly equal to the internal resistance of the fan, and an increase in the axial width of the blades

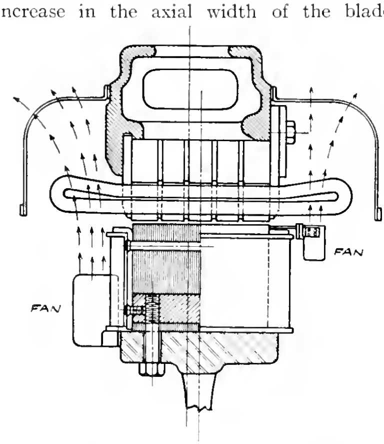


Fig. 12. Section of a Type of Alternator in Which the Fans Are Required to but Slightly Increase the Quantity of Air Circulated

results in a much greater increase in capacity than in the former case.

Item 5

One of the curves in Fig. 13 is a pressure volume curve of a fan and its similarity to a field characteristic is easily seen.

Salient Revolving Field Poles as Fans

Viewed as a fan only, field poles are inefficient especially as regards their ability to force air through the armature ducts. However, the conditions under which they are used may be such that they cannot be econ-

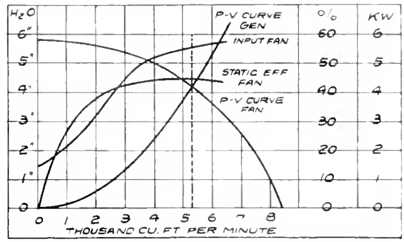


Fig. 13. Characteristic Curves of one of two Fans Employed for Ventilating a Turbo-alternator of 3000-kv-a., 1500-r.p.m. The Pressure-volume Curve of the Generator is also shown

Power-volume Curve of the Fan
Static Efficiency Curve of the Fan
Pressure-volume Curve of the Fan

omically supplemented by other ventilating devices.

In addition to the fan action they provide agitation of air over the surfaces at the air gap which is of considerable importance in reducing the thermal drops at the surfaces as shown by the fact that with the same quantity of air circulated through a machine and the same distribution of losses, the temperatures will be much lower when the machine is rotating than when standing still.

When the ends of the machine are not enclosed the poles circulate a relatively large amount of air over their own ends and over the ends of the armature winding. The quantity of air which a properly designed fan can force through the passages shown in Fig. 10 is closely proportional to the outside radius of the fan. The quantity which a pole piece forces through similar passages is approximately proportional to the radial length of the pole. Therefore if the ratio, radial length to outside radius of the field, is large, the addition of fans to increase the static pressure will be of little benefit, especially as in such cases the inlet to the fan is usually obstructed by bearings or couplings. For salient pole revolving field alternators, small diameters, relatively great radial lengths of pole, short axial lengths of cores, high rotative and peripheral speeds and free passages for air at the ends, produce a machine in which dependence must be placed on the poles to properly ventilate it.

Pressures Required to Pass Air Through an Electrical Machine

In order to properly design a fan for ventilating a machine the volume of air and the resistance of the air passages must be known. For the former the rule of 100 cu. feet per minute per kw. of loss may be used. The latter cannot be calculated. There are accurate formulæ for determining the resistance of air ducts that are relatively straight and of nearly uniform section such as are used in ventilating buildings, where the resistance is principally due to friction on the sides of the duct. In the air passages of electrical machines from 80 to 90 per cent of the resistance is due to the agitation of the air. The friction of the air on the surfaces may be likened to the resistance of a copper wire and the friction due to the agitation of the air to the reactance of the wire. If the wire were in a tangle the resistance could be laboriously calculated with fair accuracy, but the determination of the reactance would be hopeless. The only satisfactory guide to the air pressure required by any machine are tests on a unit very similar in size and proportions to the one under consideration.

Other conditions remaining constant the volume of air varies as the square of the pressure, so knowing the relation of pressure and volume at one point for any machine the relations for all points may be easily determined.

In Fig. 13 are given the characteristic curves of one of the fans for ventilating a steam turbine alternator of 3000-kv-a. capacity and 1500-r.p.m. Two fans supplied a total of 10600 cu. ft. per min. A curve showing the pressure required to pass different volumes of air through the generator is also shown in this figure. These volumes for the generator are divided by two so that the curve may be compared with the curves for one fan. The curves of the fan were from tests made independent of the alternator. The intersection of the pressure-volume curve of the fan and alternator fixes the volume and pressure at which the combination will operate.

If a greater quantity of air was desired the air passages of the alternator could be improved which would lower its pressure-volume curve; or the fan blades could be changed to give greater pressure thereby raising the pressure-volume curve of the fan.

Summary

Where the temperatures are the limiting feature in the capacity of an electrical machine marked reduction in cost per kv-a. may often be made by an improvement in ventilation. This improvement should be based on a knowledge of the laws of heat flow through materials and surfaces, the properties of air as a cooling medium, and the proper means for circulating the air.

The fans should be suitable for the duty which they are to perform, i.e. their volume and pressure must bear a reasonably close relation to the resistance of the air circuit. A low pressure fan for a high resistance air circuit is as unsuitable as a low voltage for long distance electrical transmission.

The specific heat and the formation of the stationary air film on surfaces are the important, and the humidity of the air and its tendency to rise when heated the unimportant, air characteristics in the ventilation of electrical machinery.

The ventilation of the station in which the machines are placed has a great influence on their temperatures. Care should be taken that cool clean air is supplied through passages of low resistance and that the heated air discharged from the machines cannot immediately re-enter. The importance of this phase of the ventilating problem justified a much greater space than is allowable in this article.

THE X-RAY SPECTRUM OF TUNGSTEN

By A. W. Hull

Research Laboratory, General Electric Company

Dr. Hull has been engaged for some time on an investigation of X-ray Spectra and is an authority on the subject. In the present article he gives a graphic description of the way in which X-ray Spectra are formed and shows numerous actual photographs of the Spectra. These illustrations are described in detail and are compared with the ordinary visible spectra—Editor.

The Nature of X-rays

Ever since the discovery of X-rays, in 1896, scholars have been divided in opinion regarding their nature. One school, led by Prof. W. H. Bragg, held that the rays consisted of high speed particles, so small and so fast that they could penetrate solid bodies. Their arguments were based mainly on the energy changes between the X-rays and the cathode rays that produce them. The other school considered the X-rays to be the same in nature as ordinary light, i.e., electromagnetic waves, and the principal evidence in favor of this view was the fact that X-rays cannot be bent or deflected by the strongest electric and magnetic fields. The question has now been settled in favor of the wave theory, and it is a beautiful example of scientific open-mindedness that Prof. Bragg, the champion of the corpuscular theory, was one of the first to accept the decisive evidence, and has become the chief exponent of the wave theory which he so long opposed. It is interesting to note that exactly the same difference of opinion existed in Sir Isaac Newton's time regarding the nature of ordinary light, and that Newton, during his whole life, believed in the corpuscular theory. We may be sure that he, too, would have been prompt to change to the now-accepted wave theory, if the decisive evidence had appeared in his life-time.

It is not the purpose of the present article to describe the beautiful experiments which led to the solution of this problem—this has been ably done by Prof. Bragg himself—([1]) but rather to present as vivid a picture as possible of the present theory and its interesting consequences.

Definition of Spectrum

Since light consists of waves of electric and magnetic force travelling through space, its quality must depend on the lengths of these waves, and, if there is more than one wave-length, on their relative intensities. The spectrum of the light is the sum total of these wave-lengths, weighted according to their intensities. The commonest form of spectrum is a photograph of the beam after it has passed through a prism or grating. The prism or grating separates the wave-lengths and sends each to a different point on the photographic plate, where it produces a blackening proportional to its intensity. The distance measured horizontally along the spectrum (*cf.* Fig. 3) gives, therefore, the wave-length, and the blackness at that point the intensity, of each constituent of the beam. If the intensity of any particular wave-length is greater than that of its neighbors it stands out as a black line, thus producing the so-called "line spectrum" that is characteristic of gases and vapors. Fig. 3 is an example. The black lines print as white lines.

In the light from an incandescent solid body, on the other hand, the intensity of neighboring wave-lengths differs but little, so that its spectrum is a continuous band, shading off gradually on each end. In this case the photograph is less satisfactory for expressing the intensity relation than a curve like Fig. 4, which represents the spectrum of incandescent tungsten at 2200° C. Here the distances measured horizontally represent wave-lengths, the same as in the photograph, but the intensity of each wave-length is represented by the vertical height of the corresponding point on the curve, instead of by the blackness.

The spectrum of X-rays, which are given out by a solid metal when it is struck by high speed electrons, is, in appearance, a combination of incandescent solid and vapor, that is, it has both the strong continuous spectrum and strong lines. The wave-lengths are, of course, much shorter than those of ordinary light.

The Mechanism of Radiation and Reflection

A ray of light consists of trains of waves sent out by the vibrating electrons in the luminous body, one train from each electron, just as a train of water waves is sent out

[1] "X-rays and Crystal Structure" by W. H and W. L Bragg. G. Bell & Sons, London, 1915.

by any vibrating object in water, or sound waves by a vibrating tuning-fork in the air. In the case of light the waves consist of electric force instead of water or air, but in all other respects they resemble water waves very closely. Picture an electron endowed with eyes standing at a point in the path of the ray of light. The electron will observe that the electric force at the point where he is standing is now upward, that is, in such a direction that an electrically charged body would be pulled upward by it, now downward, now up, now down, etc., in regular sequence, with a periodicity which is called the "frequency" of the light; and if, at the instant when a crest is passing him, that is, when the electric force is upward and at maximum intensity, he looks backward to the next approaching crest, the distance to this crest is a wave-length of the light. The electron will also report that the electric force, instead of being alternately up and down, may be to the right and left respectively, or in any other direction at right angles to that in which the rays are travelling; and that the electric force is always accompanied by a magnetic force at right angles to it. But being electrical, he will be chiefly concerned with the electric force, and since reflection depends on electrons, our interests are identical with his.

We may now give a picture of reflection. The observing electron of the preceding paragraph will experience the pull of the electric force, and, unless he is very firmly anchored,—and we have good evidence that most of the electrons in matter are only loosely held to their positions in the atoms—will soon find himself riding on the wave, moving up and down in synchronism with it. And being electrical, he cannot oscillate in this way without sending out waves of electric force, like the electrons in hot bodies. These secondary waves constitute reflected light. The reflected rays are to be looked upon as new rays, not the primary ones turned back, although it is, of course, the same energy, slightly diminished, that appears in these reflected rays. A good analogy is a motor-generator generating alternating current of the same frequency as the primary current.

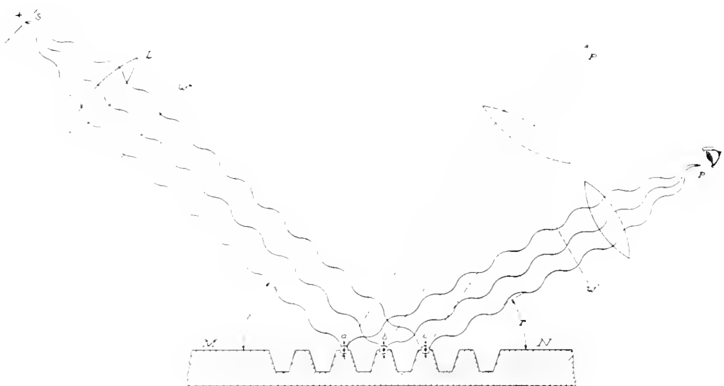


Fig. 1. Diffraction Grating Spectrometer

The Formation of Spectra

The picture of reflection just given can now be applied to explain the separation of different wave lengths of either X-rays or ordinary light into a spectrum. To obtain the spectrum of a beam of ordinary light we select a small portion of it by means of a narrow slit S, Fig. 1, make its rays travel in parallel lines by a lens L, and let them fall on a grating M-N The grating consists of a plate of glass or metal ruled with a large number of fine, parallel grooves. Those electrons in the grating surface upon which the light falls are set into oscillation by it and each one becomes a new source of light waves which it sends out in all directions.

In order to obtain the spectrum of our source of light we have only to add up these secondary wavelets, each with its proper phase. If the wavelets sent out by two electrons, *a* and *b*, Fig. 1, arrive at a point *P* in exactly opposite phase, the electric force due to one will always be downward when that due to the other is upward, and of the same magnitude, i.e., we shall have at every instant two equal and opposite electric forces at that point. The resultant electric force will therefore be zero continuously, and if the eye be placed there the electrons in the retina that cause the sensation of sight will not be set into vibration. If, however, the waves arrive at *P* in the same phase, their electric forces add, and the light is doubled.

The wavelets from the grooved portions need not be considered, as their phase relations are so irregular that their resultant is always small. The locus of points at which the wavelets from the plane areas *a*, *b*, *c*, etc., arrive in the same phase may be found from geometry as follows:

The forced oscillation of the electrons in the metal surface follows exactly the exciting wave, so that the secondary wavelets, at the moment of starting out, are in phase with the primary. The relative phase of the different rays at *P* depends, therefore, only on the distances that the rays have to travel from *S* to *P*. A part of the distance, that from *S* and *P* to planes W_0 and W_1 perpendicular to the direction of the rays respectively, we know to be the same for all rays on account of the action of the lens, so that the distances to be compared are from W_0 to W_1. It is evident at once from the figure that this distance is exactly the same for all rays provided the "angle of incidence," *SbM* is equal to the "angle of reflection" *PbN*. This gives the law of ordinary reflection, and is true for all wave-lengths, and independently of whether the surface *M N* is continuous or broken by scratches. If the surface is continuous this is the only direction in which the secondary waves are all in phase, that is, this is the only direction in which light is reflected. But if the surface is broken by grooves equally spaced, there is another direction *P′* in which the optical distance *S-P′* for rays from consecutive plane areas (*a*, *b*, etc.) differs by just one wave-length, so that the wavelets from *a* arrive just one wave-length ahead of those from *b*, those from *b* one wave-length ahead of those from *c*, etc. They will thus be in phase at *P′* and light of this wave-length will be intense at *P′*. For a

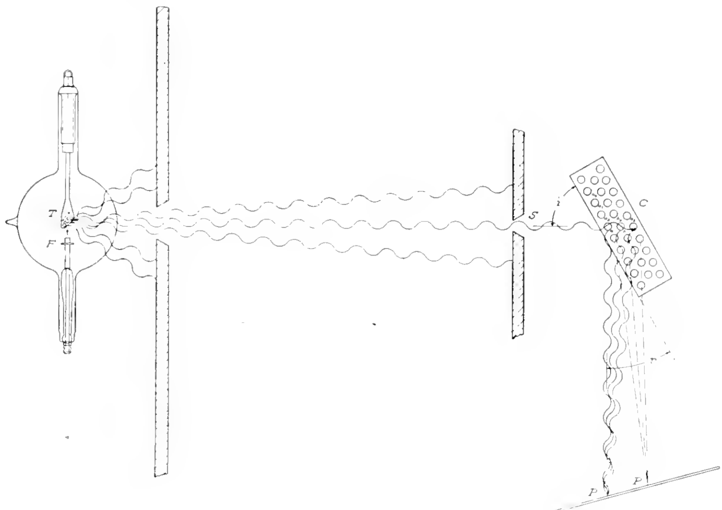


Fig. 2. The Crystal X-ray Spectrometer

different wave-length the wavelets will not be in phase at P', but will be at some other point P''. Thus the different wave-lengths will be separated and form a spectrum.

It is also possible for the wavelets from a to arrive at some point exactly two, three, or four wave-lengths ahead of those from b, and so be in phase. The spectra thus formed are called spectra of the "second order," "third order," etc. A photograph of the complete spectrum will generally contain several orders, some of them overlapping each other.

In the case of X-rays the picture is still simpler; for the wave-lengths are so short that we are able to use for a grating a natural crystal such as rock salt, in which the individual atoms take the place of the little faces a, b, c, of Fig. 1. Crystallography teaches that the atoms in crystals are arranged in regular, equidistant planes, and Prof. Bragg and his son have been able, by means of X-ray spectra, not only to confirm this hypothesis but to find the exact positions of the atoms. They find that the atoms in each plane are equally spaced in parallel rows. These rows of atoms correspond to the narrow plane surfaces between grooves in the diffraction grating. The only difference between the crystal and the grating is that the X-rays penetrate several thousand planes deep, so that the crystal is like a pile of semi-transparent gratings, all equidistant and with their lines parallel.

The use of the crystal as a grating is shown graphically in Fig. 2, where F represents the hot filament cathode of the X-ray tube, T the target, C the crystal, and P the photographic plate. The electrons of the "cathode ray" stream fall upon the target and set the electrons of the atoms in its surface into violent vibration. It is easy to conceive how the frequency of vibration caused by one of these blows, from an electron moving with half the velocity of light, should be much higher than that caused by a bump from another atom, such as gives rise to the visible light of a hot body.

These vibrating electrons of the target send out the high frequency electric waves which we call X-rays. They travel out in all directions, and a portion of them, passing through the narrow slit S, fall on the crystal C, and cause the electrons in its atoms to vibrate and radiate secondary wavelets. These secondary wavelets then travel to the photographic plate P and there reinforce or annul each other according to their phase relations, as in the case of the visible spectrum already discussed.

To find the proper phase relations it is best to proceed in two steps, first considering the atoms in a single plane, and then the relation of the planes to each other. For a single plane the phase relations are exactly the same as for the grating, since the plane with its rows of atoms acts just like a grating. We need, for the present purpose, only the first relation deduced above, namely, that the wavelets, from all the atoms in the plane will be in phase with each other provided the angle of incidence of the rays on the plane is equal to the so called "angle of reflection," the angle at which that part of the secondary rays which we are considering leaves the crystal. Any one atom in the plane may therefore represent the phase of all of them, provided we keep the angles of incidence and reflection equal.

The second part of the problem is to find under what conditions the wavelets from the atoms in the first plane are in phase with those from the second, etc. Let us take as representative atoms from the different planes, those which lie in a straight line parallel to the primary beam, as a_1, b_1, c_1, etc., Fig. 2. (If necessary the planes may be imagined to slide over each other until these atoms are in line.) The primary wave $s\ a\ b\ c$ reaches b later than a, so that the phase of oscillation of the electrons of b, and hence of the wavelets which they send out, will be behind those of a. The wavelets from b also have a greater distance to travel to P than those from a, so that they will be still more behind in phase when they arrive at P. If, however, they are a whole wave-length, or any whole number of wave-lengths behind, they will be in phase, and the electric forces of the two will add. Exactly the same relation will exist between the wavelets from c and b, d and c, etc., since the planes are equidistant. Hence the wavelets from all the atoms in the crystal will be in phase at P when two conditions are fulfilled: (1) the angle of incidence must be equal to the angle of reflection; (2) this angle must be such that the wavelets from successive planes differ in phase by some integral number of wave-lengths. We then obtain a registration on the photographic plate at P, of one wave-length of the primary beam. For a different wave-length the wavelets will be in phase at some adjacent point P' on the photographic plate, provided we rotate the crystal until the angles of incidence and reflection are again equal, and of the proper value for this new wave length. Thus by continuous rotation of the cyrstal, which is accomplished by a motor and worm gear, all the wave-lengths in the beam are successively registered.

According to the second condition given above, the same wave-length may be registered at several different positions on the plate, corresponding to phase differences of one, two, three, etc., wave-lengths between wavelets from consecutive planes. Hence if the crystal is rotated far enough, several complete spectra will be obtained, called respectively the first, second, third, etc., order spectra. The intensity of the higher orders is very small, so that usually not more than three orders are visible. Fig. 6 shows the so-called "*K*" lines of tungsten in two orders, and Fig. 5 in three orders.

The photographic plate gives the correct values of the wave-lengths present in the beam, but not the intensity. In order to obtain this we make use of the fact that when X-rays pass through a gas they make it electrically conducting. Hence if the rays are allowed to enter an "ionization chamber," which consists simply of two oppositely charged plates, a current will flow through the gas between the plates. This current can be

Fig. 3. Visible Spectrum of Tungsten Vapor. (Wave Lengths in Aengstrum Units)

measured by a sensitive electrometer and is proportional, if the gas is dense enough to absorb nearly all the rays, to the intensity of the rays. Thus by putting the ionization chamber in place of the photographic plate, and reading the electrometer at regular intervals while the crystal is being rotated, one obtains the intensities of all the wave-lengths in the spectrum. The spectrum shown in Fig. 4, was obtained in this way.

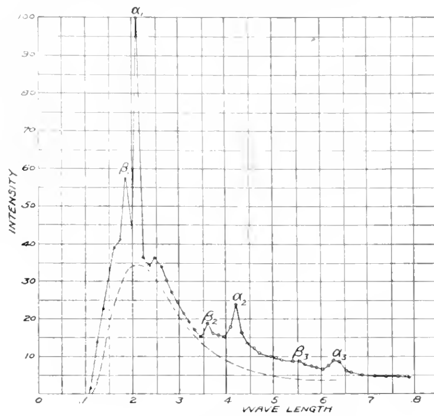


Fig. 4. X-ray Spectrum of Tungsten at 100,000 Volts, Obtained by the Ionization Chamber

Description of the Spectrum

The X-ray spectrum of tungsten, obtained as described above, is shown in Figs. 4, 5 and 6. It consists of a "continuous spectrum" extending over four octaves (from the wave-length $\lambda = 0.12 \times 10^{-8}$ cm. to $\lambda = 2 \times 10^{-8}$ cm.), and 16 lines. Four of these lines on the short wave-length end of the spectrum are very close together and are known as the *K* series. They are usually designated as α^1, α, β and γ. In Fig. 5, these four lines appear as only two, the "α doublet" appearing as a single line, and the β and γ lines being likewise too close to appear separately. The other 12 lines form another group, with wave-lengths nearly ten times those of the *K* series, and are known as the *L* series.

Fig. 6 shows a photograph taken in the manner described above, with a Coolidge tube having a tungsten target, running at 100,000 volts and 1.2 milliamperes. The rock salt crystal (*C*, Fig. 2), was 40 cm. from the target *T* and 56 cm. from the photographic plate, and was kept in continuous rotation during the four-hour exposure.

The photograph shows three of the four "*K*" lines of tungsten, the α doublet and the strong β line, in the first and second orders (marked with subscripts 1 and 2 respectively). The γ line, which is just to the left of the β line, is too weak to show. The wave-lengths of these lines are 0.212, 0.208, and 0.185 Aengstrom units* for the two α lines and the β line respectively. The wave-length of the β line, which is the shortest line that has been observed in the tungsten X-ray spectrum, is a little less than $\frac{1}{10,000}$ of the wave-length of the shortest ultraviolet line ($\lambda = 2700$ Aengstroms) that has been found in the spark spectrum of tungsten vapor.

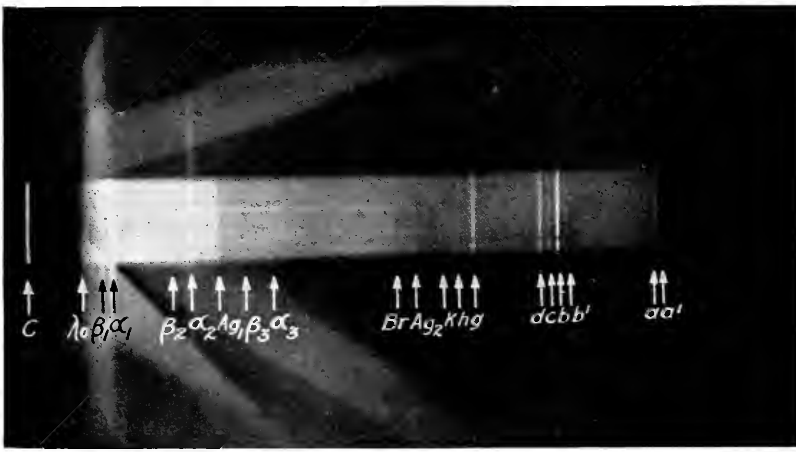


Fig. 5. Complete X-ray Spectrum of Tungsten at 100,000 Volts

Fig. 5 is taken under the same conditions of current and voltage as Fig. 6, but the photographic plate was only one-third as far, 19 cm., from the crystal, and the crystal was rotated through a larger angle so as to obtain a larger portion of the spectrum. The time of exposure was six hours. On this photograph C is the undeviated primary beam of rays which has passed straight through the crystal, and marks the zero line from which to measure the lines on the spectrum. The wave-lengths of these lines are approximately proportional to their distance from this zero line, except for the lines of 2nd and 3rd order, whose distances must be divided by 2 and 3 respectively.

The wave-length marked λ_0 at the extreme left of the photograph, the shortest wave-length present in the spectrum, is connected in a very interesting way with the velocity of the electrons which impinge upon the target in the X-ray tube, and produce the rays. If we speak in terms of frequency instead of wave-length, the frequency of this limiting wave-length multiplied by Planck's universal constant "h," the so-called "quantum," is exactly equal to the kinetic energy of the impinging electron. This relation has been checked over the whole range of voltage from 20,000 to 100,000 volts, and is more than a coincidence. It is another of the striking mathematical relations which the "quantum theory"† has brought to light, and which, though not at present understood, must have an extremely intimate connection with the mechanism of atomic structure.

The lines marked α_1, α_2, α_3 and β_1, β_2, β_3 are the first, second and third orders respectively of the α and β lines of the "K" series. The two α lines show separately in the second order, but not in the first. The γ line is not visible.

The band whose edge is marked Ag_1 is an absorption band of the silver in the photo-

* The Aengstrom unit $\frac{1}{100,000,000}$ cm., is the standard unit for expressing the wave-lengths of visible light, and is used here for the sake of comparison. The wave-length of ordinary green light is 5000 Aengstrom units.

† For a brief review of the quantum theory see Dushman, G. E. Rev., Sept., 1914.

graphic plate. For all wave-lengths shorter than this wave-length Ag_1, (0.488 Aengstroms), silver has an especially strong absorption. Since photographic action depends upon the amount of light which the sensitive film absorbs, and since about 99 per cent of the energy of X light goes through the plate without absorption, it is evident that an increase in the absorbing power of the silver will cause a large increase in blackening.

The band Ag_2 is also due to the silver, and is caused by the "second order" reflection of these same wave-lengths, striking the plate this time at a point twice as far from the central line C. In the same way the band Br is due to the special absorption, by the bromine atoms in the silver bromide of the photographic plate, of all wave-lengths shorter than 0.926 Aengstroms.

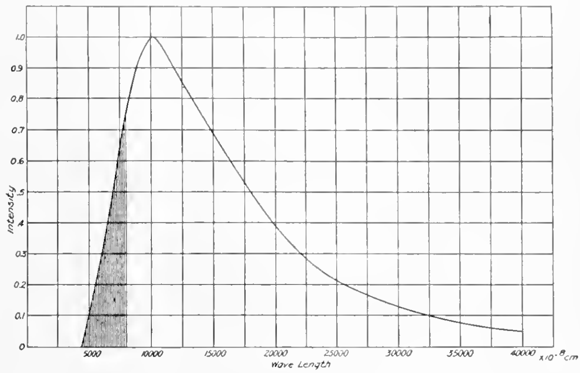


Fig. 7. Spectrum of Incandescent Solid Tungsten

There is one other absorption band, which shows clearly on the original photograph, just to the left of Br. It is due to the special absorption, by the minute trace of rubidium in the glass of the X-ray bulb, of all wave-lengths shorter than 0.79 Aengstroms. In this case special absorption means a loss of light to the photographic plate, hence the spectrum to the left of Rb is less black than that to the right. The absorption bands due to the other constituents of the glass fall too far to the right to show on the photograph.

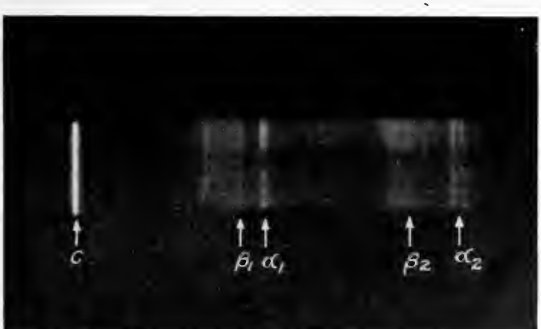


Fig. 6. X-ray Spectrum of Tungsten—The "K" Lines

All known elements have these X-ray absorption bands, and their positions are much more regular and more simply related to the material than are the bands in the visible spectrum. As far as known every element has two absorption bands for X-rays, one beginning at a wave-length just beyond its K series on the short wave-length side, the other just beyond its L series. The wave-lengths at which each of these bands begin, for the different elements, are very nearly proportional, inversely, to the squares of the "atomic numbers" of the respective elements.* The physical meaning of this relation also, like the quantum, is not yet known. Its simplicity and exactness give it significance.

The rest of the lines, those to the right of Ag_2, all belong to the "L" series. For convenience of identification they are lettered a-k. Their wave-lengths range from 1.47 Aengstroms for "a" to 1.033 for "k." They are all in the first order.

* The atomic number of an element is the number of its position in a table arranged according to atomic weight, beginning with hydrogen equal to one, helium two, etc. It has been found to be more intimately connected with the chemical properties of the atom than the atomic weight, and is probably very closely related to the number of electrons in the atom.

For the purpose of comparison the spectrum of tungsten vapor, made luminous by an electric spark, is shown in Fig. 3. The lines do not show very clearly because they are so numerous. Compared with the complexity of these visible spectra, some of which contain as many as 60,000 lines, the X-ray spectra are strikingly simple. This simplicity makes the X-ray spectra especially useful, both for scientific investigation and as a means of chemical analysis.

The continuous spectrum, which appears as a continuous background in Figs. 5 and 6, is shown graphically in Fig. 4. This was obtained by the use of an ionization chamber and electrometer, in place of the photographic plate, as explained above. The current and voltage were the same as for Figs. 5 and 6, viz., 100,000 volts and 1.2 milliamperes. The ordinates of points on the curve give the intensity of the corresponding wave-lengths, whose values, in Aengstroms, are given by the abscissas. The circles mark the experimental measurements as read from the electrometer.

The curve shows clearly the repetition in the first, second and third orders, of the α and β lines shown in the photographs of Figs. 5 and 6. It also shows the relative intensity of the lines as compared with the continuous spectrum upon which they are superimposed. The continuous spectrum is, like the lines, present in all three orders, so that to obtain the true relative intensity of the different wave-lengths in the beam it is necessary to separate these different orders. This has been done for a lower voltage, 70,000, and the resulting values are shown in the dotted curve, Fig. 4. Here the K lines are absent, as the voltage, 70,000, was not high enough to excite them. For comparison the visible and infra-red spectrum of incandescent tungsten at 2200° C., which is approimately the temperature of the filament of a Mazda lamp, is given in Fig. 7. The shaded portion represents the visible part. If the wave-lengths in Fig. 7 were all reduced ten thousand fold, it would coincide very nearly with the dotted curve in Fig. 4.

ELECTRIC CONDUCTORS

Part II

By Charles Proteus Steinmetz

Chief Consulting Engineer, General Electric Company

In the first installment of this article, which was published in our May issue, the properties of metallic, electrolytic and pyroelectric conductors were discussed; and also those of carbon, which possesses some properties peculiar to itself. In the present installment the characteristics of insulators are first considered, after which the more unusual forms of conduction are dealt with, such as that through gas, vapor and vacuum, disruptive conduction, arc conduction and electrotonic conduction. The article is concluded with a review of the substance of the two installments.—Editor.

Insulators

(16) As a fourth class of conductors may be considered the so-called insulators, that is, conductors which have such a high specific resistance that they cannot industrially be used for conveying electric power, but on the contrary are used for restricting the flow of electric power to the conductor, or path, by separating the conductor from the surrounding space by such an insulator. Insulators also have a conductivity, but their specific resistance is extremely high; for instance, the specific resistance of fiber is about 10^{12}, of mica 10^{14}, of rubber 10^{16} ohm centimeter, etc.

As the distinction between conductor and insulator is therefore only qualitative, depending on the application and more particularly on the ratio of voltage to current given by the source of power, sometimes a material may be considered either as insulator, or as conductor. Thus when dealing with electrostatic machines, which give high voltages but extremely small currents, wood, paper, etc., are usually considered as conductors, while for the low voltage high current electric lighting circuit they are insulators; and for the high power very high voltage transmission circuits they are on the border line—are poor conductors and poor insulators.

Insulators usually, if not always, have a high negative temperature coefficient of resistance, and the resistivity usually follows approximately the exponential law:

$$r = r_o\, E^{-\frac{a}{T}} \qquad (3)$$

where T = absolute temperature. That is, the resistance decreases by the same percentage of its value for every degree C. For instance, it decreases to one-tenth for every 25 deg. C. rise of temperature, so that at 100 deg. C. it is 10,000 times lower than at 0 deg. C. Some temperature resistance curves of insulating materials with log r as ordinates, are given in Fig. 14.

As the result of the high negative temperature coefficient, with a sufficiently high temperature the insulating material, if not destroyed by the temperature, as is the case with organic materials, becomes appreciably conducting, and finally becomes a fairly good conductor, usually an electrolytic conductor.

Thus the material of the Nernst lamp (rare oxides, similar to the Welsbach mantle of the gas industry) is a practically perfect insulator at ordinary temperatures, but becomes conducting at high temperature, and is then used as a light-giving conductor.

Fig. 15 shows for a number of wet resistance insulating materials the temperature resistance curve at the range where the resistivity becomes comparable with that of other conductors.

(17.) Many insulators, however, and more particularly the organic materials, are chemically or physically changed or destroyed before the temperature of appreciable conduction is reached, though even these show a high negative temperature coefficient. With some of these substances, as varnishes, etc., the conductivity becomes sufficient at high temperatures (though still below the carbonization temperature) to permit appreciable energy loss under high electrostatic stress, as in the insulation of high voltage apparatus, from leakage current through the insulation, and in this case rapid i^2r heating and final destruction of the material may result. That is, such materials, while excellent insulators at ordinary temperature, are unreliable at higher temperature.

It is quite probable that there is no essential difference between the true pyroelectric conductors and the insulators, but the latter are merely pyroelectric conductors in which the initial resistivity and the voltage at the maximum point b are so high that the change from range (2) of the pyroelectrolyte (Fig. 4) to range (3) can not be produced by increase of voltage. That is, the distinction between pryoelectric conductor and insulator would be a qualitative one; i.e., that in the former the maximum voltage point of the volt-ampere characteristic is within experimentol reach, while with the latter it is beyond reach.

Whether this applies to all insulators, or whether amongst organic compounds, as oils, there are true insulators which are not pyroelectric conductors, is uncertain.

A positive temperature coefficient of resistivity is very often met in insulating materials, such as oils, fibrous materials, etc. In this

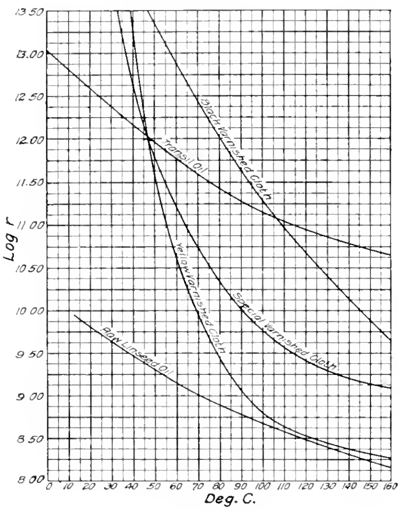


Fig. 14. Resistivity-temperature Characteristic of Insulators

case, however, the rise of resistance at increase of temperature remains permanent after the temperature is again lowered, and the apparent positive temperature coefficient is due to the explosion of moisture absorbed by the material. With insulators of very high resistivity, extremely small traces of moisture may decrease the resistivity many thousand fold, and the conductivity of insulating materials very often is almost entirely moisture conduction, that is, not due to the material proper but to the moisture absorbed by it. In such a case prolonged drying may increase the resistivity enormously, and when dry the material then shows the negative temperature coefficient of resistance incident to pyroelectric conduction.

Gas, Vapor and Vacuum Conduction

(18.) As a further and last class may be considered vapor, gas and vacuum conduction. Typical of this conduction is the fact that the volt-ampere characteristic is dropping, that is, the voltage decreases with increase of current, and that luminescence accompanies the conduction, that is, there is conversion of electric energy into light.

Thus, gas and vapor conductors are unstable on constant potential supply, but stable on constant current. On constant potential they require a series resistance or reactance to produce stability.

Such conduction may be divided into three distinct types: spark conduction, arc conduction, and true electronic conduction.

In spark conduction the gas or vapor which fills the space between the electrodes is the conductor. The light given by the gaseous conductor thus shows the spectrum of the gas or vapor which fills the space, but the material of the electrodes is immaterial, that is, affects neither the light nor the electric behavior of the gaseous conductor, except

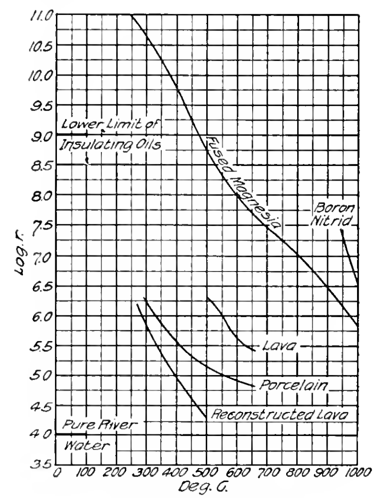


Fig. 15. Resistivity-temperature Characteristic of High Temperature Insulators

indirectly, insofar as the section of the conductor at the terminals depends upon the terminal surface.

In arc conduction, the conductor is a vapor stream issuing from the negative terminal or cathode and moving towards the anode at high velocity. The light of the arc thus shows the spectrum of the negative terminal material, but not that of the gas in the surrounding space, nor that of the positive terminal, except indirectly, by heat luminescence of the material entering the arc conductor from the anode or from the surrounding space.

In true electronic conduction, electrons existing in the space or produced at the terminals (hot cathode) are the conductors. Such conduction thus exists also in a perfect vacuum, and may be accompanied by practically non luminescence.

Disruptive Conduction

(19.) Spark conduction at atmospheric pressure takes place in the form of a disruptive spark, streamers and corona. In a partial vacuum, it is the Geissler discharge or glow discharge. Spark conduction is discontinuous, that is, up to a certain voltage (the disruptive voltage) no conduction exists, except the extremely small true electronic conduction. At this voltage conduction begins and continues as long as the voltage persists, or if the source of power is capable of maintaining considerable current the spark conduction changes to arc conduction from

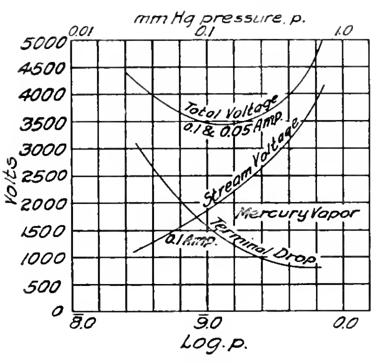


Fig. 16 Volt-pressure Characteristic of Geissler Tube

the heat developed at the negative terminal supplying the conducting arc vapor stream. The current usually is small and the voltage high. At atmospheric pressure, especially, the drop of the volt-ampere characteristic is extremely steep, so that it is practically impossible to secure stability by series resistance; but the conduction changes to arc conduction if sufficient current is available, as from power generators; or the conduction ceases because of the voltage drop of the supply source, and then starts again because of the recovery of voltage, as with an electrostatic machine. Thus spark conduction also is called *disruptive conduction* and *discontinuous conduction*.

Apparently continuous—though still intermittent—spark conduction is produced in the form of corona at atmospheric pressure by capacity in series to a gaseous conductor

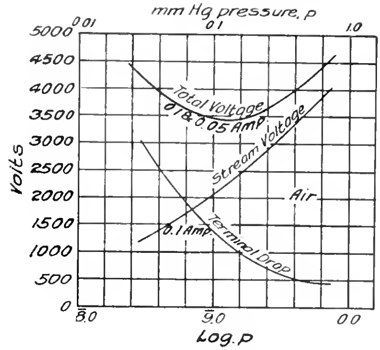


Fig. 17. Volt-pressure Characteristic of Geissler Tube

on an alternating voltage supply, and as Geissler tube conduction at a partial vacuum by an alternating supply voltage with considerable reactance or resistance in series, or from a direct current source of very high voltage and very limited current, such as an electrostatic machine.

In the Geissler tube or vacuum tube, on alternating voltage supply, the effective voltage consumed by the tube at constant temperature and constant gas pressure is approximately constant and independent of the effective current, that is, the volt-ampere characteristic is a straight horizontal line. The Geissler tube thus requires a steadying resistance or reactance for its operation. The voltage consumed by the Geissler tube consists of a potential drop at the terminals, the "terminal drop," and a voltage consumed in the luminous stream, the "stream voltage." Both greatly depend on the gas pressure, and vary with changing gas pressure in opposite directions: the terminal drop decreases and the stream voltage increases with increasing gas pressure, and the total voltage consumed by the tube thus gives a minimum at some definite gas pressure. This pressure of minimum voltage depends on the length of the tube, and the longer the tube the lower is the gas pressure which gives minimum total voltage.

Fig. 16 shows the voltage-pressure characteristic at a constant current of 0.1 ampere and 0.05 ampere of a Geissler tube of 1.3 cm. internal diameter and 200 cm. length, using air as conductor, and Fig. 17 the characteristic of the same tube with mercury vapor as conductor. Figs. 16 and 17 also show the two component voltages, the terminal drop and the stream voltage, separately. As abscissae are used the log of the gas pressure, in millimeters of mercury. As seen, the terminal drop decreases with increasing gas pressure, and becomes negligible compared with the stream voltage at atmospheric pressure.

The voltage gradient per inch centimeter length of stream varies from 5 to 20 volts, at gas or vapor pressure from 0.06 to 0.9 mm. At atmospheric pressure (760 mm.) the disruptive voltage gradient which produced corona is 21,000 volts effective per cm. The specific resistance of the luminous stream is from 65 to 500 ohms per cm^3 in the Geissler tube conduction of Figs. 16 and 17— though this term has little meaning in gas conduction. The specific resistance of the corona in air, as it appears on transmission lines at very high voltages, is of still higher magnitude.

Arc Conduction

(20) In the electric arc, the current is carried across the space between the electrodes or arc terminals by a stream of electrode vapor, which issues from a spot on the negative terminal—the so-called cathode spot—as a high velocity blast (probably of a velocity of several thousand feet per second). If the negative terminal is fluid, the cathode spot causes a depression, as the result of the reaction of the vapor blast, and is in a more or less rapid motion, depending on the fluidity.

As the arc conductor is a vapor stream of electrode material, this vapor stream must first be produced, that is, energy must be expended before arc conduction can take place. The arc therefore does not start spontaneously between the arc terminals if sufficient voltage is supplied to maintain the arc (as is the case with spark conduction) but the arc has first to be started, that is, the conducting vapor bridge must be produced. This can be done by bringing the electrodes into contact and separating them, or by a high voltage spark or Geissler discharge, or by the vapor stream of another arc, or by producing electronic conduction as by an incandescent filament. Inversely, if the current in the arc stops even for a moment, conduction ceases, that is, the arc extinguishes and has to be restarted. Thus arc conduction may also be called *continuous conduction.*

(21) The arc stream is conducting only in the direction of its motion, but not in the reverse direction. Any body which is reached by the arc stream is conductively connected with it, if positive towards it, but is not in conductive connection if negative or isolated, since if this body is negative to the arc stream an arc stream would have to issue from this body to connect it conductively, and this would require energy to be expended on the body before current could flow to it. Thus only if the arc stream is very hot and the negative voltage of the body impinged by it very high, and the body small enough to be heated to high temperature, may an arc spot form on it by heat energy. If therefore a body touched by the arc stream is connected to an alternating voltage, so that it is alternately positive and negative towards the arc stream, conduction will occur during the half wave when this body is positive, but not during the negative half wave (except when the negative voltage is so high as to give disruptive conduction), and the arc thus rectifies the alternating voltage, that is, permits current to pass in one direction only. The arc thus is a *unidirectional conductor*, and as such is extensively used for *rectification* of alternating voltages. Usually vacuum arcs are employed for this purpose, mainly the mercury arc, due to its very great rectifying range of voltage.

Since the arc is a unidirectional conductor, it usually can not exist with alternating currents of moderate voltage, for at the end of every half wave the arc extinguishes. To maintain an alternating arc between two terminals, a voltage is required sufficiently high to restart the arc at every half wave by jumping an electrostatic spark between the terminals through the hot residual vapor of the preceding half wave. The temperature of this vapor is that of the boiling point of the electrode material. The voltage required by the electrostatic spark, that is, by disruptive conduction, decreases with increase of temperature, and for a 13 mm. gap is about as shown by curve I in Fig. 18. The voltage required to maintain an arc, that is, the direct current voltage, increases with increasing arc temperature, and therefore with increasing radiation, etc., about as shown by curve II in Fig. 18. As seen, the curves I and II intersect at some very high temperature, and such materials as carbon, which have a boiling point above this temperature, require a lower voltage for restarting than for maintaining the arc; that is, the voltage required to maintain the arc restarts it at every half wave of alternating current, and such materials thus give a steady alternating arc. Even materials of a somewhat lower boiling point, in which the starting voltage is not much above the running voltage of the arc, maintain a steady alternating arc, because in starting the voltage consumed by the steadying resistance or reactance is available. Electrode materials of low boiling point, however, can not maintain steady alternating arcs at moderate voltage.

The range in Fig. 18 above the curve I is therefore that in which alternating arcs can exist; in the ranges between I and II, an alternating voltage can not maintain the arc, but unindirectional current is produced from an alternating voltage, if the arc conductor is maintained by excitation of its negative terminals, as by an auxiliary arc. This therefore is the rectifying range of arc con-

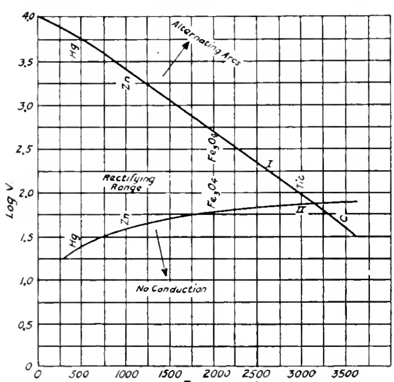


Fig. 18. Rectifying Characteristic of Vapor Conduction

duction. Below curve II all conduction ceases, as the voltage is insufficient to maintain the conducting vapor stream.

Fig. 18 is only approximate. As ordinates are used the logarithm of the voltage, in order to give better proportions. The boiling points of some materials are approximately indicated on the curve.

It is essential for the electrical engineer to thoroughly understand the nature of the arc, not only because of its use as an illuminant in arc lighting, but more still because acci-

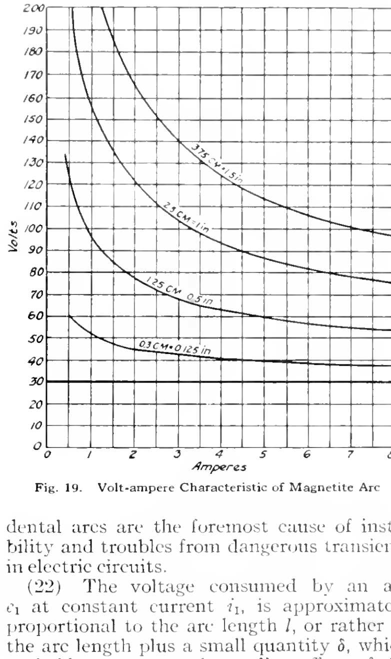


Fig. 19. Volt-ampere Characteristic of Magnetite Arc

dental arcs are the foremost cause of instability and troubles from dangerous transients in electric circuits.

(22) The voltage consumed by an arc e_1 at constant current i_1, is approximately proportional to the arc length l, or rather to the arc length plus a small quantity δ, which probably represents the cooling effect of the electrodes.

Plotting the arc voltage e as a function of the current i at constant arc length, gives dropping volt-ampere characteristics, and the voltage increases more rapidly with decreasing current the longer the arc. Such characteristics are shown in Fig. 19 for the magnetite arcs of 0.3; 1.25; 2.5 and 3.75 cm. length.

These curves can be represented with good approximation by the equation

$$e = a + \frac{c(l+\delta)}{i} \qquad 1)$$

This equation, which originally was derived empirically, can also be derived by theoretical reasoning:

Assuming the amount of arc vapor, that is, the section of the conducting vapor stream, as proportional to the current and the heat produced at the positive terminal as proportional to the vapor stream and thus the current, the power consumed at the terminals is proportional to the current. As the power equals the current times the terminal drop of voltage, it follows that this terminal drop a is constant and independent of current or arc length—similarly as the terminal drop at the electrodes in electrolytic conduction is independent of the current.

The power consumed in the arc stream, $p_1 = e_1 i$, is given off from the surface of the stream, by radiation, conduction and convection of heat. The temperature of the arc stream is constant, or that of the boiling point of the electrode material. The power therefore is proportional to the surface of the arc stream, that is, is proportional to the square root of its section and therefore to the square root of the current, and proportional to the arc length l plus a small quantity δ, which corrects for the cooling effect of the electrodes. This gives:

$$p_1 = e_1 i = c\sqrt{i}\,(l+\delta)$$

or:

$$e_1 = \frac{c(l+\delta)}{\sqrt{i}} \qquad (5)$$

as the voltage consumed in the arc stream.

Since a represents the power consumed in producing the vapor stream and heating the positive terminal, and c the power dissipated from the vapor stream, a and c are different for different materials, and in general are higher for materials of higher boiling point and thus higher arc temperature. c however depends greatly on the gas pressure in the space in which the arc occurs, and decreases with decreasing gas pressure. At atmospheric pressure when l is given in centimeters, it is, approximately:

$a =$	13 volts for mercury
$=$	16 volts for zinc and cadmium
$=$	30 volts for magnetite
$=$	36 volts for carbon
$c =$	31 for magnetite
$=$	35 for carbon
$\delta =$	0.125 cm. for magnetite
$=$	0.8 cm. for carbon

The least agreement with the equation (4) is shown by the carbon arc. It agrees fairly well for arc lengths above 0.75 cm., but for shorter arc lengths the observed voltage is lower than given by equation (4), and approaches for $l=0$ the value $c=28$ volts. It seems as if the terminal drop a (=36 volts with carbon), consists of an actual terminal drop $a_o=28$ volts, and a terminal drop of $a_1=8$ volts, which resides in the space within a short distance from the terminals.

Stability Curves of the Arc

(23) As the volt-ampere characteristics of the arc show a decrease of voltage with increase of current over the entire range of current, the arc is unstable on constant voltage supplied to its terminals at all values of current.

Inserting in series to a magnetite arc of 1.8 cm. length (shown as curve I in Fig. 20), a constant resistance of $r=10$ ohms, the voltage consumed by this resistance is proportional to the current, and is thus given by the straight line II in Fig. 20. Adding this voltage II to the arc voltage curve I, gives the total voltage consumed by the arc and its series resistance, shown as curve III. In curve III, the voltage decreases with increase of current, up to* $i_o=2.9$ amperes, and the arc thus is unstable for currents below 2.9 amperes. For currents larger than 2.9 amperes the voltage increases with increase of current, and the arc is thus stable. The point $i_o=2.9$ amperes, thus separates the unstable lower part of curve III from the stable upper part.

With a large series resistance, $r'=20$ ohms, the stability range is increased down to 1.7 amperes, as seen from curve III′, but higher voltages are required for the operation of the arc.

With a smaller series resistance, $r''=5$ ohms, the stability range is reduced to currents above 4.8 amperes, but lower voltages are sufficient for the operation of the arc.

At the stability limit i_o in curve III of Fig. 20, the resultant characteristic is horizontal, that is, the slope of the resistance curve II, $r=\frac{e'}{i}$, is equal but opposite to that of the arc characteristic I, $\frac{de}{di}$. The resistance r required to give the stability limit at current i is thus found by the condition:

$$r = \frac{de}{di} \qquad (6)$$

Substituting equation (4) in (6) gives:

$$r = \frac{c\,(l+\delta)}{2\,i\sqrt{i}} \qquad (7)$$

as the minimum resistance to produce stability, hence:

$$ri = \frac{c\,(l+\delta)}{2\sqrt{i}} = .5\,e_1 \qquad (8)$$

* Intersection of heavy line with curve III.

where e_1 = arc stream voltage, and:

$$E = e + ri$$

$$= a + 1.5\frac{c\,(l+\delta)}{\sqrt{i}} \qquad (9)$$

as the minimum voltage required by arc and series resistance to best reach stability.

Equation (9) is plotted as curve IV in Fig. 20, and is called the stability curve of the arc. It is of the same form as the arc characteristic *I*, and derived therefrom by adding 50 per cent of the voltage e_1 consumed by the arc stream.

The stability limit of an arc on constant potential thus lies at an excess of the supply voltage over the arc voltage $e = a + e_1$, by 50 per cent of the voltage e_1 consumed in the arc stream. In general, to get reasonable steadiness and absence of drifting of current, a somewhat higher supply voltage and larger series resistance than given by the stability curve IV, is desirable.

(24.) The preceding applies only to those arcs in which the gas pressure in the space surrounding the arc, and thereby the arc vapor pressure and temperature, are constant and independent of the current, as is the case with arcs in air at "atmospheric pressure."

With arcs in which the vapor pressure and temperature vary with the current, as in vacuum arcs like the mercury arc, different considerations apply. This in a mercury arc in a glass tube, if the current is sufficiently large to fill the entire tube, but not so large that condensation of the mercury vapor can not freely occur in a condensing chamber, the power dissipated by radiation etc., may be assumed as proportional to the length of the tube, and to the current

$$p = e_1 i = c\,l\,i$$

thus:

$$e_1 = c\,l \qquad (10)$$

that is, the stream voltage of the tube, or voltage consumed by the arc stream (exclusive terminal drop) is independent of the current. Adding here to the terminal drop a, gives as the total voltage consumed by the mercury tube:

$$e = a + c\,l \qquad (11)$$

for a mercury arc in a vacuum it is approximately:

$$c = \frac{1.4}{d} \qquad (12)$$

where d = diameter of the tube, since the diameter of the tube is proportional to the surface and therefore to the radiation coefficient.

Thus:

$$e = 13 + \frac{1.4\,l}{d} \qquad (13)$$

At high currents, the vapor pressure rises abnormally, due to incomplete condensation,

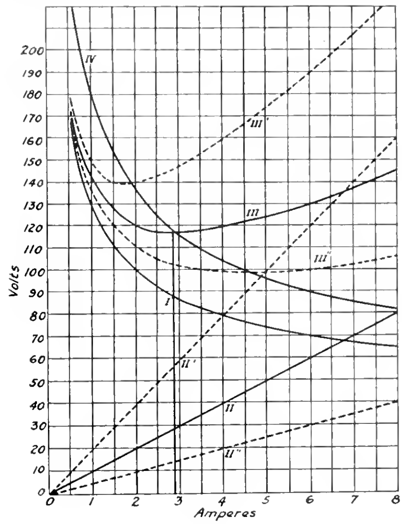


Fig. 20. Stability Characteristic of Arc

and the voltage therefore rises, and at low currents the voltage rises again, due to the arc not filling the entire tube. Such a volt-ampere characteristic is given in Fig. 21.

(25) Whence it follows that the voltage gradient in the mercury arc, for a tube diameter of 2 cm., is about 3/4 volt per cm., or about 1/20 of what it is in the Geissler tube, and the specific resistance of the stream, at 4 amperes, is about 0.2 ohms per cm. cube, or of the magnitude of 1/1000 of what it is in the Geissler tube.

At higher currents, the mercury arc in a vacuum gives a rising volt-ampere characteristic. Nevertheless it is not stable on constant potential supply, as the rising characteristic applies only to stationary conditions; the instantaneous characteristic is dropping. That is, if the current is suddenly increased, the voltage drops regardless of the current value, and then gradually, with the increasing temperature and vapor pressure, increases again to the previous value, a lower value or a higher value, which ever may be given by the permanent volt-ampere characteristic.

In an arc at atmospheric pressure, as the magnetite arc, the voltage gradient depends

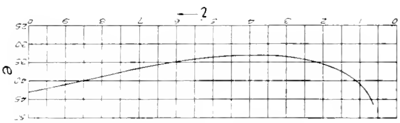


Fig. 21. Volt-ampere Characteristic of Vacuum Mercury Arc. $L=40$ Cm. $D=2.2$ Cm.

on the current, by equation (1), and at 4 amperes is about 15 to 18 volts per cm. The specific resistance of the arc stream is of the magnitude of 1 ohm per cm. cube, and less with larger current arcs; thus of the same magnitude as in vacuum arcs.

Electronic Conduction

(26) Conduction occurs at moderate voltages between terminals in a partial vacuum as well as in a perfect vacuum, if the terminals are incandescent. If only one terminal is incandescent, the conduction is unidirectional, that is, can occur only in that direction, which makes the incandescent terminal the cathode, or negative. Such a vacuum tube then rectifies an alternating voltage and may be used as rectifier. If a perfect vacuum exists in the conducting space between the electrodes of such a hot cathode tube, the conduction is considered as true electronic conduction. The voltage consumed by the tube depends on the temperature of the cathode, and decreases with increasing temperature; it is of the magnitude of arc voltages, and hence is very much lower than in the Geissler tube. The current is of the magnitude of arc currents, and hence is much higher than in the Geissler tube.

(27) The complete volt-ampere characteristic of gas and vapor conduction would thus give a curve of the shape shown in Fig. 22. It consists of three branches separated by ranges of stability or discontinuity: viz. the branch *a*, at very low current, electronic conduction; the branch *b*, discontinuous or Geissler tube conduction; and the branch *c*, arc conduction. The change from *a* to *b* occurs suddenly and abruptly, accompanied by a big rise of current, as soon as the disruptive voltage is reached. The change *b* to *c* occurs suddenly and abruptly, by the formation of a cathode spot, anywhere in a wide range of current, and is accompanied by a sudden drop of voltage. To show the entire range, as abscissae are used log $(l+i)$ and as ordinates log $(l+e)$. The addition of it under the logarithm makes it equal zero for i or $e=0$, and thus avoids the excessive distortion of curve shape for low values of the variables.

Review

(28) The various classes of conduction: metallic conduction, electrolytic conduction, pyroelectric conduction, insulation, gas, vapor and electronic conduction, are only characteristic types, but numerous intermediaries exist, and transition from one type to another by change of electrical conditions, of temperature etc.

As regards the magnitude of the specific resistance or resistivity, the different types of conductors are characterized about as follows:

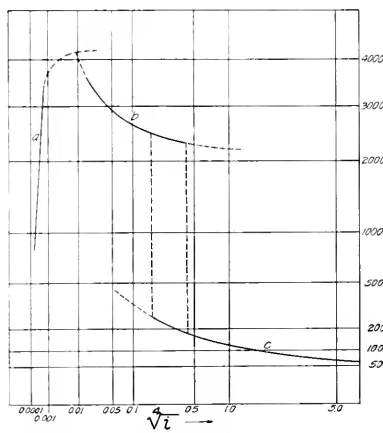


Fig. 22. Approximate Volt-ampere Characteristic of Gaseous Conduction

The resistivity of metallic conductors is measured in michrom centimeters.

The resistivity of electrolytic conductors is measured in ohm centimeters.

The resistivity of insulators is measured in megohm centimeters and thousands of megohm centimeters.

The resistivity of typical pyroelectric conductors is of the magnitude of that of electrolytes, ohm centimeters, but extends from this down towards the resistivities of metallic conductors, and up towards that of insulators.

The resistivity of gas and vapor conduction is of the magnitude of electrolytic conduction; arc conduction of the magnitude of lower resistance electrolytes, Geissler tube conduction and corona conduction of the magnitude of higher resistance electrolytes.

Electronic conduction at atmospheric temperature is of the magnitude of that of insulators; with incandescent terminals it reaches the magnitude of electrolytic conduction.

While the resistivities of pyroelectric conductors extend over the entire range, from those of metals to those of insulators, typical are those pyroelectric conductors having a resistivity of electrolytic conductors. In those with lower resistivity, the drop of the volt-ampere characteristic decreases and the instability characteristic becomes less pronounced; in those of higher resistivity, the negative slope becomes steeper, the instability increases, and streak conduction or finally disruptive conduction appears. The streak conduction, described under pyroelectric conductors, probably is the same phenomenon as the disruptive conduction or break down of insulators. Just as streak conduction appears most under sudden application of voltage, but less under gradual voltage rise and thus gradual heating, insulators of high disruptive strength, when of low resistivity as a result of absorbed moisture, etc., may stand indefinitely voltages applied intermittently, so as to allow time for temperature equalization but will quickly break down under very much lower sustained voltage.

VOLTAGE REGULATION FOR ELECTRIC LIGHTING SYSTEMS

By George P. Roux

Consulting Engineer, Philadelphia, Pa.

The following article combines an exposition of the commercial motives that brought about the voltage regulation of lighting systems, a technical instruction of the electrical values involved, and a description of the apparatus used. A tabulation of the Public Service Commission's rules for permissible voltage variations in various states is included. The performance characteristics of incandescent lamps, small motors, and heating appliances on varying voltages are described. Recommendations for the proper location of voltage regulators are given. The article is concluded by a description of the various types of voltage regulators and an explanation of the particular advantages of each.

In a system of distribution radiating from a central station, consisting either of feeder circuits or transmission lines serving a number of substations connected thereto, and where lighting and power are supplied or loads having different characteristics, the voltage regulation throughout cannot be maintained from the generating station to meet the individual requirements of each centre of lighting distribution from which lighting circuits emanate.

It is therefore necessary to provide certain means whereby each individual lighting system is made practically independent and able to govern its own voltage regulation, which can then be adjusted to suit any special condition or requirement proper to each case.

The autonomy of each lighting system is specially required where a single circuit transmission line is used. When there are two lines, one can be used in some cases to supply the lighting load, while the other supplies the power load; however, such operating conditions impair the continuity of the service in case of accident to one of the lines. A better regulation is possible in this way, yet it is a uniform regulation which may well suit the requirements of a given centre and still be entirely inadequate to others. Hence ideal conditions are reached when each lighting system is made independent of the regulation of the transmission line or feeder system from which it is supplied.

Ideal conditions are those that permit and insure a good and reliable service to consumers, which, besides being continuous and available at all hours, must be constant in its voltage regulation, or varying within limits that will not affect the efficiency of the service.

There is no better reason for complaint, nor one more justified, than a deficiency or low voltage in a lighting service. It is provoking and justly called outrageous because it causes a conspicuous deficiency in the intensity of the light that cannot pass unnoticed and that can be assimilated as a shortage in the weight of the commodity served. Such conditions, in many cases unavoidable, exist too often in many lighting systems, and they invariably reflect on the standard of service offered by a lighting company, with disastrous results where there is compet tion. Deficiencies that were accepted at first, during the early period of the industry, are no longer tolerable with the present development of electrical apparatus.

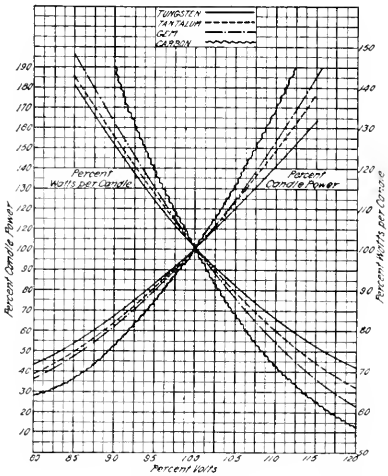


Fig. 1 Characteristic Curves of Incandescent Lamps

Incandescent lamps are greatly affected by variations of voltage, specially when the fluctuation exceeds 5 per cent above or below normal. This sensitiveness is due to the increase or decrease in the temperature of the filament. The comparative performances of carbon, gem, tantalum and tungsten lamps are shown in Fig. 1. An increase of candle-power and wattage is coincident with an increase of voltage to the detriment of the life of the lamps, reverse conditions are found with a decrease of voltage. It is to be noted that the tungsten lamp in all cases indicates a marked superiority over all others in that it shows a smaller percentage of variation of candle-power under similar operating conditions, because its high positive temperature coefficient of resistance partly compensates for the variation of voltage.

The performances shown in Fig. 1 emphasizes the importance of close voltage regulation with regard to both quality and economy of the service, and practically limit the permissible variation within 2½ per cent above and 2½ per cent below the rated voltage of the lamps in service. They further demonstrate the importance of selecting lamps of proper voltage rating, and justify a supervision by the electric company of the lighting installation of its customers.

The matter of potential regulation is recognized by most of the Public Service Commissions in their rules governing electric service, the following tabulation gives the voltage fluctuation allowed by these bodies.

In power installations voltage variation is not as serious a matter as it is in lighting service, and a greater range of fluctuation is allowable. However, it must be remembered

VARIATIONS PERMISSIBLE IN THE VOLTAGE OF ELECTRIC LIGHTING SERVICE AT THE CONSUMER'S CUT-OUT

State	Per Cent Variation from Standard Voltage		Duration of Variation	Period of the Day
	Above	Below		
Connecticut	5	3	1 minute	From sunset to 11 p.m.
D. of Columbia	3	3	Not stated	During lighting hours
D. of Columbia	10	10	Not stated	At any other hours
Indiana	3	3	Not stated	During (whole) day
Illinois	5	5	1 minute	During (whole) day
Maryland	6	6	Not stated	From sunset to 11 p.m.
Missouri	3	5	1 minute	From sunset to 11 p. m.
Missouri	5	10	1 minute	11 p.m. to sunset
New Jersey	3	3	5 minutes	From sunset to 11 p.m.
Oregon	3	5	5 minutes	From sunset to 11 p.m.
Oregon	5	10	5 minutes	11 p.m. to sunset
Pennsylvania	5	5	1 minute	During (whole) day
Wisconsin	3	10	Not stated	During lighting hours
Wisconsin	10	3	Not stated	At any other hours

that a decrease of voltage reduces the torque of induction motors in the ratio of

$$\frac{\text{Rated Voltage}^2}{\text{Applied Voltage}^2}$$

with also a reduction in the power output and increase of the current consumption. A rise of voltage increases the value of the magnetizing current and also slightly raises the power-factor. In both cases there results an increase in the temperature of the motor, this effect being more pronounced at lower voltage.

Line transformers and other industrial appliances are affected to some degree by variations in the supply voltage as are induction motors; reduced capacity and increased temperature follow a reduction of voltage, and increased core loss at higher voltage. Heating appliances are affected like the incandescent lamps by variations of voltage. All these conditions are conducive to bad regulation.

The importance of good regulation is self evident; continuity and convenience of service coupled to a steady voltage command business, bring customers, and add to the revenue. It is well known that the best advertisement for any business is a contented customer. Towards this goal are bent all the efforts of all public utilities and nothing is spared to achieve this end and to eliminate any factor that might impair the reliability of the service.

Regulation

The voltage regulation in a network of distributing conductors emanating from a substation fed from a transmission line is governed, first, by the regulation at the generating end; second, by the regulation of the step-up transformers; third, by the transmission line; fourth, by the step-down transformers; fifth, by the regulation of the distributing lines; sixth, by the regulation of the distributing transformers; and seventh, by the nature of the load connected thereon.

It can be seen that the regulation is affected by a number of factors, always variable and constantly changing; thus the regulation is not the same all over the system. The changes in regulation depend mostly on the value and character of the load carried, and changes in power-factor greatly offset the regulation.

To remedy these changing conditions in a lighting system it is important to so select the point where the potential regulator is to be installed and connected as to obtain the best results, and to accurately determine the amplitude of the voltage variations which in turn determine the range of boost and buck of the regulator.

As a matter of fact, considering a given point on a transmission line system, for instance a substation, it is fair to assume that a convenient voltage can be impressed on the high-tension windings of the step-down transformers to meet the operating conditions of the locality to be served, as these transformers are provided with taps which permit of adjusting the secondary voltage from time to time as required, should any change in the supply voltage occur due to the loading of the transmission line.

It is also the practice in such a system to compensate for the increase in potential drop on the transmission line with increase in load, as during peak hours, by boosting the generator voltage during such periods, although sometimes conditions exist which do not permit this operation, and in such a case it must be taken into account in determining the size of the potential regulator.

In general the problem is reduced to the regulation of the substation itself, and the lines emanating therefrom, with due allowance for transmission line regulation throughout the twenty-four hour period of the day.

Voltage regulation is the ratio of maximum voltage difference between two given load conditions (usually no load to full load) to constant, initial, or impressed voltage.

In alternating-current circuits there are a number of elements which affect this regulation, as for instance inductive and non-inductive load, and which are not found in continuous-current circuits.

The voltage regulation of an alternating-current circuit is the ratio between the resultant of its resistance and reactance, that is to say, its impedance from no load to full load, varying according to the character of the load, or in other words, its power-factor.

The impedance can be written:

$$R = \sqrt{Ro^2 + Ri^2}$$

Where R = Impedance
Ro = Ohmic resistance
Ri = Reactance

For more simplicity, the following formula can be used, which gives in most cases results accurate enough, as they will be found within

2/100 of 1 per cent if the regulation does not exceed 20 per cent.

$$R = Ro + \frac{Ri^2}{2\ Ro}$$

We thus have vectorially Fig. 2.

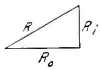


Fig. 2

The voltage drop of the circuit will therefore be found by the application of Ohm's law, substituting for the value of ohmic resistance that of the impedance, except for high-tension and long transmission lines where other factors like conductive reactance and leakage current should be taken into account.

Thus voltage drop $e = \frac{RI^2}{100\ E}$ = Per cent drop.

It can be seen at once that inasmuch as the value of I, or the amperes in a line, varies according to the power-factor, the voltage drop, and hence the regulation, will also vary accordingly.

Graphically the regulation diagram of a transmission line can be shown as in Fig. 3.

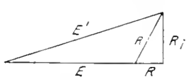


Fig. 3

In a transformer these same conditions will prevail, and the per cent regulation of such an apparatus under non-inductive load can be written:

$$E = \sqrt{(100+Ro)^2 + Ri^2}$$

or sufficiently accurate for practical purposes, as follows:

$$E = Ro + \frac{Ri^2}{2\ Ro}$$

these values being expressed in percentages.

If therefore we have a transformer connected at the end of a transmission line, graphically the regulation of both will be represented thus, Fig. 4:

The total drop, being vectorially added, is represented by E_2.

If we now add to the above the distributing system from the low-tension side of the step-down transformers at the substation to the consumer side of the distributing transformer, we have Fig. 5.

The point O is the generating end, and the point A the receiving or delivery end to the consumer, where it is intended to maintain a constant voltage regardless of any variation in the intervening links.

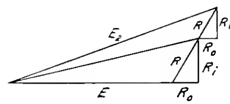


Fig. 4

Line and apparatus connected between O and A constitute the complete circuit and its regulation is the sum of the regulation of each individual link.

The ideal would naturally be to install at A a potential regulator. This would be so costly as to be prohibitive, if such a device were provided for each consumer.

However, by grouping loads of the same character on a distributing circuit, or loads that will not interfere with each other to any appreciable extent, and by providing an adequate cross section of conductor for the load it has to carry; it is possible in practice to assume that this part of the system can be effectively controlled from B; that is, at a point where the circuit leaves the secondary side of the step-down transformer in the substation. A glance at Fig. 5 will show that this is evidently the best location for the potential regulator.

The regulation from no load to full load of most lighting transformers under a power-factor of 0.8, which can be taken as the average condition of lighting systems, never exceeds 3 per cent as a rule.

The regulation of a transmission line, properly calculated and under ordinary conditions, should not exceed 10 per cent, and an average of 6 per cent maximum is rather more desirable. This drop is compensated for in most cases by boosting the voltage at the generating end during peak lighting hours, and in practice the difference of voltage is reduced to 3 per cent.

The maximum boost required in practice from a potential regulator to meet the worst operating conditions is therefore:

Transmission line	3 per cent
Step-down transformer	3 per cent
Distributing line	4 per cent
Distributing transformer	3 per cent
Total	13 per cent

A potential regulator having a range of 10 per cent boost and 10 per cent buck is therefore ample to satisfy these conditions with some margin, if the secondary voltage of the step-down transformer is adjusted by means of taps to a little above normal under no-load conditions, so that the potential regulator will then buck about 5 per cent, leaving 2 per cent margin for the worst conditions outlined above.

There is no objection to limiting the maximum buck to 5 per cent under normal, as an excess of voltage at the generating end is more easily controlled than a deficiency, and furthermore the probabilities are that a lower rather than a higher voltage will exist at the power house.

Voltage Regulators

Under the conditions outlined above, a steady voltage can be maintained by means of automatic feeder regulators, which, when properly selected, keep the potential of the line to which they are connected practically constant, even if there are wide variations in the potential of the source of supply or wide variation in the potential drop of the line regulated, as is found in many instances where power load is supplied from the same circuit as the lighting load. For all practical purposes these apparatus are able to maintain a voltage well within the commercial limits of good regulation.

Thus a station or substation equipped with the proper type of potential regulators is (so far as maintaining a constant voltage in its distribution lines is concerned) entirely independent of any variation in the voltage impressed at the source of supply; provided, of course, that the potential regulators are

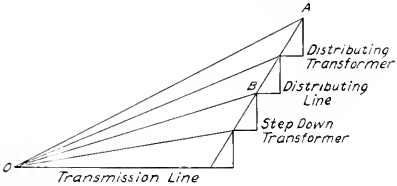


Fig. 5

of such a type, size and capacity as to offset the magnitude, amplitude, and frequency of these fluctuations. Such regulation or control of the voltage delivered to the line or feeder can be made entirely automatic and adjustable to take care of changes in voltage that arise from changes in load requirements; and yet if necessary, this regulation can also be effected by hand. The automatic regulation can be adjusted to maintain the voltage constant at a predetermined point on the system, or at the outgoing point of feeders,

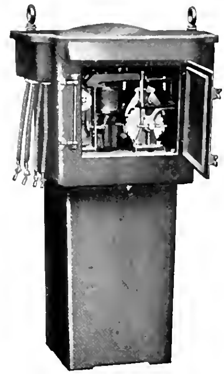


Fig. 6. Pole Type Regulator

or on the busses of a distributing switchboard, depending upon the requirements.

In certain cases, specially on long distribution lines, additional feeder potential regulators of the pole type can be installed at points that are beyond the reach of the station potential regulator, so as to boost the voltage and compensate for drop of potential that may be due to insufficient copper for peak loads; the conductors being large enough for the service under ordinary conditions, and therefore the expense of increasing their size being unwarranted.

Such conditions occur in cities where a feeder runs through the business section and continues in the residential district, at which place the pole type potential regulator may be installed to great advantage, besides the one at the station. In the early hours of the evening this feeder will be heavily loaded in the business section, and in spite of the potential regulator at the station it would be a case of either keeping a voltage too high for the business district in order to have it right in the residential section, or vice versa. The pole type regulator on such an occasion will boost the voltage in the residential section, thus maintaining a uniform voltage throughout the entire length of the feeder.

Without this pole type regulator it would be necessary to run a feeder for the business district and another one for the residential section at a cost, and with possibly many engineering difficulties to overcome, that might not be justified or feasible.

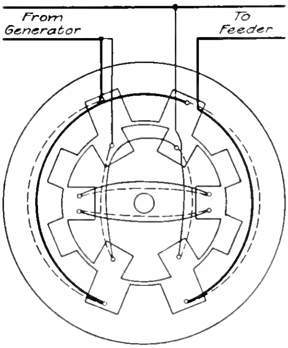


Fig. 7. Diagrammatic Sketch of Single-phase Induction Type Regulator

The effects of potential regulators on a lighting feeder system are manifold and are worthy of mention:

Better service and better illumination, thus eliminating at least one source of complaint, and in some way reducing the size of the delinquent account; customers meeting their bills more promptly when satisfied with the service.

More satisfactory operation of electric appliances now extensively used in the homes, especially heating apparatus.

Better accuracy of watthour meters or current metering devices.

Increase in sale of current, due to the fact that a decrease in voltage carries with it a decrease in illuminating power of the lamps. It must also be borne in mind that a voltage carried below normal is a serious loss to the company, as the percentage of power consumed by the lamp decreases approximately as twice the percentage decrease in voltage.

An excess of voltage above normal is by no means better, as the consumption of power is increased, together with the intensity of illumination, which may be undesirable. The company on its side has to suffer the cost of increase in lamp renewals due to the shorter life, or if tungsten lamps are paid for by the consumer, dissatisfaction follows as a result of premature breakages.

It must also be noted that another effect of a potential regulator is to permit the operation of feeders under temporary overload, and yet maintain good service instead of requiring expenditures for additional feeders, as in the case cited above.

Finally, the automatic feature of this regulating device reduces the operating cost of the plant, as less attendance and manual labor are required.

There are now two types of potential regulators on the market, the induction type and the transformer type, both of which are automatic.

The induction type, made for single and polyphase circuits, is better adapted where there is no sudden variation of voltage in the source of supply and in general meets the ordinary and usual requirements in most cases. The moving element of this type of regulator is somewhat heavy, with considerable inertia, and a certain torque is required, which makes it slower in action than the transformer type. However, its efficiency

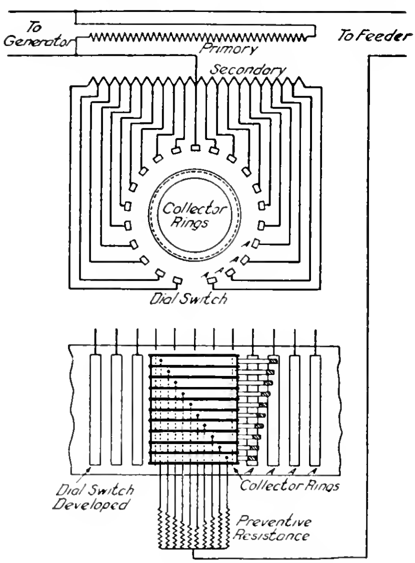


Fig. 8. Sketch of Dial Switch Voltage Regulator

and other features of construction are better than the transformer type.

The transformer type is quicker in action, the moving element being very light and consisting of a commutator which connects more or less of the winding of the secondary of a transformer. This type is specially adapted where there are sudden changes and wide variations of voltage in the supply line—such conditions as are found in electric railway service or where large induction motors are operated with frequent starts or fluctuating load.

In emergency cases a three-phase motor with wound rotor could be used to accomplish the same result as the induction type manually operated. An outfit of this kind acts practically as a single-phase induction type feeder regulator, according to the position given to the rotor with respect to the stator, representing the primary and secondary respectively of the induction regulator.

The single-phase type of potential regulator is better adapted to lighting service on polyphase circuits than the polyphase type, as it is very seldom that all of the phases have exactly the same load characteristic, and they are always somewhat out of balance—conditions unfavorable to the efficient operation of a polyphase potential regulator. For this service one single-phase potential regulator is provided for each phase.

The capacity of a potential regulator is determined by the amount of voltage boost or buck from normal and the volt-amperes of the line on which it is to be connected.

The boost or buck is determined by the particular conditions of the circuit to be controlled and may vary from 5 to 10 per cent, and sometimes more. A chart taken from a curve-drawing voltmeter, recording the 24 hour voltage at a point of the system selected with a view to improving the regulation and during a period of the greatest demand if possible, will readily indicate the maximum fluctuation of voltage to be compensated, and with an allowance for future increase in the load requirements of the circuit will determine the amount of buck and boost of the feeder voltage regulator that must be provided.

However, as the amount of machining work, the dimensions, sizes, floor space and weight vary very little in a potential regulator, whether built for a 5 or 10 per cent variation of voltage, there is a small difference in its cost, and therefore it is generally better to provide for a greater variation in the regulating range. This provision may be found very useful under special conditions, allowing for possible future increases or changes in the operating requirements as it occurs from time to time on some systems where temporary overloading happens quite frequently.

From the operation and maintenance point of view a feeder regulator requires practically the same care and attention that an ordinary transformer demands. The moving parts and driving mechanism are very rugged and need no special attention other than the ordinary routine maintenance.

Voltage regulators, like every other induction apparatus, require protection against potential disturbances. Very strange to say, an amazing percentage of both transformers and regulators are operated with inadequate protection, when any is provided at all. The safety-first campaign which has done so much good in the prevention of accident and the protection of human life should be carried further and extended with equal care and vigor to the protection of apparatus and properties, for many injuries to apparatus cause in turn injuries to human beings, either directly or indirectly.

The peculiar relation of the secondary winding of a voltage regulator, consisting of a transformer coil in series with the line to which it is connected, gives all the conditions of a circuit with high inductive reactance which acts as a breakwater in case of surge or disturbance. This coil receives all the brunt of the impact and transmits it, with serious liability of damage, to the primary winding, and may result in breakdown of the insulation of both windings, as the conditions are ideal for the building up of excessive and destructive voltage.

Lightning arresters, which in all cases should be provided on all lines entering or leaving the station, offer partial protection, but as they are liable to act with a certain time lag, and at a time when the surge is reflected back, some damage may result.

A by-pass such as is afforded by the electrolytic aluminum cell by-pass arrester, which will become operative only at times of disturbance, shunting the series coil of the regulator, that is, practically reducing to zero the value of the inductive reactance of the secondary winding, is to be recommended, as it relieves the strains on the winding to a harmless value. A lightning arrester between the regulator and the busbar or source of supply will complete the protection as far as the present advancement of the art permits

TWO *VERSUS* THREE REACTORS FOR CURRENT LIMITATION IN THREE-PHASE FEEDER CIRCUITS

By F. H. Kierstead

Transformer Engineering Department, General Electric Company

The discussion of this subject is based on the question of economy, including the first cost of the reactances and floor space. Where the short circuit current is limited by magnetic forces between transformer coils or feeders, by heating, or by maximum rupturing capacity of single-phase oil switches, in all of which cases the stresses are virtually in proportion to the maximum current in any phase, the three reactor method is shown to be the cheaper; but where it is only required to limit the volt-amperes on short circuit it may be more economical to employ only two reactors, especially where the cost of current is low compared with the cost of reactors.—Editor.

In the past it has been generally assumed, as a matter of course, that current limitation in three-phase circuits requires reactors in each phase. It may be well, however, to discuss the advantages and disadvantages of inserting reactors in only two of the phases of a three-phase feeder circuit. Of course two reactors cannot afford protection to a grounded Y system, unless the Y be grounded through a resistance, since a ground on the phase having no reactance in it completes a circuit for the flow of current which has no current limiting protection. If the system, however, be an isolated one or grounded through a resistance high enough to limit the flow of current to ground from the unprotected phase to a safe value, two reactors can furnish protection.

Whether the use of two reactors as a method of protection will be economical depends, first, upon the relative cost of the reactors required by each method, and second, upon the amount of loss in efficiency of other apparatus in the circuit due to the unbalanced voltage caused by the unsymmetrical distribution of reactance in the method of protection using only two reactors. In the discussion hereafter, the method requiring reactors in only two phases will be called the "two-reactor method," while the method requiring reactors in three phases will be called the "three-reactor method."

The relation between the cost of the reactors required for each method of protection depends on the relative kv-a. capacities of the single reactors, which in turn depend on the relative values to which the short-circuit current must be limited in each case.

It is therefore necessary first of all to settle upon the relative values to which the short-circuit current must be limited for each method of protection, that is, the highest allowable current in any phase for each method of protection; and since with the two-reactor method of protection the current during a three-phase short-circuit is much larger in one phase than in the other two, while with the three-reactor method the short-circuit currents in all three phases are equal, these relative values are not at once apparent.

In order to decide the question of economy it is necessary to examine the circuit in which the reactors are to be placed to see what phenomena, produced by excessive current, first reach such dangerous values as to require limitation, and thus determine the current limit of this circuit; in other words, to determine whether this limitation is fixed by magnetic forces, either between transformer windings or between phases of feeder cables, by heating in any connected apparatus, or by rupturing capacity of oil switches or continuity of service.

If the current limitation be determined by magnetic forces between transformer coils, or by heating anywhere in the circuit, or by the maximum rupturing capacity of the single-phase oil switches, then, since these limiting conditions depend almost entirely on the maximum current in any one phase, and only slightly, if at all, on the current in the other phases, the maximum short-circuit current in any phase must be limited to the same value for either method of protection.

If magnetic forces between phases of the feeder determine the limit of the short-circuit current, then, since these forces do not depend alone on the current in any one phase but upon the mutual influences of the currents in all three phases, the current limitation is dependent upon the manner in which the currents in each of the phases divide, and must be so set that forces are limited to a given fixed value, whatever be the method of protection. Now during a three-phase short-circuit on a line protected by the two-reactor method, the current in the phase having no reactor in it is much greater than the currents in the other two phases and it would appear that (for equal forces) the maximum current could be higher with this protection than with the three-reactor method where the currents in all three phases are equal. However this is not the case as is shown by the following consideration.

Let

$I_1 = I_2 =$ Currents during a three-phase short-circuit, in phases in which reactors are placed.

$I_3 =$ Current in the other phase. There may or may not be reactors in this place.

$\theta =$ Phase displacement between I_1 and I_3.

$-\theta =$ Phase displacement between I_2 and I_3.

$F =$ Short-circuit force between all three phases.

*Then

F is proportional to I_3, I_1, $(\cos\ \theta) + I_3$, I_2, $(\cos - \theta)$

But

$$I_1\ (cos\ \theta) = \frac{I_3}{2}$$

and

$$I_2\ (cos - \theta) = \frac{I_3}{2}$$

Therefore F is proportional to I_3^2 and providing I_3 remains fixed is constant for all values of I_1 and I_2. Therefore the magnetic forces between cables during a three-phase short-circuit are the same with either method of protection, providing the maximum current in any phase be kept the same.

The above discussion deals only with three-phase short-circuits for the reason that the forces between feeder cables are greatest with this fault.

It is therefore shown that if current limitations be required to protect transformer winding and feeder cables from excessive forces, or to protect any apparatus from excessive heating, or to limit the kv-a. that a single-phase oil switch must rupture, then the maximum short-circuit current in any phase must be limited to the same value, irrespective of the method of protection used. The capacity of the single reactors required by the two-reactor method to meet the above conditions is three times as great as that of the single reactors required by the three-reactor method, or the total capacity of the reactors required by the former method is twice as great as that required by the latter method.

The above conclusion is obtained as follows:

Let

$I_3 =$ Three-phase short-circuit current in the phase of a circuit protected by the two-reactor method in which there is no reactor.

$I =$ Three-phase short-circuit current in each phase of a circuit protected by the three-reactor method.

$E =$ Circuit voltage.

$X_a =$ Reactance of each reactor with the three-reactor method.

$X_b =$ Reactance of each reactor with the two-reactor method.

$X_c =$ Inherent reactance of the circuit.

Then

$$I = \frac{E}{\sqrt{3}\ (X_a + X_c)}$$

and

$$^*I_3 = \frac{\sqrt{3}\ E}{3\ X_c + X_b}$$

But

$$I = I_3 \text{ for equal forces}$$

Therefore

$$X_b = 3\ X_a$$

*Proof

Let

$E_{M3-1} =$ Maximum value of the voltage between phase 3 and 1

$\theta_{2-3} =$ Instantaneous value of voltage between phase 3 and 1

$e_{2-3} =$ Instantaneous value of voltage between phase 2 and 3.

i_1, i_2, and $i_3 =$ Instantaneous value of current in phase, 1, 2 and 3.

$\theta =$ Any time from the zero value of e_{3-1}

θ''_3 and $\theta'_3 =$ Periods from zero value of e_{3-1} to the time when i_3 is zero.

X_1, X_2, and $X_3 =$ Reactance in phases 1, 2 and 3.

From equations

$$e_{3-1} = i_3\ X_3 - i_1\ X_1 = E_{m3-1}\ sin\ \theta$$
$$e_{2-3} = i_2\ X_2 - i_3\ X_3 = E_{m3-1}\ sin\ (\theta - 120)$$
$$o = i_1 + i_2 + i_3$$

is obtained

$$i_3 = \frac{E_{m3-1}}{X_2\ X_1 + X_3\ X_1 + X_2\ X_3}[X_2\ sin\ \theta - X_1\ sin\ (\theta - 120)]$$

$$I_3 = \frac{1.11}{\pi}\int_{\theta'_3}^{\theta''_3} i_3\ d\ \theta$$

$$= A\ [2\ (X_2 + \tfrac{1}{2} X_1)\ cos\ \theta'_3 + \sqrt{3}\ X_2\ sin\ \theta'_3]$$

* This is discussed in detail by I. W. Gr[illegible] in Proceeding of A I.E.E., January 8, 1915.

Where

$$A = \frac{0.5E}{X_2 X_1 + X_3 X_1 + X_1 X_3}$$

$$\theta_3' = cos^{-1}\left(\frac{2}{\sqrt{3}}\frac{X_2}{X_1} + \frac{1}{\sqrt{3}}\right)$$

Let

$$X_1 = X_2 = X_c + X_b$$
$$X_3 = X_c$$

Then

$$I_3 = \frac{\sqrt{3}E}{3X_c + X_b}$$

In general if the total kv-a. capacity of two reactors be twice as great as the total kv-a. capacity of three other reactors then the two reactors will cost 25 per cent more and occupy 15 per cent more space than the three reactors. Therefore, for the above class of protection the reactors required by the three-reactor method are cheaper and require less space than the reactors required by the two-reactor method.

If current limitation is required to protect three-phase oil switches from injury or to preserve the continuity of service of a circuit (that is, to prevent a serious drop in voltage of the system when a short-circuit occurs on one of its branches), then it is necessary to limit the kv-a. which flows during short-circuit to a given fixed value, irrespective of the method of protection. In order to do this, it is necessary to have the capacity of the single-phase reactors, required by the two-reactor method, twice as great as that required by the three-reactor method This is shown by the following example:

If at the time of a three-phase short-circuit the full line voltage is impressed across the reactors then the short-circuit kv-a. is given by the formulæ:

Kv-a. $= \sqrt{3}EI$ for the three-reactor method

$$= \frac{E^2}{X}$$

and

Kv-a. $= 2EI_1$ for the two-reactor method,

$$= \frac{2E^2}{X_1}$$

Where

E = The circuit voltage

X = Reactance of each reactor for the three-reactor method

I = Short-circuit current in each phase for the three-reactor method

X_1 = Reactance of each reactor for the two-reactor method.

I_1 = Short-circuit current in the two phases with reactors for the two-reactor method.

But since the kv-a. must be the same for each method of protection

$$\frac{E^2}{X} = \frac{2E^2}{X_1}$$

therefore

$$X_1 = 2X$$

The total reactance required by the two-reactor method will be 1.33 times as great as that required by the three-reactor method, and the cost of the reactors required by the former method will be 15 per cent less and occupy 10 per cent less space than those required by the latter method. For this class of protection the reactors required by the two-reactor method are cheaper and require less space.

It has been shown in the foregoing analysis that in order to protect the majority of apparatus from injury the total reactance required by the two-reactor method of protection must be 100 per cent greater, will cost 25 per cent more, and will occupy 15 per cent less space than the total reactance required by the three-reactor method. On the other hand, if protection to three-phase oil switches or insurance of continuity of service determines the limit of the short-circuit current, then the total reactance required by the two-reactor method is only 33 per cent greater, costs 15 per cent less and occupies 10 per cent less space than the total reactance required by the three-reactor method. Therefore, from the standpoint of cost of reactor, the most economical method of protection depends on the class of apparatus or service that determines the limit of the short-circuit current.

Economy based on the cost and dimensions of the reactors alone would be narrow, and judgment of the relative values of the two methods of protection must take into account the loss in efficiency in the operation of connected apparatus due to the unbalanced voltage diagram resulting from the use of the two-reactor method that is not met with in the use of the three-reactor method. As an illustration of this, consider a circuit which is to be protected so that the maximum short-circuit current is limited to twenty times normal. Then, if the protection were afforded by the three-reactor method, 5 per cent reactive drop in each phase would be required; if it were protected by the two-reactor method, 15 per cent reactive drop would be required in two of its phases, and no drop in the other phase.

The foregoing considerations lead to the general conclusion that the two-reactor method of current limiting protection is uneconomical, although in isolated cases where it is desired to protect three-phase oil switches, or to preserve continuity of service of a circuit, and where the cost of the reactors is high as compared to the cost of power, such a method might be economical.

INDUSTRIAL CONTROL

Part I

The general extension of the application of electric energy to almost all classes of industry makes "industrial control" a subject of vast and increasing importance. For this reason we plan to run a series of articles covering the various forms of control apparatus used in several different industries. The present contribution is the first of the series.—Editor.

Introduction to the Series

By *magnetic control* of a motor one understands a system whereby all of its functions are performed by electro-magnets. If a part of the functions is performed by electromagnets and a part by manual operation, the system of control is understood to be *semi-magnetic*. If the acceleration of the motor is performed automatically, the control system is said to be *automatic*.

In applying electric motors to drive the various machines in the industrial field, the chief advantages gained have been found to be:

(1) Decreased power consumption and an increased production for a given equipment. The reliability of the electrical appliances has permitted the employment of inexperienced operators.

(2) Automatic control, whereby the operator manipulates only a master switch, the control panel being located at a remote point, often in a separate room.

(3) Perfect control of the work performed and close speed adjustment.

(4) Increased safety, which applies to the power plant, transmission line, motors and control, also safeguards on the driven machine. The safety of the operator and the driven machines has been insured by:

(a) No live parts exposed, thereby preventing accidents due to the operator coming in contact with current carrying parts of the appliances.

(b) The initiative of the operator required before restarting the machine after it has stopped as a result of overload or loss of power.

It is generally considered that the ability to properly control the electric motor has been the most important factor in increasing the application of electric drive for industrial purposes. The ultimate question has been one of economics. What has been said of one industry applies to all; viz., "improved methods have cheapened production, this in turn has increased the demand and this again has stimulated further effort toward economy of manufacture."

In the initial fields of motor application manually operated controllers, either of the dial or drum type, were employed, and there are many applications where this type of control is still applicable. But the time has arrived when magnetic control predominates, the chief features being:

(1) Automatic acceleration, independent of the operator.

(2) Remote control, enabling the operator to closely follow the work.

(3) Nicety of control and predetermined set speeds.

(4) Regulation of the starting period, reversing, and stopping by means of dynamic braking.

(5) Improved condition of the factory by the absence of belts, pulleys, etc., and the use of self-contained tools.

Many industries now employ electric drive as a result of the perfection of magnetic control.

Rubber mill calender drive has attained high efficiency by means of close speed control, convenience of manipulation, continuity of service, and practically "fool-proof" operation.

Printing presses were among the first to employ magnetic control. Large presses are controlled from a small group of push buttons giving "jog," "slow," "fast," "run," and a "safe-run" snap switch.

Steel mills have made enormous advances during the past ten years, by the use of dynamic control for a-c. operated mine fans, rolls, etc. By means of adjustable speed control for large a-c. motors, one mill is said to have increased its production 25 per cent over engine-driven conditions.

Machine tools have greatly increased in efficiency due to adjustable speed motors and flexible magnetic control, especially planers, boring mills, and lathes for special services.

In marine work proper magnetic control has been the means of electrically operating the large-powered auxiliaries, including anchor windlass, capstan, stearing gear, and the propulsion of the ship.

Other industries may be mentioned, including mine hoists, cranes, dredges, paper machinery, arc welding, etc.

The control problem in the above industrial applications has been very carefully worked out and details concerning many of the same will be discussed in future issues.

L. C. Brooks

THE ECONOMIC CONTROL OF THE ELECTRICAL APPARATUS USED IN THE RUBBER INDUSTRY

By Harris E. Dexter

Industrial Control Department, General Electric Company

With the continued increase in the application of electric drive to the various industries and the increase in the requirements of operation in order to improve the efficiency and safety of operation, the element of control is becoming more and more prominent. In the early applications of electric drive, manually operated controllers, either of the drum or dial type, were considered satisfactory for nearly all requirements. There are many applications where this type of controller is still applicable. However, in applications where the control is more or less complicated, where the motors must be started, stopped, and reversed frequently, and where safety of the operator is to be considered, the automatic magnetic control is necessary—so that now the question of control and control appliances is employing considerably more thought than was the case a few years ago.

General

The advent of the electric motor into the rubber industry brought with it, as it did in practically every other industry which it has invaded, the problem of proper control; that is, the problem of controlling the motor in the most convenient and efficient manner, and at the same time not sacrificing any of the features which tend toward maximum production and minimum waste of material. The idea in view in writing the present article is to try to outline briefly some of the more important problems encountered in the rubber mill industry as seen from the standpoint of the control engineer, in a manner such that the layman can readily comprehend, and as far as possible to give a description of the various types of control which may be used to solve the problem.

This, like the majority of the control problems, is fundamentally an economic problem, and as such may be treated under two heads:

(A) Increase in production due to proper control.

(B) Saving in upkeep and maintenance due to the protection afforded the motor and connected machines by the control apparatus.

In nearly every line of work, particularly in cases where speed control is necessary, marked gains in the rate of production are noticeable when full magnetic control is used in preference to either hand or semi-magnetic control. The chief reason for this is that the control performs its various functions entirely automatically, and this leaves the operator's mind free to look after the production, whereas with either hand or semi-magnetic control, his attention must be divided between the motor and the work produced.

For this reason the full magnetic type of control is readily seen to have a very great advantage over its two rivals, although sometimes somewhat higher in first cost, because even a small increase in production will very soon over-balance a considerable difference in first cost. Then again, increase in production means that more material can be manufactured with the same amount of money invested in machinery and buildings.

The other factors which govern the economic operation of the equipment are the cost of upkeep and maintenance. From this point of view the full magnetic control has at least as great, if not greater, advantage over its rivals, because of the protective features which it embodies.

With this type of control, all the functions are performed automatically and consequently no injury can come to the equipment by carelessness on the part of the operator. The operator merely designates the time when the operation shall take place and the actual operation is performed automatically. This also has the advantage in that the operator may be unskilled as far as the electrical equipment is concerned and need only understand the characteristics of the particular material being produced. This factor tends greatly to lessen the labor problem and also to decrease the cost of manufacture.

In the rubber mill industry, the machines may be divided into two classes; first, the calenders, and second, the crackers and the mixing and warming mills, etc. The machines of this latter class are usually run from the same shaft and are spoken of as the "mill line." Both of these classes of machines require entirely different types of control because of the difference in the service for which they are used. Of the two, the calender is much the more difficult to control properly. and affords by far the most interesting problem to the control engineer. In return for this, however, when equipped with the proper control, the calender shows the greatest gains due solely to adequate control apparatus. On the other hand, due to its infrequent starting and stopping, the mill line is a comparatively simple device to control and in return shows practically no gain due to the control except for the safety feature which may be incorporated.

Before starting a detailed description of any particular form of control, it is well to first consider a few of the essential points which every control should have:

(a) Start the motor properly, i.e., to protect it during its starting period.

(b) Maintain the current at a minimum value consistent with the required starting conditions.

(c) Protect the motor properly during operation. If a control equipment fulfills the above requirements, it will contain all of the fundamentals necessary for satisfactory operation.

Mill Line

The "mill line" is run at constant speed and owing to the high power peaks which are required by individual machines, a fairly large number of machines are usually driven by the same motor in order to cut down the total rated motor capacity. These motors, very commonly, run as high as 600 or 700 h.p. Owing to the size and the infrequent starting of the motors used to drive "mill lines" and to the fact that the equipment is operated at constant speed, it is usually preferable to use alternating current as a power supply whenever it is available. When alternating current is used, the motors are either of the wound rotor or synchronous type.

The control equipment for the wound rotor type of motor usually consists of an oil switch for the primary and a drum controller for the secondary. Overload protection is obtained by use of overload relays on the oil switch. The equipment is started by closing the oil switch in the primary and then accelerating the motor to full speed with the drum controller which cuts out the resistance in the secondary. This oil switch is supplied with a low voltage release which may be tripped from any one of the mills in case of emergency. This would open the oil switch and disconnect the motor from the power supply.

When the synchronous motor is used it is generally supplied with an oil switch having both overload relays and low voltage release and in addition to these requires a field switch, field rheostat, a field ammeter and an ammeter for measuring the line current. This type of motor is started as a squirrel-cage motor, and when it has come up to nearly synchronous speed the field switch is closed and the motor pulls into synchronism. The same protective features may be furnished with this equipment as with the wound rotor type of motor.

With either of the above equipments the hand control is perfectly satisfactory and considerably cheaper than a magnetic equipment. From the standpoint of increase in production it is doubtful if any gains whatever could be made by substituting a magnetic equipment. The only real argument in favor of a magnetic equipment is that it would not require a skilled man to start the motor. However, this argument is not very strong because the "mill line" is started only a few times a day, and, as a factory of this kind usually has at least one man who is familiar with electrical apparatus, it is not a great handicap to have him responsible for the starting of this equipment.

Calenders

In discussing the subject of calender control, it is best considered under three heads; hand, semi-magnetic and full magnetic control. Owing to the fact that magnetic control adds very little to the flexibility of alternating current control for calender operation, it is very seldom that anything other than hand control is used for this kind of service, and consequently all discussion in this article on alternating current apparatus will be limited to hand control. However, all three types of control are applicable to direct current although the semi-magnetic and magnetic are the ones most often found in use.

Hand Control

For calendar operation with hand control on alternating current motors, either a squirrel-cage or wound rotor type of motor may be used, or a shunt motor for direct current.

When using a squirrel-cage motor, it is generally of the two-speed type and connected to the calender by means of a friction clutch. This type of motor gives two distinct operating speeds which are obtained by using two independent windings on the stator. The control for this type of equipment, except for the very smallest type of motor, generally consists of a drum type pole-changing switch and a hand compensator For small motors the pole-changing switch may be used without the compensator and the motor may be started by being thrown directly upon the line. The "threading-in" speed for entering the fabric in the rolls is obtained by slipping the clutch. After the material has entered the rolls, the clutch is closed and calender operates at constant speed until the particular operation is finished, the exact speed depending upon the setting of the pole-changing switch. This type of equipment gives very good results for small calenders requiring 25 h.p. or less, and where the small variety of products manufactured requires practically only the same speed for all work done on the calender.

For calenders of larger capacity and those requiring a greater number of operating speeds, squirrel-cage motors are sometimes used in connection with a multiple frequency system. The control for this equipment is exactly the same as that referred to above for the single frequency. This arrangement, however, calls for a motor generator set to furnish the different frequencies required for the control and necessitates not only a greater first cost but a considerable additional expense for maintenance and upkeep. Either of the above types of control are unsatisfactory when a very great variety of material is to be handled and where ease and convenience of operation is an essential factor in the rate of production. With either equipment the speed can only be changed by steps and then by disconnecting the motor from the line and reconnecting to a different winding of either the motor or generator. This means that at best the calender can have comparatively few operating speeds and that considerable time must be consumed in changing from one speed to the other, or in changing from the running speed to the "threading-in" speed, and vice versa.

When a slightly more flexible control is required, and still only for a small range in speed, the wound rotor type of motor is sometimes used. This type of motor is generally either geared directly to the calender or connected by a chain drive. The control usually consists of an oil switch for the primary, and drum controller and resistance for the secondary. With this arrangement, overload and low voltage protection are provided by the oil switch and the speed control is obtained by a drum controller which varies the value of resistance in the secondary. It is possible, with this type of control, to get a speed reduction of approximately 50 per cent and still have the motor remain stable. However, owing to the fact that the regulation for a wound rotor type of motor is very poor when running with resistance in the secondary, it is usually unsatisfactory to use this type of motor for calender work when a speed reduction greater than 15 per cent is required. A "threading-in" speed of approximately 33 per cent may be obtained by inserting resistance in the secondary. In addition to the disadvantages mentioned above, this equipment is subject to all the faults present in hand control apparatus. For example:

(a) It is slow in operation.
(b) Satisfactory operation depends to large extent upon the operator.
(c) It is inconvenient to operate.
(d) The operator's attention is divided between the operation of the motor and work produced.

Hand control for calender operation with direct current is generally used with shunt motors and consists of a drum controller with armature and field points. This type of control is subject to all the faults mentioned above and owing to the fact that nearly all factories are supplied with alternating current, hand control is very seldom used with direct current. If a more flexible control is needed than can be had with alternating current, the manufacturer seldom stops with hand control but goes to either semi-magnetic or full magnetic control.

Semi-Magnetic Control

The semi-magnetic control generally found in operation is very little better than hand control, except that by the substitution of a master controller for a large drum controller the mechanical operation performed by the operator is made a great deal easier. If the semi-magnetic control is made entirely fool-proof there will be very little difference in cost between it and the full-magnetic control and still it will not have the advantages which the full magnetic control has.

Full-Magnetic Control

Before we discuss the full magnetic direct control which, as far as calender operation is concerned, is without doubt the ideal control, we will briefly outline just what is expected of a full magnetic control.

(A) The control should be push button operated and allow:

1. Starting at "threading-in" or basic speed.
2. Accelerating to predetermined speed.
3. Reduction to "threading-in" speed.
4. Stopping.
5. Making an emergency stop.

(B) The control should contain the following features:

1. Overload and low-voltage protection.
2. Quick and positive stopping of the calender when shut down.
3. Convenient method of securing speed adjustment.
4. Provisions for reversing in case of emergency.

The d-c. full magnetic control is made to suit either of two arrangements: a single-voltage two-wire, or two-voltage three-wire equipment. The single-voltage equipment is used with speed ranges of 3 : 1 or less, while the two-voltage scheme is used with speed ranges in excess of 3 : 1. This gives a general idea of what is required of a control equipment for calender operation. A minute description of the panel follows:

When the panel is placed on the same floor as the operator and in a convenient position for the operator to reach, overload protection is usually procured by an instantaneous

Fig. 1. Field Rheostat Panel

hand reset overload relay and the reversal of the motor is accomplished by use of a double throw switch located in the armature circuit and usually placed on the panel. If the panel is located below the floor or in some other inaccessible place which is difficult for the operator to reach, it is usually more satisfactory to equip the panel with an electrically reset overload relay and to substitute reversing contactors for the double throw switch. This puts the complete operation directly under the control of the operator, even though the panel may be located in some remote place.

The main control station consists of a push button station which is generally placed on the calender housing. For a non-reversing equipment this station contains "Run," "Stop," "Slow" and "Fast" buttons, while for the reversing equipment an additional button is furnished for reversing.

With either of these equipments, the line contactor cannot be closed without pushing the "Run" button. This assures the operator that should the voltage on the line fail while the motor is running, the equipment will not start up again when the voltage returns, until the "Run" button is pushed. This prevents the operator from being caught in the rolls due to the voltage suddenly returning after failure.

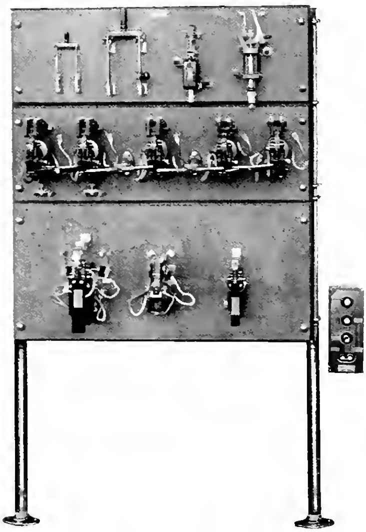


Fig. 2. 50-h.p., 230-volt Full Magnetic Reversible Control Panel with Push Button Station

Under ordinary operation, this equipment is stopped by pushing the "Stop" button and is brought to rest by a dynamic brake. Whenever it is necessary to reduce to the "threading-in" speed from "high" speed, this is accomplished by pushing the button marked "Slow." This brings the equipment from the then running speed down to the "basic" (full field) speed, which is used for "threading-in" and keeps the machine running at this speed until the "Fast" button is operated, at which time the motor again returns to the predetermined speed for which the field rheostat is set. The field rheostat for this equipment is generally mounted on a slate base approximately 18 inches wide and having a frame for floor mounting. This panel, on account of its small size, can be placed right at the calender, thus affording a very convenient means of speed adjustment. Fig. 1 shows a cut of one of the rheostat panels.

Fig. 2 shows a reversible equipment for a 50-h.p., 250-volt motor with push button station. This panel is for operating a motor on a single voltage system and is equipped with forward, reverse, dynamic brake, and accelerating contactors. The push button station at the right is for operating the panel and gives "Run," "Stop," "Forward," "Reverse" and "Slow-down" features. This push button should be used for operating the equipment under ordinary running conditions. For emergency stopping, however, a small master switch is furnished similar to that shown in Fig. 3. This switch is reset by hand and is suitable for operation by a rope. This rope may be located around the calender, so that it can be reached from all sides of the machine. When the calender is stopped by use of this emergency switch, the dynamic brake is applied in the same way as when the calender is stopped in the ordinary manner. In addition to this, it is impossible to again start this equipment until the emergency switch is reset by hand, and when it has been reset the machine must be started from the main control push button station.

Fig. 3. Emergency Stop Switch

In Fig. 4 is shown a wiring diagram of a single voltage reversible 75-h.p., 3 : 1 speed equipment with four emergency switches. This is one of the standard equipments furnished by the General Electric Company. The panel contains a main line switch, con-

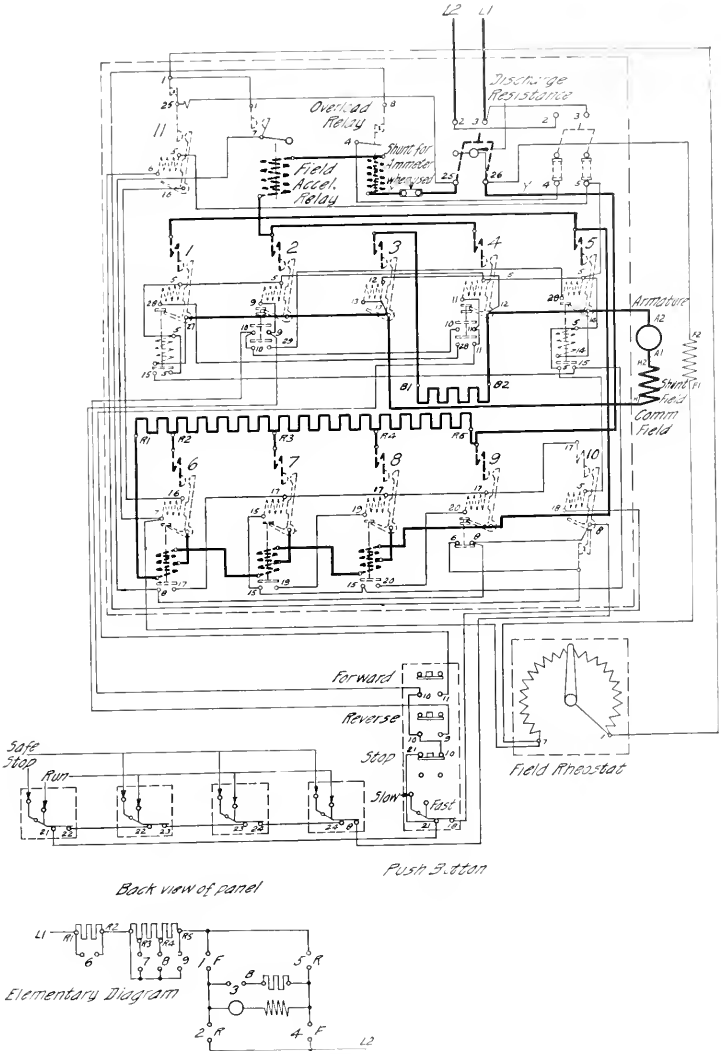


Fig. 4. Diagram for Control of a Single-voltage Reversible 75-h p. Motor

trol switch, overload relay, line contactor, dynamic brake contactor and accelerating contactors. The main line switch is furnished with an extra clip so that when the line switch is opened the field of the motor may discharge through a resistance designed for

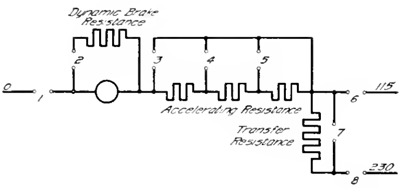


Fig. 5. Arrangement of 3-wire 2-voltage Panel Connections

that purpose. When the line switch is opened, the main motor circuits only are opened. This permits the operator to try out the panel without starting the motor. If the operator desires to work on the panel he should also open the control switch and this will entirely disconnect the panel circuits from the line. The overload relay is of the instantaneous type and is used only to protect the motor from severe overloads, or short circuits. The field accelerating relay that is put on the panel is set for about 135 per cent current and is not put on with the idea that it will function every time that the motor is started, but is used more as a safety device and is only intended to operate when the motor is trying to accelerate a very heavy load. In this instance the motor will draw sufficient current to close the relay and thus put full field on the motor and give it sufficient torque to accelerate the load. Any load which the motor will not start under full field conditions would be sufficient to open the overload relay and thus save the motor from injury.

The three-wire two-voltage panel conforms to the same general layout of connections as the two-wire single-voltage equipment using the proper number of contactors for accomplishing its purpose. A diagramatic scheme of connections is shown in Fig. 5.

From a close inspection of this sketch it will be seen that the transfer from one voltage to the other is made without taking power off the motor. This is of decided advantage to a control equipment for a rubber calender because, owing to the heavy friction load, if the power were taken off the motor even for a fraction of a second, the motor would slow down to a considerable extent before being connected to the higher voltage. All of the acceleration on armature resistance is accomplished with full field on the motor for both voltages. In the single-voltage equipment, when the "Run" button is pushed, the motor accelerates to "threading-in" speed, which is full field, low-voltage speed (115-volt). After the fabric has entered the rolls, the operator may accelerate to predetermined speed either on low-voltage (115-volt) or high voltage (230-volt), depending on which of the two "accelerating" buttons is pushed. The control is so interlocked that when the operator is running on the high voltage (230-volt) connection and the low-voltage (115-volt) "accelerating" button is pushed, nothing will happen, and this is true when running on the low-voltage (115-volt) weak field speed. It is possible, however, to go from either weak field speed down to "threading-in" speed and back by use of the push button station. In slowing down from high voltage (230-volt) weak field to the "threading-in" speed, the speed is very quickly decreased by dynamic braking. In reducing from the weak field speed low-voltage (115-volt) to the "threading-in" speed, dynamic braking is not necessary, and if used would only add an extra complication without giving any real benefit. On stopping, either from the main control station or the emergency station, the dynamic brake is applied as with the single-voltage equipment.

In surveying the entire calender control problem, it is evident that at the present time there is only one real satisfactory solution to the problem: i.e., to use a full magnetic direct current control, thus giving the operator absolute control of the calender and allowing him to adjust the speed to suit his particular needs with the least expenditure of energy and time. It also gives the greatest range of speed adjustment to the calender and consequently suits the calender for an extremely wide variety of product.

Conclusion

In reviewing this subject, it is readily seen that the underlying reason why this problem must be solved is one of economics:

This problem has been solved by developing a full magnetic push button control, operated for use on either a two-wire, single-voltage, or a three-wire two-voltage circuit, which is considered to be the best on the market at the present time. This control affords the following advantages which are not obtainable with any other type of control:

(a) Increase in production, because the operator's entire attention is given to production.

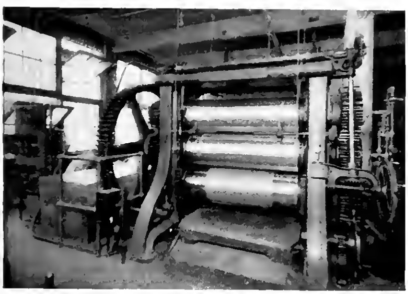
(b) Minimum waste of time in making the various speed changes consistent with a satisfactory operation of the equipment.

(c) All functions of the control are performed automatically and independent of the operator, who merely designates the time when a particular operation shall take place.

(d) Skilled operators are unnecessary.

Even if the first cost of the control is slightly higher than some of the substitutes mentioned earlier in this paper, it is readily seen that even a small advantage in any one of the above factors would soon more than pay for the difference in first cost.

In choosing a control, the manufacturer should not be influenced too strongly by the first cost of the piece of apparatus to be purchased, but should rather be governed by the cost per article for the finished product. In other words, the entire process should be studied and after all the items mentioned above have been considered the equipment should be purchased which shows the largest gain. For calender control the full magnetic direct current type of control completely meets all of these requirements.



40-h.p., 400/800-r.p.m., 220-volt Direct-current Motor Driving a 22- by 60-in. Rubber Calender

40-h.p., 720-r.p.m., Form M, 440-volt Alrernating-current Motor Driving a 10- by 36-in. Rubber Refiner

INCANDESCENT HEADLIGHTS FOR STREET RAILWAY AND LOCOMOTIVE SERVICE

By P. S. Bailey

Street Lighting Engineering Department, General Electric Company

The first part of this article comprises a very interesting narration of the attempts that have been made to develop an inexpensive but satisfactory equipment for first concentrating light into a beam and then projecting the efflux. After having explained how modern manufacturing methods have successfully accomplished this end commercially, the author classifies the present-day incandescent headlight requirements. In connection with these class divisions, he describes and illustrates the equipment that has been designed for each and gives photometric performance curves of the different types.—Editor.

The rapid development and commercialization of Mazda C incandescent lamps, with concentrated filaments, has stimulated the design and standardization of several devices for projecting light from such sources. Aside from its application to the stereopticon, the flood-lighter and the incandescent searchlight, the gas-filled lamp is being used with ever-increasing frequency as an illuminant in headlights for street railway cars, electric locomotives and steam locomotives.

*It is generally conceded by those familiar with the art that the parabolic mirror, and the glass parabolic mirror in particular, is

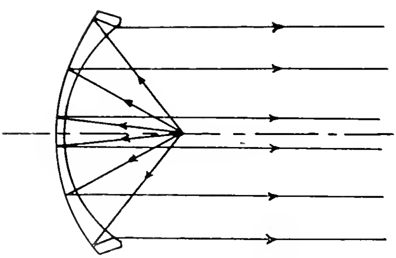


Fig. 1. Diagram showing the Production of Chromatism of Light Rays by a Mirror

both theoretically and practically the best reflector for searchlights and other comparatively long distance emission illuminants. This is as old as searchlight technics itself.

Until rather recently many experts in the searchlight realm and many opticians held the opinion that it would not be feasible to grind a parabolic mirror from glass. It was easier to employ the well-known (in optics) cylindrical method of grinding. Working along these lines, Col. Mangin of the engineer corps of the French army very ingeniously conceived the idea of constructing a projector mirror in the form of a concave-convex lens coated with silver on the convex side. This important improvement was made in 1874 and the mirror was found to have optical properties closely approaching those of the parabolic mirror. It could be produced with precision and facility. Due to its design (the convex and concave curvatures being described by different radii) there was a considerable absorption of light due to the necessary thickness of glass at the edges.

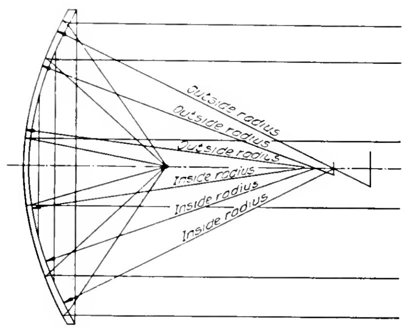


Fig. 2. Diagram showing the Meniscus Mirror Curvatures Used by Siemens and Halske

In addition, there was a loss of rays reflected by the incident face, these being unavailable for long distance emission. Chromatism of light rays also occurred due to the prismatic action of the mirror. See Fig. 1.

Siemens and Halske in their search for a suitable reflector produced the meniscus mirror with a silver backing. This consisted of several concentric rings cut by the "arc" grinding process. The mean radii of curvature of these rings corresponded to the radii of curvature at the respective points of the parabola to be substituted. See Fig. 2. This development closely resembled the parabolic mirror. The reflector was precise and could be cheaply manufactured. The light rays

* Elektrotechnische Zeitschrift, "Electricity on Board Ships", by O. Krell.

reflected by the incident face were available for long distance emission. But loss of light occurred at the crevices formed by the adjacent rings.

Digressing for a moment we may consider the catoptric arrangement of Fresnel, the celebrated French physicist, which was built up of totally reflecting rings, subtending an angle of light of sufficient size to produce a well defined beam. See Fig. 3.

The lens could be ground with precision due to the existing knowledge of the cylindrical and plane processes, but at rather high cost. Breakage also was an undesirable factor.

Concentration of the focii of the several rings or zones upon one point was difficult. A dislocation of the light source from the common focus caused aberration or deflection of the light rays from the path normal to them, which with totally reflecting prisms takes place in the opposite direction, or contrary to aberration from the parabolic reflector embodying the principles of dioptrics. A study of this type of lens will reveal the fact that there is considerable reduction in luminous power.

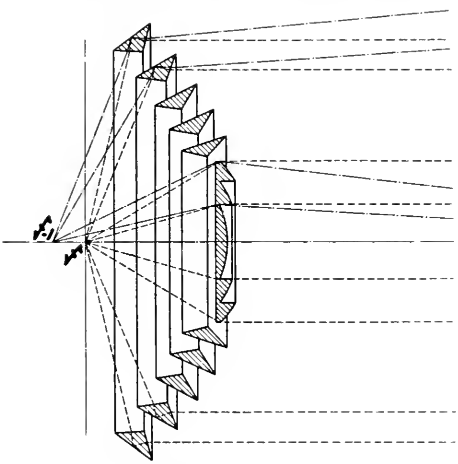


Fig. 3. Diagram of a System of Totally Reflecting Rings Originated by Fresnel

It remained for Siegmund Schuckert and Professor Munker, of Nuremburg, to accomplish the long-sought-for feat of grinding a parabolic mirror from one piece of glass. Their first efforts did not by any means produce a reflector with accurate curvature, but they marked an historic milestone of progress in the year 1885.

Methods of testing the curvature of parabolic mirrors notably those of Colonel Tschikolew and others, the details of which must be omitted here, caused improvements to be rapidly made, so that now these devices are quite generally acknowledged to be superior to all others for projecting light through comparatively long distances.

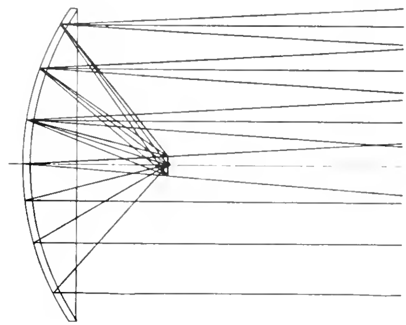


Fig. 4. Diagram showing the Reflection of Light Rays from a Parabolic Mirror

The specular surface of the parabolic mirror reflects all incident rays of light emanating from its focus, parallel with its optical axis. See Fig. 4. If it were possible to locate a point source of light at the focus of such a reflector the resultant beam projected would cover a circular field the cross-section of which would equal in diameter that of the parabolic mirror. A perfectly parallel beam would be of little use as the area illuminated would not be sufficiently large. It is, therefore, of practical advantage to have concentrated light sources of finite dimensions since a limited dispersion of the light rays is of great value in locating objects at a distance. But as the effectiveness of an illuminant, when used with the parabolic reflector, depends greatly upon its concentration into small dimensions, it is obvious that the nearer the illuminant approaches zero dimensions while still retaining a high intrinsic brilliancy the nearer do the resultant effects approximate the sharply outlined beams so important in the projection of light.

Exhaustive tests have shown that for a general commercial proposition, combining effectiveness of beam, low initial cost, maintenance, etc., the polished parabolic reflector of metal or silvered glass has many points of superiority to recommend it for use in incandescent headlights.

Electric street railway requirements may be divided into three classes; city, suburban

Fig. 5. A Recessed Dasher Type Car Headlight for City or Suburban Service

and interurban. The first requires in most cases simply a marker on the front end of the car as the streets are usually well illuminated from other sources. The second requires sufficient illumination to enable the motorman to pick up objects on the dimly lighted streets of outlying districts. While, in the third case powerful projected beams are necessary since there is often no light on the right of way and the speed of the cars is frequently accelerated to sixty miles an hour or more and it is imperative that the motorman pick up an object at a sufficient distance to allow him to bring his car to a stop that he may avoid striking it.

It is at present customary to use both stationary and portably mounted headlights for suburban street railway service and portable devices for interurban requirements.

Fig. 5 shows a recessed dasher type headlight for permanent attachment to the car dasher applicable to city or suburban service. Three iron castings are used assuring great rigidity of construction. The main cylindrical casing encloses an accurately finished glass parabolic reflector with silvered back and contains also a ball and socket focusing mechanism so necessary in securing nice adjustment of the lamp filament at the focal point of the reflector. The casing supports a door hinged at the top and positively latched at the bottom. A circumferential flange extending outwardly from the door protects the glass door-pane from injury. A hinged support is provided for the casing so that it may be swung away from the back portion which is permanently mounted to the car dasher. Access to the focusing mechanism is thereby easily gained. The casing is held in the closed position by a bolt opposite the hinge which threads into a tapped hole in the back. Care has been taken to so design the back support that it does not interfere with the lowering of the front vestibule window. All joints are water-tight and the latch is so constructed that the trolley rope cannot catch. Conduit connection for 1/2-in. conduit pipe is arranged at the bottom of the back portion. Fig. 6 shows a detail view of a similar headlight to that mentioned above, but for flush mounting on the car dasher.

Either of these headlights may be used with the incandescent lamps listed in Table I.

Fig. 7 shows photometric results in terms of apparent beam candle-power obtained with several Mazda B lamps referred to above when used in the dasher headlights.

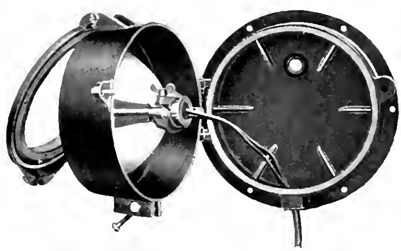


Fig 6. A Headlight similar to that shown in Fig. 5 Except that it is Designed for Flush Mounting on the Car Dasher

Fig. 8 shows apparent beam candle-power obtained when using the 6-volt, 36-watt Mazda C lamp in headlights shown in Figs. 5 and 6. It is interesting to note the great increase in apparent beam candle-power obtained when the low-voltage, high-current Mazda C lamps are used, thereby making plain the advantages obtained from the well concentrated filaments operating at high efficiency. Unfortunately the high-current lamps may not yet be used efficiently on 550- or 660-volt trolley circuits due to the high total wattage consumed. When storage batteries may be economically used no obstacles present themselves to the use of these lamps. The same is true with respect to their use on a-c. circuits where a compensator may be applied. On existing 25-cycle circuits, such lamps may be easily applied and the fluctuations in frequency are not observable as they are in the case of the electric arc.

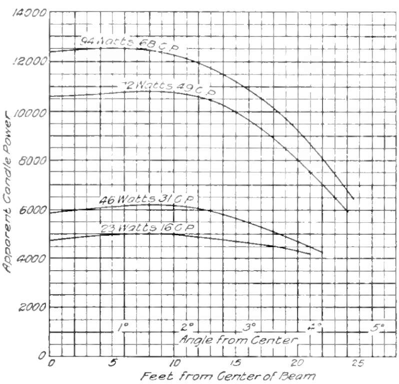


Fig 7. Photometric Test Curves of an Incandescent Dasher Type Headlight, with 110-volt Mazda B Lamp and Crystal Silvered Parabolic Reflector $8\frac{3}{8}$-in. Diameter $1\frac{1}{4}$-in. Focus. Readings Taken at 300 Feet

Figs. 9 and 10 show steadying and combination steadying and dimming rheostats which may be used in series with 110-volt, 23-, 36-, 46-, 56-, 72- and 94-watt lamps on 550- or 600-volt circuits. These are provided with removable enamelled units and when installed for service are fitted with a perforated steel box for protecting them.

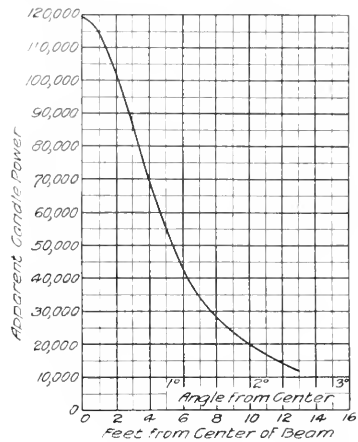


Fig. 8 Photometric Test Curve of an Incandescent Dasher Type Headlight, with 6-volt, 6-ampere, Mazda C Lamp and Crystal Glass Silvered Parabolic Reflector $8\frac{3}{8}$-in. Diameter $1\frac{1}{4}$-in. Focus. Readings taken at 300 Feet

Headlamps may be operated in series-multiple with groups of lamps inside the cars according to Table II.

Fig. 12 is a facsimile of a new portable headlight with struck-up steel casing and deep glass parabolic mirror reflector. It has much to commend it to the operator. Rigid

TABLE I

Volts	Watts	Bulb	Base	Type
$5\frac{1}{2}$ & 6	36	G-$18\frac{1}{2}$	Med. screw unskirted	Mazda C
105 to 130	23	G-$18\frac{1}{2}$	Med. screw unskirted	Mazda B
	36	G-$18\frac{1}{2}$	Med. screw unskirted	Mazda B
	* 46	G-25	Med. screw unskirted	Mazda B
	* 56	G-25	Med. screw unskirted	Mazda B
	* 72	G-25	Med. screw unskirted	Mazda B
	* 94	G-25	Med. screw unskirted	Mazda B
	† 23	S-19	Med. screw unskirted	Mazda B
	† 36	S-19	Med. screw unskirted	Mazda B

* Light center length of $2\frac{1}{16}$ inch should be specified.
† Equipped with regular type filaments. All others mentioned have focus type filaments.

TABLE II

Wattage of Head Lamp	Bulb	Light Center Length in In.	In Series with Car Lights
23	G-$18\frac{1}{2}$	$2\frac{1}{16}$	1 circuit of four 23-watt lamps
36	G-$18\frac{1}{2}$	$2\frac{1}{16}$	1 circuit of four 36-watt lamps
46	G-25	$2\frac{1}{16}$	2 circuits of four 23-watt lamps
56	G-25	$2\frac{1}{16}$	1 circuit of four 56-watt lamps
72	G-25	$2\frac{1}{16}$	2 circuits of four 36-watt lamps
94	G-25	$2\frac{1}{16}$	1 circuit of four 94-watt lamps

construction and light weight are two important features. Furthermore, the focusing mechanism can be operated from the car vestibule or from the ground and the lamp may be easily and quickly adjusted.

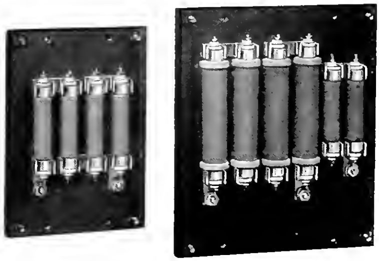


Fig. 9 and Fig. 10. Steadying and Combination Steadying and Dimming Rheostat Resistance Tubes

This headlight may be used for either suburban or interurban service with the lamps listed in Table III.

TABLE III

Volts	Watts	Bulb	Base	Type
SUBURBAN SERVICE				
105 to 130	23	G-18½	Med. screw unskirted	Mazda B
	36	G-18½	Med. screw unskirted	Mazda B
	46	G-25	Med. screw unskirted	Mazda B
	56	G-25	Med. screw unskirted	Mazda B
	72	G-25	Med. screw unskirted	Mazda B
	94	G-25	Med. screw unskirted	Mazda B
INTERURBAN SERVICE				
5½ & 6	36	G-18½	Med. screw unskirted	Mazda C
	72	G-18½	Med. screw unskirted	Mazda C
	108	G-18½	Med. screw unskirted	Mazda C
30 to 34	100	G-25	Med. screw unskirted	Mazda C
	150	G-25	Med. screw unskirted	Mazda C
110	250	G-30	Med. screw unskirted	Mazda C

Fig. 11 shows the apparent beam candlepower obtained when using the 110-volt, 94-watt Mazda B lamp and Fig. 13 shows the results obtained from the 6-volt, 12-ampere lamp in headlight, see Fig. 12.

Fig. 14 depicts a headlight primarily designed for interurban service. The casing is the same as that used in Fig. 12 but in this case a shallow parabolic glass mirror with long focus is used for accommodating the larger lamps using G-40 bulbs. The 80-volt, 4-ampere Mazda C focus type lamp is a standard accessory which permits the retaining of the rheostats formerly used for operating 80-volt, 4-ampere carbon arc headlights, if this is desired. The 110-volt, 500-watt Mazda C focus type lamp may be used, for which a special rheostat is necessary. Smaller lamps may be used but with less efficient results than when operated in the headlight shown in Fig. 12.

Fig. 15 shows the apparent beam candlepower obtained from headlight Fig. 14 when equipped with the 80-volt, 4-ampere Mazda C lamp.

Another interurban type of headlight equipped with a 16-in. diameter silvered metal parabolic reflector is shown in Fig. 16. This is designed for the highest speed interurban service and may be used with the 80-volt, 4-ampere or the 110-volt, 500-watt Mazda C lamp. Glass mirrors of the diameter used in this headlight are yet too expensive to consider.

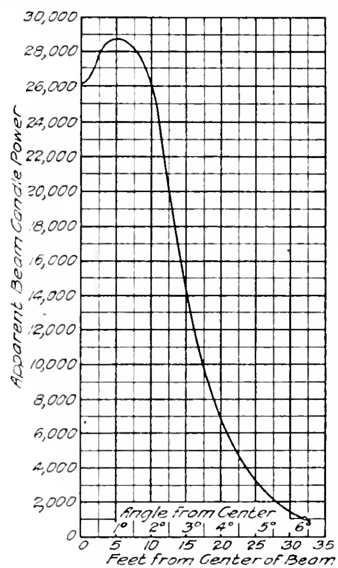


Fig. 11. Photometric Test Curve of Incandescent Headlight, Fig. 12, with 110-volt, 94-watt Mazda B Lamp and 12-in. Diameter Silvered Glass Parabolic Reflector. Readings taken at 300 Feet.

Fig. 17 illustrates a comparatively new spring suspended headlight of very rugged, cast iron construction and small dimensions, for mining locomotive service. It is equipped with glass reflector, ball and socket focusing mechanism, guarded door, and is water- and dust-proof. It is far more efficient than the antiquated types of incandescent headlights formerly used for this class of service.

Other fields for the incandescent headlight are rapidly developing and causing an ever-increasing demand. Electric trunk line service, as recently exemplified in the Chicago, Milwaukee and St. Paul electrification, required the development of a mogul headlight to be mounted on both ends of the electric locomotive; one is shown in Fig. 20.

The Chicago, Milwaukee and St. Paul lines, traversing, as they do, states whose statutes require an illuminant of 1500 unreflected candle-power, made imperative the construction of a headlight which would accommodate a pendant mounted 34-volt, 750-watt, focus type Mazda C lamp. So large a headlight made necessary a rolled-up steel casing with a spot welded back and, since it had to carry the classification numbers of the loco-

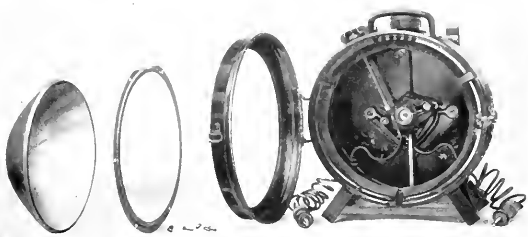


Fig. 12. A Portable Interurban Type Headlight with Struck-up Steel Casing and Deep Glass Parabolic Mirror Reflector

motive, number boxes were arranged for on both sides of the headlight projecting at angles of approximately 30 degrees. Metal stencils stamped with the number of each locomotive, backed with opal diffusing glass

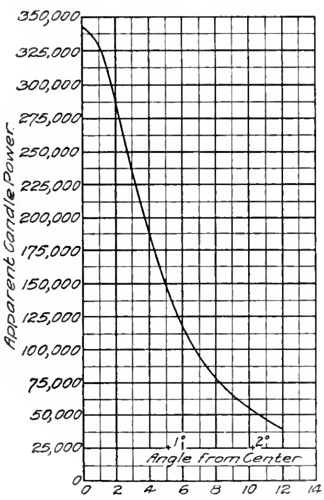


Fig. 13. Photometric Test Curve of Incandescent Headlight, Fig. 12, with 6-volt, 12-ampere, Mazda C Lamp and Silvered Glass Parabolic Reflector 12-in. Diameter 2¼-in. Focus. Readings taken at 300 Feet.

Fig. 14 A Portable Interurban Type Headlight Having the Same Casing as that Shown in Fig. 12 but Having a Shallow Parabolic Glass Mirror Reflector

and fronted with clear glass, are carried in the number box doors. The numbers are illuminated by direct light from the lamp passing through slots in the reflector.

These headlights are equipped with a ball and socket focusing mechanism and a solid cast iron base. A 20-inch parabolic silvered metal reflector is used.

The heat radiated from the high wattage lamp calls for special attention to ventilation and requires a door pane of solid, heat resisting glass which will also withstand severe mechanical shocks and the impact of the bodies of birds, which becoming blinded by the intense light fly against the glass like moths towards a flame.

This headlight when equipped with the 34-volt, 1500-c-p. lamp will give approximately 1,150,000 apparent beam candle-power, which is ample for all that is required

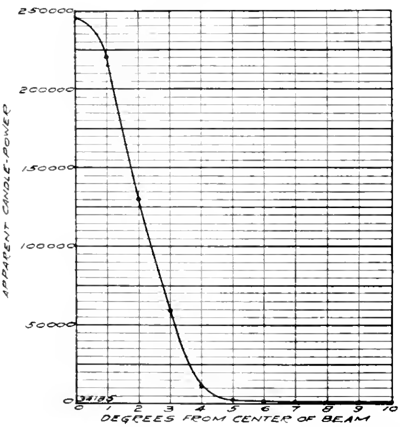


Fig. 15. Initial Distribution of Candle-power in a Horizontal Plane from a 4-ampere, 80-volt, Mazda C Headlight Lamp. Readings taken at 100 Feet; Parabolic Glass Reflector 11-in. Diameter; Lamp Upright

of it. It is without question the most powerful incandescent headlight in commercial operation today.

Fig. 18 shows photometric results obtained with the 34-volt, 1500-c-p. Mazda C lamp.

The current supply for the lamp is taken from slip rings on the 9-kw. control generator at 96 volts. It is then transformed to 34 volts and a tap is provided on the transformer secondary to give one-half voltage for dimming purposes.

The maximum operating speed of the passenger locomotives is 60 miles per hour; full load speed is from 25 to 30 miles per hour. The freight locomotives operate at a maximum of 30 miles per hour and the full load speed is 15 miles per hour.

This type of headlight, it may easily be seen, is just as applicable for steam locomotive use and may be specially equipped to handle

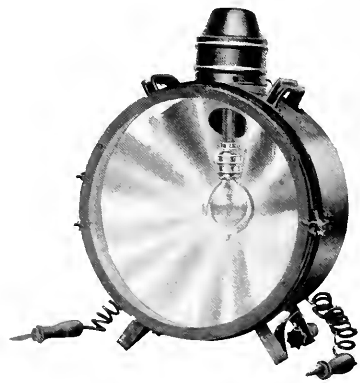


Fig. 16. An Interurban Type Headlight with 16-in. Diameter Silvered Metal Reflector for High-speed Service

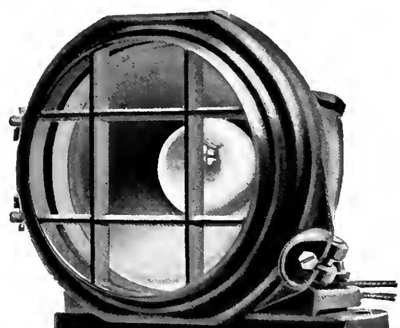


Fig. 17. A Spring Suspended Headlight for Mining Locomotive Service

the smaller lamps if desired, so that the specifications embodied in the report of the Committee on Locomotive Headlights issued by the American Railway Master Mechanics Association may be easily met.

Another type of headlight of lesser power has been developed for the Canadian Northern Railroad as shown in Fig. 19. A struck-up steel casing with side number boxes arranged similarly to those previously described is

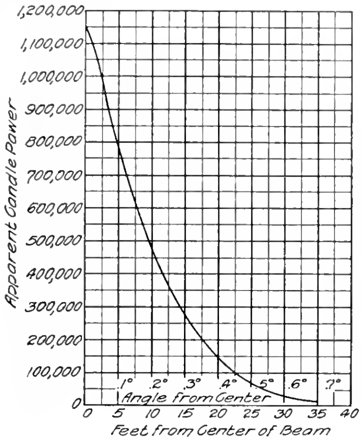


Fig. 18. Incandescent Projector Curve of 23.7-ampere Mazda C Lamp and Polished Silver Parabola 20-in. Diameter 2¾-in. Focus. Readings at 300 Feet.

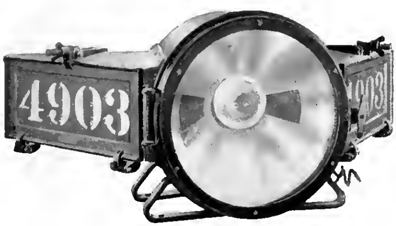


Fig. 19. The Type of Electric Headlight Used on the Canadian Northern Railroad

employed. The lamp is mounted horizontally and adjusted by means of a ball and socket mechanism located at the back of the casing. A shallow, silvered metal parabola provides means of forming the projected beam. A 6-volt, 12-ampere focus type Mazda C lamp is used. This headlight is extremely attractive wherever a compact headlight of considerable power is required.

A type of headlight has also been developed for use on gasolene electric cars. A cast iron casing with 20-inch silvered parabolic reflector and horizontally mounted ball and socket focusing mechanism comprises its main component parts. A special 65-volt, 150-watt Mazda C lamp is provided to

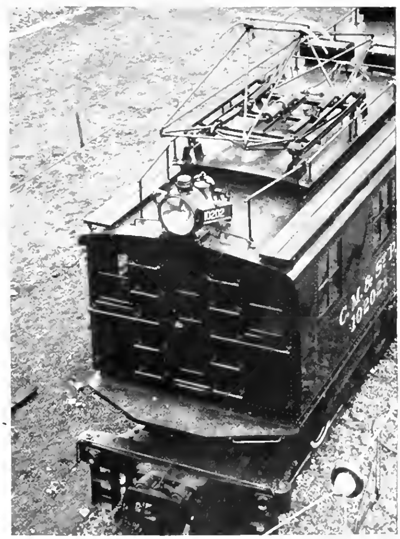


Fig. 20. A Mogul Headlight Mounted on One of the Electric Locomotives of the Chicago, Milwaukee and St. Paul Railway

furnish the necessary light, but a 34-volt, 100- or 150-watt or a 6-volt, 72- or 108-watt lamp can be accommodated.

Thus it will be seen that many important developments have occurred within the last few years and that thought has been given to the general subject. It has been impossible within the space at the author's disposal to amplify. Descriptions of numerous devices involving special designs have been necessarily omitted as well as data applying to a number of standard marker headlights for street cars.

EXPLOSION-PROOF MOTORS OPERATING IN MINES

By C. W. Larson

Engineer Mine Locomotive Engineering Department, General Electric Company

The author describes some of the precautions taken by the Department of the Interior to insure that explosion-proof motors for use in mines are really what they are meant to be, namely, safe. A brief description of the safety features of the motor is given and the test results are recorded.—Editor.

To minimize the hazards of explosions in gaseous mines, it has fallen upon the manufacturer to furnish equipment of special design. The apparatus, however, can not be put in service before it has been subjected to tests under government supervision.

Fig. 1. The Permissibility Plate that is Attached to Explosion-proof Coal Cutting Equipment

To this end, the Department of the Interior, the Bureau of Mines, in Washington have a branch department with a testing station at Pittsburg, Pa. At this station, experimental tests are made in order to determine whether the apparatus is safe to operate in gaseous mines or not and if the apparatus stands up in test in accordance with the Bureau of Mines regulations, a permit is issued as illustrated in Fig. 1, which must be fastened to the apparatus in a conspicuous place.

Definition of "Explosion-Proof"

The Bureau of Mines has applied the term "explosion-proof" to motors constructed so as to prevent the ignition of gas surrounding the motor by any sparks or flashes, or by the explosion of gas or of gas and coal dust that may occur within the motor casing.

Definition of "Permissible"

The Bureau of Mines considers any motor to be permissible when it is the same in all respects as a sample motor that has passed certain tests made by the Bureau and when it is installed and used in accordance with the conditions prescribed by the Bureau.

In 1911, the General Electric Company was requested by the Sullivan Machinery Company to build such a motor and the writer accordingly designed the unit about to be described.

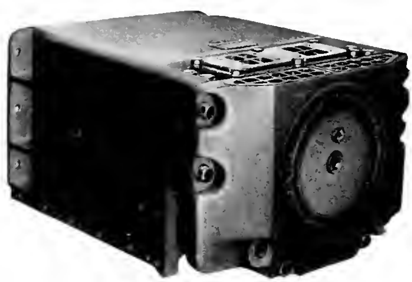


Fig. 2. A 30-h.p., 250 500-volt Motor with Muffler

This motor is known as the CY-24. It is a 30-h.p. machine operating at 250 and 500 volts and was completed and shipped to the Government Testing Station in Pittsburg in December of the same year. The motor is of the class provided with relief openings designed to relieve the internal pressure when explosions occur within its frame and at the same time cool the products of combustion discharged through the relief openings, thus lowering the temperature so that it will not ignite the mine gases.

Since the ignition temperature of mine gas (or methane) is 650 deg. C., it is evident that an explosion-proof motor to be successful, should discharge the products of an internal explosion only when reduced in temperature below this figure.

The motor assembled with protective devices in place is shown in Figs. 2 and 3, and Fig. 4 shows the motor taken apart with the protective devices removed from the frame heads. These devices are the circular rings shown at the extreme ends of the picture and consists of a number of sheet steel disks with spacers between each which provide openings through which the exploded products are exhausted and cooled to a safe temperature.

While the motor was preliminarily subjected to explosion several times, it was not until November, 1913, that the final tests were made. At this time, the motor was subjected to a series of fifty tests and in all of these the protective devices proved entirely successful. In fact, the pressure inside the frame did not exceed seven pounds per square inch. Consequently, the gases expelled through the protective devices became practically cooled off to the temperature of the motor itself, and therefore the surrounding gas-filled air remained unexploded.

This motor is used exclusively by the Sullivan Machinery Company for driving their coal cutter shown in Figs. 5 and 6. While the motor itself proved entirely successful, it was necessary to have starting controller and rheostats also enclosed in explosion-proof chambers. The design of these was carried out by the Sullivan Machinery Company and they were so arranged that when an explosion takes place in the chambers the contents must pass through the motor protective devices and thus become cooled to the required temperature.

The entire outfit was tested with the results given in the table on the following page. The internal pressure did not exceed 50 lb. in any part of the apparatus.

Fig. 3. Another View of the Motor shown in Fig. 2

After this test, the final permit was issued to the Sullivan Machinery Company as shown in Fig. 1.

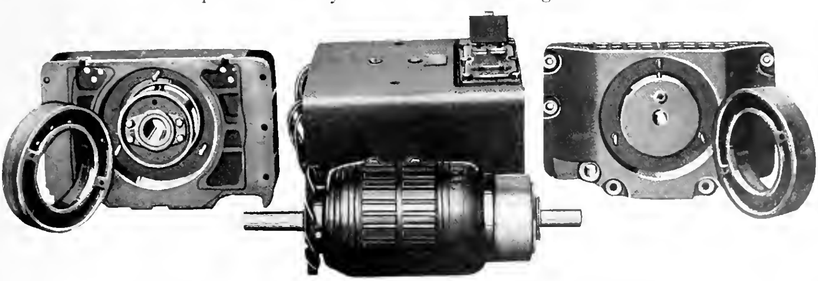


Fig. 4. The Motor shown in Figs. 2 and 3 Disassembled, showing Mufflers

To the writer's knowledge this is the first equipment of its kind approved and permitted to be run in gaseous mines. There are several hundred in daily operation, and up to the present writing there has been no report of failure of any kind.

Fig. 5. Motor and Mechanism of Coal Cutter Illustrated in Fig. 6

TESTS OF COAL CUTTERS

Number of Tests	Percentage of Gas or Dust	Cover Condition	Puncture*	External Flames	Dangerous After-burning†
13	8.6 gas	seated	None	None	None
13	8.6 gas	raised	None	None	None
10	8.6 dust	raised	None	None	None
4	8.6 dust	raised	None	None	None
10	7.0 dust	raised	None	None	None
10	7.0 dust	raised	None	None	None

TESTS OF CABLE REEL

Number of Tests	Percentage of Gas or Dust	Cover Condition	Puncture*	External Flames	Dangerous After-burning†
1	8.6 gas		None	None	None
9	8.6 dust		None	None	None
5	7.0 dust		None	None	None
10	7.0 dust		None	None	None

*The term puncture means the ignition of gaseous mixtures surrounding a motor casing by flames discharged from it.

†The term afterburning is applied to the combustion, immediately after an explosion within an explosion-proof casing, of a gaseous mixture that was not within the casing at the time of the explosion, but was drawn in subsequently while the products of the explosion were cooling

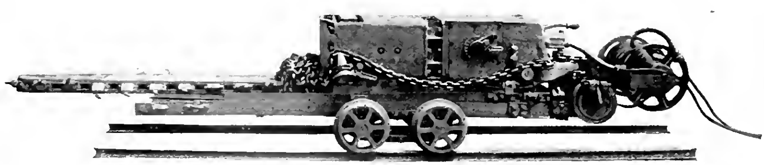


Fig. 6. A Coal Cutter Equipped with Explosion-proof Motor

THE DYNAMIC BALANCE OF MACHINES

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

A body at rest produces no external dynamic effect. If mounted on a shaft and rotated, each elemental or narrow cross-section of the body in a plane perpendicular to the axis of the shaft tends to revolve about a right axis passing through its center of gravity; and if the centers of gravity of all the sections lie in the axis of the shaft, this tendency is initially satisfied and no effort or force is required to exercise it, and each section, and therefore the body as a whole, is in running, or dynamic balance—the vector sum of the forces produced in each section by the rotation is zero, and thus no external effect results; the body runs quietly regardless of the speed.

If, on the contrary, the centers of gravity of some of the cross-sctions, and therefore the axes about which they tend to revolve, do not lie in the axis of the shaft (which we will assume to be practically rigid, as is generally the case) these sections, and therefrom the body as a whole, are dynamically out of balance. The vector sum of the forces in all the sections will no longer be zero, but surplus or unbalanced forces will exist, which may produce undesirable external effects, appearing most commonly in the form of annoying or harmful vibrations, depending upon the masses involved, the speed and the environments, and sometimes further resulting in excessive twisting and bending stresses in the shaft, and undue journal friction, heating and wear.

Since it is only necessary that the centers of gravity of the cross-sections lie in the axis of the shaft in order for them to be in dynamic balance, this result can be accomplished with practical accuracy, in the majority of cases of machine design, and thus for the body as a whole, by the method of standing, or static balancing, when the construction permits the separate balancing of a sufficient number of sections, or parts, in this manner before they are finally assembled, and particularly such parts as methods of manufacture compelled by commercial exigencies may render liable to be out of balance in their finished state. For example, it may be advisable to balance the commutator and armature of an electric motor separately in this way. Furthermore, the gear-wheel or pulley on the shaft, constituting a part of the whole revolving body, should also be in balance, as in fact, it is supposed to be, when received from the maker.

Again, the size and operating speed may make it desirable to balance parts of the armature and commutator bodies before they are assembled and the coils and bars are applied—it is easy for the designer to picture a structure that will be in perfect balance, as far as the drawings are concerned, but they do not take into account the effect of variations in density of the metal, especially in castings, the presence of blow-holes, deformation by irregular shrinkage, etc., which may make balancing necessary by application of metal pieces at proper places to compensate for the defects mentioned, or the cutting off or boring out of metal for the same purpose.

In static balancing the axis of the piece may be centered on a temporary shaft set horizontally on level straight edges, and weight so added, or taken away that the piece remains stationary in any position in which it is rolled along the edges, which indicates that the center of gravity lies in the axis, and thus that the piece is balanced. Or for greater refinement for higher operating speeds an apparatus may be employed in which the axis of the piece, say, a single steam-turbine disk, is vertically centered over a straight line joining and representing the prolongation of two knife-edges of a horizontal rocking table on which the disk is supported. Balance is indicated, when the rocking table remains horizontal for any position of the disk about its axis.

But there are practical limits to the application of the static method of balancing for running operation, however refined. The body may not be separable into sections along the shaft for individual balancing, and therefore must be balanced as a whole. It may be a single casting with two sets of radial spider-arms wide apart in axial direction for support of other parts, say, the laminated steel core and coils of an armature; and even should the casting happen to be in practical balance for good running, the laminated core and coils, when applied, may destroy the balance.

The body, either the casting or the completed armature, can be statically balanced as a whole, it is true, or so that the center of gravity of the whole mass lies in the axis of the shaft, by adding or subtracting weight at points suitably located circumferentially, although placed anywhere axially. But suppose a set of spider-arms at one end of the body thus balanced, considered by itself as a section thereof, does not have its center of gravity in the axis of the shaft, it will then be dynamically out of balance, and naturally so will be the whole armature; and the condition will be worse if the other set of spider-arms is also out of balance, and especially if its center of gravity is on the opposite side of the axis. In such a case the method of dynamic balancing is resorted to, when feasible of application.

Without dwelling on details of the apparatus employed, of which there are variations in design, it is sufficient to state in general that the body is rotated at operating speed with the shaft and bearings spring-held so as to permit a slight oscillation produced by the out-of-balance condition. The shaft is chalked or leaded, and by gradually advancing a metal stylus until it delicately touches the shaft at the high point of the oscillation a corresponding mark is made, which indicates the location where the weight should be changed. The weight is altered and the test repeated until balance is obtained for that end, when the stylus mark will encircle the shaft. The other end is then balanced in the same way, which completes the balance of the body as a whole in respect to the journals in which the shaft is held.

This is the best that can be accomplished practically, when the body as a whole has to be dynamically balanced; and it will run quietly, if the construction, and especially the shaft, is stiff enough to stand without undue strain the stresses that may be set up by out-of-balance sections. If the construction is weak, however, a good dynamic balance need not be expected; the strains produced by out-of-balance sections may set up incurable oscillations, which may manifest themselves in extended vibrations, and noises varying from a disagreeable rumble to a clashing roar, not to mention hot and cut bearings, and possible crystallizing of material and breakdown. Naturally, we do not here include the possible clatter and singing of laminations in some types of electric machines, and windage, which likewise may amount to a roar in a large machine, as they do not relate to the subject of balancing.

Then there is the case of small high-speed machines, say, small motors, where the cost factor practically prevents close attention to balance until the armature is completed, and thus dynamic balancing, if any balancing is required, must be resorted to.

Finally, we have rotating machine constructions so large and massive that they do not practically lend themselves to more than an approximate balancing by the static method, and for the dynamic balancing of which it is not commercially practicable to install a special apparatus of the general character heretofore indicated, because it would have to be of comparatively huge dimensions, would be very costly and would not be used enough to warrant the outlay. In this case such balancing as is practicable is accomplished under running conditions by shifting weights by the cut-and-try method, the effort being to minimize vibrations in the machine, its foundations and surroundings, and bearing friction, until good continuously-running conditions are obtained.

We have heretofore specifically dealt only with rotary bodies, but may include broadly among the machines that have to be balanced, when necessary, by cut-and-try method those having connected rotating and oscillating and reciprocating members, for example, the crank, pitman, piston-rod and piston of a reciprocating steam engine. Here balancing is a complicated compromise between purposely produced surplus dynamic effects of out-of-balance rotation of one body and the dynamic effects of other connected non-rotating, but moving bodies, taken in connection with suitably adjusted energy transference from the bodies to the steam by compression of the latter. The balance at best is a rough one compared with that obtainable for a rotary body alone; in practice it is attained by careful attention to original design, as far as possible, and improved, if found essential, by redistribution of weight in one or more of the moving parts of the completed machine, or change in the steam compression by proper valve adjustment, or both.

Time was, when rotative speeds, taken in connection with the masses involved, represented dynamic effects much less in amount than we find common today. The ever growing urgency that machines shall attain the highest practicable efficiency calls for speeding-up rotating elements—in electrical machines, for instance, the copper and accompanying iron must travel as fast as possible, in this almost over-fast era, and sometimes the materials are, in fact, made to travel too fast, and out-of-balance manifests itself, which would not have been the case had not the chase for exceeding efficiency resulted in the exaggeration of dynamic effects not before of noticeable or serious amount; hence the necessity for still better balancing.

And on top of the refinement in balancing necessary for engineering reasons, comes a growing insistence on a condition of reasonable quietude in relation to the operation of machines in many of their applications, which may be expressed as proceeding from a condition of nerves—people are getting more "touchy;" their perceptive faculties for noise and vibrations are more acute and more easily upset than formerly; there is jolt and jar and clangor enough without adding to it, when avoidable, and with the rapidly increasing use of machines, as the electric motor, in the home and business places, no noise or vibration of distracting amount should enter with them; and in the factory, where line shafting and belts have been supplanted by motors, the continuous purr of the former must not be replaced by an annoying high-pitch tremble or deep rumble coming from ill-balanced motors—not forgetting screechy commutator brushes, albeit outside the present topic. And it may not be amiss to add, as a reminder, that the quiet machine, other things being equal, will get the market.

Naturally, a physically perfect balance is not attainable; therefore a good-enough balance is the result to be sought, which leads us to the point that a balance good enough for a certain environment may be a bad out-of-balance in other surroundings—a machine that runs quietly on a floor, or even less massive support, as far as our senses are affected thereby, may kick up unendurable antics by way of vibrations and noises, if placed on some frail support, say, a shelf fixed to a thin partition; and a large high-power machine that seems as docile as a kitten when on a massive monolith of concrete, may act like a roaring lion, if set up on a steel structure, built however strong within reason, threatening destruction to everything around.

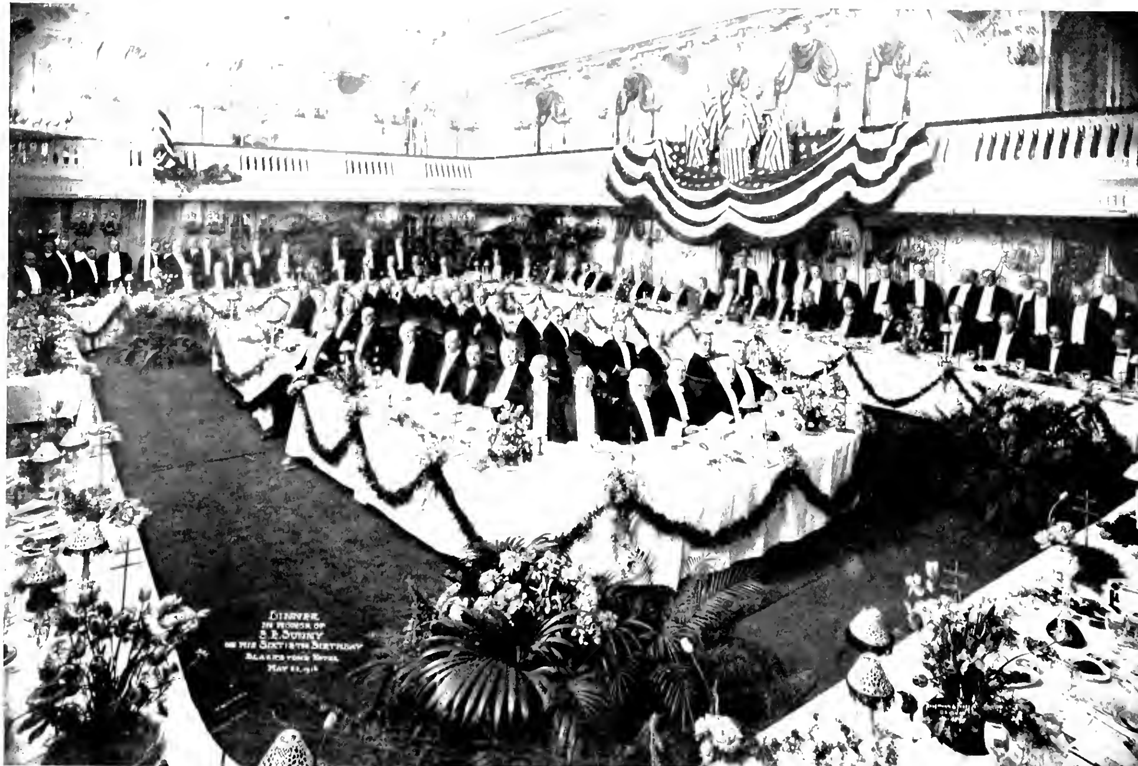
It goes without saying that a machine should be so designed and built as to be efficient and durable within practicable limits, and so that it cannot be harmed merely by its own operation. When this object is attained the refinement to which the balance should be carried depends upon conditions under which the machine is installed and used. Generally, in the case of a high-power machine of individual design, to meet specific requirements, the refinement of balance is limited to that necessary for durability and economy of operation, and the making of a proper foundation is relied upon to minimize extraneous vibrations and noise through such out-of-balance conditions as remain.

But commercial requirements also call for the designing of standard types of machines, made in quantities to meet quick demands of a general market. In this case the refinement of balance depends upon the average place and condition of use, as far as can reasonably be prejudged. Nevertheless, should one of these machines happen to be installed under adverse conditions, especially conditions that resonate with such out-of-balance as the machine may have, it is promptly blamed for the trouble and quite likely condemned; whereas often it might easily be made to run all right by exercising a little common-sense in slightly modifying the surroundings.

For example, a machine set directly on a floor may cause disagreeable vibrations, which might be overcome by setting it up on a boxing filled with concrete. The very annoying hammer of a high-speed reciprocating engine set on a ledge of rock, which was transmitted in the dead of night to homes throughout the neighborhood, was permanently suppressed by interposing a medium of India rubber between the engine bed and ledge, and under the heads of the anchor-bolts. In another case six high-speed engines, balanced as perfectly as the design practically permitted, and installed on a flooring supported by heavy iron beams, oscillated the beams to a dangerous extent; the resonating cause of the trouble was removed by placing along under the center of the floor beams a lighter beam supported on columns of ordinary heavy iron pipe set on the concrete basement floor; the light beam bore only an insignificant part of the weight, but stopped the oscillation. Analagous examples might be mentioned almost without limit, representing the exercise of good judgment in nullifying at comparatively small expense the undesirable effects that machines have tended to produce under adverse surroundings.

In conclusion: when a machine is apparently badly out of balance, do not be in haste to condemn it. Look into the conditions of its use and see whether they may not reasonably be so modified as to cause the apparently undue out-of-balance to disappear—else it may prove to be largely oneself, from the all-around technical and also commercial point of view, that is in reality out-of-balance.

CHAS. L. CLARKE.



PHOTOGRAPH OF GUESTS AT DINNER GIVEN TO BERNARD E. SUNNY

See Opposite Page

A DINNER GIVEN TO BERNARD E. SUNNY, PRESIDENT OF THE CENTRAL GROUP OF BELL TELEPHONE COMPANIES, ON THE OCCASION OF HIS SIXTIETH BIRTHDAY

As this banquet was of such an unusually interesting nature and those gathered together included many of the most notable men in the electrical industry of America, we have made abstracts of the speeches for the benefit of our readers.—EDITOR.

The Crystal Ball Room of the Blackstone Hotel in Chicago was the scene of a notable gathering on Monday night, May 22nd, when a number of personal friends of Bernard E. Sunny, president of the Central Group of Bell Telephone Companies assembled to celebrate the sixtieth anniversary of his birth.

Those present included the presidents of the American Telephone and Telegraph Company, the General Electric Company, the Commonwealth Edison Company, the Westinghouse Company, together with leading bankers, manufacturers, merchants, distinguished members of the bar, the clergy and the medical professions, scientists, publishers, and men who have won fame and fortune in practically every walk in life.

Judge Charles S. Cutting was the toastmaster and Dr. Frank Gunsaulus presented the testimonial, a massive silver plaque, suitably inscribed and bearing the facsimile signature of all the dinner hosts.

THE TOASTMASTER: Gentlemen, it is no small thing to have been able to complete sixty years of successful business life. We are here to-night to pay tribute to that fact, and to the greater and much more far-reaching fact that the character of the man and the achievements which have been his are of such character as requires a meeting of this kind.

One is reminded, I think, to-night of one of the most notable banquets that this country has ever seen. At the time of the completion of the Atlantic cable there was given to Cyrus W. Field and to Morse, the inventor of the telegraph, a banquet in the City of New York which had about its board a collection of notables connected with the then known science of electricity, the like of which had never before been seen, and on that occasion there was made an address by William Cullen Bryant, the poet, in which he depicted as perhaps only a poet can, the wonders which had been wrought by electricity, and in glowing words he painted his poetic picture of the slender cable connecting the two continents.

Scarce fifty years have passed since then, and now not only the realms of the deep but also the unexplored regions of the air return their tribute to the power of electricity. Not only the little spark which moves the electric light, but the human voice travels far and sure over the lines.

If the people who gathered at that banquet in New York could see the exact achievement of the science of electricity in the matter of human communication today they would be as much astounded as were the people of that time at what had then been accomplished. All achievement in the line of innovation comes as a rule in three particular ways, at least there are three stages of its development. At first we have the men who delve after truth in scientific research. We can all name them. We remember Franklin, of course, our own Franklin, and LeSage and Ampère and Volta and Galvani, those men who with their experiments made possible the next set of people who came with the spark of invention to add to their ideas. They were the inventors and there was Wheatstone and Morse and all the rest of them whose names are as familiar as can be, and latterly Bell, the great inventor of the telephone. But all these, though doing great things and entitled to much respect and reward from the people, would have been practically useless but for that third estate, if you please, which brings about the practical achievement of the thing which the inventor has made possible. These are the administrators, the men who took up these things and made them practical, who organized, systematized and spread abroad the blessings which the others had made possible, so that all the world could have them. We know the names in that connection of Cyrus W. Field, and of Sibley and others who were among the great administrators, who put time and money and brains into the dissemination of the knowledge which was necessary for this development.

I can see about this board to-night those who have succeeded these first ones. They are no less entitled to credit than they.

They have gone on from where their predecessors left the science, and have brought the problem of administration and dissemination to such a stage of perfection that we take as a matter of course to-day that which was the wonder of the ages but yesterday.

And to-night we are here to pay tribute to one of these administrators, and other administrators have gathered to add their testimony to that of other admirers. To-night this notable assembly, these men who have done things, come from near and afar to burn incense at the altar of one who has successfully, prudently and ably administered the trust which has been committed to him.

It would be useless for me to attempt to speak on that subject further. I simply have the privilege of introducing to you one who can say much more, I take it, from intimate knowledge than it would be possible for me to do, one who has had much to do with this administration matter himself and knows whereof he speaks. I had intended perhaps to give some little biography of this gentleman, but I became so entangled in various titles that I could not possibly undertake to remember what they were, and for fear that I might call him an executive officer when, in fact, he was a director, or that I might say something else which would be offensive, I have concluded to introduce Mr. Samuel Insull simply as the President of the Commonwealth Edison Company, an administrator of note, who will speak on the subject of the evening.

Mr. Insull: Mr. Toastmaster, Mr. Sunny, and Gentlemen: I esteem it a very great honor to rise on this occasion and pay my tribute to the sterling worth of my intimate friend, Bernard E. Sunny. Like most of us engaged in the electric business, he rose from the bottom. He started life as a telegraph operator in Brooklyn. Later on he came to this city, and during most of his business career his record has been an open book in this community.

In the early day of the industry, he passed from his work as a telegraph operator to an association with the development of the Bell Telephone in Chicago, and later on, in the early days of the electric lighting business, was one of the principal officials of the largest company at that day operating in the City of Chicago, the Chicago Arc Light and Power Company.

A few years later he became the western manager in this city of the sales department of the Thomson-Houston Electric Company, the electric manufacturing company of Boston, and later of its successor, the General Electric Company. Passing from that branch of electric work, he became the vice-president of the American Telephone and Telegraph Company resident here in Chicago, and to-day, as chief executive of the subsidiary telephone companies in the Middle West, he operates a telephone business having a gross revenue of thirty-six millions of dollars, having two millions and a half of telephone subscribers, and covering a territory probably one-fifth of the United States, which is practically an empire in itself. That is in short Mr. Sunny's career in the electrical business.

But to those of us here who are his neighbors, we know Mr. Sunny, not alone as an enlightened operator of public utilities, but we know him as a citizen of the first order, a man who has served the community in which he lives to the very best of his ability. (Applause.)

I well remember a number of years ago when Mr. C. A. Coffin, now chairman and then president of the General Electric Company, informed me that the Board of Directors of that Company proposed to elect Mr. Sunny a vice president of the company. (He was then their Western manager resident here.) I replied to Mr. Coffin that while it was a compliment to Mr. Sunny it was a far greater compliment to the company for which he was working, as it was an extremely valuable asset to them to be represented in this community by so distinguished a citizen as Mr. Sunny. (Applause.)

During the twenty-four years that it has been my privilege to live in Chicago I have had the most intimate relations with Mr. Sunny. Often in the early days we were on the opposite side of the fence so far as business was concerned, but whether those relations were the relations of the purchaser and the seller of electrical machinery, or in later years the relations of fellow workers in the public utility field, I have always found him to be actuated by the highest sense of business honor and to possess the greatest possible appreciation of his duty as a semi-public official.

On the personal side, the intimate personal relations that it has been my pleasure to enjoy with him, I do not think that this is an occasion that I wish to refer to them, except to say that they have been amongst the pleasantest business relations that I have had since it has been my pleasure to live in this community.

When the idea of entertaining Mr. Sunny at dinner on his birthday was suggested by some of his friends in the electrical business, we had intended that it should be in the form of a surprise party to him, but as we went along the idea developed into such a large function that we were compelled to take him into our confidence, and our only regret to-night is that he was aware of what was coming off before he entered the room.

I can assure you, Mr. Sunny, that on behalf of your fellow workers in the electrical business we hope to have the pleasure of congratulating you on a great many birthdays in the future. (Applause.)

Mr. Guernsey: It is an especial pleasure to me to be here to-night. The first thing that I did in my present position was in connection with a negotiation that Mr. Sunny had pending with the City of Chicago about three years and a half ago. This brought me into contact with him; and as this is an occasion where, on more than any other, perhaps, personalities are proper, I desire to refer to a little incident which occurred at that time which I may say was in a sense my introduction to Mr. Sunny. I had come from a territory where conditions were such that when I found here that we received fair treatment from the newspapers I was rather surprised, and when I met the owner of one of your papers here I spoke of it, and expressed our appreciation of their attitude, but he cut me right off. He said:

> "That is nothing; you don't owe us anything. Mr. Sunny is a man who has stood for honesty and integrity and good government in this city for years, and he is entitled to the treatment he is receiving, and you are under no obligation to us, whatever." (Applause.)

That was my introduction to Mr. Sunny.

Mr. Sunny was with the Chicago Telephone Company until 1888, when there were six thousand telephones here. This job was not large enough for him, and so he left to afford the job time to grow up to the man. And for twenty years he was engaged in one or another of the electrical enterprises to which reference has been made. When they had developed this exchange here to some two hundred and twenty-thousand telephones, they thought perhaps the job was big enough for the man, and the man came back to undertake it; but he did not think it was big enough, and so he developed it to five hundred twenty-five thousand, and then that was not big enough, and so they put on Wisconsin, they put on the rest of Illinois, they put on Michigan, they put on Ohio, they put on Indiana, they gave him with his connecting telephones two and one-quarter millions, and then Mr. Sunny said, "Now, then——" and this is where he stands today, "I have a man-sized job; I have a job that is big enough, and I am big enough for the job," and now, gentleman, he is ready to begin to show you what he can do. (Applause.)

There is another thing that has been running through my mind as I have been sitting here. Here is this man who, as Mr. Insull says, has developed himself from a telegraph operator until he is the chief executive of this organization that covers, I think Mr. Insull said, nearly one-fifth of the United States, an enormous organization serving an enormous number of people, serving them efficiently and well; and he is here with his friends because his friends called him here to congratulate him. As he looks back it has seemed to me that one thought that must hold a prominent place in his mind is this: That in addition to the success, that, if I may use the expression, sweetening the success, is the fact that his work has had in it the element of service. His work has been a public work.

Mr. Rice: It gives me great pleasure and I consider it a special privilege to be here tonight to add my tribute to that of others to my friend of many years, Mr. Sunny. I first met Mr. Sunny nearly thirty years ago, and when I received an invitation to attend his sixtieth birthday anniversary I thought it very strange. It did not seem possible that he could be sixty years old, and when I see him again to-night I still think there is something wrong, some error has been made in respect to the statistics. But when I think of the work which he has accomplished I admit that he must be as old as he claims. I see around me here quite a number who can remember that time thirty years ago, remember something of the condition of the electrical industry. The electric light industry was really then in its infancy. Only a very few years had passed since the incandescent lamp had been invented by Edison. The arc lamp and incandescent lamp were about the only things electrical besides the telephone and telegraph that were known. The street car were still driven by horses as the trolley car was just born.

Just think of what has happened during this period in which Mr. Sunny has been working in Chicago. I will not attempt to enumerate the changes that have taken place. They are well known to you all, but when you think of the changes which have been produced by the trolley car, the electric light, the electric motor, the electric transmission of power to long distances permitting of the conservation of the energy of distant water powers, the wonders of the wireless telegraph and telephone, the X-ray and all other electrical devices, and then consider the changes in other than electrical fields, such as the automobile and flying machine, it is no wonder that our minds become confused and we feel that the whole world and our relations to it are rapidly changing. Now, of course, we know as a scientific fact that changes are constantly taking place and that no phenomenon is ever exactly repeated, but it is a consolation to remember, it seems to me, that there is one thing that does not apparently change. If you read your Bible or the old Greek and Latin philosophers, I think you will agree that the one thing that does not change is human nature. The mind of man as expressed in human nature and human character is the same today as it was ages ago, and as I believe it will be ages hence.

If our friend Sunny had lived two thousand years ago, I think he would have made the same success then, he would have won the admiration and respect and confidence and affection of his friends, would have been the same inspiration to all of his associates at that time as he is today, and if he were to live two thousand years from now he would repeat the same performance.

Mr. Sunny, you have many friends. I cannot deny that in the presence of all your friends here, but I do not believe that you have any friends that are more sincere or more loyal or who have a greater affection for you than the friends that you made during your long and distinguished term of service with the company with which I have the honor to be associated. In speaking for myself and my associates, we wish you a long and happy life in the midst of your loving family, and among your many friends, old and new. (Applause.)

Mr. Vail: Mr. Toastmaster, Mr. Sunny, Ladies and Gentlemen: Never before in my life have I more deeply regretted my inability to respond in a fitting manner to an inspiration like this. It is with hesitation and reluctance that I attempt to speak to-night, feeling that it is impossible for me to voice my respect and admiration for the guest of the evening, but it did seem little for me to lay aside that reluctance and hesitation and join this notable group in this demonstration.

It recalls to me to-night my first visit to Chicago in connection with the telephone business. I had been connected with the mail service, where I had achieved some reputation, and had left the mail service to take up the "Yankee Toy" as they called it, which gave me some notoriety, and my acquaintance with some people in Chicago gave me admission to a circle more or less representative as are the people who are assembled here to-night. I talked to them about the telephone. They listened, some with curiosity, some with badly concealed skepticism, some with slight credulity, but after deliberation there was no indication of responsiveness. After some work in other directions I assembled a group of young fellows, some of them who had been my associates in the mail service, with lots of initiative, lots of uncapitalized work and energy, but little money with which to bridge over the terrible gap between anticipation and realization. Just about that time the Western Union, headed by those names that you could conjure with in Chicago, Anson Stager, Norman Williams, and others, concluded that they wanted to go into the telephone business. This, of course, created a panic in my little band to such an extent that we had to take over the business ourselves in Boston. About this time Mr. Sunny became associated with the company and after a short period, which seemed very long at that time, we succeeded in convincing the Western Union that they did not want the telephone business; that they had better retire, so they retired and left the telephone business with us, and they continued the telegraph business. An attorney-general not very long ago concluded also that there should be a separation between the telegraph and telephone (laughter) which I think was much to the retardation of commercial development in many lines.

Many of those who were first approached, afterwards became permanently identified, financially and officially, with the Chicago Telephone Company.

Mr. Sunny, as I said, connected himself with the business, became permanently identified with its progress for the next eight years, when he left it to occupy himself with the upbuilding of new industries, in which he gained experience and probably more material substance than he would have, had he continued in the telephone business. It was after an absence of twenty years that he returned to his first love, where he found a much enlarged field and much greater requirements than when he left and to which he brought a sufficiency of all that was needed.

We always like to speak of anything that will add to our self-respect. It is a coincidence that my direct connection with the telephone business was in 1878, one year before Mr. Sunny came. My separation from the active participation in the business was in 1887, one year before Mr. Sunny left. My return to the business was in 1907, after twenty years, one year before Mr. Sunny came back. There may be significance in this coincidence. The fact that I speak of it shows that I think there was some.

Gentlemen, we are living in an age in which it does seem as if words, promises, assertions carry more weight than deeds, accomplishment or fact. If it were not for such occasions as this, it would seem as if a life of good work, of honest endeavor, had no reward except in the self-satisfaction that always comes from being at all times able to maintain your self-respect. Mr. Sunny's whole career has been one of deeds and accomplishments, modest and gentle in action with a quick perception of possibilities, reflective deliberation and decision, and a persistent determination when once decided. He has established himself in the estimation of his fellows as one of the leaders of the country. When a man has spent his mature life in one community and has been identified with its social, economic, industrial and civic development, and has been foremost among those active in the betterment and progress, when such a man has reached through his own efforts, through recognition by others of his own qualities, the highest administrative position in one of the chief enterprises of the section, and when at three score years he is honored, as is our guest this evening, by the best of the community to which he belongs and the foremost among those with whom he has associated, what can be said of any one to give such compliment greater expression? (Applause.) May he be given many more years in which to live and be an inspiration to the coming generation which must in the future fill our places. (Applause.)

THE TOASTMASTER: I have a telegram or two that perhaps ought to be read at this time. I read from Mr. William G. Beale the following telegram:

"I am sorry I cannot be physically present at the dinner to celebrate your birthday to-night, but I am with you and others in spirit and send you my hearty congratulations and good wishes. May you have many happy returns of the day."

From Mr. Julius Rosenwald I have this:

"But for the fact that I must preside at the Annual Meeting Dinner of the Associated Jewish Charities to-night I would be with you to extend my congratulations to my friend B. E. Sunny on his birthday anniversary. Please tender Mr. Sunny my best wishes that he may have many more years of usefulness to our community in which he is one of the most efficient and public spirited members."

From Mr. C. A. Coffin, New York:

"It is a source of great regret that personal and domestic considerations prevent my being present at the dinner in honor of Mr. Sunny, the fineness of whose character and the value of whose achievements command the admiration of all, and whose devotion to principle, loyalty to friends and zeal in every good cause hold the unfading affections of multitudes of friends."

MR. BYLLESBY: Judge Cutting, Mr. Sunny and Gentlemen: It is futile for even so old a friend and admirer of Mr. Sunny as I am to attempt to add anything to the merited honors he is receiving this evening. I am a very old friend of Mr. Sunny's, my acquaintanceship going back nearly as far as Mr. Vail's. Mr. Vail has spoken of the early workers in the electrical business and emphasized what is a fact—that the earliest were those who most delved after truth.

Mr. Vail has spoken of Mr. Sunny's interesting career, having started originally in the old Western Union business, and then his talents landed him with the telephone company, and then with that wonderful prescience of which every man in the electric lighting business was possessed, he was seized by the electric lighting interests, and we had him as our co-worker for a long period, and finally Mr. Vail, with his blandishments, came along and landed him back in the telephone company, very much to our regret. I do not know any man who could have had a more successful career than Mr. Sunny has had, but I feel that if he had not been lured back to the telephone company and had stayed with the electric light and power interests, Mr. Sunny might perhaps have gone to even greater lengths.

There is very little any one can say beyond what has been said this evening. I have wintered and summered with Mr. Sunny for the twenty-eight years since I first met him.

He came into my office in Pittsburgh when, as a young man, I was the executive of the Westinghouse Electric Company, of which Mr. Tripp is now chief executive, and from my first interview up to the present time, and I hope it will last as long as life lingers, I have always had an increasing regard for Mr. Sunny. Mr. Sunny is no accident. Mr. Sunny represents to my mind the very best ideal of the successful man, a man who has achieved his success by patient, persistent industry, by everlastingly being true to his convictions, by being true to his friends, a man who performs his duties without any brass band or without "fuss and feathers." In every sense of the word, gentlemen, and I am speaking from an acquaintanceship running on to past twenty-eight years, Mr. Sunny qualifies up to the highest standard of the successful American business man, true to his duties, fearless in the right, courageous and true to his friends. And with my mind this evening dwelling upon the marvelous success of this typical American, our honored guest of the evening, Mr. Sunny, there has been continually running through my mind an echo from my childhood—from the church-going days—when there was read, as a part of the morning lesson, in that far-away period, the following verse: "Seest thou a man diligent in his business, he shall stand before kings. He shall not stand before mean men." Mr. Sunny, I offer you my heartfelt and deeply admiring tribute. (Applause.)

Dr. Gunsaulus, after making an address full of humorous remarks and appreciation of Mr. Sunny, concluded as follows:

Dr. Gunsaulus: Now, we believe that Mr. Sunny, according to all these stories to-night, which are interesting indeed, especially to his pastor who certainly doesn't want to bury him, is the sole author of all this splendid success. Do you know Mrs. Sunny? If you know Mrs. Sunny, you know how far from the mark these brethren have gone when they give the honor to Mr. Sunny. He is the example of what man may be if he behaves himself well for sixty years, but he is a far greater example of what a man may be if he obeys his wife. This woman has put her touch upon all his life, upon all his activity, and upon all his achievement.

We say the future for our friend. It is too late?
Ah, nothing is too late till the tired heart shall cease to palpitate.
Cato learned Greek at eighty
And Sophocles, among his peers
Did win the prize when after seventy years.
Goethe, at Weimar, toiling to the last,
Wrote Faust when seventy years were past.
Chaucer, at Woodstock with the nightingales,
Did give to man the Canterbury Tales.

These are indeed exceptions, my friends, but they prove how far the northern stream of our life may flow into the northern region of our lives, where life and little else than life itself survives. The future to our friend. Sixty years has left him with us, a glorious man, panoplied and successful, and in the name of this City, in the name of the church who loves him and has honored him as her officer; in the name of these associations which have created for us the new and brilliant day by science and invention and discovery; in the name of all that manhood means, and purity and truth and faithfulness; and in the name of the boys and girls, the women and men who work for him and under him, and love him as they labor in their places, employed by his great company; in your name and in mine, I present to Mr. Sunny this tribute of our affection, this reward for years of devotion, this symbol of our love.

The Toastmaster: There are times in the life of every successful man, I take it, especially when one is surrounded by loving admiring friends, when he wishes the toastmaster would take a little more time before he is called to his feet, and I feel that our friend to-night perhaps may be in that mental condition, but alas! there is no help for him. The time has come; the hour has struck; the seal is set; and the die is cast. Ladies and Gentlemen, I present to you the guest and the hero of the evening, the man of the hour, our friend, B. E. Sunny. (Applause.)

Mr. Sunny—Ladies and Gentlemen: I never realized before that a man could be miserably embarrassed from an excess of spotlight and yet be supremely happy. The fact rather makes clear the paragraph in the letter from back home which said, "At present Aunt Mary is enjoying poor health." (Laughter.) Nor did I realize before that reaching sixty years of age was an event of special significance. In the olden time it generally meant that curfew was about to ring on one's activities, a period of carpet slippers, weak tea, stewed prunes and one cigar a day, and if your wife happened to have more pull with the physician than you had you would lose the one cigar. (Laughter.) But we are living in an age of high efficiency, and all things are changed, and reaching sixty years of age now means that you must quit dawdling and do something. There is an abundance of evidence in the support of this theory.

Mr. Vail went back in the telephone business at sixty-two, when there were three million telephones, and now there are nine million. We owe to his initiative, his enterprise and his courage the development of the transcontinental telephone, and later the remarkable achievements in wireless telephony. We could multiply instances where the rule has worked out in any number, but it is not necessary. We will concede that the theory is correct. So that I, therefore, realize that I have taken on a new and greater responsibility. The eyes of the world are on me, and I am expected to do something or somebody.

Just what I shall do I have not determined. Colonel Roosevelt, we realize, cannot be with us always, so that I think I shall have to solve the problem of perpetual motion.

I had word from a telephone subscriber a few days ago that I would be entitled to a niche in the Hall of Fame if I would suppress the operator on his end of the line who rolled her R's so recklessly. (Laughter.) He says, "She not only rolls them but she spins them."

I greatly appreciate the tremendous compliment that Mr. Vail has paid me by coupling me up even to the extent that according to the calendar we kept step together during the past thirty or thirty-five years or more. Tl e incident rather recalls a story that was told some months ago to a revenue cutter in the New York harbor that used to start out about eight o'clock in the morning if the weather was fine and work around the harbor and quit service at five o'clock at night. The captain and the officers were all very important, very dignified, and they were very much surprised one day to be told that they would have to go down to some point in Delaware. They were very much shocked, for the reason that this broke into their usual routine, and furthermore it kept them out all night. About three o'clock in the morning the officer on watch saw a great hull looming up in the darkness, and he called out, "Who's there?" And a voice from the hull called back, "This is the *Royal Bengal Tiger*, ninety days from Calcutta. Who are you?" "Oh! This is the *U. S. Grant*, and we have been out almost all night."

The comparison between Mr. Vail and myself leaves off, I am sorry to say, with the calendar. My friends, you must know—I am sure you do know—how impossible it is for me fittingly or adequately to thank you for this beautiful evening or to express my appreciation of the many generous and complimentary things which have been said by the various speakers, and added to it all I have this beautiful, this exquisite gift. It all makes me feel like an utter bankrupt. I simply cannot pay you the debt that I owe you. Rich as I am in so many splendid friendships, I am poor indeed in language to express the gratification which fills my heart. I accept it all, the little which I may deserve, the much you have lavished in such whole-souled affection—I accept it not for myself, but to share with my best friend and helper, one whose love and confidence have been true and constant and whose high ideals have been a daily inspiration—my wife. (Applause.)

And I thank you for your comradeship, for your friendship over so many years. I have regarded them always as among the earth's choicest blessings, and I pray that I shall always have them. Thank you.

Those present were:

John Jay Abbott
W. Rufus Abbott
B. J. Arnold
Clifford Arrick
G. H. Atkin
Wm. G. Beale
J. G. Barry, Schenectady, N. Y
Thos. W. Berry
E. K. Boisot
Wm. L. Brown
J. W. Buell
A. W. Burchard, New York, N. Y.
Leonard A. Busby
H. M. Byllesby
Dan'l A. Campbell
Newcomb Carlton, New York, N. Y.
H. E. Chubbuck, Peoria, Ill.
W. J. Clark, New York, N. Y.
B. H. Conkling
R. W. Cox
D. M. Cummings
F. W. Cushing
Chas. S. Cutting
H. W. Darling, Schenectady, N. Y.
Chas. G. Dawes
Jos. H. Defrees
T. E. Donnelley
H. O. Edmonds
G. E. Emmons, Schenectady, N. Y.
John V. Farwell
Elbert C. Ferguson
L. A. Ferguson
Bernard Flexner
J. B. Forgan
D. R. Forgan
B. S. Garvey
Chas. H. Gaunt
John F. Gilchrist
N. T. Guernsey, New York, N. Y.
Dr. F. W. Gunsaules
W. J. Hagenah
Ernest A. Hamil
Albert W. Harris
Fred T. Haskell
Angus S. Hibbard
H. F. Hill
J. H. Hiland
Chas. S. Holt
J. W. Hosmer
R. W. Hosmer
Arthur S. Huey
E. D. Hurlbert
Martin J. Insull
Samuel Insull
Noble D. Judah
H. H. Kohlsatt
Victor F. Lawson
T. D. Lockwood, Boston, Mass.
J. R. Lovejoy, New York, N. Y.
Frank O. Lowden
J. J. Mitchell
W. I. Mizner
H. L. Monroe
D. A. Moulton
L. E. Myers
Homer W. McCoy
Dr. J. D. McGowan
Adolph Nathan
E. C. Noe
LaVerne W. Noyes
J. J. O'Brien
Jos. E. Otis
Chas. C. Perry, Indianapolis, Ind.
Chas. W. Price, New York, N. Y.
A. H. Revell
Geo. M. Reynolds
E. W. Rice, Jr., New York, N. Y.
Harrison B. Riley
Theo. W. Robinson
E. P. Russell
Chas. Schweppe
John W. Scott
L. A. Seeberger
D. E. Shanahan
John G. Shedd
W. P. Sidley
Solomon Smith
John A. Spoor
A. A. Sprague, 2nd
Homer Stilwell
J. E. Stuart
Arthur E. Sunny
Guy E. Tripp, New York, N. Y.
Fred W. Upham
Theo. N. Vail, New York, N. Y.
A. S. Van Westrum
Frederick T. Vaux
Chas. Wacker
Roy O. West
Frank O. Wetmore
Jno. E. Wilder
Walter O. Wilson

IN MEMORIAM

William Stanley, celebrated inventor and organizer in the electrical industry of this Country, died at his home at Great Barrington, Mass., on May 14, in his fifty-eighth year.

Mr. Stanley was born in Brooklyn, N. Y., on November 22, 1858. His parents were William and Elizabeth Parsons Stanley.

After graduation at Williston in '76, young Stanley entered the class of '81, Yale Academic, under protest, but, much to the disgust of his parents and with many forebodings of his family and friends, left college in a short time.

After leaving Yale, Mr. Stanley found employment in the firm of Charles T. Chester & Company, the principal manufacturers of telegraph instruments of that time, but soon left Chester to go into the nickel-plating business on his own account with a Mr. Willey at 47 Ann Street. Much to the surprise of their friends, the firm cleared up a tidy sum the first year.

At that time Hiram Maxim (now Sir Hiram), the distinguished inventor, came to Mr. Stanley's father for legal assistance in organizing the United States Electric Lighting Company, for which Mr. Curtis acted as Secretary. Young Stanley was so greatly fascinated with Maxim and his work that he promptly sold his electro-plating business and hired out as assistant to Maxim at 50 cents a day. By strenuous study and application he soon mastered the elementary principles of the electric machines and devices then made, and began to try to improve upon them. His first invention was an improved system for exhausting incandescent lamps by which a high vacuum could be obtained in a shorter time than was then usual. The pumping system was patented, was successfully operated, and is still used by manufacturers of incandescent lamps.

WILLIAM STANLEY

In 1880 Maxim visited the Paris Exposition, and remained abroad to perfect his rapid-fire gun, and young Stanley joined, for a short time, the staff of assistants about Dr. Edward Weston, the distinguished physicist and engineer. Later, in 1882, Mr. Stanley started a small laboratory of his own in Englewood, N. J., where he attempted unsuccessfully to "misuse the principles of chemistry" to produce a novel type of storage battery.

At this time, in 1882, the principal problem before the electrical engineers of the world was how to transmit electrical energy over a considerable distance, such as a mile, without an excessive expenditure for the conductors on which to carry the current. Many endeavors to solve this problem were suggested by distinguished engineers and inventors, but none proved commercially successful. Stanley studied and worked at the problem, attacking it from many sides, but for more than a year failed to devise any broad and satisfactory solution. In 1883, while studying lead storage batteries and battery systems, with which continuous currents are used, Mr. Stanley got the first suggestion of a plan that later, in 1885, he worked out into a new and general solution of the problem. It occurred to him that if the electromotive forces produced in the windings of magnets by alternating currents could be proportioned to properly regulate the flow of the electric currents, the size and therefore the cost of the conductors conveying the currents could be greatly reduced by generating currents at high electrical pressure at the station or plant and reducing the pressure at the customer's premises by a special design of induction coil now known as a transformer. Stanley studied this subject very carefully, but did not succeed in perfecting it at that time.

In 1884, before the new system was worked out, Stanley made an arrangement with Mr. George Westinghouse by which he moved to Pittsburg and undertook to design and build dynamos, motors, and other appliances for the Westinghouse interests in consideration of salary and an interest in the business that should thus be developed, while Mr. Westinghouse undertook to furnish the capital to develop Mr. Stanley's inventions, should they prove commercially useful. This alliance resulted in the formation of the Westinghouse Electric Company to develop Mr. Stanley's inventions.

During 1884 he built several types of generators and motors, and installed a factory for making incandescent lamps, devoting most of his time to the production of these devices and little to new inventions.

In the spring of 1885 he made his first "convertor," now called "transformer," and operated it at the Pittsburg shops for a few days. During the summer and early fall of 1885, although in poor health he worked out the conditions that have since been employed in what is known as the alternating-current system. As soon as he was satisfied that the new plan would be successful, he endeavored to interest Mr. Westinghouse to furnish the funds necessary to construct a plant to demonstrate its success or failure. Mr. Westinghouse, however, was fully occupied with the distribution of natural gas at Pittsburg, the building of new types of engines and prime movers and was just entering a number of newly developed fields of work, so that he was unable to give very much attention to the subject and was disinclined to furnish the necessary funds.

Unsuccessful in attempting to obtain the necessary funds to prove his plan, Mr. Stanley then sold a large portion of his small capital and devoted the proceeds to the construction of a plant with which to try out the system at Great Barrington, Mass. The apparatus required for this system was novel and new. It was designed and built by Mr. Stanley and his assistants at his laboratory at Great Barrington, and tested out in the fall of 1885. The current was generated at Mr. Stanley's laboratory and conveyed by wires attached to the village elms for a distance of about half a mile to the center of the town. Tests were made over artificial distances that proved that by means of the new system the current could be carried with a very small loss over distances that were enormously greater than any before attempted.

During the winter of 1886 Mr. Westinghouse and his friends came to Great Barrington, saw the plant in operation, and undertook to produce at Pittsburg the transformers and generators designed by Stanley.

The first alternating-current plant equipped by the Westinghouse Electric Company was started at Buffalo in the fall of 1886. Since that time over 7000 different towns and cities in the United States have adopted the system. It is exclusively used wherever it is desired to carry electric current for more than a very short distance. From the modest beginnings of 1885 the alternating-current system has grown until today the annual production of alternating-current machinery is larger than any other type in the electrical business.

Shortly after the demonstration at Great Barrington, Mr. Stanley devised what is known as the auto-transformer, a modification of the ordinary transformer that is used for many purposes.

Later he devised several new kinds of alternating-current generators, two new kinds of alternating-current motors that have been widely used, and, with Mr. J. F. Kelly, a plan for neutralizing the induction on telephone lines, upon which the selective features of wireless telegraphy are founded.

In 1888 Mr. Stanley built the first induction wattmeter, an instrument that is used for measuring the energy wherever the alternating-current service is employed.

In 1890 the Stanley Electric Manufacturing Company at Pittsfield, Mass., was organized by Mr. Stanley and his associates, Mr. J. F. Kelly and Mr. C. C. Chesney. This company developed a number of novel and useful devices, and boldly advocated the transmission of power over long distances. In fact, they were the pioneers of the modern long-distance transmission of power. The Stanley Company was afterwards purchased by the General Electric Company, with which Mr. Stanley was connected at the time of his death.

On December 22, 1884, Mr Stanley married Miss Leila C. Wetmore, of N. Y., who, with five sons and two daughters, survives him.

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 Company, Schenectady, New York.

WATER FLOW: SALINE METHOD OF MEASUREMENT

(169) Some rivers contain an appreciable amount of saline compounds, such as calcium sulphate and carbonate. Would the presence of these compounds render measurements inaccurate when made as described in "The Saline Method of Water Flow Measurement as used in the Acceptance Test of a Pumping Plant" (W. D. Peaslee) G. E. REVIEW, February, 1916, p. 132?

The calcium sulphate and carbonate contents of any river water are very small as these salts are to a great extent insoluble. Therefore the solution formed by the slight dissolving is extremely dilute and is almost entirely ionized. The conductivity of a solution is a function of the number of free ions in the solution and of their velocity. In other words, it is a compound function of the mobility of the ions.

When an electrolyte is added to a dilute electrolytic solution of another kind, the resulting conductivity is still a function of the mobility of the ions; and, provided no common ion exists between the two electrolytes, the increase of conductivity will be a direct function (in dilute solutions) of the added electrolyte. Since the calcium carbonate or sulphate has no common ion with sodium chloride, the existance of these first two salts in the water will not introduce any error in the determinations for the solutions are very dilute in the method of measurement described.

Any substance in the water which would react upon sodium chloride would cause errors in this method, but neither of the calcium salts mentioned has this effect. Furthermore, so far as has been determined there is no reagent commonly met in river waters that reacts with sodium chloride. Of course if such a reagent were met, the method could still be used in its titration form, but this operation would be rather complex for it would require accurate gravimetric analyses of all the samples and a study of the resulting combinations.

As a matter of absolute precision it is impossible at present to say that the presence of such substances, especially colloids, will have no effect on the accuracy obtained with this method of measurement. It is known, however, that the effect of the calcium salts mentioned has no determinable effect when solutions of the dilution met under these conditions are considered. It is quite safe to say that the error in the electric method due to any impurities likely to be found in any river water will be less than the personal error in reading any commercial electrical instrument, and is certainly much less than one-tenth of one per cent. With the titration method, the error introduced is absolutely nil unless, as before stated, the impurities react with the sodium chloride.

Therefore, the titration or the electric method can be applied in the presence of the calcium salts named in the question with absolute assurance of freedom from error within very much less than one-tenth of one per cent. Unless great precautions are taken, the titration method will give more accurate results with unskilled operators than will the electrical; although it has been found that results much closer than one per cent error are obtained by unskilled operators with the electrical method.

W.D.P.

TRANSMISSION LINE: VOLTAGE TO GROUND

(170) (a) If a transmission line is not grounded is there a voltage from the line conductors to ground? (b) If a wire of the above line broke and lay on the ground, what would be the voltage from the unbroken wires to ground? Would a current flow between the unbroken wires and ground? If there will be one, what will be its amount?

(a) A voltage does exist from each wire to ground because each conductor acts as one plate of a condenser with respect to the ground (as well as to each other wire). The capacity relationship of any one conductor to ground is the same as that of the remaining two; therefore, the three line-to-ground voltages are equal. In value, such a voltage will be exactly the same as if the line had a grounded neutral, or 57.7. per cent of the line-to-line voltage.

(b) In the case of a broken wire on the ground, the equality of the capacity relationship as described would be disturbed and a new state of equilibrium established. Under these new conditions the broken conductor would assume ground potential and the capacity voltages to ground of the other two conductors would increase from 57.7 per cent of line-to-line voltage to practically line-to-line voltage.

A current, called capacity current, will flow from the two unbroken wires to ground in this case as in the former case (a) in which current flows from all three wires to ground. The amount of the current flowing under conditions (a) is called the normal charging current. In the case (b) the capacity current in the two non-grounded wires increases to about 1.35 times normal; and the capacity current in the grounded wire up to the location of the ground increases to twice normal.

E.C.S.

ERRATUM:

Through error a wrong illustration was used for Fig. 2 of "Modern Switchboard Practice" by John W. Upp, GENERAL ELECTRIC REVIEW, June, 1916, p. 434. The correct illustration appears on this notice and recommendation is made that it be clipped and pasted over the one that appeared in the June REVIEW.

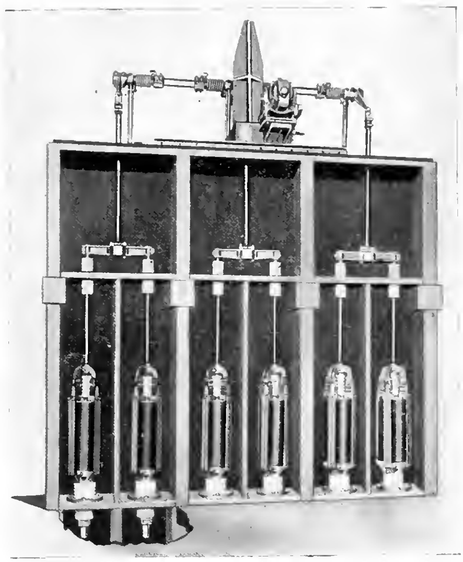


Fig. 2. Oil Break Circuit Breaker with Tanks Arranged in Tandem and Separated by Barriers

General Electric Review

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Manager, M. P. RICE — Editor, JOHN R HEWETT — Associate Editor, B. M. EOFF — Assistant Editor, E. C. SANDERS

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August, 1916

CONTENTS

Pacific Electric Railway three-car all-steel limited train at Covina on the main line of the San Bernardino Division. Each car is equipped with Form GE-254, 145-h.p., 600/1200-volt ventilated motors and Type M automatic control. These trains in express service operate at maximum speeds of 60 miles per hour on tapped field connections

(See page 706)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

The special course of lectures on Illuminating Engineering which is to be given under the auspices of the University of Pennsylvania and the Illuminating Engineering Society at Philadelphia is well worthy of special note. We publish an article by Professor C. E. Clewell in this issue giving detailed information concerning these lectures. This course of lectures should awaken considerable interest in the engineering world beyond the scope of the lectures themselves, as their inauguration raises the general question of advanced education on technical subjects for those engaged in professional activities.

The general subject of technical education is of the utmost importance, and at the same time presents many difficulties. It is far easier to criticize present methods and curricula than it is to make practical and useful suggestions for their betterment. The rapid advance made in the scientific profession in recent years has imposed a most difficult task on those striving to make modern education meet the demands of present day requirements.

Such lecture courses as that under consideration should form a valuable addition to other educational work, and they present the great advantage of being designed to dissiminate the latest technical knowledge amongst those actually engaged in technical and commercial work. The value of lectures of this nature, of course, largely depends upon the knowledge of the lecturer and his power to impart knowledge to his audience. In this respect those responsible for the course of lectures on Illuminating Engineering seem to have been particularly fortunate.

We hope this same general scheme will be followed in many other directions. Our various conventions cover a most useful field, but their functions are different from a lecture course. The papers read before conventions are of great value in bringing up-to-date knowledge before the technical public, but their educational value must always have certain limitations and the subjects can very seldom be planned to embrace anything like a satisfactory scope.

Specialization, with all its commercial advantages is largely responsible for making it so difficult for those actively engaged in professional work to keep up with the broad study of any particular subject. But if lecture courses could be designed to give the busy man the chance of periodically reviewing the broad advances made in his profession, it would be a distinct advance in the right direction. We feel that there are many institutions and sociteies that could greatly add to their usefulness by following the example of the Illuminating Engineering Society.

We understand that the Illuminating Engineering lectures are to be printed and distributed in bound volumes when the course is completed. These books in themselves should be invaluable as containing the most up-to-date knowledge on the subject. Should this general scheme find favor in other directions, as we hope it may, and lead to other technical lecture courses being inaugurated under the auspices of various societies, it might lead to the bringing into existence of some of the finest text books possible.

THEORIES OF MAGNETISM

Part II

By Saul Dushman

Research Laboratory, General Electric Company

This article is a continuation of that which appeared in the May number of the Review and contains a discussion of the facts regarding the relation between temperature and magnetic properties, including the well known Curie's law. The theoretical bearing of these observations will be dealt with in a subsequent issue.—Editor.

Theories of Ferromagnetism

In Part I of this paper we gave a "Classification of Magnetic Phenomena" and then proceeded with a discussion of the relation between magnetic intensity and magnetizing force. Summarizing the observations described in that section we can state the following:

1. The magnetic intensity of ferromagnetic substances is a complex function of the magnetizing force, and depends also in a number of cases on the previous history of the material.

2. The magnetic intensity of para- and diamagnetic substances is directly proportional to the field strength.

To the scientific mind the mere observation of a number of facts is a very unsatisfactory method, to say the least, of contemplating a field to which these facts relate. Inevitably the imagination attempts to reach beyond the observations and formulates some physical image which shall, by analogy with more familiar observations, "explain" the phenomena observed.

Now we observe that if a magnetized steel bar is cut up into small portions, each of these portions still retains its magnetic properties, no matter how small they may be. This leads us to conclude that magnetism is a specific property of the ultimately smallest particles which we can identify as steel. In other words we conclude that some or all of the molecules of a magnetized bar of iron or steel are themselves infintessimally small magnets possessing north and south poles and capable of orientation about their centers. But now arises the question, "What is the mechanism by which these molecules become magnetized? Or, assuming the molecules to be permanently magnetized, how can we explain the complex relations observed between magnetic intensity and magnetizing force in the case of ferromagnetic substances?"

The attempts to answer these questions have led to a number of different suggestions each of which is historically very interesting. Poisson imagined that the process of magnetization consists in making each molecule a magnet, that is "the question how induction happens is only shifted from the bar to the molecules themselves and is brought no nearer to a solution."

The relation between magnetism and electricity suggested to Ampére a theory of magnetic molecules which in a more or less modified form has been retained up to the present. He assumed that the magnetic polarity of the molecules of iron is due to the presence of electric currents revolving about the centers of the molecules in absolutely resistanceless paths. This suggestion, which must have been rather difficult to understand before the advent of the present electron theory of metallic conduction, is now interpreted in terms of this theory and we conceive the magnetism of the elementary magnets as due to electrons revolving in central orbits about the magnetic axes of the magnets. We shall show in a subsequent section that the electron theory is thus able to give us a physical image not only of the elementary magnets of ferromagnetic substances, but also a very plausible explanation of the manner in which it is possible for some substances to exhibit diamagnetic susceptibility.

Weber's theory of ferromagnetism may be considered as the first serious attempt to formulate an explanation of the phenomena of magnetic induction. Weber assumed that the molecules are permanently magnetized, but in the unmagnetized state the axes of these elementary magnets point in all directions at random. However, under the influence of a magnetic field these magnets tend to set themselves more and more with their axes along the direction of the field, just as a compass-needle tends to set itself along the lines of force of the earth's magnetic field.

"Weber supposes that each molecule, in its normal state, is in equilibrium under the influence of the forces from all the neighboring molecules, and that when it is moved out of this position by the action of an external magnetic field, the forces from the other molecules tend to restore it to its old position. It is, therefore, clear that so long as the external field is small, the angle through which each axis is turned by the action of the field, will be exactly proportional to the intensity of the field, so that the magnetization induced in the body will be just proportional to the strength of the inducing field. In other words, for small values of H, the susceptibility must be independent of H.

There is, however, a natural limit imposed by the intensity of the induced magnetization. Under the influence of a very intense field all the molecules will set themselves so that their axes are along the lines of force. The magnetization induced in the body is now of a quite definite intensity, and no increase of the inducing field can increase the intensity of the induced magnetization beyond this limit."(1)

Thus Weber's theory accounts quite satisfactorily for the phenomenon of saturation intensity. It does not, however, account for the phenomena of hysteresis and retentiveness, nor does it accurately represent the facts observed regarding magnetization in weak fields. According to Weber the I-H and B-H curves of a ferromagnetic substance would assume some such form as that shown in Fig. 2. Maxwell, therefore, modified Weber's theory by assuming, in analogy with mechanical strain, that in the initial stages of magnetization, the molecules are perfectly free to

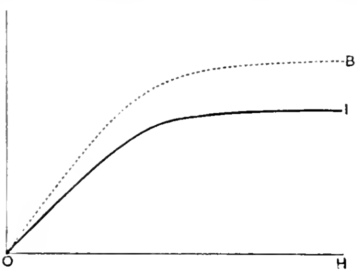


Fig. 2

return to their original positions on the removal of the magnetizing force, just as a stretched wire will contract again to its original length on the removal of the tension. If, however, the deflection of the molecular axes exceeds a certain value, then "the elastic limit," as it were, has been passed and the molecules return only partially or very slowly to their original position after removal of the magnetizing force.

Maxwell's modification of Weber's theory, has however, solved the difficulties inherent in the latter only slightly. The most satisfactory explanation of magnetic induction phenomena in the case of ferromagnetic substances at the present time is apparently that suggested by Ewing. We cannot do better than quote his own remarks on this subject: (2)

"The matter becomes immensely simplified if we put aside all these arbitrary postulates regarding controlling force and resistance to turning, and inquire what is the character of the constraint the molecules necessarily suffer through the forces which they exert on one another in consequence of the fact that they are magnets. It appears that this constraint is sufficient to account for the observed characteristics of the process of magnetization, that it completely explains hysteresis, and that it at least offers a clue to those complicated variations of magnetic quality which are known to be caused by the variation of such physical conditions as temperature or stress.

"In proceeding to consider the equilibrium of the molecules under their mutual magnetic forces, it is clear that we cannot confine our attention to any one molecule. For the directive force that acts on any one molecule depends on the positions of the molecules which surround it, and becomes altered when these are disturbed. We cannot investigate the equilibrium of the individual without including in the question the equilibrium of its neighbors. When an external force is applied, they, as well as it, are deflected, and the constraint they exercise on it suffers change. What must be studied is the configuration of the group as a whole, and the manner in which the group becomes distorted, broken up, and rearranged in the process of applying and removing an external magnetizing force."

Ewing distinguishes three stages in the magnetization curve of any ferromagnetic substance. "In the first stage (A, Fig. 3) the susceptibility is small and there is almost no retentiveness. In the second stage the magnetism is acquired with great readiness, and much of it may be retained if the force be removed (B, Fig. 3). In the third stage

(1) J. H. Jeans, Electricity and Magnetism, p. 407.
(2) Ewing, Magnetic Induction, etc., p. 287 ff.

(*C*, Fig. 3) the growth of the magnetism is again slow, and what is acquired in it does not contribute much to the residual magnetism."

These three stages are just such as this theory lead us to expect. In order to test his

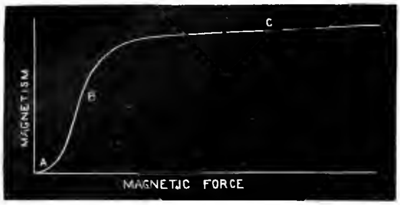


Fig. 3

theory, Ewing carried out a large number of experiments with gradually increasing numbers of small magnets. With a group of four magnets, the results obtained are illustrated in Fig. 4. As the number of magnets used in the experiments was increased he was able to approximate more closely to the typical curve shown in Fig. 3 and was even able to reproduce the ordinary hysteresis loop. (3)

A very full discussion of all these theories will be found in Ewing's work, to which the reader is therefore referred for more details. The main reason for introducing the above remarks in this connection is that this so called molecular theory of magnetism has been found to be exceedingly useful in interpreting a large number of observations regarding not only the relations between magnetic intensity and magnetizing force, but also the effects of temperature on para- and ferromagnetic substances, and a number of relations between magnetic properties and mechanical forces. We, therefore, shall find this point of view of great help when discussing the above relations. Ewing's greatest contribution to the theory of magnetic phenomena has undoubtedly been this suggestion of the existence of molecular magnets which exert forces upon each other, thus constituting, as it were, an intermolecular field whose intensity depends upon the strength of the magnetizing force. The same idea has been further elaborated by Weiss and Gans in their theories of ferromagnetism. The discussion of these theories must, however, be postponed for a subsequent section.

Effect of Temperature on Magnetic Properties

Generally speaking the magnetic properties of substances are dependent in such an extremely complex manner upon so many factors that any attempt to discuss the specific influence of any one factor, such as temperature, irrespective of the effect of other factors, must prove to a certain extent unsatisfactory. On the other hand there are certain facts with regard to the effect of temperature on the magnetic properties which while modified by the influence of other factors, notably chemical composition, are yet of such a very general nature that they may be properly discussed under the above heading.

(*a*) *Ferromagnetic Substances*

The number of investigations dealing with the effect of temperature on the magnetic properties of iron, nickel and cobalt and their alloys is naturally very large. The most classic papers in this field are undoubtedly those of Hopkinson which were published between 1887 and 1890. (4)

The range of temperatures employed varied from room temperature to over 800 deg. C. More recently these experiments have been extended to extremely low temperatures such as that of liquid air and even lower.

Within a range of about 100 deg. C., the magnetic susceptibility of ferromagnetic substances is but slightly affected by changes in temperature. At higher temperatures, however, there is a gradual decrease in the value

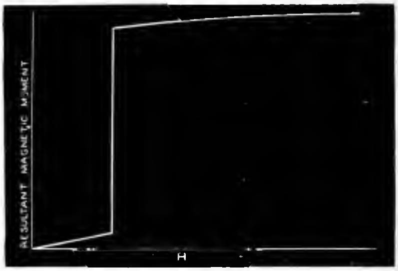


Fig 4

of the intensity of magnetization (I) for given field strength. This decrease becomes more and more rapid with increase in temperature, until within a certain range of temperature

(3) Loc. Cit. p. 338.
(4) Ewing, loc. cit. pp. 160–184.

there occurs an abrupt diminution in magnetic properties, and above a certain point known as the *critical temperature* (or *Curie point*) the substance becomes practically paramagnetic. The curves shown in Fig. 5 illustrates this phenomenon in the case of soft iron.(5) The ordinates give intensity of magnetization. It will be observed that the curves drop very abruptly about 750 deg. C. which is the critical temperature for iron, and that above 800 deg. C., the value of I is over a thousand times smaller than at lower temperatures, as shown by the right-hand portion of the curve for $H = 1000$.

The effect on the permeability (μ) or susceptibility (κ) varies with the field strength. Under a weak magnetizing force the permeability increases gradially with the temperature, rises rapidly to a maximum value around the critical temperature and then decreases rapidly to an extremely small value. Under stronger magnetizing forces, the permeability remains practically constant (or tends to decrease gradually when very strong fields are used) with an increase in temperature, but decreases more or less rapidly near the critical temperature.(6) Considering the effect on the H-B curve (see Fig. 3), increased temperature lowers the horizontal part (C, Fig. 3) and shifts the initial portion (A) more to the left, that is, with increase in temperature the intensity of magnetization tends to reach the limiting value at much lower field-strengths, but this limiting value (I_m) is lower at higher temperatures.(7)

Experiments on the effect of cooling different steels to the temperature of liquid air have yielded results which on the whole are in agreement with those obtained at higher temperatures.(8) A magnetization curve corresponding to 190 deg. C. lies initially below and finally above that corresponding to room temperature.

The fact that magnetized iron or steel lowers its magnetism when heated above a certain temperature has been known ever since the time of Gilbert. Further investigation has shown the existence of other important changes in the properties of ferromagnetic substance metallographic at the same critical temperature. Thus a study of iron at different temperatures shows that there is a change in crystalline structure from the so-called alpha iron to the beta form at 756 deg. C. In the beta region which extends from 756 deg. to 920 deg., the specific susceptibility (κ) follows an hyperbolic law up to 820 deg. and then decreases more rapidly until the beta-gamma transition temperature is reached. (See point A, Fig. 5). At 1280 deg. C. (B, Fig. 5) the gamma iron changes into delta form, and this again melts around 1365 deg. C. In each of the gamma and delta region, χ, *the specific susceptibility* varies inversely as the absolute temperature—which relation, as we shall see below, is true of a large number of paramagnetic substances.(9)

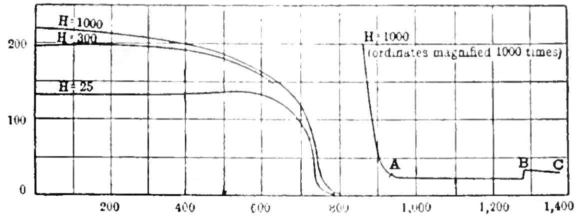


Fig. 5

Table VI gives the critical temperature or Curie point for a number of ferromagnetic substances with the authorities on each case. It has been found that slight traces of impurities exert a profound influence upon the temperature of the Curie point; however, this phase of the subject will be discussed in a subsequent section.

An interesting phenomenon which can be mentioned in this connection is that of *thermomagnetic hysteresis*. The metal which has been demagnetized by heating does not usually regain its magnetism when cooled just below the critical temperature. There is a lag between the temperature at which the magnetism disappears on heating and that at which it reappears on cooling. This lag may extend over several hundred degrees.(10)

Especially is this noticeable in the case of certain nickel steels. Thus Hopkinson

(5) This figure is taken from G. F. Stradling, "Modern Theories of Magnetism," J. Franklin Inst., *180*, 173, 1915. The experiments on which the curves are based were carried out by P. Curie. See also du Bois, Rapports du Congrès, etc., p. 468.

(6) Ewing, Magnetic Induction in Iron and other Metals, pp. 166–7.

(7) Ewing, p. 165, etc.

(8) J. G. Gray and A. D. Ross, Trans. Far. Soc. 8, 117 (1912).

(9) Stradling, loc. cit., p. 180.

(10) Ewing, loc. cit., p. 180–181.

found that an iron-nickel alloy containing about 25 per cent nickel is practically non-magnetizable ($\mu = 1.4$ for all values of H) at ordinary temperatures; but below 0 deg. C. it becomes as strongly magnetic as cast-iron ($\mu = 62$ for $H = 40$) and then retains its magnetism until it is heated to about 580 deg. C. On further heating the alloy becomes paramagnetic and remains so till it is cooled below the freezing point of water.

A very comprehensive study of this phenomenon in the case of nickel and manganese steels has recently been carried out by Hipert, Colver Glauert and Mathesius.(16) Fig. 6 which is taken from their papers shows the characteristic thermomagnetic hysteresis loop for a 25.4 per cent nickel alloy. The arrows indicate the direction in which the heating and cooling were carried out. The field strength used was 300 gauss.

A closely related phenomenon in the case of ferromagnetic metals is the effect of heat treatment in actually changing the magnetic properties. An immense amount of literature has been published upon this subject alone. Thus it is possible from metals of identically the same chemical composition to produce either a ferromagnetic or paramagnetic material by varying the temperature at which the metal is quenched. In the case of Heusler's alloys this feature becomes very marked. There is no doubt that all such phenomena as the effect of heat treatment

TABLE VI

CRITICAL TEMPERATURES OF FERROMAGNETIC SUBSTANCES

Iron, α form	756 deg. C.	P. Curie
Iron, β form	920 deg. C.	P. Curie
Iron, γ form	1280 deg. C.	P. Curie
Magnetite		
(Fe_3O_4)	536 deg. C.	P. Curie
	589 deg. C.	P. Weiss(11)
	555 deg. C.	du Bois(12)
Cobalt-ferrite		
($Fe_2 Co$)	520 deg. C.	du Bois
MnBi	360–380 deg. C.	S. Hilpert(13)
MnSb	310–320 deg. C.	S. Hilpert
MnAs	45–50 deg. C.	S. Hilpert
MnP	18–25 deg. C.	S. Hilpert
Heusler Alloy	310 deg. C.	P. W. Gumaer(14)
Nickel	340 deg. C.	P. Curie
	376 deg. C.	W. W. Stifler(15)
Cobalt	1075 deg. C.	W. W. Stifler(15)

(11) Quoted by E. H. Williams, The Electron Theory of Magnetism, p. 57.
(12) Trans. Far. Soc. *8*, 211 (1912).
(13) Trans. Far. Soc. *8*, 207 (1912).
(14) Quoted by J. Kunz, Congress App. Chem. 1912, *22*, 199.
(15) Phys. Rev. *33*, 268 (1911).
See also Wedekind, Magnetochemie, p. 23.
(16) Trans. Far. Soc. *8*, 134 (1912).
Z. f. Elektrochemie, *17*, 250 (1911); *18*, 55 (1912).
Wedekind, loc. cit. ,p. 25.
(17) Journ. d. Phys. (3) *4*, 197, (1885).

and mode of aging are really the result of altering the molecular structure of the metal, and their discussion therefore belongs properly to the section dealing with the relation between chemical composition or molecular structure and magnetic properties.

(*b*) *Paramagnetic and Diamagnetic Substances*

Figs. 7 and 8 illustrate the relation between specific susceptibility and temperature in the case of some typically diamagnetic and paramagnetic substances respectively.

In general, we find that the ***diamagnetic susceptibility does not change with temperature***, except where some change of state is involved. On the other hand, the ***paramagnetic susceptibility decreases with increase in temperature*** and from an examination of a large

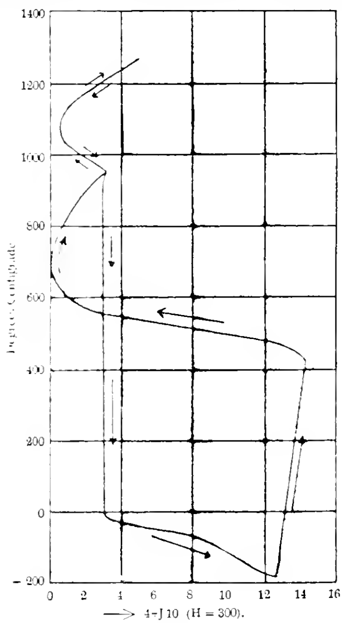


Fig. 6

number of cases, Curie deduced the relation(17) that the specific susceptibility of para-magnetic substances varies inversely as the absolute temperature, that is,

$$\chi = \frac{C}{T} \qquad (14)$$

where C is a constant, which has been designated as Curie's constant.

As illustrations of Curie's law we give in Table VII some of the results obtained in the Cryogenic Laboratory at Leyden on the specific susceptibility of different paramagnetic substances at low temperatures.

Table VIII gives the values of Curie's constant, C, for a number of substances, together with the interval of temperatures over which the law has been found to be valid.

Curie's Law has been confirmed for a large number of solutions of paramagnetic substances (over a considerable range of temperatures) by the investigations of Wiedemann, Plessner, Townsend and Oxley and du Bois.[18]

Weiss and Foex[19] have found that for a number of ferromagnetic substances, above the Curie point, the following form of equation agrees well with the experimental data:

$$C = \chi\ (t-\theta) \qquad (15)$$

where θ is a constant for each substance and t denotes the temperature in degrees C.

Some of the results upon which they base this equation are given in Table IX. It will be observed that in the case of magnetite they have had to assume different values of θ for successive intervals of temperature. Since it is possible in this manner to break up any curve into a number of straight lines, the confirmation of the above equation in this case alone would not signify much. However, in the case of cobalt, nickel, and iron, the

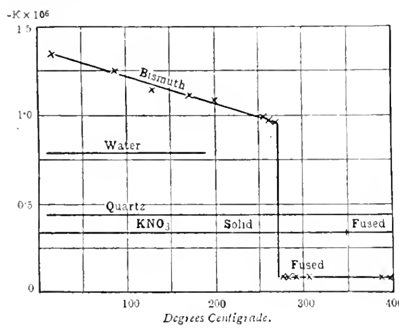


Fig. 7

equation seems to have a real foundation and the values of θ obtained agree quite well with those actually observed for the critical temperatures.

Curie's law is, however, not generally true for para-magnetic substances, nor does it hold accurately at extremely low temperatures. An excellent summary of the investigations on the deviations from Curie's law at low temperatures has been published by E. Oosterhuis.[20]

From equation (14) it is evident that as the absolute zero is approached the susceptibility

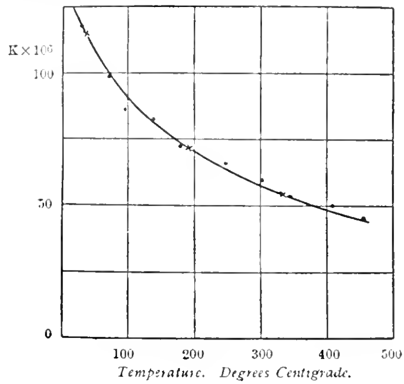


Fig. 8

ought to increase very rapidly, until it becomes infinitely great at the absolute zero itself. According to Oosterhuis, the majority of the substances investigated in the Cryogenic Laboratory at Leyden may be reduced to the following three types:

(a) In this class (e.g. crystallized $FeSO_4$; crystallized $MnSO_4$, etc.) Curie's law is valid down to the temperature of liquid nitrogen, but for temperatures below this the relation $C = \chi\sqrt{T}$ seems to hold better. K. Onnes and Perrier[21] found that in the case of liquid oxygen and dysprosium oxide this relation held for a large range of temperatures; but at the temperature of liquid hydrogen χ seemed to become *constant*.

(b) In the second class of substances (e.g. anhydrous $MnSO_4$), χT diminishes from room temperature down and the relation

$$C = \chi\ (T+\triangle) \qquad (16)$$

appears to hold down to the temperature of liquid nitrogen. In this equation $\triangle$ is a constant for any one substance. At lower temperatures further deviations appear.

(18) See the summary by R. H. Weber, Jahrbuch d. Radiaktivitat und Elektronik, 12, 74 (1915); also du Bois, lo[illegible] p. 496 for a list of values of C for different salts.

(19) Tables Ann. 2, 390 (1913).

(20) Proc. of Amsterdam Academy of Sciences *16*, 432 (1913).

(21) Comm. from Leyden, No. 116, April, 1910.

(c) In the case of platinum and palladium, χ changes only slightly with temperature; and from the temperature of boiling nitrogen to that of liquid hydrogen, it is practically constant.

In a subsequent section will be discussed the theory which has been suggested in explanation of these deviations, but in this connection the most important fact that it is desired to emphasize is this general tendency for the susceptibility of paramagnetic substances to become constant (instead of increasing indefinitely) as the absolute zero is approached.

Honda and Owen[22], in a series of elaborate investigations on the magnetic properties of the different chemical elements, came to the conclusion that Curie's law is not at all true for the majority of paramagnetic elements and, furthermore, that in the case of a large number of diamagnetic elements

(22) Ann. d. Physik, *32* 1027 (1910) and *37*, 657 (1912)

TABLE VII

SPECIFIC SUSCEPTIBILITY OF PARAMAGNETIC SUBSTANCE AT LOW TEMPERATURE

T	$\chi \times 10^6$	$\chi T \times 10^6 = C \times 10^6$
Pulverized Manganese Chloride, $MnCl_2$ *		
290.8	106.5	30970
169.6	183.4	31100
77.4	403	31190
70.5	440	31020
64.9	480	31150
20.1	1419	28520
17.8	1589	28280
14.4	1881	27090
Crystallized Ferrous Sulphate, $Fe\,SO_4 . 7\,H_2O$ **		
289.6	41.5	12010
77.45	154.5	11970
20.33	555.4	11270
17.01	641.6	10920
13.93	757.2	10540
Iron Ammonium Alum, $Fe_2(SO_4)_3\,(NH_4)_2\,SO_4 . 24\,H_2O$ **		
290.	30.4	8820
170	51.8	8790
64.6	137.0	8850
17.9	492.0	8810
14.7	598	8790

* K. Onnes and Oosterhuis, Tables Annuelles, *3*, 288 (1914).
** K. Onnes and Perrier, Tables Annuelles, *2*, 389 (1913).

TABLE IX

MODIFIED FORM OF CURIE'S EQUATION APPLIED TO FERROMAGNETIC SUBSTANCES ABOVE THE CURIE POINT

Substance	Interval of Temperatures (Deg. Centigrade)	$C = \chi(t-\theta)$	θ
Artificial magnetite	581– 622	0.00445	581
	622– 680	0.00682	558
	710– 770	0.0105	433
	770– 900	0.0180	194
	900–1360	0.028†	0
Nickel	380– 412	0.0066	364
	412– 870	0.00555	372
Cobalt	1170–1241	0.0217	1131
	1241–1303	0.0182	1149
Electrolytic iron	774– 828	0.0395	744
	829– 920	0.0273	790
	920–1395	0.072	1067
	1395–1421	0.0046	1230

† According to Curie's results on natural magnetite.

TABLE VIII

CURIE'S CONSTANT FOR VARIOUS MATERIALS

Material	$C \times 10^6$	Interval of Temperatures	Authority
Oxygen	33700	20 deg.— 450 deg. C.	P. Curie (23)
Air	7830		P. Curie (23)
Palladium	1520	20 deg.—1370 deg. C.	P. Curie (23)
Magnetite	28000	850 deg.—1360 deg. C.	P. Curie (23)
Cast Iron	38500	850 deg.—1267 deg. C.	P. Curie (23)
Gadolinium Sulphate	21000	—259 deg.— 17 deg. C.	Perrier & Onnes(24)
Ferrous Sulphate	11000	—259 deg.— 17 deg. C.	Perrier & Onnes(24)
Ferric Sulphate	17000	—208 deg.— 17 deg. C.	Oosterhuis & Onnes(25)
Manganese Chloride	30000	—258 deg.— 17 deg. C.	Oosterhuis & Onnes(25)

(23) London Electrician, *66*, 500 (1912); also du Bois, Rapports du Congres, *2*, 460 (1900).
(24) Loc. cit.
(25) Loc. cit.

the law already enunciated (that the susceptibility does not vary with the temperature) is absolutely contradicted by the facts.

Tables X and XI taken from Owen's paper summarize the results observed with regard to the temperature variation in susceptibility of both paramagnetic and diamagnetic elements. In view of these results, Kunz has gone so far as to conclude that "It seems to me not justified to maintain Curie's rule, as there are many more exceptions than confirmations. The same is true for diamagnetism...... There are only very few elements which do not vary within the whole temperature range."(26)

(26) Eighth International Congress of App. Chemistry, *22*, 187 (1912).

TABLE X

EFFECT OF TEMPERATURE ON SUSCEPTIBILITY OF DIAMAGNETIC ELEMENTS

No Effect	Increase with rise in temperature	Decrease with rise in temperature
B Cryst. (400° to 1200°)	*Be*	*C* Amorphous
C Diamond (−170° to 200°)	*B* Cryst. (+170° to 400°)	*C* Ceylon-graphite
C "Sugar" carbon	*C* Diamond (200° to 1200°)	*Cu*
Si Cryst.	*Ag*	*Zn* (+300° to 700°)
P White	*I* (−170° to +114°	*Ga* (−179° to 30°)
S Cryst. and pptted.	*Hg* (−170° to −39°)	*Ge* (−170° to 900°)
Zn (−170° to 300°)		*Zr* (500° to 1200°)
As		*Cd* (300° to 700°)
Se		*In* (−170° to 150°)
Br (−170° to 18°)		*Sb* (+50° to +631°)
Zr Cryst. (−170° to 500°)		*Te*
Cd (−170° to 300°)		*I* (+114° to +200°)
Sb (−170° to 50°)		*Tl*
Cs		*Pb* (−170° to 327°)
Au		*Bi* (−170° to 268°)
Hg (−39° to +350°)		
Pb (327° to 600°)		

TABLE XI

EFFECT OF TEMPERATURE ON SUSCEPTIBILITY OF PARAMAGNETIC ELEMENTS

No Effect	Increase with rise in temperature	Decrease with rise in temperature
Li	*Ti* (−40° to 1100°)	[*O*]
Na (−170° to 97°)	*V* (500° to 1100°)	*Al* (−170° to 657°)
Al (657° to 1100°)	*Cr* (500° to 1100°)	*Mg*
K (−170° to 150°)	*Mo* (−170° to 1200°)	*Ti* (−180° to −40°)
Ca (−170° to 18°)	*Ru* (+550° to 1200°)	*Mn* (250° to 1015°)
V (−170° to 500°)	*Rh*	[*Fe*]
Cr (−170° to 500°)	*Ba* (−170° to 18°	*Co* (above 1150°)
Mn (−170° to 250°)	*Ir*	*Ni* (350° to 800°)
Rb	*Th*	*Cb* (−170° to 400°)
W		*Pd*
Os		Rare earth metals
		Ta
		Pt
		U

ELECTRIC LOCOMOTIVES FOR INTERURBAN SERVICE

By S. T. Dodd

Railway and Traction Engineering Department, General Electric Company

The tonnage capacity of an electric locomotive depends, not only on its own characteristics, but on the service in which it is engaged. The same locomotive may be worked to its full capacity by different weights of trains depending on whether the service is switching, or through freight, or a combination of these two; and this fact becomes a source of uncertainty when comparing different locomotives with each other. In the following article, the author selects three typical classes of service and shows that any locomotive service may be looked on as a combination of these three types in varying proportions. He analyzes the conditions which limit the capacity of a locomotive in each of these three services and develops the corresponding formula which expresses the limiting weight of the train in each case. These formulæ define the tonnage capacity of a locomotive as accurately as is possible. The latter part of the article describes a number of small locomotives recently built and defines their tonnage capacity in terms of the formulæ developed in the first part.—Editor.

The electric locomotive in trunk-line service has been the subject of numerous recent articles and discussions; but the spectacular results claimed for and obtained by such locomotives should not be allowed to distract attention from the development of the small electric locomotive or from the extension of its use on interurban roads. As a matter of fact, existing electric roads are turning to an investigation of the possibilities of freight traffic in proportion as they learn the limitation of their opportunities in the direction of passenger traffic. That this freight traffic is developing and is showing increasingly favorable results is indicated by the fact that there is annually being added to the rolling stock equipment of interurban roads in the United States an average of 30 to 50 small electric locomotives having an aggregate tonnage of 1000 to 2000 tons.

One feature that retards the development of the small locomotive for interurban service is the variation in the conditions of service and equipment encountered on various roads. The variation in train weights to be handled, the difference in grades, and the varying character of service in different localities, demand differences in the weight of the locomotives, in the motor equipments, and in the gear ratios or the motor capacities. These differences, combined with the variation in the line voltage and the mechanical standards of various roads, make an almost endless variation in the possible designs of small locomotives. It is hoped that, with the growth of standardization of railway equipments, some of these variations may be eliminated; and if a definite effort is made toward standardization by both manufacturers and users, it might be possible to standardize the small locomotive into a relatively few types. The result of such standardization in any industry has always been the promotion of the growth of that industry by a reduction in the cost of the product and consequently an increase in the use of and demand for its output. Such standardization in the equipment of small locomotives would have the effect of greatly increasing the scope and economy of locomotive service on interurban roads with a corresponding effect upon their freight traffic.

When comparing different locomotives under different conditions, one of the first difficulties that presents itself is the stating of a common definition of locomotive capacity. The difficulty is due to the fact that the capacity of a locomotive depends on the service in which it is engaged. This service varies with every installation, and with the same locomotive it varies from day to day. The service sometimes consists of purely switching work, and sometimes of hauling cars in through traffic. Sometimes the work is on a level and again on grades of various amounts. The limitation of locomotive capacity may depend on the slipping of the wheels, the commutation of the motors, or the overheating of the equipment. It will never be possible to standardize locomotive service thoroughly, on account of these variations in service conditions. However, any service may be analyzed as a combination of three typical or standard conditions; and, by clearly defining these typical services and expressing the capacity of the locomotive in each of them, an expression may be obtained for the capacity of the locomotive in any service which is a combination of these three in varying proportions. These conditions which will be called the typical locomotive services are described in the following.

Service *A*: Switching

A pure switching service consists of a series of short runs with varying weights of trains and is mainly a problem in acceleration. The average distance moved over between accelerations is short and the schedule speed is low. A number of tests made in steady switching service, both in trunk-line yards and in interurban yards, indicate that the average movement is from 200 to 400 ft. and that the schedule speed (distance divided by time for an extended period) is from $2\frac{1}{2}$ to 3 m.p.h. The current used consists of relatively high peaks for short periods, corresponding to the acceleration periods. During the remainder of the time, the locomotive is drifting or standing still.

The equipment for a locomotive for such service should have characteristics such as to enable it to exert tractive efforts up to the slipping point of the wheels. The speed is immaterial as it rarely reaches full value; and the motors should be geared for the lowest possible speed to secure an economical consumption of current and a low first cost of equipment. The maximum weight of the train that can be handled is that which can be started at the slipping point of the wheels. Assuming 25 lb. per ton to cover acceleration and friction, and assuming an available tractive effort of 25 per cent of the weight on the drivers, the following expression gives the tonnage capacity of the locomotive or, in other words, the limiting weight of the train it can handle.

$$\text{Max wt. of train in tons} = \frac{\text{Wt. of loco. in lb.}}{4\times 25}$$

Service *B*: Continuous Freight Haulage over a Rolling Profile

An absolutely continuous freight haulage over a rolling profile is never encountered in practice. It is always mixed with a certain amount of switching and accelerating service; nevertheless, it can be discussed as a typical service which determines certain limitations of locomotive capacity. A rolling profile can be defined as a profile wherein the grades are so short that the increased current in ascending them is not sufficient to seriously raise the temperature of the equipment, and wherein the speed lost in ascending one short grade is compensated for by that gained in descending the other side. Such grades will not exceed a length of 1000 to 2000 ft. The weight of the train that can be handled over such a profile may be limited by one of several factors.

(**a**) *Heating*. Assuming that the service is continuous, not modified by stops and starts, the weight of the train cannot exceed that which will require a tractive effort corresponding to the continuous capacity of the motors. For a train friction of 10 lb. per ton, the following formula gives the limiting weight of the train.

Max. wt. of train in tons:

$$= \frac{\text{Tractive effort at continuous capacity}}{10}$$

The increased current due to accelerations will modify this value in practice and generally reduce the limiting weight just given.

(**b**) *Acceleration*. The weight of the train cannot exceed that which can be started on the level by the maximum tractive effort of the locomotive. This is the same limitation as previously stated under Service *A*. The expression for the limiting weight of the train is, therefore,

$$\text{Max. wt. of train in tons} = \frac{\text{Wt. of loco. in lb.}}{4\times 25}$$

(**c**) *Grades*. The weight of train cannot exceed that which can be hauled up the maximum grade without exceeding the slipping point of the wheels. The question of acceleration on these grades can be omitted, as the grades are assumed to be relatively short and all the acceleration to take place of the level. Based on this requirement, the following formula determines the limiting weight of the train.

Max. wt. of train in tons:

$$= \frac{\text{Locomotive wt. in lb.}}{4\times(\text{grade resis. plus } 10)}$$

Of these three limitations, (**a**), (**b**), and (**c**), whichever gives the smallest value for the limiting weight of train is the determining factor in defining the tonnage capacity of the locomotive for Service *B*.

Service *C*: Continuous Freight Haulage Against a Grade

Continuous freight haulage against a grade is never met in practice; but when grades are several miles in length the temperature of the equipment soon reaches a point which corresponds approximately to that which would be reached in continuous service, particularly if the equipment is started up the grade with motors which are already heated by previous service. The weight of the train that can be handled in such a service may depend on either of two factors.

(***a***) *Heating*. The weight of the train cannot exceed that which would require a tractive effort on the grade corresponding to the continuous capacity of the motors. This gives the following expression for the limiting weight of the train.

Max. wt. of train in tons:

$$= \frac{\text{Continuous tractive effort}}{\text{Grade resis. plus } 10}$$

Fig. 1. A Standard 40-ton 600-volt Locomotive

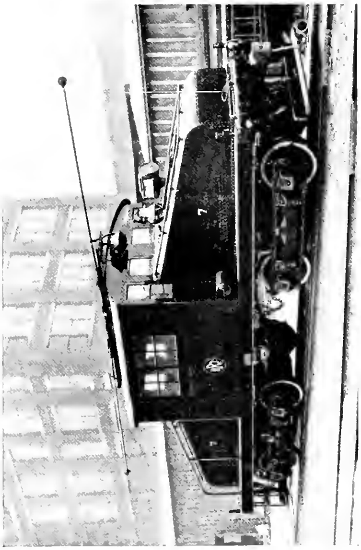


Fig. 2. One of the 55-ton 600-volt Locomotives Used by the Transit Development Company

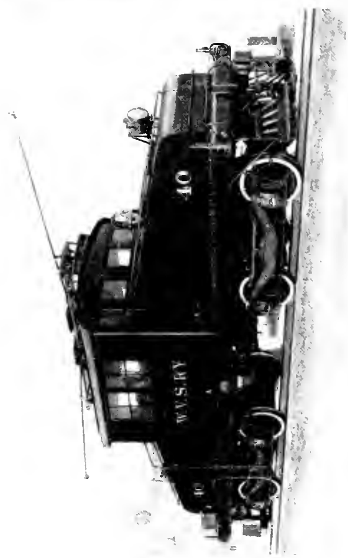


Fig. 3. A 50-ton 1200-volt Locomotive Used by the Willamette Valley Southern Railway

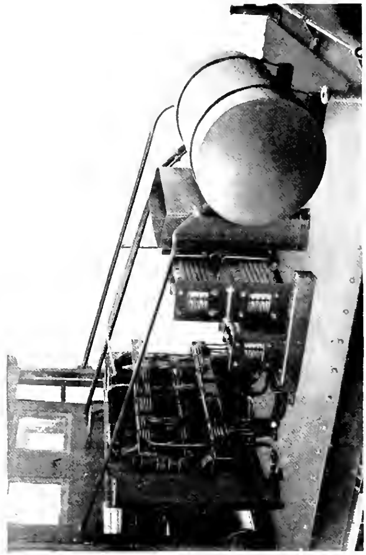


Fig. 4. Locomotive Shown in Fig. 1, End Cab Removed Showing Apparatus in Place

(*b*) *Acceleration.* The weight of the train cannot exceed that which can be accelerated on the grade. Assuming, as before, 25 lb. per ton to cover friction and acceleration, and a limiting tractive effort of 25 per cent of the weight on the drivers, the following expression gives the limiting weight of the train.

Max. wt. of train in tons:

$$= \frac{\text{Wt. of loco. in lb.}}{4\ (\text{grade resis. plus } 25)}$$

Of the two limitations, (*a*) and (*b*), whichever gives the smallest value for the limiting weight of the train is the determining factor in defining the tonnage capacity of the locomotive for Service *C*.

Summary

In order to render the preceding statements more convenient of application, they have been grouped in the following as formulæ. The following symbols are used:

T = Weight of trailing train in tons.
L = Weight of locomotive in tons.
W = Weight of locomotive in pounds.
G = Gradient expressed in per cent.
C = Tractive effort of locomotive at continuous capacity of motors.

Train friction is assumed at 10 lb. per ton.

Acceleration is assumed at 15 lb. in addition to friction.

The preceding expressions for the tonnage capacity of a locomotive reduce to—

Service *A*. (Switching)

$$T = \frac{W}{100} - L = 19\ L$$

Service *B*. (Haulage over a rolling profile)

(*a*) $T = \frac{C}{10} - L$

(*b*) $T = \frac{W}{100} - L = 19\ L$

(*c*) $T = \frac{W}{4\ (20\ G + 10)} - L = \frac{L\ (49 - 2G)}{2\ G + 1}$

Service *C*. (Haulage over a continuous grade)

(*a*) $T = \frac{C}{20\ G + 10} - L$

(*b*) $T = \frac{W}{4\ (20G + 25)} - L = \frac{L\ (95 - 4G)}{4\ G + 5}$

Under any service the different conditions, (*a*), (*b*), and (*c*), give different values for the maximum weight of train. The smallest of these values is the limiting tonnage capacity of the locomotive.

Example

Application of these formulae to a particular case:

Assuming a 60-ton locomotive which is equipped with motors that at their continuous capacity can develop a tractive effort of 15 per cent of the weight on drivers or 18,000 lb., what is the tonnage capacity or weight of the train that the locomotive is capable of handling in various services?

There results from applying the foregoing formulae:

Service *A*. (Switching)

$$T = 19\ L = 1140 \text{ tons}$$

Service *B*. (Haulage over a rolling profile)

(*a*) $T = \frac{C}{10} - L = 1740$ tons

(*b*) $T = 19L = 1140$ tons

(*c*) $T = \frac{L\ (49 - 2\ G)}{2\ G + 1}$

= 2950 tons on level
= 940 tons on 1 per cent grade
= 540 tons on 2 per cent grade
= 370 tons on 3 per cent grade

Service *C*. (Haulage over a continuous grade)

(*a*) $T = \frac{C}{2\ G + 10} - L$

= 1740 tons on level
= 540 tons on 1 per cent grade
= 300 tons on 2 per cent grade
= 198 tons on 3 per cent grade

(*b*) $T = \frac{L\ (95 - 4G)}{4\ G + 5}$

= 1140 tons on level
= 660 tons on 1 per cent grade
= 475 tons on 2 per cent grade
= 380 tons on 3 per cent grade

From these figures the tonnage capacity of this locomotive can be stated as follows:

For Service *A* (Switching) the tonnage capacity is 1140 tons, determined by the slipping point of the wheels in acceleration.

For Service *B* (Haulage over a rolling profile) the tonnage capacity on a level road is 1140 tons, determined by (*b*) the acceleration; on a road with grades of 1, 2, or 3 per cent the tonnage capacity is 940, 540, or 370 tons respectively, determined by (*c*) the slipping of the drivers while running at speed up the grade.

For Service *C* (Haulage over a continuous grade) the tonnage capacity on a level road is 1140 tons, determined by the acceleration; on grades of 1, 2, or 3 per cent it is 540, 300, or 198 tons respectively, determined by (*a*) the heating of the motors.

Application

In making applications to concrete cases it must be borne in mind that the formulæ are only a general guide. They give the tonnage capacity under certain defined conditions but there will generally be modifications due to actual service conditions. For example, in the last paragraph the tonnage capacity given on grades of 1, 2, or 3 per cent is determined by the heating of the motors, assuming that they do no work except straight haulage up the grade. In case stops and accelerations have to be made, the heating will be affected and the tonnage capacity will be modified by the radiation during stops and the increased current during acceleration. For accurate results, a careful study must always be made of all the service conditions.

DESCRIPTIONS OF TYPICAL LOCOMOTIVES

In the following a brief description is given of some of the types of small locomotives which have been recently installed for interurban freight and switching service. Such locomotives are frequently rated on the basis of the tractive effort and speed which they will develop at the one-hour rating of the motors with a 75-deg. C. rise in temperature; however, it would be of interest to compare the locomotives on the basis of their tonnage capacity along the lines developed in the preceding paragraphs. Consequently, following the description of each locomotive, there will be found a statement of its tonnage capacity on this basis.

General Electric Standard Forty-Ton Locomotive

Fig. 1 shows a three-quarter view of what may be termed a standard electric switching locomotive in the sense that in size and capacity it meets the requirements of a great number of interurban requirements.

It is of the swivel-truck type and weighs 40 tons all of which is on the drivers. It has a steeple cab with the main operating cab in the center of the platform. In the sloping end cabs are located the rheostats, contactors, and other auxiliary apparatus. The apparatus is all placed and wired before the end cab is placed in position. Fig. 4 shows this apparatus in place before the end cab is mounted. For inspection of the apparatus and for minor repairs, doors in the end cab allow admission to the interior. Fig. 5 shows the arrangement of these doors and the accessibility of the apparatus through them. The locomotive is equipped with Type M two-speed control which gives seven steps with all the motors connected in series and five steps motors in series-parallel. At the rated load of the motors, the locomotive will develop a speed of 8 m.p.h., and running free will develop approximately twice that speed. Locomotives which are exact duplicates of the one

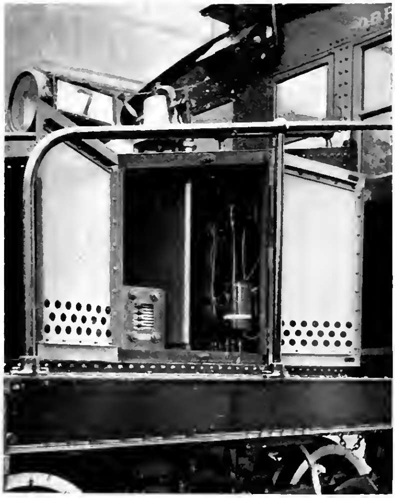


Fig. 5. Locomotive shown in Fig. 1, End Cab in Place but with Doors Opened to Permit Inspection

here described are in use on the lines of the Albany & Southern Railroad and the Ohio Valley Traction Company. A number of other roads have in service locomotives of this general type but with various modifications to suit individual requirements.

Weight of locomotive	40 tons
Equipment	4-GE-257-600-volt motors
Rated tractive effort	13,600 lb.
Speed at rating	8 m.p.h.
Tonnage capacity	
Service A. (Switching)	760 tons

Transit Development Company

The Transit Development Company is using a number of electric locomotives for handling freight from the docks and railroad terminals in the city of Brooklyn to ware houses, factories, and other points in the city. Fig. 2 shows one of two 55-ton units which were installed in 1914.

Because of having been designed purely for switching service, switchman's steps were furnished at the ends of the locomotive rather than the pilots which are shown in Fig. 1 and which are frequently required for locomotives operating on interurban lines. The control is Type M three-speed, a type which is adapted particularly to a locomotive that requires a large range of speed with an economical use of current on as many points of the range as possible. This control gives seven steps with all the motors connected in series, six steps motors in series-parallel, and five steps motors in parallel.

Weight of locomotive	55 tons
Equipment	4-GE-212-600-volt motors
Rated tractive effort	17,200 lb.
Speed at rating	20 m.p.h.
Tonnage capacity	
Service *A*.(Switching)	1045 tons

Willamette Valley Southern Ry.

The Willamette Valley Southern Ry. is an interurban road running south from Oregon City, Oregon, a distance of 32 miles to Mt. Angel, and furnishing freight as well as passenger facilities. Fig. 3 shows a 50-ton 1200-volt locomotive which is used in handling freight over its lines.

Weight of locomotive	50 tons				
Equipment	4-GE-207-600/1200-volt motors				
Rated tractive effort	14,800 lb.				
Speed at rating	10.8 m.p.h.				
Grades	Level	0.5%	1%	1.5%	2%
Tonnage capacity					
Service *A*. (Switching)	950				
Service *B*. (Rolling profile)	790	790	780	575	450
Service *C*. (Continuous grade)	790	370	230	160	118

Chicago, Milwaukee & St. Paul Ry. (Great Falls)

In the town of Great Falls, Mont., an electric locomotive is used in the terminal freight yards of the Chicago, Milwaukee & St. Paul Ry. This locomotive is shown in Fig. 6. It is operated from a 1500-volt trolley, the current being collected by a pantograph. The locomotive shifts and distributes freight cars, and makes up trains and delivers them to the steam locomotives at the limits of the electrified zone. The control is Type M insulated for 1500 volts and gives ten steps with all the motors connected in series, and nine steps motors in series-parallel.

Weight of locomotive	50 tons
Equipment	4-GE-207-D-750 1500-volt motors
Rated tractive effort	12,700 lb.
Speed at rating	9.5 m.p.h.
Tonnage capacity	
Service *A*.(Switching)	950 tons

Fort Dodge, Des Moines & Southern Ry.

The Fort Dodge, Des Moines & Southern Railway is a converted steam railroad extending from Fort Dodge to Des Moines, a distance of 80 miles with a total trackage of 120 miles. The road crosses a number of transcontinental lines including the Chicago, Milwaukee & St. Paul, The Chicago & Northwestern, The Illinois Central, and The Rock Island. Freight traffic consists in the transportation of coal and gypsum originating along the line of the road, and in the distribution of miscellaneous freight received from steam road connections to be delivered to points along the line.

Five electric locomotives, each of 40 tons weight, were furnished in 1911; two of 60 tons weight in 1912; and two of 60 tons weight in 1915. Fig. 7 shows a three-quarter view of a "1915" locomotive. This is of the box-cab swivel-truck type with the apparatus mounted in the center of the cab. Fig. 10 is a view of the interior looking down the passage-way to the motorman's position at the other end. It shows the dynamotor-blower and air reservoir and the contactors mounted above them. Fig. 11 shows the location of the rheostats mounted in the central compartment. The locomotive is of 60 tons weight and is equipped with Type M control for 1200 volts.

Weight of locomotive	60 tons				
Equipment	4-GE-251-600/1200-volt motor				
Rated tractive effort	21,400 lb.				
Speed at rating	14 m.p.h.				
Grades	Level	0.5%	1%	1.5%	2%
Tonnage capacity					
Service *A*. (Switching)	1140				
Service *B*. (Rolling profile)	1140	1140	935	690	540
Service *C*. (Continuous grade)	1140	800	535	385	297

Fig. 6 A 50-ton 1500-volt Locomotive Used by the Chicago, Milwaukee & St Paul Railway

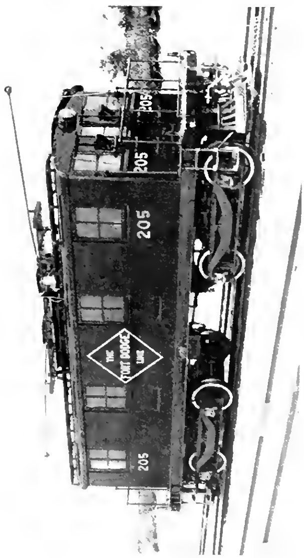


Fig. 7. One of the 60-ton 1200-volt Locomotives Used by the Ft. Dodge, Des Moines & Southern Railway

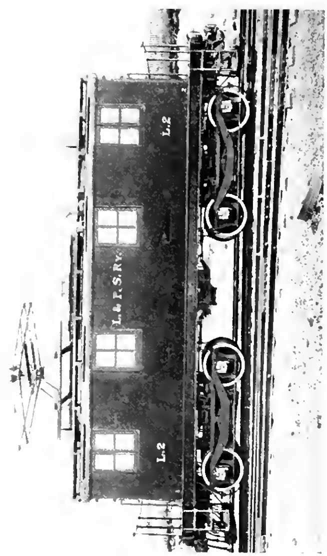


Fig. 8. One of the 60-ton 1500-volt Locomotives Used by the London and Port Stanley Railway Company

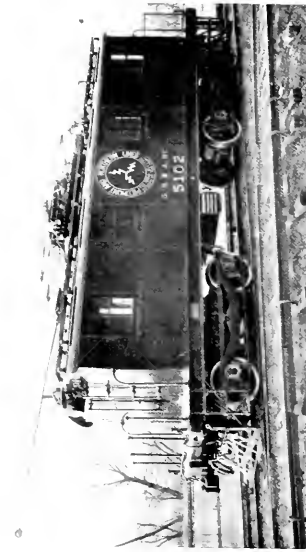


Fig. 9. One of the 60-ton 1500-volt Locomotives Used by the Piedmont & Northern Railway Company

London and Port Stanley

The Ontario Hydro-Electric Power Commission of Ontario, Canada, was formed to develop the water-power of the province and to apply the power industrially. In connection with this development the railroad between London, Ont., and Port Stanley was built and electrically equipped for operation at 1500 volts d-c. The road is designed to handle freight and to distribute this to points along its line. Three locomotives for this service were supplied in 1915, one of

Fig. 10. Interior View of the Locomotive Illustrated in Fig. 7, Showing the Dynamotor Blower Set, Contactor Bank, and Rheostat Compartment all in the Apparatus Compartment

which is shown in Fig. 8. The control is Type M and gives ten steps with all the motors connected in series and seven steps motors in series-parallel.

Weight of locomotive	60 tons				
Equipment	4-GE-251-750/1500-volt motors				
Rated tractive effort	21,500 lb.				
Speed at rating	17.1 m.p.h.				
Grades	Level	0.5%	1%	1.5%	2%
Tonnage capacity					
Service *A*. (Switching)	1140				
Service *B*. (Rolling profile)	1140	1140	935	690	540
Service *C*. (Continuous grade)	1140	755	483	347	266

Piedmont & Northern Railway Company

The lines of the Piedmont & Northern Railway Company embrace an extensive electric system running from Charlotte, N. C., through North and South Carolina, and touching such important towns as Greenville, Spartanburg and Anderson, S. C. There are over 100 miles in operation and there will be over 200 miles when the present plans are completed. The road makes connections with the Southern Railway, the Seaboard Air Line, and the Carolina, Clinchfield & Ohio. There

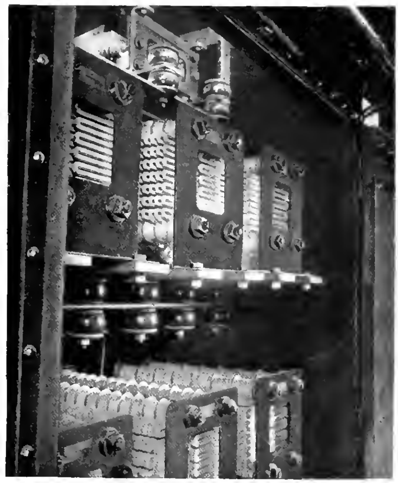


Fig. 11 A Near View of the Rheostat Compartment of the Locomotive Shown in Fig. 7

are numerous cotton mills along the line and the traffic consists of freight originating at these mills and of material distributed from the railways to the mills. The line is operated at 1500 volts direct current.

Six locomotives were supplied for the Greenville, Spartanburg and Anderson section in 1913. A view of one of these locomotives is shown in Fig. 9. The locomotive is of a swivel-truck type with a box cab and ample end platforms at the ends of the cab. The apparatus is located in the center of the cab where there is plenty of room for insulation and clearances around it. The locomotive is equipped for forced ventilation of the motors; the intake for the blower can be seen in Fig. 9 under the sills at the side of the locomotive.

A pantograph is supplied for collecting current at 1500 volts from the catenary overhead construction on the interurban sections of the road and trolleys are supplied for the collection of current at 600 volts in the towns. The weight of the locomotive is 63 tons.

Weight of locomotive	63 tons				
Equipment	4-GE-212-750/1500-volt motors				
Rated tractive effort	19,500 lb.				
Speed at rating	19.5 m.p.h.				
Grades	Level	0.5%	1%	1.5%	2%
Tonnage capacity					
Service *A*. (Switching)	1140				
Service *B*. (Rolling profile)	1140	1140	935	690	540
Service *C*. (Continuous grade)	1140	540	340	240	180

University of Michigan

The University of Michigan uses for switching service a small locomotive, illustrations of which are shown in Figs. 12 and 13. Car-load freight for the University is delivered at the spur tracks of the Michigan Central lines approximately one mile from the power-house on the University campus. These cars must be pulled through the town and through the University grounds for delivery. In order to eliminate the smoke and noise of the steam locomotive, this spur track has been electrified. The power supply for the University is a 250-volt direct-current three-wire system with grounded neutral and 500 volts between outside wires. Two trolley wires are used thereby forming a metallic circuit which is supplied with 500 volts from the outside wires of the system. Two bow trolleys are supplied on the locomotive insulated from each other and each makes contact with a trolley wire. Under the coal pockets at the power-house it is impossible to install trolley wires and consequently a third-rail is used. The locomotive has, therefore, in addition, two third-rail shoes for current collection. Arrangement is made for operation from the two bow trolleys, or from the two third-rail shoes, or from one third-rail shoe and one bow trolley.

The weight of the locomotive is 28 tons. It is equipped with four GE-98 motors and Type K control which gives six steps with all the motors connected in series and five steps motors in series-parallel.

Weight of locomotive	28 tons
Equipment	4-GE-98-600-volt motors
Rated tractive effort	8,000 lb.
Speed at rating	4.9 m.p.h.
Tonnage capacity	
Service *A*. (Switching)	530 tons

Harlan & Hollingsworth Corporation

The Harlan & Hollingsworth Corporation has been using since 1912 the electric locomotive shown in Fig. 14. This is in operation in the car building plant at Wilmington, Del., and is used for switching cars and handling freight around the yards. A switchman's step is furnished at the end of the locomotive instead of an iron pilot as the locomotive is used entirely for yard work. The width of the body has been reduced below the standard on account of the contracted space in which the locomotive sometimes has to work. For this reason, the door is placed in the side of the cab instead of opening upon the car platform as is the ordinary construction with the small locomotives which have been previously illustrated.

Weight of locomotive	35 tons
Equipment	4-GE-57-500-volt motors
Rated tractive effort	10,000 lb.
Speed at rating	7.3 m.p.h.
Tonnage capacity	
Service *A*. (Switching)	665 tons

South Manchurian Railway

The South Manchurian Railway is handling the output of the Fushun Collieries by means of electric locomotives. Fig. 15 shows one of three locomotives furnished for this purpose in 1914. The duty of the locomotive consists in handling trains of 400 to 500 tons on the lines connecting the collieries with the main steam line of the South Manchurian Railway over grades of 1 per cent to 1¼ per cent. Headroom limitations made it necessary to furnish a locomotive with an especially low roof. In order to obtain the low cab roof without seriously inconveniencing the operator, a specially constructed floor is required in the operating position, in the center cab; this arrangement gives an interior height of 6 ft. 4 in. from the floor to the roof of the cab with a total height from the rail head to the roof of 10 ft. 6 in. The locomotive is designed for operating on 1200 volts. The control is Type M and gives six steps with all the motors

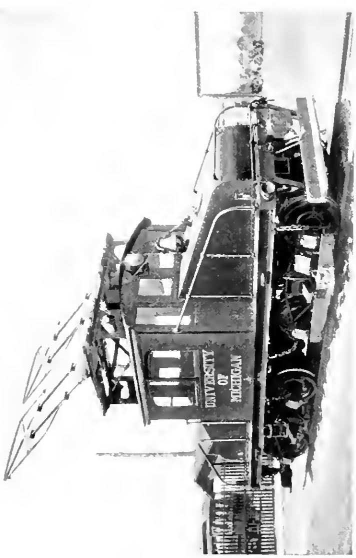


Fig. 12. A 28-ton 600-volt Locomotive Used by the University of Michigan

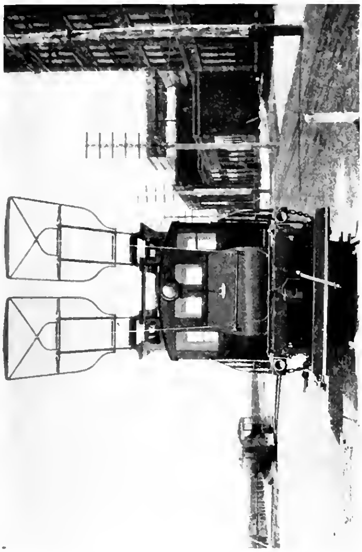


Fig. 13. An End View of the Locomotive Shown in Fig. 12

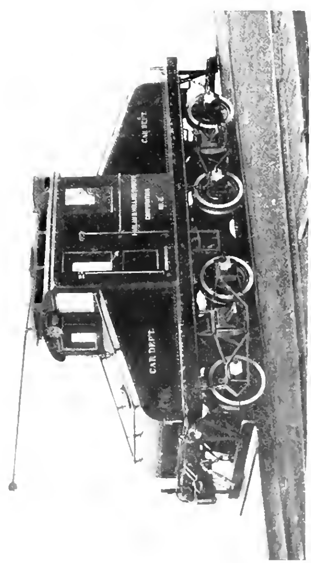


Fig. 14. A .5-ton 500-volt Locomotive Used by the Harlam & Hollingsworth Corporation

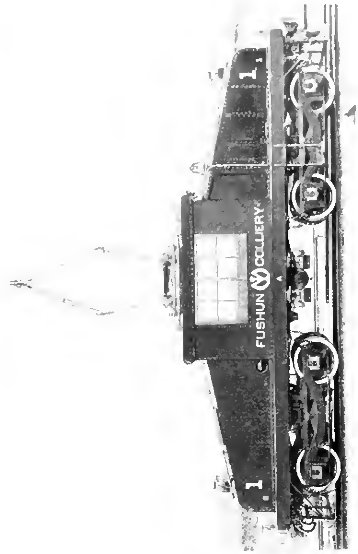


Fig. 15. One of the 42-ton 1200-volt Locomotives Used by the South Manchurian Railway

connected in series and four steps motors in series-parallel.

Weight of locomotive	42 tons				
Equipment	4-GE-206-600/1200-volt motors				
Rated tractive effort	10,400 lb.				
Speed at rating	14.1 m.p.h.				
Grades	Level	0.5%	1%	1.5%	2%
Tonnage capacity					
Service *A*. (Switching)	800				
Service *B*. (Rolling profile)	608	608	608	480	380
Service *C*. (Continuous grade)	608	285	175	120	88

Havana Central Railway

The Havana Central Railway of Havana, Cuba, operates the electric lines radiating from Havana into the surrounding country. These lines carry not only passengers but a large quantity of freight between the city of Havana and the plantations and mills along the line of the road. Ten 40-ton electric locomotives were installed for this purpose in 1906; and three 60-ton locomotives were added to the equipment in 1913. Fig. 16 shows the fourth 60-ton locomotive which was added in 1916. The locomotive is built for 600 volts and is equipped with Type M three-speed control. The locomotive thus obtains the advantage of a wide range of speed with an economical use of current at all speeds, which is characteristic of this type of control. The control gives seven steps with all the motors connected in series, six steps motors in series-parallel, and five steps motors in parallel, a total of eighteen steps with three operating positions in which all external resistance is cut out of the circuit.

Weight of locomotive	60 tons
Equipment	4-GE-69-motors
Rated tractive effort	22,000 lb.
Speed at rating	2.8, 6.2, and 13.2 m.p.h.
Tonnage capacity	
Service *A*. (Switching)	1140 tons

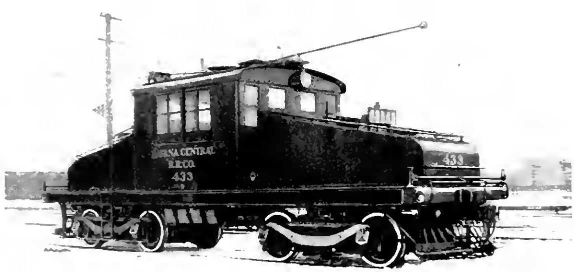


Fig. 16 One of the 60-ton 600-volt Locomotives Used by the Havana Central Railway

THE HALES BAR HYDRO-ELECTRIC POWER STATION OF THE CHATTANOOGA AND TENNESSEE RIVER POWER COMPANY

By Philip Torchio

Chief Electrical Engineer, New York Edison Company

The Hales Bar hydro-electric power station is one of the largest in the South; and the dam was built to meet the requirements of the government engineers, as it was designed primarily for the improvement of river navigation. This beneficial result was secured for an important industrial section of the country without any expense to the government, as the entire financial burden involved in the construction of the dam was borne by the Chattanooga & Tennessee River Power Company. This article indicates clearly the engineering difficulties encountered in the design, construction, and operation of the plant, and it outlines as well the exceptionally advantageous results which have been secured by the interconnection of two power systems operating under different hydraulic conditions.—Editor.

The hydro-electric development at Hales Bar on the Tennessee River is of unusual interest to the engineering fraternity, not only on account of its size, but because of the exceptional problems involved in its construction, and the alterations in the original equipment recently imposed by changing commercial conditions, whereby a considerable percentage of the capacity of the plant, which was originally designed for 44,000-volt output, will be delivered at a potential of 120,000 volts.

This article will therefore deal with three phases of the situation, the first covering the general conditions affecting the primary design and operation of the power station; the second a brief outline of the arrangement of the hydraulic and electrical machinery prior to the alterations now being made; and the third, an analysis of the reconstruction work, necessitated by the installation of new waterwheel-driven generators, which is now in progress.

In order to understand the reasons for adopting the hydraulic equipment first installed, some reference to the problems which confronted the designing engineers is necessary.

While the normal condition of the Tennessee River is that of a quietly flowing stream giving a dependable water supply, it is also subject to extreme fluctuations in the rate of flow; the minimum is less than 6000 cu. ft. per second, and the maximum exceeds 600,000 cu. ft. per second. The natural fall of the river bed for a considerable distance both above and below Hales Bar averages less than one foot per mile. Above Chattanooga the drainage area is 21400 square miles.

Ordinarily the variations during the year give a water flow range about as follows: two months 8,000-16,000 cu. ft. per second; eight months 12,000-60,000 cu. ft. per second with occasional floods giving temporary rates of more than one hundred times the minimum flow.

Hales Bar is about 33 miles down stream from Chattanooga and formerly prevented steamboat navigation during periods of low water. The dam was therefore constructed primarily for the improvement of navigating conditions and insures a minimum channel depth of five feet on that section of the river extending from Muscle Shoals to Chattanooga, a distance of approximately 170 miles. At the same time the right to develop a hydro-electric plant was granted to the Chattanooga and Tennessee River Power Company, and in this way the water power rendered available by the construction of the dam was made to serve the double purpose of improving navigation and generating electric energy.

The dam is 1200 ft. in length with an average height of 63 ft. and is built of cyclopean concrete. The power-station is located at the eastern end of the dam, while the western end terminates in the outer wall of the lock which has an inside width of 60 ft., a length of 312 ft., and gives a 40-ft. change in elevation in one flight. For the electrical operation of this lock, conductors for transmitting the current supply are laid in a passageway in the dam.

A single sluiceway is provided to supply water to the lower pool when no water is passing over the dam or through the powerhouse, otherwise the dam contains no openings. Three-foot flashboards are used to further conserve the water supply. Due to the absence of sluices, the water flowing over the crest of this dam during floods exceeds in depth and volume that passing over any other dam in the world.

The general layout of the power station is shown in Figs. 1 and 2. The generating section consists of seven bays, each containing two waterwheel driven generators. Ten of these generators of 3133-kw. capacity were

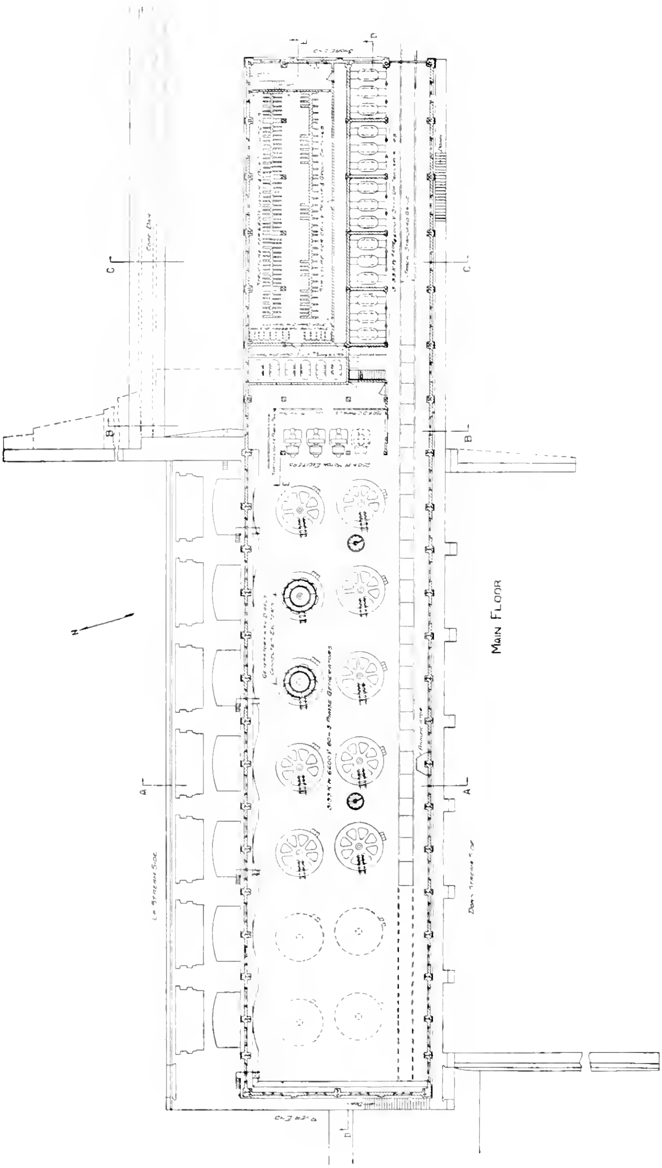
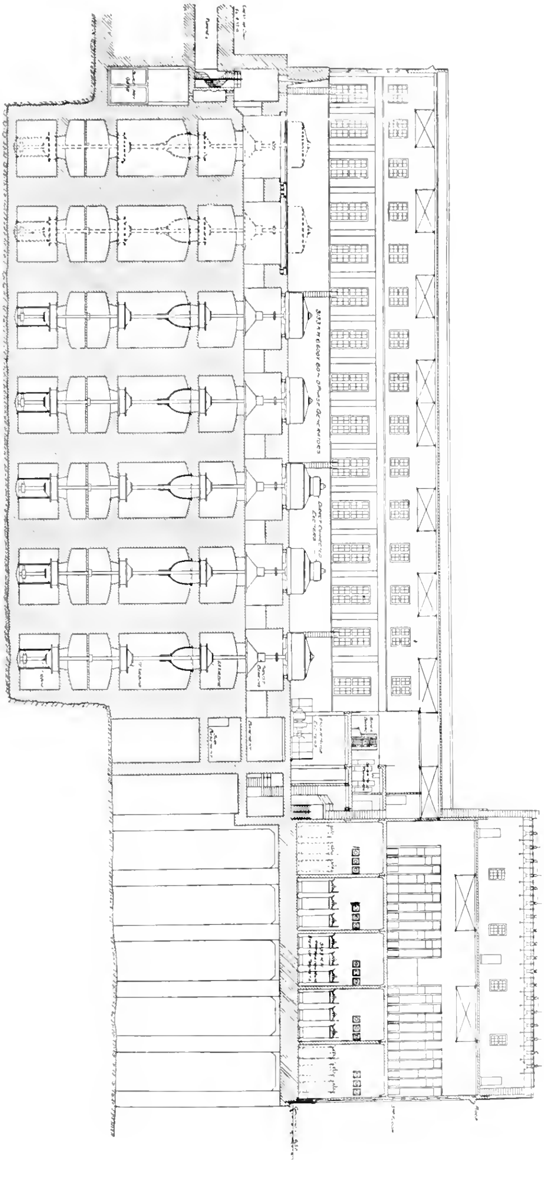


Fig. 1. Plan of Hales Bar Hydro-Electric Power Station Showing the General Arrangement of Generators, Exciters, Transformers and Switching Apparatus

installed on the original plan, while space was reserved for four 3750-kw. units shown in outline; thus an ultimate output of about 46,000 kw. could be secured.

The details of the hydraulic machinery for a typical bay are indicated in Fig. 3. With low water flow the maximum hydraulic head of $39\frac{1}{2}$ ft. is secured, while under extreme flood conditions the backing up of the tailrace water reduces the available drop to 19 ft. As current was to be supplied for varied lighting, traction, and commercial enterprises, it was imperative that the output of the station should not be too heavily affected by fluctuations in the water flow and an arrangement of three water wheels was selected so that relatively high outputs could be maintained at all stages throughout the 20-ft variation in the available hydraulic head, and especially at minimum heads occurring at flood periods.

Each generating set consists



Section D-D.

Fig. 2. Sectional Elevation of Hales Bar Hydro-Electric Power Station showing Arrangement of the Wheel Pits and Turbo-Generator Sets

of the generator and three turbines all mounted on a common vertical shaft, with the entire weight of the rotating element carried by a suspension bearing which is located on a separate floor below the generator; the total live load thus imposed is 144,500 lb.

For the two lower turbines 72-inch wheels are used, and they are so designed as to neutralize the hydraulic thrust when in operation. The upper wheel is 63 inches in diameter and it discharges into a draft-tube which insures the fullest utilization of the available head.

Under conditions of normal flow, only the two lower turbines are used; the upper unit is put into service when high water reduces the operating head and correspondently reduces the power output. In this way a smaller variation of generator output is rendered possible under all conditions of stream flow. This arrangement also gives approximately equal minimum total station outputs both at minimum stream flow and maximum flood. The turbine sets operate normally at 112.5-r.p.m., and at that speed each can deliver 4250-h.p. under a 35-ft. head.

The ten three-phase, 60-cycle, 6600-volt, 64-pole generators are each rated at 3133 kw., are capable of withstanding momentary swings of 4500 kw. at unity power-factor, and can operate at 75 per cent above the normal speed of 112.5-r.p.m. for one hour without injury. At their rated

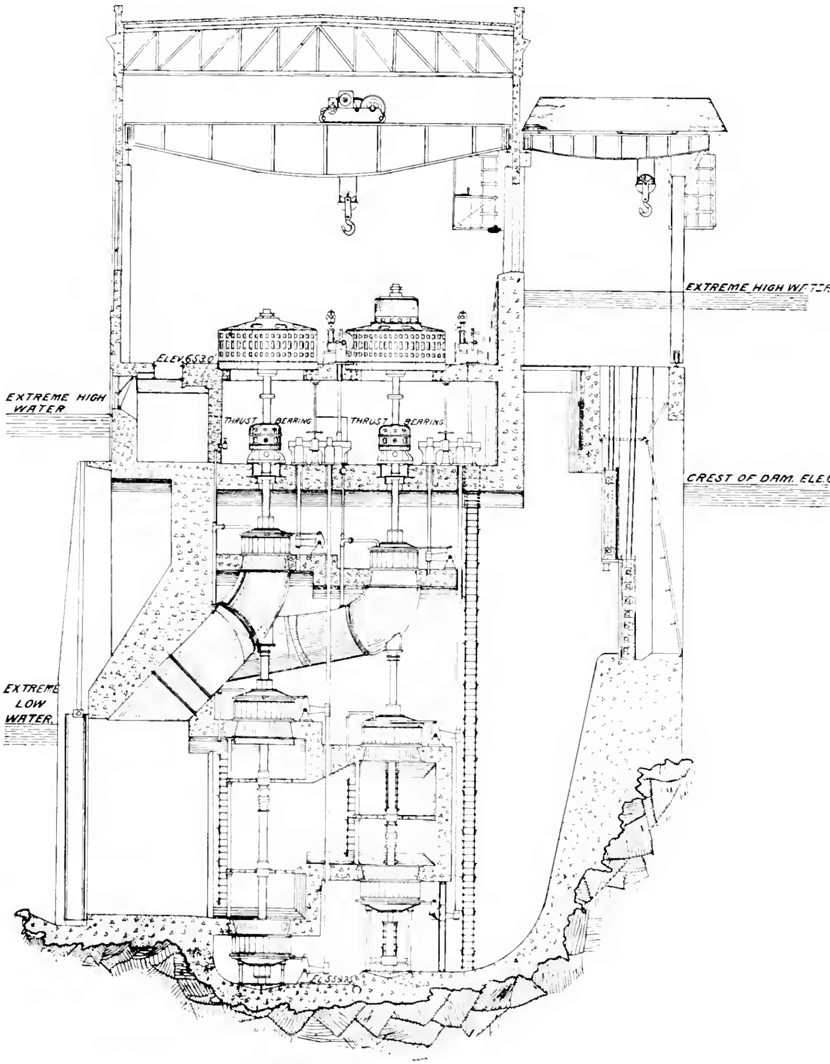


Fig. 3. Original Arrangement of Turbines for Generator Drive

output, at unity power-factor, their regulation is about 10 per cent and their efficiency including friction and windage losses 95.5 per cent. The total weight of each machine is about 127,500 lb.; the rotor and shaft, coupled to the turbine shaft, weight about 50,000 lb.

The original generators are installed in two rows of five units each (See Fig. 1), and are located on the main floor of the operating room. Two of them are equipped with self-contained 100-kw., 250-volt exciters mounted directly on the generator shaft (See front cover), while additional excitation and current for battery charging is provided by four motor-generator sets, each consisting of a 250-kw., 250-volt, 720-r.p.m., direct current generator driven by a 375-h.p., 220-volt induction motor. The motor and generator in each set are direct coupled, mounted on a common base, and form a compact and self-contained unit.

The remaining station equipment comprises exciter, lighting and power, and control switchboards, step-down and step-up transformers, 6600-volt and 45,000-volt circuit breakers and buses, multiplex, electrolytic, and horn lightning arresters, choke coils, and storage battery.

With ten generators in service, commercial operation was started in November, 1913, and current was delivered to the substation in Chattanooga over an 18-mile twin circuit, steel-tower transmission line.

As already stated the power-station was primarily intended to carry a general commercial load and its machinery was designed for greatest possible uniformity of output irrespective of variations in the rate of flow of the river; the storage afforded by the 33-mile section of the river extending from Hales Bar to Chattanooga giving an ample water supply for both power and navigation purposes. However, an unforseen outlet for a large percentage of the plant capacity presented itself, with certain limitations which made necessary some radical changes in part of the generating equipment in order that greater efficiency during periods of low-water flow might be secured, even if it entailed a corresponding diminution of efficiency and output during high-water periods.

Briefly stated, the situation involved the delivery of current by the Hales Bar station to augment the capacity of another hydro-electric system during low-flow periods. The latter system had the ordinary water power conditions, under which the effective hydraulic head and the volume of water varies directly with the rise and fall in the rate of stream flow, whereas we know that at Hales Bar the available head varies inversely with the stream flow. The mutual benefit to be derived from the interconnection of the two systems under these circumstances is obvious.

The necessary changes are now nearing completion, and four new generators (See Fig. 6), each rated at 3750 kv-a., are being installed in the two outer bays of the power station shown in outline in Fig. 1, and the wheel-pits for the next two generators are being altered, as each of these six units will be direct driven by a single-runner turbine. These turbines have a capacity smaller than could have been obtained from the 5090 h.p. three-runner type units originally contemplated; in fact, their maximum output is not much greater than the smaller units of the first installation; also the output at low heads is very much less than in the former type. However, the turbine efficiency at high heads, occurring at low stream flow, is very much greater, which was the desideratum under the new conditions. Notwithstanding the smaller capacity of the turbines, the capacity of the new generators was retained at 3750 kw. as originally contemplated so as to have a liberal margin for operating at power-factors lower than unity.

The nature and extent of the alterations involved in the adoption of the new generating sets can be readily understood by reference to Figs. 3 and 5. In the place of three turbines on each driving shaft, a single-runner, inward and downward flow reaction turbine of the Francis type has been utilized. This turbine is 82 inches in diameter, and the present blade form and pitch were decided on only after a number of models had been constructed and subjected to exhaustive tests at Holyoke, in order to produce the wheel best adapted in all essentials to the existing conditions at the Hales Bar plant. In some cases these tests gave indicated hydraulic efficiencies as high as 90.2 per cent.

The water approaching the turbines passes through carefully moulded concrete scroll cases, so that it enters between the wicket gates on the periphery of the turbine with uniform velocity at all points. The discharge to the tail-race is made through reinforced concrete draft-tubes; the homogeneous moulding of scroll cases and draft-tubes producing a simple monolithic wheel-pit, structurally strong, and guiding the water from intake to tail-race with low friction losses.

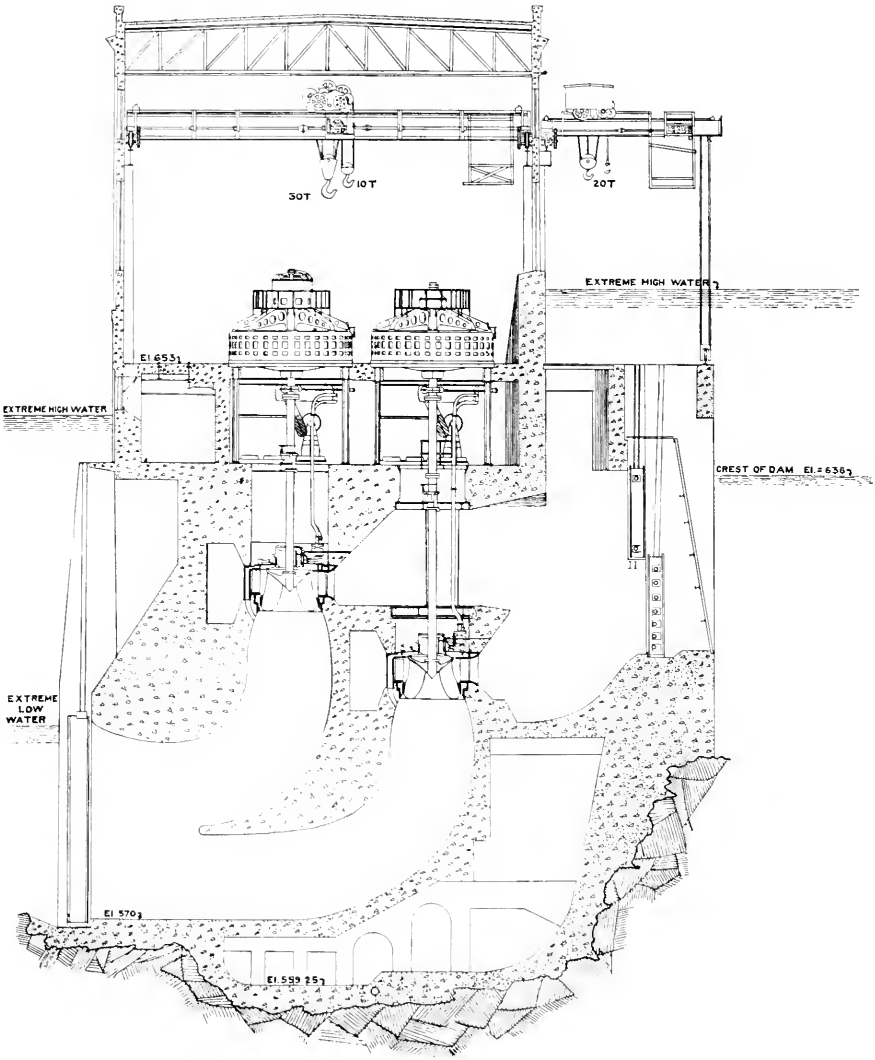


Fig. 4. Arrangement of Single Runner Turbines for New Generators

The new turbines develop 4415-h.p. at 100-r.p.m., under a 38-ft. head, and four of them will be operated at that speed, while those driving the two 3133-kw. generators previously installed will conform to the generator speed of 112.5 r.p.m. The rotating element of the turbines located on the up-stream side of the power-station weighs about 41,700 lb.; that on the downstream side, due to the shorter shafts (See Fig. 4) weigh 8000 lb. less. The three-runner turbine rotors have a uniform weight of about 77,000 lb.

In the original generating sets, the bearings are installed on a separate floor between the turbine and the generator and are each subjected to a live load thrust of 144,500 lb.; but for the new units the bearings are located above the generator and are mounted on rigid brackets which are solidly bolted to the generator stator frame. Due to the shorter shafts and simpler arrangement of the new units, the live load imposed on the thrust bearing is only about 131,500 lb. for the up-stream generator sets, and 123,500 lb. for the downstream sets.

In conjunction with the already stated increased efficiencies secured by the new hydraulic machinery it is interesting to note that also the generators, under test, exceeded the guaranteed efficiencies for all loads by a liberal margin.

The new generators (See Fig. 6), are 72-pole machines, and, at 100-r.p.m., have a rated capacity of 3750 kw., three-phase,

Fig. 5. View in Generator Room showing Installation of 3750 Kw. Units

60-cycles, 6600-volts, as compared with 3133 kw. for the older units (both ratings being at unity power-factor). In addition to the thrust bearing two guide bearings are provided, and two of the sets also carry 100-kw., 250-volt direct-connected vertical exciters. The total weight per machine is about 141,000 lb.; the rotor and shaft weigh 50,600 lb. Momentary overloads up to 4400-kw. at 80 per cent power-factor can be carried without injury and operation at 75 per cent over-speed for one hour, or a runaway speed of twice the normal rate, can be safely imposed.

Guarantees for these machines were made in accordance with the new A.I.E.E. rules

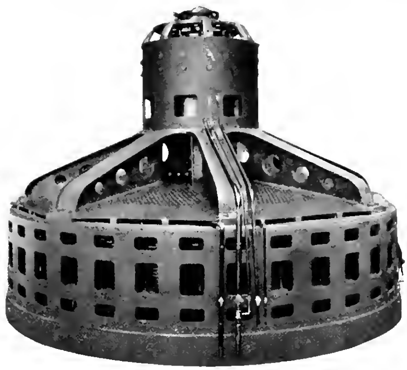


Fig. 6. 72-Pole, 3750-Kw., Three-Phase, 60-Cycle, 6600-Volt, 100-R.P.M. Generator with Self-Contained Exciter

and the efficiencies include full short-circuit core loss as well as the losses in the field rheostat. The guaranteed efficiencies are given in Table I:

TABLE I

Load in Per Cent	Unity Power-Factor	80 Per Cent Power-Factor
25	88.0	85.2
50	93.3	91.3
75	94.6	93.0
100	95.4	93.9

The machine selected for test was equipped with its suspension thrust bearing, and conditions simulating as closely as possible those of service operation were imposed. For all loads the actual efficiencies as measured were higher than the guaranteed efficiencies, and for a 25 per cent overload at unity power-factor 96.18 per cent efficiency was indicated.

With the concomitant changes made in the switching and protective apparatus and the addition of three 10,000-kv-a., 6600 120,000-volt transformers, the Hales Bar station can now deliver 30,000-kw. at 120,000 volts, while the remaining capacity exclusive of the local distribution load is transmitted as before over a 44,000-volt line. The switching arrangements between the generators and outgoing lines are indicated in Fig. 7.

Throughout the development, the electrical work was done under the direction of Mr. T. E. Murray, consulting engineer, and the hydraulic and mechanical installation was designed and supervised by Mr. John Bogart, consulting engineer of the Chattanooga & Tennessee River Power Company.

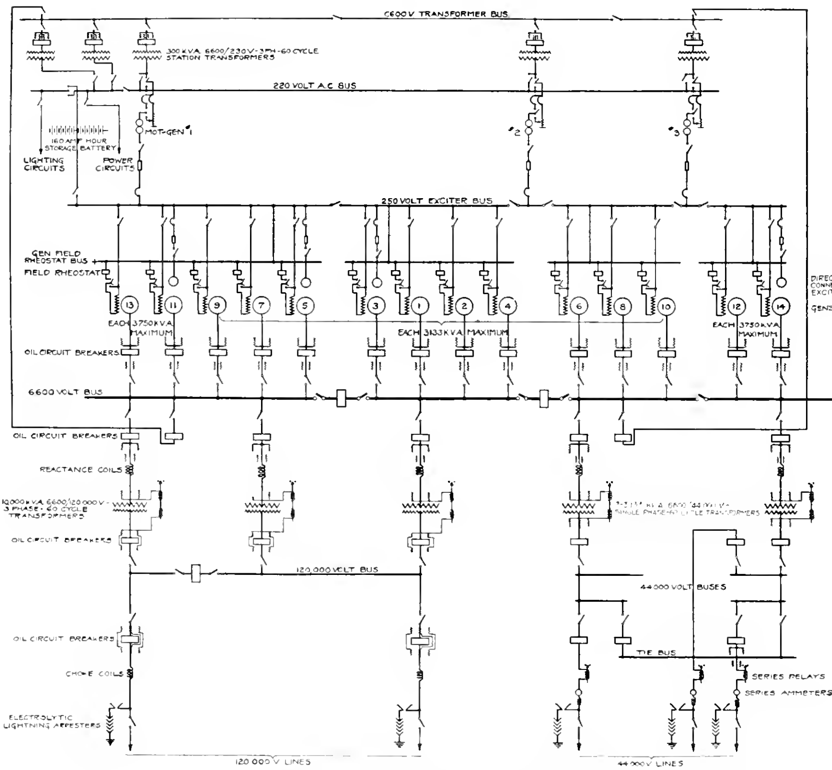


Fig. 7. One-Line Wiring Diagram of the Hales Bar Power Station showing the Present Arrangement of the 44,000-Volt and 120,000-Volt Circuits

ELECTRICITY IN COAL MINE HAULAGE

Part I

By William P. Little

Power and Mining Department, General Electric Company

In the early stages of coal mining, when operations were confined to within a hundred feet or so of the service, haulage to the shaft was by man or animal power. As the shafts became deeper and the hauls longer the steam engine was applied to this service at first; but the development of the electric locomotive provided the ideal method of haulage and was quickly appreciated by the mine owners. This article gives a detailed discussion of the best practice in the design of electric locomotives and other electrical equipment for coal mine service; the present installment covering the mechanical and electrical features of the locomotive, and the second installment including some haulage calculations and suggestions for the trolley system, substation arrangement, and methods of remedying locomotive troubles.—Editor.

Haulage is one of the most important problems which confronts the mine operator of today, for upon this depends not only the output of the mine but also the profits to the owners. Inadequate or unscientific methods of haulage have many times been the fundamental reasons for abandoning a mine as unproductive or worked out, and these same mines in recent years have been again put into operation after revising the haulage system on scientific principles and are paying a fair return to the operators on the money invested.

In the infancy of the coal mining industry only the coal within a few hundred feet of the shaft or slope was mined, and inasmuch as these shafts were only driven into the richest veins the cost of production was small and the haulage presented no such complicated problems as it does today. All the coal which the hoist could handle was easily conveyed to the shaft by means of man-power or mules. As the working faces receded from the shaft, however, the problem assumed larger proportions and gained more importance, for in following the veins they also followed the rolls and thus encountered grades where the man or mule-power was inadequate to get the car to the shaft. Also the time element had to be taken into account, and a quicker method of getting the loaded car from the working faces to the shaft or the slope and the empties back to the miners had to be employed. Of course, the cost of haulage also increased with the length of haul, and cheaper methods had to be devised or the mine abandoned as unproductive.

It was at this time that the mules began to be superseded by mechanical methods, specially in the main haulage, although even today many mines do all their gathering with the mule. The use of steam was natural for the first haulage engines, but with their first high initial cost, high upkeep expense and low efficiency, they have not been able to compete with electricity. The use of steam locomotives is objectionable for underground work, because of the gases given off, the necessary high headroom required, and the fire hazard involved. Compressed air as the motive power for this work also has its disadvantages in its low efficiency and limited radius of action due to the small storage capacity. The use of the gasolene locomotive is limited to mines where the ventilation is such that the exhaust is not objectionable.

The Electric Locomotive

The electric locomotive, however, seems to have solved the haulage problem and is now recognized as the most successful motive power for mine haulage systems, and there is perhaps no other industry in which the application of the electric locomotive for haulage has received such thorough appreciation. Its high efficiency, mechanical strength, dependibility, and simplicity of control make it the most economical and compact tractor available. The last characteristic is a most important one for underground operation where the headroom is limited and where the cost of increasing the height would naturally increase the cost of mining. Its radius of operation is practically unlimited, for with cable reel and crab devices not even the trolley wire is necessary in the entries for gathering. There are no objectionable gases given off to further polute the not too fresh air. The main haulage roads are always free from gas, so that there is no danger from the use of the trolley locomotive on these roads. With crab devices on the gathering locomotive it is unnecessary for the locomotive to enter the chambers; hence the danger of igniting the gas at the working face from the operation of the motor is eliminated. The electric locomotive requires the minimum of attention and is so simple in operation that anybody with a few hours practice can successfully operate it.

There has been a constant improvement in the structural details of the electric mine locomotive as the designing engineers have

Fig. 1. An Outside Frame Type Mine Locomotive

become better acquainted with the arduous service normally encountered in mining operation and the increased demands made upon the locomotive. Due to the low headroom and the tractive requirements, mining locomotives from the first have been exceptionally compact and mechanically strong, and the earliest type of locomotive built by the General Electric Company after 22 years of almost continuous service is still in operation. Four general types are now commonly used, which may be divided into two classes, viz., locomotives for main haulage and gathering locomotives. The former class includes the straight trolley locomotive, generally ranging from 10 to 25 tons, while the latter class embraces locomotives equipped with cable reel, crab device or a combination of both, and storage battery. The storage battery locomotive presents such an entirely different problem, and its economical and satisfactory operation is so dependent upon the duty, cycle and conditions of its operation, that it will not be considered here, except to say that its popularity amongst the mine operators is steadily increasing, due no doubt to improvements in the design and in the construction of the storage battery. These gathering locomotives generally range from four to seven tons.

The two-motor locomotive is generally recognized as the standard type for mine work. There are two general types of this locomotive, one in which the side frames are inside the wheels, and the other in which the side frames are outside the wheels. The outside frame allows the maximum space between frames for mounting the wheels and other parts of the equipment for a given track guage, renders the journal boxes and motors more accessible for repairs and inspection, and gives somewhat more cab space at the operating end for the motorman. Also the factor of safety is higher, inasmuch as the wheels and brakeshoes are all enclosed by the frame, thus making it impossible to get a foot caught in the wheels or under the wheels, and there are no projections upon which clothing, etc., can catch when the locomotive passes a person in a narrow road.

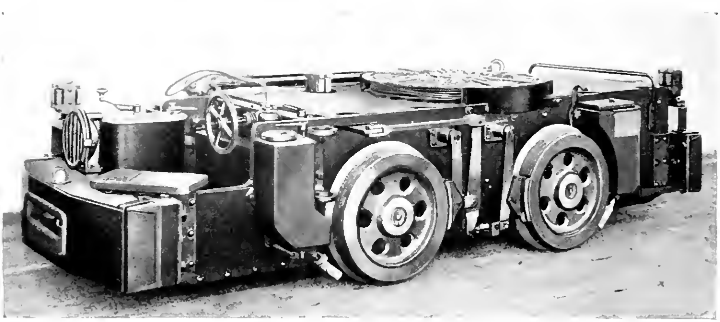


Fig. 2. An Inside Frame Type Mine Locomotive

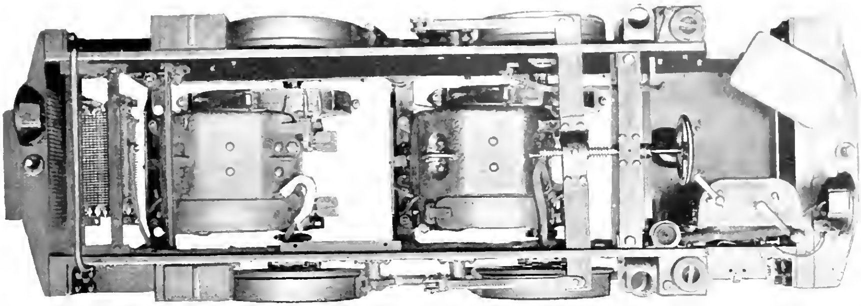


Fig. 3 Top View of the Equipment of an Inside Frame Mine Locomotive

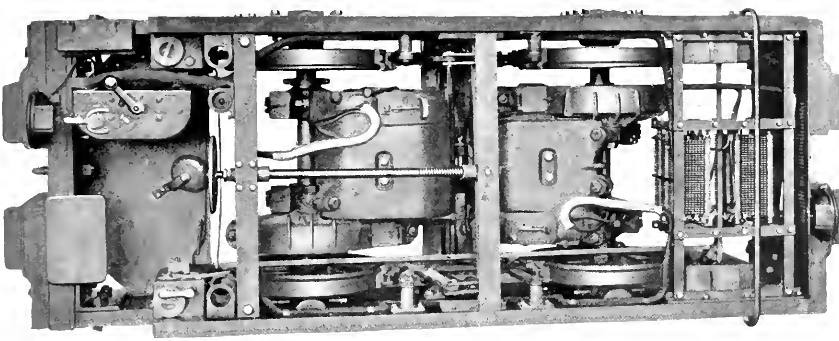


Fig. 4. Top View of the Equipment of an Outside Frame Mine Locomotive

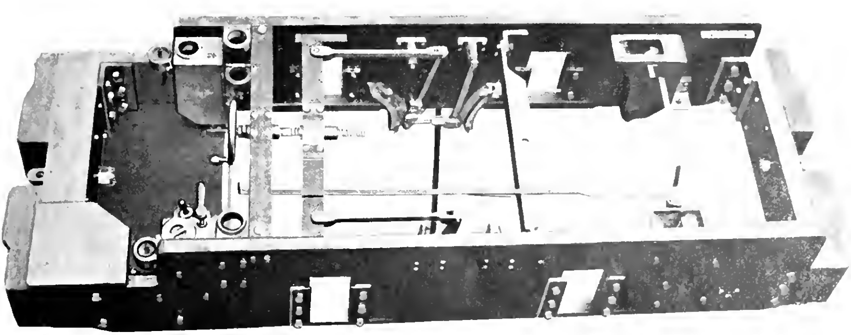


Fig. 5. View of the Locomotive shown in Fig. 4, but without Electrical Equipment

However, the overall width is greater and in cases where entries are narrow, especially in old mines, the above advantages might be negligible in comparison to the expense required to widen the roads the necessary amount to allow the use of the outside frame. The inside frame type restricts to a certain extent the space available for motors and equipment between the wheels, thus making it less easily accessible than the outside frame type; but on the other hand it allows for minimum overall width and in old mines or mines where the props are set close to the track or the space on the side of the track is otherwise limited, this disadvantage is overruled.

There are two standard methods of mounting motors; namely, in tandem, where the rear motor is placed between the axles and the other motor between the forward axle and the front end frame, and central, where both motors are placed between the axles. The former arrangement permits of short wheel-base and is adopted for light and medium-weight locomotives, as these are usually the ones required to operate over sections of track having short radius curves. On the heavier locomotives—those generally used for the main haulage—the motors are mounted central, for the roads are usually straight or have long radius curves, and the longer wheel-base gives greater stability to the locomotive. In either case the arrangement of the locomotive should be proportioned to give an equal distribution of weight between both pairs of driving wheels. Sometimes to meet exceptional conditions the motors are end mounted; that is, each motor is placed between the axle and the end frame. This permits of minimum wheel-base.

Mechanical Equipment

The best practice on locomotives is to use side frames of rolled steel plate. This gives a construction of extreme rigidity and one that has maximum resiting power to shocks, and is almost indestructible. The end frames are of steel channels which are fitted with heavy wood bumpers except on the larger locomotives, where it is sometimes necessary to equip them with solid cast iron bumpers in order to get enough weight for the locomotive capacity. The steel side frames are cut from a single piece of plate, to which are securely bolted the sand boxes, motor suspension lugs, trolley sockets and journal box guides. All joint surfaces should be carefully machined and fitted to secure accurate alignment of the parts, thus preventing no internal stresses and strains which might cause trouble or even the disablement of the locomotive. The end frames and side frames should be held rigidly together by heavy steel angles and through-bolts of ample size to give a large factor of safety. The bumpers and couplers, of course, must be designed to meet the requirements of the cars which they have to haul. To prevent cars from climbing over the locomotive in case of derailment or collision, strong guard lugs or climbing stops should always be provided on top of the bumpers.

The journal boxes commonly used are of the regular railway type with removable linings and are lubricated from oil cellers filled with saturated waste. These linings are made of a special alloy of bearing brass and are so designed as to remain in position in case of derailment. These journal boxes support the weight of the locomotive through helical springs, two concentric springs being used on the larger sizes, while one spring is sufficient to support the weight on the smaller sizes. The springs must withstand very severe shocks and must therefore be made of high grade spring steel.

Of course the wheels of a locomotive are subject to continual replacement, and rolled steel or steel-tired wheels, while their initial cost is more than that of iron wheels, have a much longer life. Iron wheels are usually furnished on standard equipment. The shape of the flange and dimension of the throat radius conform in the majority of cases to the MCB standards, thus giving the same clearances between flange and rail as obtain in regular railway practice. The two wheels are a unit, pressed on and securely keyed to the heavy steel axle, and are furnished for replacement in this way unless the operator has facilities for pressing on and off his own wheels. For outside frame locomotives plate type wheels are commonly used, while with inside frame locomotives the spoke type wheels give easier access to the journal boxes.

There are two general types of brake mechanism used, namely, the vertical screw type where the brake wheel operates in a horizontal plane, and the horizontal screw type where the brake wheel operates in a vertical plane. The tension in either case is obtained by means of a threaded screw to which is fitted a nut which in the former case carries the chain and in the latter an equalizer bar from the ends of which connecting rods lead to the brake levers on either side. The pitch of the thread should be such that a slight exertion on the part of the motorman produces ample pressure on the brakeshoe, and the thread long enough to automatically compensate for the brakeshoe wear. With

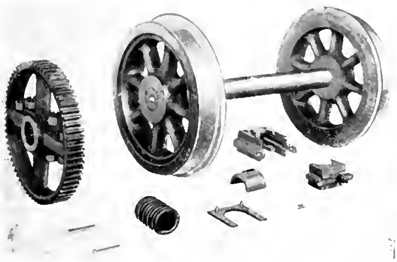


Fig. 6. Steel-tired Type Wheels, Axle, Gear, Journal Box and Double Journal Springs for Outside Frame Type of Mine Locomotive

this screw tension scheme for operating the brakes they are automatically locked in any position in which they are left without the use of pawls or rachets. The shoes should be easily removable so as to facilitate their replacement when worn. This can be accomplished by having the shoe proper a separate casting, carried on a supporting head attached to the brake hangers. A set screw on the hanger operating against a lug in the side of the shoe will hold it securely in place. By loosening this set screw the worn shoe may be removed around the periphery of the wheel and a new one dropped into

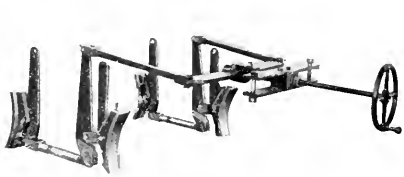


Fig. 8. Horizontal Screw Type Brake Rigging for Inside Frame Type of Locomotive

place. This work can be done from above and requires only 15 to 20 minutes to change a complete set. Cast steel shoes are found to be most satisfactory, because in addition to the longer life they exert a dressing action on the wheel tread.

Every locomotive should be equipped with ample sand boxes and arranged so that the rails may be sanded ahead when running in either direction. The operating levers should be within easy reach of the motorman and the valves positive in their action, else

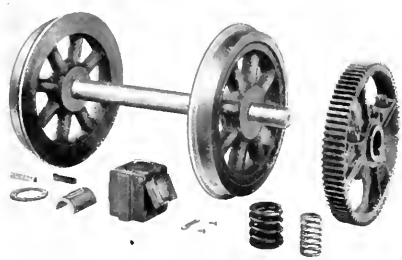


Fig. 7. Steel-tired Tpye Wheels, Axle, Gear, Journal Box and Single Journal Spring for Inside Frame Type of Mine Locomotive

on failure to close the motorman might be without sand when it is very urgently needed. The sand pipes feeding on to the rails should be constructed of some flexible material so as not to be broken off when the locomotive is derailed, or by coal and rock on the track.

Electrical Equipment

A controller with four "on" positions, two for each direction of motion, one with motors in series and one with motors in parallel, has been found to give ample flexibility. The controllers are usually of the magnetic blow-

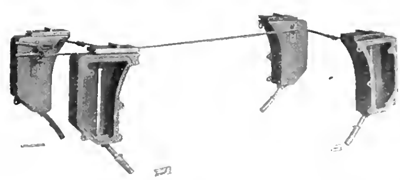


Fig. 9. Sand Boxes and Rigging for Outside Frame of Steel Plate Locomotive

out type and designed for the extremely rough and arduous service which they have to undergo in coal mine work. The main and reverse cylinders should be so interlocked that it is impossible to operate the reverse unless the main cylinder is in the "off" position. This latter cylinder provides for speed regulation with the motors in series or parallel. This system permits of starting the motors in parallel, and of exerting their maximum tractive effort in starting the load independently of each other, so that the slip-

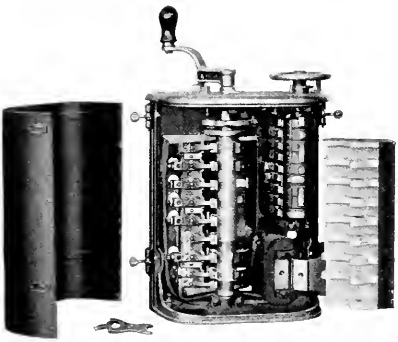


Fig. 10. Interior View of a Mining Locomotive Controller

page of one motor does not affect the other. This is a valuable feature where heavy trains are handled. The series connection effects a considerable economy in current consumption, since the locomotive will develop a given draw-bar pull with one half the current required with the motors in parallel; the speed of course being reduced in approximately the same ratio. Without this series connection, operation at slow speed when gathering or going around bad curves and over bad sections of track would have to be accomplished by means of the rheostat at a considerable waste of energy. When the operating handle is in the "off" position all parts of the motor and rheostat equipment should be dead and the controller should not allow of the practice of "bucking" the motors, which is quite a common method with motormen for retarding the train. It is very injurious to the motor equipment and liable to cause trouble. Large contact blocks and fingers are essentials for durability, and the latter should have some means for easily adjusting the pressure. All segments and fingers should be easily removable so that their replacement can be made in the shortest possible time and with the least amount of trouble.

The rheostat should be so arranged as to be easily accessible and replacement accomplished with the minimum amount of time and energy. The size of the rheostat depends upon the size and voltage of the locomotive, a complete equipment ranging from three to eight boxes, each box consisting of from 25 to 35 grids. The grids are usually of cast metal, arranged on three steel tie rods with an insulating sleeve of mica and mounted between cast iron or pressed steel end frames. These frames are provided with lugs, thus allowing a number of boxes to be assembled together to form one unit, and in case of burn-out to permit a complete set to be mounted in the locomotive in very short time. The grids should have ample cross section and space between sections to facilitate ventilation, and staunch construction is imperative owing to the severe requirements.

The design of the trolley is dependent usually upon local conditions, but that most extensively used and adopted as a standard mine trolley has the trolley wheel mounted in a swiveled harp which permits of its alignment with the trolley wire irrespective of the direction of the trolley pole. The wooden trolley pole is inserted into a swivel base which fits into a socket on either side of the locomotive, thus permitting use on a system with trolley wire strung on either side of the track. The swivel base contains a spring which keeps the pressure of the wheel against the trolley practically uniform throughout the limits of vertical variation, and the swivel harp permits of wide lateral variation. The pole, being of wood, is an insulater, and connection is made to the motors by means of a flexible cable fastened to the pole and terminating in a contact plug which fits into a socket on the locomotive. The trolley pole should be so located as to be easily handled by the motorman without having to leave his position, because in reversing the motion of travel of the locomotive the pole should always be swung around so as to be trailing, thus avoiding the liability of breaking the pole against the roof or crossovers, as well as injury to the motorman from being hit with the pole.

To protect the electrical equipment of a locomotive from excessive overloads or short circuits, either a fuse or magnetic blowout breaker should be used.

The use of gathering locomotives equipped with either cable reels or crab devices for handling cars between the working chambers and the main or cross entries is now recognized as the most efficient method of operation, and the employment of mules for this work is rapidly becoming obsolete. The high cost and maintenance of mules, their rapid depreciation and the fact that one locomotive will replace several mules leave no logical reason for retaining them in the mines for this work. Furthermore, in mines where the veins are thin it is frequently necessary to increase the height of the roof along the roadway to permit of the use of even the smallest animals. This involves a heavy increase in development charge, which, by using the gathering locomotives, is not required. Moreover, the locomotives are capable of handling larger numbers of cars, thereby materially increasing the output without any additional development work.

There are two types of cable reels used on gathering locomotives, the power for driving the reel being furnished through chain and sprocket from the locomotive axle, or by an electric motor. With the former method the sprocket is driven through clutches and friction disks, and the speed of the reel is to a certain extent dependent upon the speed of the locomotive. When unwinding the cable the reel is disconnected from the driving device by means of the clutch and the speed has to be controlled by a brake in order to prevent the reel from unwinding too fast and allowing more cable to be run off than is required. When running out from the chambers the

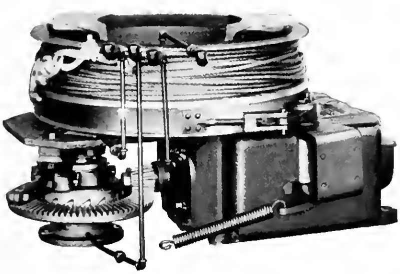


Fig. 11. A Motor-driven Cable Reel

clutch is thrown in, but the speed of the reel is dependent on the speed of the locomotive wheels and axles, so that any slippage (which is a frequent occurrence, inasmuch as the trip out from the chambers is generally loaded) has to be compensated for by releasing the clutch; otherwise the tension on the cable would in many cases be sufficient to break it. This also occurs in going around curves, since the travel of the locomotive does not at all represent the length of cable out. Therefore this method of reel drive offers

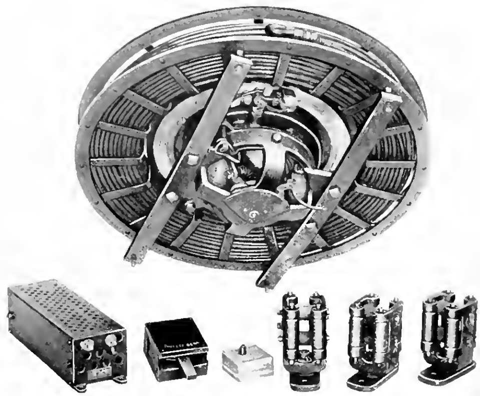


Fig. 12. Motor-driven Cable Reel Complete with Guides, Resistance, Switch, etc.

many disadvantages, the main one being that the motorman's attention is continually necessary in operating the reel and his attention is detracted from the operation of the train and the road ahead.

The motor-driven cable reel is fast superseding the chain-driven type and is a radical departure from it, and its introduction for this service marks a new area in the development of the gathering locomotive. Its approval by practical mine operators and superintendents removed the last objections to the use of locomotives for this class of work and proved beyond a doubt that the simplicity of its construction and operation was clearly apparent to these men.

This reel is usually driven through reduction gearing by means of small vertical series wound motors. It is supported by the motor frame and rotates on a ball bearing between the main gear and the top of the motor. The motor is connected directly across the line in series with a permanent resistance which protects it from heavy rushes of current. A fuse and switch should also be inserted in this circuit, the switch to disconnect the motor from the line when the reel is not being used and the fuse to protect it from short circuit. The motor must have sufficient capacity to permits its being operated for any length of time without overheating.

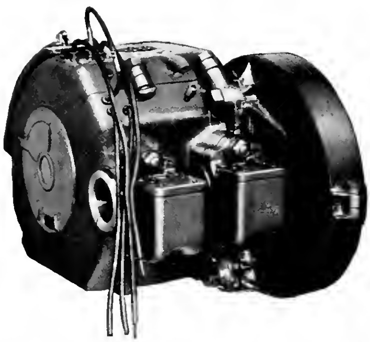


Fig. 13. Split Frame Traction Motor for Mining Locomotive

The reel should have a capacity for enough flexible cable to reach from the trolley wire in the main entry to the end of the deepest chamber. The cable is subject to very rough usage; it is dragged along the road-bed and snapped against the sides of the roadway, so that its insulation must needs be very good. The locomotive end of the cable is connected to some collecting device on the reel, which in the majority of cases is a copper ring on the under side, the current being fed from it to the motor by means of carbon brushes. When leaving a main entry to a chamber the cable is hooked over the trolley wire and as the locomotive moves forward the reel unwinds the cable, overhauling the motor which acts as a series generator with a counter-torque of sufficient amount to keep the cable taut. Owing to this braking effect of the counter-torque the reel ceases to rotate as soon as the locomotive comes to a standstill. When the locomotive starts back in the opposite direction the motor action comes into play and reels up the cable. The tendency of the motor is to produce a peripheral speed at the rim of the reel that is higher than the lineal speed of the locomotive, so that there is a constant tension on the cable which insures its being wound compactly and never being overrun by the motor. The operation is entirely automatic, there being no shifting levers or switches to manipulate, so that the motorman is free to devote his entire attention to the operation of the locomotive.

The motors are, of course, the most essential and important part of any locomotive equipment, and the latest construction in this class of apparatus is the result of extensive experience in the design of motors for mine work. The features that appeal most strongly to the practical mine men and a full knowledge of the severe service required of these motors have been the important factors in their design.

In the construction of the motors for this service the following requirements should always be kept in view:

First. Maximum capacity within gauge limitations.

Second. Continuous capacity.

Third. Accessibility for inspection and repair.

Fourth. Large bearing surface to minimize wear.

Fifth. Protection against dust and moisture.

Sixth. Accurate machining to insure interchangeability of parts.

Seventh. General staunch construction to withstand rough usuage.

All locomotive motors are series wound. The frames are of soft cast steel and the best designs are of split frame type, the two halves being held together by four or five bolts.

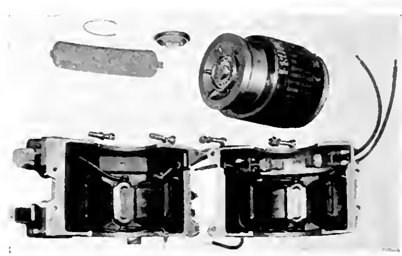


Fig. 14. Split Frame Type Motor shown Disassembled

Splitting the frame has been found to offer the greatest advantages of accessibility for replacing armatures and field coils.

The armatures are supported by separate malleable iron heads which carry the armature bearings. By means of a channeled joint surface, machined on the periphery, the heads are clamped securely between the upper and lower halves of the frame.

The motor is suspended from the lower half of the frame by means of lugs and axle brackets, this form of construction rendering the motor readily accessible for inspection and repair without the necessity of dismounting it or even disturbing the suspension bar. By taking out four or five frame bolts the upper half may be lifted off, exposing the entire interior for inspection. By removing two or three bolts from the gear case the upper half may be removed and the armature taken out. Tapped holes in the bearing plates for inserting eye bolts will greatly facilitate the handling of the armature.

A large handhole is quite essential over the commutator end, through which the commutator and brushes may be inspected, the commutator cleaned, and the brushes renewed. The cover for the handhole should be dust-proof and securely held into place by a cam locking lever. Through this opening and the handhole at the commutator end gauges can be inserted to determine the amount of air gap, thus affording a check on the amount of bearing wear. When the air gap becomes excessive it is an indication that the bearings have been worn and should be renewed to prevent the armature from striking on the pole pieces. The armature and field leads should be heavily insulated and brought through the frame in insulating bushings.

The best method of suspending the motor is from a steel suspension bar which is supported on the locomotive side frames through spiral springs. This spring suspension is a very important feature, because it greatly reduces the shocks on the gearing and bearings, and also the pounding on the rails, thus diminishing the maintenance expense of both track and locomotive.

With this type of motor the removal of wheels and axles is effected with a minimum amount of labor. It is only necessary to unbolt the two axle caps, remove the stay plates and journal boxes and suspend the axle side of the motor with a temporary sling. When the end of the locomotive is lifted the motor will tilt slightly and allow the axle to clear the brackets. The wheels may then be rolled out and a new set replaced without disturbing the suspension bar or disconnecting the wiring cables.

The armature cores should be built up of soft iron laminations to prevent eddy current and hysteresis loss. The armature should be so constructed as to make it possible to remove the shaft without disturbing the windings or commutator. Because of the severe service to which motors for haulage work are subjected, the armature has to be occasionally rewound and the coils should be so constructed that they can be replaced with the minimum amount of labor and expense. To accomplish this the armature coils should be form wound, several coils being bound together to form one poly-coil, which is insulated from the adjacent coils and pressed to exact shape and size in molds. The coils are then covered with the insulating material, which should be of high quality and should give ample protection both electrically and mechanically. The windings can be exceptionally well protected from dust, oil or mechanical injury by extending the pinion end core-head under the end windings with a flange reaching up past the ends of the coils and covering the windings at both ends with a strong canvas dressing securely bound in place. Stout binding wire imbedded flush with the core surface will hold the coils securely in their slots and prevent them from flying out.

Fig. 15. Armature Core and Commutator for Mining Locomotive

The field coils should also be form wound to facilitate replacement and should be amply insulated and protected. The vacuum process of insulation gives the best results. The coils, after being wound on forms, are wrapped with tape and then by means of vacuum process are filled with an insulating compound. After this treatment they are dipped in insulating varnish and wrapped with asbestos tape and thoroughly filled with japan. The coils are dipped several times and baked after each dipping. This method produces a coil which is practically impervious to moisture and very strong mechanically. The coils are compact and solid and fit tightly over the pole pieces, where they are held securely in place by formed spring steel flanges which are pressed against the coils by the pole pieces when the latter are bolted into place.

As the commutator is one of the vital parts of a motor, too much care cannot be taken in its construction or the selection of the material with which it is built. The commutator segments are made of hard drawn copper bars and insulated throughout with mica. They are securely held together by "V" clamping rings which are insulated from the bars with mica cones. The mica between the segments should be made soft enough to wear down evenly with the commutator bars, else the brushes will chatter and cause sparking and pitting of the commutator. It is also essential that the shells and clamping rings be accurately machined to fit the commutator segments perfectly, thus insuring a rigid commutator throughout its life and the prevention of a great deal of commutator trouble. The long life of the commutator is also dependent upon a liberal wearing depth being allowed on the segments.

The brush-holders should be so constructed as to be readily adjusted for the wear of the commutators and for removal and replacement. The carbons brushes slide in finished ways and are held tightly against the commutator by pressure fingers. Independent fingers for each brush give uniform pressure throughout the working range of the brush and allow each brush to compensate for uneveness in the wear of the commutator.

The armature bearings are either ball bearings or babbitt sleeve bearings. With the ball bearings the wear is negligible and continual checking of the air gap to find out if the bearings are worn to such an extent as to allow the armature to rub on the pole pieces, and their continual replacement, are not necessary. This alone is a very valuable feature, for unless the air gap is checked continually the armature may strike the pole pieces, the result being short circuits and an endless amount of trouble and delay. Specially in the case of a main haulage locomotive is this a very serious matter. If babbitt bearings are used, the sleeve supporting the babbitt should be of bronze and so constructed as to support the armature from the pole pieces, even when the babbitt is all worn or melted out. This, however, does not necessarily prevent the condition referred to above, for when this is known to be the case by the motorman they become careless in checking the air gap, the result being that perhaps the armature may run for days on the sleeve and wear it down to such an extent that the armature will rub on the pole pieces.

The axle linings are made of a special heavy bronze and are lubricated from oil cellars filled with saturated waste. The aim should be to provide bearings on all motors of the largest possible size compatible with good engineering practice, because experience has shown that large bearings greatly minimize maintenance and wear.

(To be Continued)

INDUSTRIAL CONTROL

Part II

ACCELERATING CHARACTERISTICS OF CENTRIFUGAL PUMPS AND FANS

By B. W. Jones

Industrial Control Department, General Electric Company

In this, the second part of our series on "Industrial Control," the author emphasizes how the different load characteristics affect the amount of control apparatus necessary in the case of centrifugal pumps and fans. This type of apparatus is only selected as an example. A great deal of useful data are given in the curves and table which accompany this article.—Editor.

One of the important factors in the industrial control field is the way in which the details of the control apparatus are made to suit the characteristics of the driven load. The centrifugal pump and fan have been selected as one of many types of apparatus which will well illustrate the importance of this application of details. There are many interesting features about centrifugal pumps and fans relative to speed regulation, etc., but only their characteristics during starting and their relation to the control will be considered.

The speed torque characteristics of a motor while starting a centrifugal pump depend upon two factors; first, the internal characteristics of the pump, and second, the external conditions under which the pump is to operate.

The internal characteristics of a centrifugal pump are discussed by Mr. Maxwell W. Day in the September, 1912, issue of the Review. A pump with a flat characteristic is compared with one with a steep characteristic and it is shown that the former type changes its load more rapidly than does the latter with a given change in speed. Assuming a 5 per cent decrease in speed for both pumps, and identical external conditions, it is shown that the flat characteristic pump ceases entirely to discharge, while the steep characteristic pump continues its discharge. However, since it would be difficult for many to determine the characteristics of a pump for which they are proposing control equipment, it has become the practice to provide for the worst condition, which is found with a steep characteristic pump.

The external conditions under which the pump may be worked are many, but two extreme cases will be considered, with the effect of each upon the amount of control apparatus required for starting the driving motor. First, the pump may be discharging against a very low static or actual head, the friction head being the principal factor. A pump used for dredging is a good example of this condition. Here the pump starts discharging at a very low speed and the speed-torque requirement of the driving motor is shown in Fig. 1, Curve A. This is the worst starting condition and requires the largest amount of control apparatus to keep the starting current peaks below a required amount. The second extreme case to be considered is that of a pump discharging against a very high static or actual head, the friction head being the minor factor. A centrifugal pump used for pumping water out of a deep mine where the lift is several

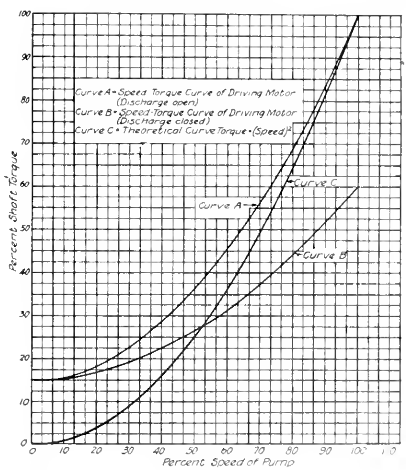


Fig. 1. Speed-Torque Curves of Centrifugal Pump During Starting Period

hundred feet is a good example of this condition. A check valve or a foot valve is placed in the pipe line and this is seated when the pump is at rest. When starting, it is necessary for the pump to reach a high enough speed to produce sufficient pressure not only to counteract the gravity pressure but also the inertia of the column of water in the pipe. The motor speed at which this valve will open depends upon whether the pump has a flat or a steep characteristic curve, a good average being 90 to 95 per cent speed. If this valve or the discharge opening be kept closed then the speed-torque characteristic of the driving motor during starting is shown in Fig. 1, curve B. If the number of starting points does not exceed four and the above high static head obtains then the accelerating characteristic curve of the motor will follow curve B, Fig. 1, because the last accelerating contactor will be closed before the valve opens. This is the best starting condition and requires the least amount of control apparatus for the motor in order to keep the starting current peaks below a required amount. Table I well illustrates this point.

Between these two extreme limits there are an infinite number of intermediate conditions, and as most pumping outfits come between these two limits intermediate conditions relative to the control equipment and electrical results should be expected.

What has been said of centrifugal pumps starting up under various external conditions holds true of centrifugal fans. If the fan discharge is fully opened then the speed-torque characteristics of the driving motor during starting is shown in Fig. 2, curve A. If the discharge is fully closed then the speed-torque requirements are shown in Fig. 2, curve B.

Table I shows the maximum current peaks corresponding to a given number of points, first, when the current limit relays are all set for 100 per cent; second, when they are set for current values determined by curve A, Fig. 1; third, when they are set for current values determined by curve B, Fig. 1; and fourth, when they are set for current values as determined by curve B, Fig. 2. The number of starting points as given in the first line for each horse power is that which is recommended. The other line is given for the purpose of showing the maximum accelerating current peaks which would be obtained if one less point were used. These current peaks and number of starting points, however, have been obtained on an assumption that the line voltage and other such factors are constant. If they are not, then the number of points or the current peaks or both will be different. If the line voltage appreciably drops due to the accelerating current peaks, then it may be advisable to use one less number of starting points than that recommended. The column under the 100 per cent current limit relays setting is

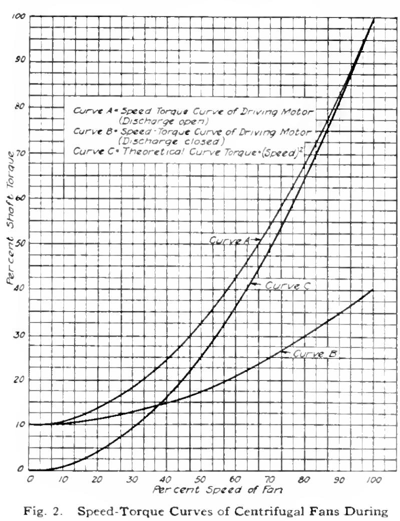


Fig. 2. Speed-Torque Curves of Centrifugal Fans During Starting Period

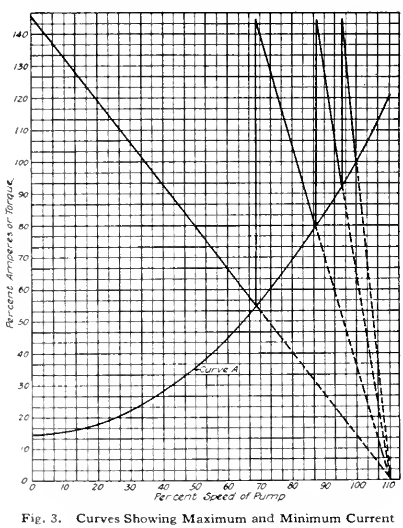


Fig. 3. Curves Showing Maximum and Minimum Current Variations when Starting a Motor Driving a Centrifugal Pump

given solely for the purpose of showing how much is gained by this detailed application. Fig. 3 illustrates the current variations and current limit settings of a four-point starter. It will be noted that the current limit settings are 55 per cent, 80 per cent and 92 per cent and the maximum accelerating current peak is 45 per cent.

Fig. 4 shows a connection diagram of a four-point starter connected to a direct-current motor. For conditions as shown in Fig. 3, No. 2 contactor would be adjusted to close when the line current decreased to 55 per cent full load; No. 3 to close after the current had again decreased to 80 per cent full load; and No. 4 to close after the current has again been reduced to 92 per cent full load. The maximum current taken from the line by so adjusting the accelerating contactors and correctly proportioning the resistance is 145 per cent.

It should be noted that if a-c. motors are used then a current limit relay for each contactor should be employed if these results are to be obtained.

Assuming that this same starter be successively connected to five motors each rated 25-h.p., 230-volt, shunt wound: then the maximum accelerating current will be for the first, starting a constant torque load, 170 amperes; for the second, starting a centrigfual pump operating against a low static head, curve A, Fig. 1, 140 amperes; for the third, starting a centrifugal fan with discharge open, curve A, Fig. 2, 140 amperes; for the fourth, starting a centrifugal pump operating against a high static head, curve B, Fig. 1, 120 amperes; and for the fifth, starting a centrifugal fan with the discharge closed, curve B, Fig. 2, 75 amperes. This very pointedly illustrates the marked difference obtained when the several identically rated motors are operated under different starting conditions.

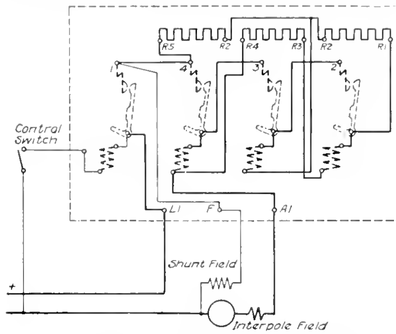


Fig. 4. Connections of Four Point Standard CR-122-B Current Limit Direct Current with Switch Control for 75 and 150 Ampers

In conclusion, it should be noted that it is not sufficient information for the industrial control engineer to know that the motor is to start a centrifugal pump or fan. He should also know under what conditions they will accelerate. Without this information it is necessary to design the control equipment to meet the worst conditions whereas, if the necessary details were known, the equipment might be made to accelerate under the most favorable conditions.

TABLE I

TABLE GIVING NUMBER OF STARTING POINTS REQUIRED FOR ACCELERATING CENTRIFUGAL PUMPS AND FANS UNDER DIFFERENT CONDITIONS

H.P.	Current Limit Relays Set for 100 per cent Current		Centrifugal Pump with Low Static Head or Centrifugal Fan with Discharge Open		Centrifugal Pump with High Static Head		Centrifugal Fan with Discharge Closed	
	No. Points	Maximum Accelerating Current	No. Points	Maximum Accelerating Current	No. Points	Maximum Accelerating Current	No. Points	Maximum Accelerating Current
0– 5	3	202	3	165	2	200	2	180
	2	288	2	250				
10– 25	4	178	4	145	3	140	3	110
	3	215	3	175				
35– 50	4	188	4	150	4	130	3	115
	3	232	3	190				
60– 75	5	176	5	140	4	140	3	125
	4	202	4	160				
80–125	5	183	5	145	4	145	3	135
	4	212	4	170				
135–300	6	179	6	145	5	143	4	110
	5	202	5	163				

1200-VOLT D-C. EQUIPMENT FOR THE PACIFIC ELECTRIC RAILWAY, SAN BERNARDINO DIVISION

By W. D. Bearce

Railway and Traction Engineering Department, General Electric Company

This article is descriptive of the San Bernardino Division of the Pacific Electric Railway. After discussing the general layout the substation equipment is described. The principal features of the motor and control equipments are given in considerable detail.—Editor.

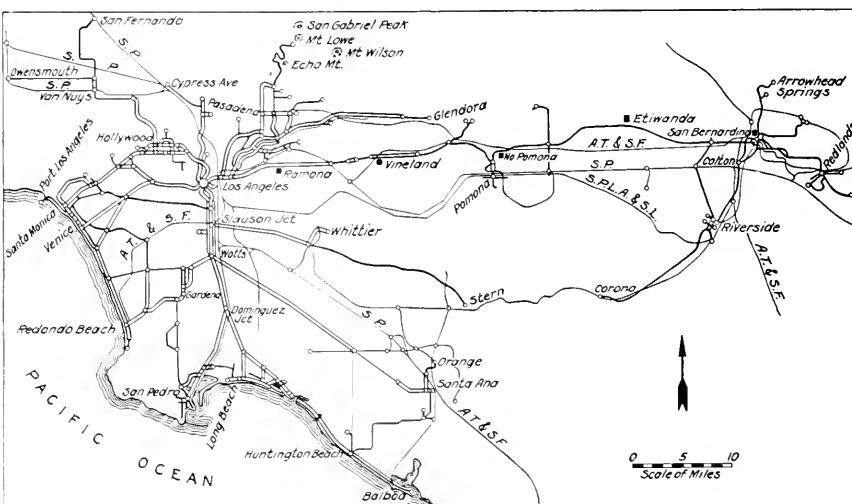
The Pacific Electric Railway System radiating from Los Angeles is the most extensive electric railway property in the world comprising a total of 1045 miles of single track including 11.4 miles of four track line, 284.46 miles of double track, 308 miles of single track and 122.5 miles of spurs, sidings, cross-overs and miscellaneous tracks.

The territory served contains a population of three-quarters of a million people for whom the railroad furnishes facilities for the transportation of large quantities of freight and express as well as city and suburban passenger service.

One of the most completely equipped branches of the system is known as the San Bernardino division connecting Los Angeles with San Bernardino and Riverside some 63 miles directly east. The last section of this division between Ontario Junction and San Bernardino was placed in operation about two years ago. The entire division is double tracked with the exception of about 20 miles. The total length of track on a single track basis now operating under the 1200-volt trolley is 114 miles. No highways are used outside of the cities as practically all tracks are laid on the Company's private right-of-way. The roadway, track and structures closely follow steam railroad standards and curves are laid with long radii and low grades.

This line for its entire length taps a highly developed orchard and vineyard country from which there is an almost continuous harvesting and shipping of various fruits together with subsidiary crops and small fruits. There are now 130 scheduled passenger trains daily of which eight in each direction are first class through trains. Others are local covering different parts of the system.

An extensive freight service is operated between Los Angeles and points east including



Map of Pacific Electric Railway System

approximately 220 cars per day all of which move between midnight and 5 a. m. Interchange connections are provided with all transcontinental steam railroads.

Electric power is purchased from the Pacific Light & Power Corporation operating large hydro-electric and steam plants on a 250-mile system. On a portion of these lines the power is transmitted at 150,000 volts but at Eagle Rock Station it is stepped down to 15,000 volts and sold to the railroad company at this voltage.

All of the railway substations operating at 1200 volts receive power at 15,000 volts, 50 cycles for operating synchronous motor generator sets without further transformation. Substations are located at San Bernardino, Etiwanda, North Pomona, Vineland and Ramona averaging 12 to 15 miles apart. Some of the buildings are of permanent brick construction and others are of sheet metal. Each of these stations contains a 1000-kw., 2-unit motor-generator set delivering 1260 volts direct current.

The sets are of the two bearing type consisting of a three-phase, 15,000-volt, 50-cycle motor rated 1120 kv-a., operating at 600 r.p.m. The direct current generator is a six-pole machine rated 1000 kilowatts at 1260 volts. It is equipped with commutating poles and compensating pole face windings enabling the machine to handle heavy overloads. Arrangement is made in each sub-

Substation at Vineland

station for starting the set from the alternating current end. The 125-volt direct current exciter mounted on one end of the set furnishes excitation for the shunt fields of the generator and the revolving field of the motor.

The pneumatically operated single-pole double-throw switch which is mounted on the frame of the generator is a combined series field short circuiting and equalizer switch. It is connected on the negative side of the machine

1200-volt Substation at Etiwanda

circuit and is therefore at ground potential thus avoiding danger from accidental contact.

The pneumatic feature was adopted to allow for remote control from the same benchboard which operates all of the other d-c. switches and circuit breakers inside the station, and the a-c. horn switches and circuit breakers outside the station.

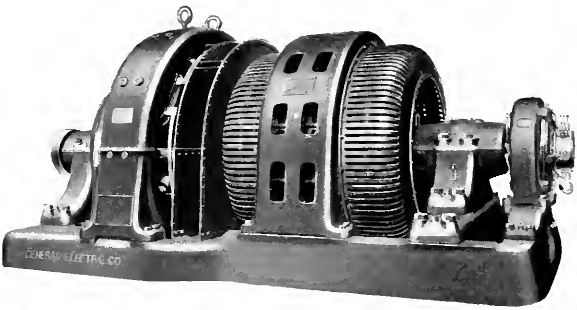
The trolley construction is of a ten-point catenary type with a 4/0 grooved trolley wire. On some parts of the system steel contact wire is being used. The feeder is of 600,000-c.m. copper equivalent aluminum, tapped to the trolley at every third pole. The cross arm carrying the feeder also supports at the other side two telephone lines, one for the dispatcher and the other for the power telephone wire.

New Rolling Stock

The Pacific Electric Company has recently placed new all-steel passenger cars in service on the 63-mile run between Los Angeles and San Bernardino. The car bodies and trucks were designed by the Railway Company and manufactured by the Pressed Steel Car Company. The general dimensions and weights of these cars are as follows:

Length over couplers	59 ft. 7 in.
Width overall	9 ft. 4 in.
Height to top of roof	13 ft. 2 in.
Wheel base of trucks	7 ft.
Weight of car complctly equipped	108,000 lb.
Seating capacity	60

Of the 24 cars, 16 are for passenger service only, six are constructed with smoking compartment and two are combination passenger and express cars. The combination cars are the same as the straight passenger equipments except that a 14-ft. express compartment is included with a corresponding reduction in seating capacity. The underframe of these cars is built up of heavy I-beams and angle irons securely bolted and riveted together forming a stiff structural unit. The side framing and roofing is also of steel angles covered with sheet steel. The interior of the car is finished in mahogany and the inside of the roof and side sheets are lined with heavy hair-felt insulation in order to afford protection against either very high or low temperatures. Combination couplers are used which serve not only for mechanical connection between the cars but at the same time make all air pipe and electrical connections, thus eliminating air hose and electric jumper cables between cars as well as the necessity for trainmen going between cars when making up trains. The maximum swing of the couplers around a 45-ft. radius curve is 60 deg. from the center line of the car.



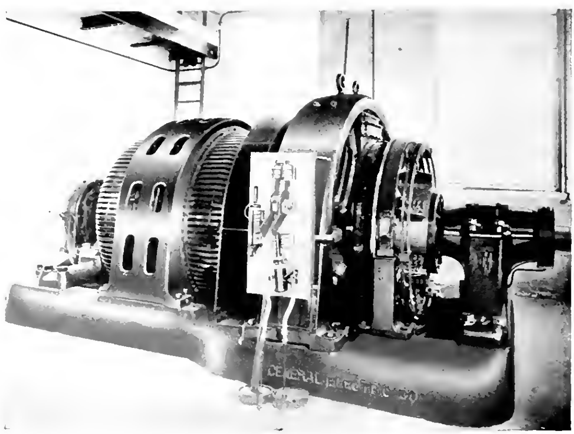
Two-unit Synchronous Motor-generator Set used in 1200-volt Substations

The trucks are of the built-up, double equalizer, swing bolster type with elliptic springs and 36-inch rolled steel wheels. Ball bearing center plates and roller side bearings are also included in the equipment.

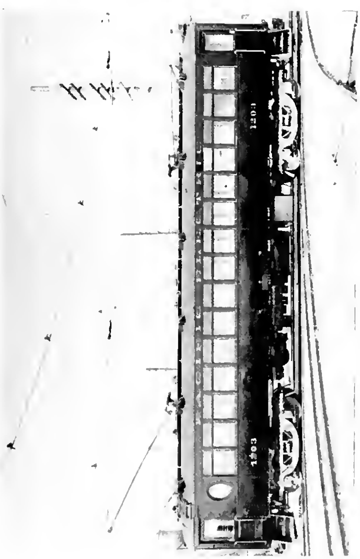
Motor Equipment

The electrical equipment of these cars includes four GE-254 motors geared for a maximum speed of 60 m.p.h. on level tangents. This motor is of the self-ventilating, tapped field, commutating pole type designed for operating two in series on 1200 volts. It has an hourly rating on permanent or tapped fields of 145 h.p. at 600 volts. The gear ratio is 55/24. Solid gears and pinions are used.

The frame is of the box type and has a nose cast integral with it for the suspension of the motor. The armature shaft bearing linings are of bronze, babbitt lined, and the axle linings are of bronze. Oil and waste lubrication is used throughout, and the oil boxes are provided with auxiliary oil wells. The frame



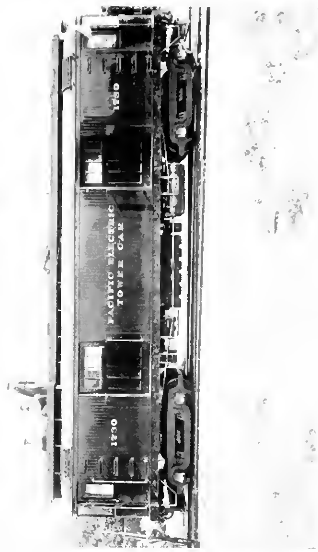
Motor-generator Set Installed in Vineland Substation showing Pneumatically Operated Switch



New 1200-volt Interurban Car Equipped with four GE-254 600/1200 Volt Motors

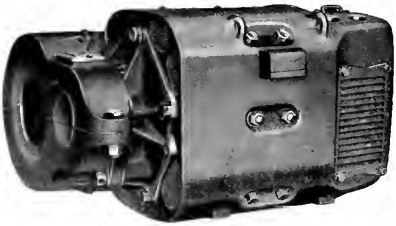
Three-car Train made up of New 1200-volt Cars on San Bernardino Division

Express Car on Pacific Electric Railway Equipped with four GE-222 600/1200-volt Motors



Tower Car on the Pacific Electric Railway Equipped with four GE-205 600/1200-volt Motors heads have drain pockets to retain any oil thrown off by the deflectors on the armature shaft, and all oil boxes are fitted with deep-lipped felt lined covers to exclude dust and water.

The armature shaft can be readily removed if required and has the bearing surfaces



GE-254 Ventilated Railway Motor

ground and rolled which gives a very smooth surface. The axle is enclosed between the bearing caps by a sheet steel dust guard.

Field coils are wound of strip copper insulated between turns with asbestos and impregnated with insulating compound by the vacuum process. The coils are held in place by spring flanges.

The motor is fitted with the G-E multiple system of ventilation. Air is drawn into the frame at the commutator end by a double fan mounted on the pinion end armature head. On entering the frame, the air divides into two streams, one passing around the armature and field coils and the other through the commutator shell and armature core to the fan. Both streams are exhausted to the atmosphere through common openings provided in the end of the frame at the pinion end. In this manner air is introduced almost directly into the armature core from the atmosphere and by traversing the length of the motor only once permits practically all parts to be effectively cooled by air at atmospheric temperature. This method of ventilating is giving excellent results and enables a high service capacity to be obtained.

Control Equipment

Each car is equipped with relay automatic, double end, multiple unit control using both magnetically and pneumatically operated control apparatus suitable for 600-1200-volt operation. The equipment embodies several special features designed to meet the requirements in interurban service and to give the maximum safety in operation.

The master controller is designed to permit the operation of as many as five equipments in multiple and is provided with a "deadman's release" handle and pilot valve which shuts off power and applies the air brakes when the motorman removes his hand from the handle.

The contactors are of the magnetic type and two magnetically operated, quick acting line breakers are used to establish and break the main line circuits. These line breakers are equipped with powerful magnetic blowouts and their effectiveness reduces the number of contactors necessary to ten. They also perform the additional function of circuit breakers by operating in conjunction with overload trip coils. They are wired in the circuit in such a manner that each carries one half the motor current and, as they establish and break the main line circuits, take most of the burning due to arcing, and therefore burning on the remainder of the equipment is reduced to a minimum. They are installed in a containing box separate from the remainder of the equipment and are conveniently located for inspection and repair.

For maximum speed operation a pneumatically operated switch is provided for tapping the motor fields. This switch is controlled by the master controller and is operative only after the circuits have been arranged for full parallel operation and interlocks are provided to prevent field tapping in any other position.

A pneumatically operated commutating switch arranges the motor circuits for full speed operation on 600 volts as well as on 1200 volts. It is controlled by combined switches and valves conveniently located in each vestibule. This switch also performs the additional function of commutating the dynamotor compressor and heater circuits, thus giving the equipment the desirable feature of having all circuits commutated by a single unit.

The control and light circuits are energized at 600 volts from the dynamotor compressor, and a protective relay is provided to prevent any possibility of 1200 volts being placed upon them.

For train operation with trailers and motor cars a 600-volt bus line is installed for feeding low-voltage circuits. When operating on 1200-volt sections this bus is energized from a dynamotor compressor and a selective relay is provided to prevent any possibility of its being connected to more than one dynamotor compressor at a time.

At a number of points on the system the 1200-volt overhead is crossed by 600-volt lines and at these points a relay on the car equipment automatically opens the motor circuits, thus preventing 1200-volt arcs being drawn across the 600-volt lines. In trains of three or more cars the motor cars on each side of the section insulators will be drawing current and motoring while the car just crossing the insulators will be inoperative.

The heating equipment consists of twelve 500-watt, 1200-volt heaters connected in series on 1200 volts and in two groups of six in series on 600 volts, changes in connections being made by the commutating switch previously mentioned.

Each car is protected by a 1200-volt aluminum cell lightning arrester enclosed in a separate compartment conveniently located on the equipment.

In addition to the new passenger equipment there are also two new express cars each equipped with four GE-222-D 600/1200-volt motors and Type M control and a tower car equipped with four GE-205-E 600/1200-volt motors and Type MK control.

ELECTROSTATIC NEUTRAL IN THE 2-PHASE, 3-WIRE SYSTEM AND DANGER UNDER OPERATING CONDITIONS

By D. H. Moore

Testing Department, General Electric Company, Pittsfield, Mass.

This article contains a great deal of important data that should be more generally known among engineers concerning the electrostatic neutral in 2-phase 3-wire systems. The general conditions prevailing in such a system are discussed and the results of some most useful tests are given. The importance of the results obtained lie in the fact that a knowledge of them may lead to avoiding fatal accidents.—Editor.

There is a quite common misunderstanding among engineers regarding the location of the electrostatic neutral in a 2-phase, 3-wire system, the general supposition being that the electrostatic neutral is located at the common, or connection, point of the phases. This misunderstanding is due, perhaps, to our more general acquaintance with 3-phase Y systems, in which the electrostatic neutral is located at the neutral or common point of the three phases.

Two-phase, 3-wire systems are generally operated non-grounded for the reason that the stress upon the system as a whole is a minimum, and also because it is best from a standpoint of safety. The grounding of any point will raise the stress upon some other portion of the system beyond the value obtained with no ground.

In a 2-phase, 3-wire system having a line voltage of 2300 volts, the theoretical voltages with different conditions of grounding are as follows:

	Voltage	Per Cent Phase Voltage
All Conditions of Grounding		
Phase 1-2	2300	100.0
Lines 1-3	3250	141.6
Phase 2-3	2300	100.0
Non-grounded		
Line 1 to ground	1710	74.5
Line 2 to ground	1085	47.2
Line 3 to ground	1710	74.5
Common Wire Grounded		
Line 1 to ground	2300	100.0
Line 2 to ground	0	0.0
Line 3 to ground	2300	100.0
Mid-point of One Phase Grounded		
Line 1 to ground	1150	50.0
Line 2 to ground	1150	50.0
Line 3 to ground	2570	111.5
One Outside Wire Grounded		
Line 1 to ground	0	0.0
Line 2 to ground	2300	100.0
Line 3 to ground	3250	141.6

The above are shown diagramatically in Fig. 1.

Current Flowing to Ground

If a low reading ammeter be connected between either line 1 or line 3 and ground in a 2-phase, 3-wire non-grounded system, a certain amount of current will be indicated, depending upon the system; that is, whether it is of high or low capacitance. With an alternator alone, the current will be of small value, but if the alternator is connected to a power distributing system having lead sheathed cables carrying current to step down transformers, the current will be appreciable.

In order to determine what this current would be in a system of high capacitance, tests were made in the Pittsfield Works' power station. The buses in the power station, while tests were being made, were fed from a 2-phase, 500-kv-a. 2300-volt, 4-wire, 60-cycle turbo alternator. The buses were connected through oil switches to the distributing mains, having single and three conductor lead covered cables connecting to step-down power transformers (shell type, mainly), located in different parts of the factory. At the switchboard the two middle wires were connected together to form a three-wire system. A 10-kv-a. transformer having a voltage ratio of 10 to 1 was connected between each outside bus and ground. The transformer was placed between the buses and ground, instead of connecting an ammeter directly between the buses and ground, because it was not considered advisable to suddenly ground the system. Fig. 2 shows the arrangement of meters, transformers, etc. used in this test. The current was varied by changing the resistance of the water rheostat connected across the low voltage winding of the 10-kv-a. transformer. The following readings were obtained:

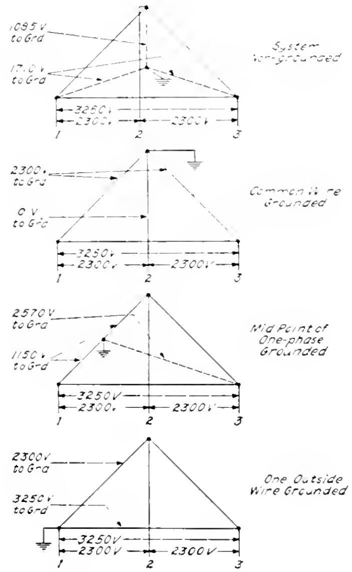


Fig. 1. Diagram of Voltage to Ground with Different Conditions of Grounding on a Two-Phase, Three-Wire System

Bus No. 1 to Ground

Line Voltage, Bus No. 1 to No- 2, 2358 Volts

Measured Voltage	Charging Current to Ground
1738	0.
1612	1.4
1506	2.05
1390	2.605
1274	3.205
1194	3.505
1120	3.755

Bus No. 4 to Ground

Line Voltage, Bus No. 4 to No. 3, 2344 Volts

1768	0.
1638	1.42
1530	1.95
1436	2.55
1316	3.095
1204	3.525
1098	3.905

From the foregoing data, values of resistance were calculated, and Fig. 3 plotted, showing the relationship between voltage and current as ordinates and resistance as abscissae. By extending the current curve from the points plotted to the point of zero resistance, the maximum value of current was obtained. In this system this amount of current (6.25 amperes) will flow if either of the outside lines are grounded by a connection of zero resistance.

Danger of Making Bodily Contact with a Circuit of Large Capacitance

In a circuit having a large amount of capacitance to ground, there is danger in making bodily contact with any of the lines, and particularly either of the outside lines. The system as a condenser (one terminal of which is the line, the other the ground, and the dielectric the insulation of the cables, alternator, and transformer windings) is discharged through the body. Whether the victim of an accidental contact will be badly burned or fatally shocked depends a great deal upon the contact made. In any event it is not safe to work upon or near such lines unless every precaution is taken to prevent any possibility of accidental grounding by bodily contact.

Before these tests were started, it was thought that the current at the moment of discharge of the system would rise to a value several times the normal charging current. In order to determine whether or not the discharge was oscillatory at the moment of making bodily contact with the circuit, an oscillogram of voltage and current under parallel conditions was taken. A non-inductive resistance unit having an a-c. resistance of 3016 ohms and a current carrying capacity of 1 ampere was made up. The value of resistance to use was determined by making actual measurement of resistance upon six subjects.

Resistance Measurements of the Human Body

First the measurements were made by a wheatstone bridge, one electrode being placed high up on the forehead, and the other grasped tightly with both hands. The resistance varied in this case from 8500 to 35,000 ohms, the average being 16,900 ohms.

In order to obtain an idea of the resistance of the scalp, measurements were taken with the electrode held in the mouth against the tongue. In this case the resistances were very much less, the average being 2830 ohms, with a maximum of 5000 and a minimum of 1800 ohms.

The difference between the reading obtained with the electrode in the mouth and electrode on the forehead will give the approximate resistance of the scalp, which is very high. The area of the electrode on the forehead was small, but it is easily seen that most of the resistance is in the skin.

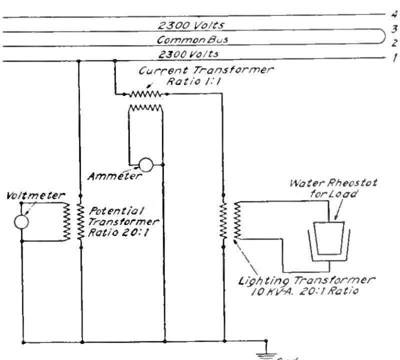


Fig. 2. Diagram Showing How Voltage Measurements were made with Current Flowing to Ground

The resistance measurements from hands to feet were taken with the wheatstone bridge. One electrode was an iron pipe held tightly with both hands, and the other was a piece of tinfoil on which the subject stood with shoes removed.

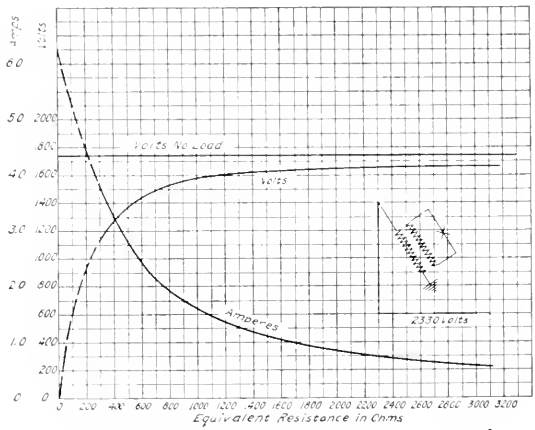


Fig. 3. Curves of Voltage and Current from Line to Ground for a 2300-volt Two-Phase System

Measurements were then made with 60 cycles a-c. 21.4 volts, by the drop of potential method. The resistance in this case was very much less.

The electrode on the forehead was approximately ½ inch in diameter, held tightly against the forehead by rubber bands. The other electrode was a ¾ inch iron pipe. This was held tightly with both hands.

Oscillograph Tests

The resistance unit was then placed in the circuit as shown in Fig. 4, in series with the shunt having a resistance of 7 ohms (to get the current for the oscillograph), making a total resistance between line and ground of 3023 ohms.

The oil switch in the circuit shown in Fig. 4 was closed several times in succession, and readings of current and voltage obtained. The average of these readings, with 2300 volts held across bus 1 to bus 2, and with generator running at 60 cycles was:

Voltage, Bus No. 1 to ground, 1662 volts.
Current, Bus No. 1 to ground, 0.55 ampere.

Voltage and current waves were then obtained at the moment of closing the oil switch. Both the voltage and current waves show a ripple at the start of each wave, and near the peak of each succeeding half cycle. The former is due to the closing of the oil switch, and the latter is a slot harmonic inherent in the design of the generator.

The oscillogram, Fig. 5, shows that there is not a sudden rush of current when the circuit is suddenly connected to ground, through a resistance of approximately 3000 ohms, which is comparable to the resistance of the human body as measured above. However, it should be kept in mind that practically all of the resistance of the human body is in the skin, and that as soon as the surface is burned at the points of contact, the resistance will decrease greatly, and permit a much larger current to flow. In this case, a maximum of 6.25 amperes is possible.

It should be noted that in two systems having the same line voltage and capacitance to ground, but operating at frequencies of 25 and 60 cycles, the charging current increases directly in proportion to the frequency of operation, and that the current flowing to ground will be proportionately larger in the latter system.

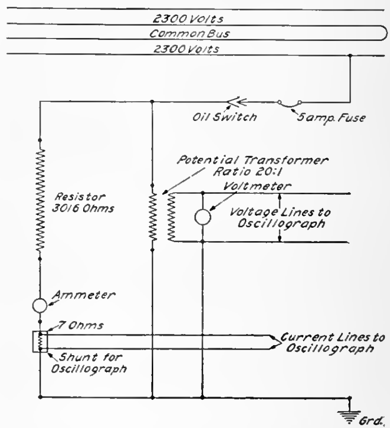


Fig. 4. Diagram of Connections for Oscillographic Test

Wheatstone Bridge Method, A-c., 60 Cycles, Drop-of-Potential Method, 21.4 Volts

Subjects	Forehead to Hands	Tongue to Hands	Hands to Feet	Forehead to Hands
1	15,000 ohms	2400 ohms	20500 ohms	3100 ohms
2	35,000 ohms	2990 ohms	..... ohms	4700 ohms
3	19,000 ohms	5000 ohms	12500 ohms	2500 ohms
4	10,000 ohms	2600 ohms	..... ohms	2100 ohms
5	14,000 ohms	1800 ohms	7200 ohms	4600 ohms
6	8,500 ohms	2200 ohms	..... ohms	1900 ohms
Average..	16,900 ohms	2830 ohms	13400 ohms	3150 ohms

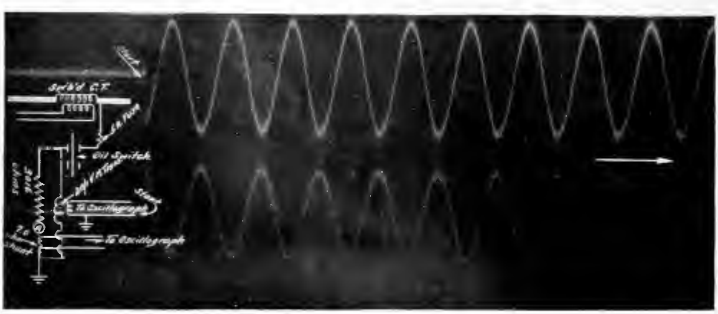


Fig. 5. Wave of Voltage (1662) at Top, and Current (0.55) at Bottom from Oscillographic Test

THE GAS-ELECTRIC SUCTION STREET SWEEPER

By W. S. Leggett

Cincinnati Office, General Electric Company

This article is descriptive of the construction, operation, and results of the "Waycleanse" street sweeper The development of this device marks a decided step in advance over the hand broom, the horse-drawn sweeper, and the flushing machine, in that it not only removes all the kinds of debris collected by the earlier types of cleaning appliances but, in addition, removes the fine densely germ-laden dust.—Editor.

It is a remarkable fact that very little real progress has been made in the cleaning of city streets. Practically the same methods are used today that were in vogue a decade ago. To be sure, the cost of removing the heavy litter has been greatly reduced by the use of flushers and power sweepers, but the fact remains that no advance has been made in the gathering of the harmful fine dust. This dust is left to be blown about by winds and fast moving vehicles.

Everyone is familiar with the common household vacuum cleaner. Since this device came into general use numerous inventors have tried to solve the street-cleaning problem with a huge vacuum cleaner, but with little success because of the great difficulty in separating the dust from the large volume of air that has to be handled. Water screens and jets, furnaces for burning the refuse, and many other schemes have been tried in an unsuccessful attempt to surmount this obstacle. It remained for Mr. Bernard Kern to evolve a final design of suction street-sweeper that really works under all operating conditions. After many years of experimenting he has succeeded in solving all the problems pertaining to this type of machine such as dust separation, gutter sweeping, and ease of control; and he now has in successful operation machines that are practical in every respect.

Mr. Kern's first experiment was made before the day of the automobile as we now know it. Therefore, it is interesting to note that he built a fairly successful steam-driven machine, shown in Fig. 1. This was purely an experimental machine and was discarded as unsuitable. His next attempt was with an electric storage battery driven machine, but this was discarded because of a lack of power and mileage. Mr. Kern's final and successful machine is of the gas-electric driven type.

This latest development is designated the

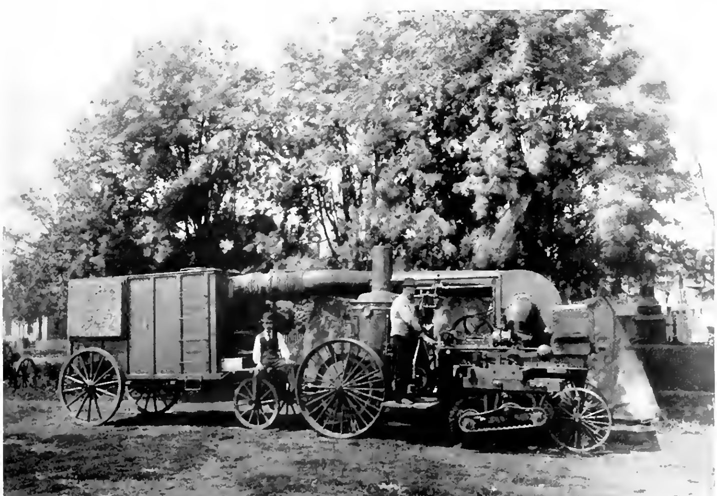


Fig. 1. Experimental Steam-Driven Machine

Fig. 2. Gas-Electric Street Sweeper

Waycleanse Suction Street Sweeper; it consists of a tractor and a trailer. The tractor carries the power plant, driving mechanism, and sweeping machinery: the trailer carries the dust separating mechanism and the dirt container. A better conception of the tractor and trailer will be obtained by reference to Figs. 2, 3, 4, and 5.

Fig. 3 Gutter Sweeper & Follow Up Sweeper in Operation

Referring particularly to the tractor, the power plant shown in Fig. 6 consists of a 7½-kw. 125-volt generator, direct connected to a 4-cylinder, 4-cycle, heavy-duty type marine engine. This engine is governed to run at a constant speed of 900 r.p.m. This power plant supplies current to a traction motor, the dust-separator motor on the trailer, a fan motor for drawing cooling air through the engine radiator, and a compressor motor for supplying compressed air for gutter sweeping. This last motor is not common to all equipments, but to the ones that are especially fitted for gutter cleaning.

The traction motor is shown in Fig. 7 and is a series-wound automobile type motor. This motor drives the rear wheels through a silent chain first-reduction, and a worm gear second-reduction. The total reduction from the motor to the rear wheels is approximately 30 to 1 so that the available torque for heavy pulls and grades is enormous. As a matter of fact it has been impossible to stall the loaded machines on the most severe grades about Sandusky, which illustrates the importance of the large gear reduction.

The traction motor is controlled by an enclosed drum-type controller which is mounted directly beside the operator. Also, adjacent to the operator is a switchboard to which is run all of the wiring from the various auxiliary motors and lights. The operator is therefore able to control any part of the whole mechanism without leaving his seat. This would be impossible with any kind of drive other than electric drive.

It has been noted that the engine drives a generator which supplies current to various motors on the sweeper. This engine also drives a countershaft which, in turn, drives the suction blower and the revolving broom through chains. The engine, being governed for constant speed at all loads, drives the broom and suction blower at the constant speeds which are most effective for sweeping. The drive is therefore a combination of gas-electric drive and straight mechanical drive, the gas-electric drive being applied to such parts of the mechanism as could not possibly be driven mechanically without great complication. In fact it would be impossible to obtain the wide range of vehicle speeds required by various pavement conditions,

Fig. 4. Showing Method of Dumping Sweepings

Fig. 5. Tractor and Trailer Uncoupled

amounts of dirt to be gathered, etc., and the constant broom, blower, and auxiliary motor speeds with anything but gas-electric drive. This drive has proven a success in every respect. It has simplified the control, has eliminated change gears and other troublesome parts, and has made possible the operation of these sweepers by men not expert in the handling of gasolene engines.

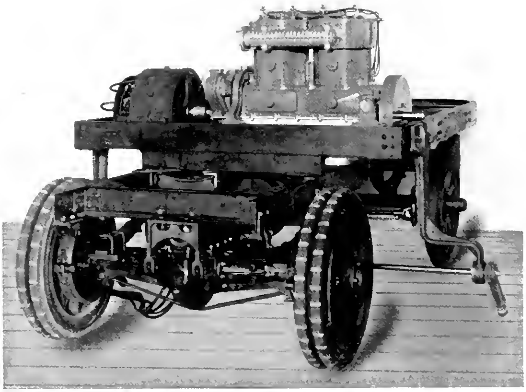


Fig. 6. Power Plant Consisting of Engine and Generator

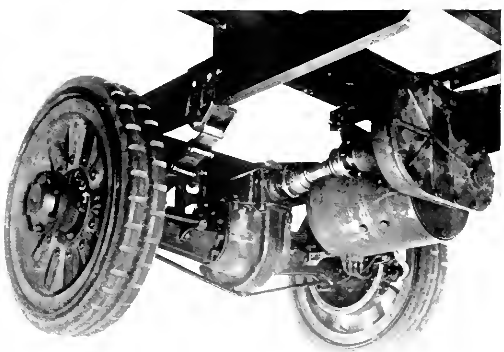


Fig. 7. Traction Motor and Reduction Gearing to Rear Axle

When in operation the sweeper moves along the street at a speed which may range from 2 to 6 m.p.h., depending on the roughness of the pavement and the amount of dirt to be removed. The revolving brush stirs up the dirt and litter, which is drawn into the dirt box in the trailer by the exhaust fan. Here the dust and dirt are completely removed from the air by an ingenious filtration process. This dirt separation is so effective that there is no dust in evidence whatsoever, even when the dirtiest of streets is being swept.

The effectiveness of this sweeper is clearly demonstrated in Fig. 8, in which is shown the dirt that was removed from 27,290 sq. yd. of old brick pavement the day after the same pavement had been cleaned by the city in accordance with old methods. The load consisted of 6580 lb. of litter, sand, etc., and 1628 lbs. of fine flour-like dust. This goes to prove that the old methods of street cleaning are ineffective in that the dust and dirt are merely pushed from the smooth parts of the pavement into the depressions and gutters, from which the wind and the fast moving vehicles scatter it.

Fig. 9 shows a load of sweepings taken from 95,040 sq. yds. of pavement after two days of rain. This proves that rain is not a very good street cleaning agent, as is the popular supposition.

During a 29-day endurance test in Sandusky, 5 miles of pavement were swept daily. From this pavement a total of 129,000 lb. of dirt was removed; and of this total 21,500 lb. was fine flour-like dust.

It has long been realized that the fine street dust is the most harmful part of the street dirt. It not only is a nuisance, but it is a real menace in that it carries deadly germs. It is therefore interesting to note the following analysis of Waycleanse sweepings made by Dr. Schimansky of Sandusky.

Bacteriological examination of Sample No. 1 from asphalt pavement showed a presence of 960,000 bacteria per gram.

Examination of Sample No. 2, consisting of heavy sweepings from asphalt block pavement, showed the presence of 4,300,000 bacteria per gram.

Examination of Sample No. 3, consisting of heavy sweepings from brick pavement, showed the presence of 3,200,000 bacteria per gram.

Examination of Sample No. 4, consisting of the very fine dust from all pavements, showed a presence of 5,600,000 bacteria per gram.

Street cleaning authorities are unanimous in their opinion that ordinary street cleaning methods are ineffective at best. They have found that flushing and scrubbing do not remove the dust, but merely glue it to the pavement or wash it to the gutters. They have learned, too, that flushing is decidedly bad because it permanently injures the pavements and clogs the sewers. They have therefore come to the conclusion that the dry sweeping of the dust by some sort of a vacuum lecaner is the only solution of the problem.

Fig. 9. Load of Sweepings after a Two Days Rain

Fig. 8. Dirt Removed from 27,290 Square Yards of Brick Pavement One Day after Cleaning by Old Method

A COURSE OF LECTURES ON ILLUMINATING ENGINEERING

By C. E. Clewell

Assistant Professor of Electrical Engineering, University of Pennsylvania

From September 21 to 28, 1916, a course of lectures on illuminating engineering is to be held in Philadelphia under the joint auspices of the Illuminating Engineering Society and the University of Pennsylvania. It is significant that this 1916 lecture course follows, after six years, a somewhat similar course which was held in Baltimore under the auspices of the Illuminating Engineering Society and the Johns Hopkins University in 1910. The new course is, therefore, no experiment, but will be the result of careful thought and planning based on the earlier experiences. The personnel of the Committee on Lectures for the 1916 course is, in fact, identical with that of the corresponding committee which was responsible for the success of the 1910 course.

The Field of Illuminating Engineering

The Illuminating Engineering Society defines the term *illuminating engineering* to include both an art and a science. In fundamentals, the scientific side depends largely on the laws of physics and of physiology; while as an art it is chiefly concerned with the applications of scientific principles to the solution of practical lighting problems. The underlying object of illuminating engineering then is to perfect the applications of light, and as such its field is limited only in the extent to which light is used and in the number and variety of interests represented by those who are thrown into more or less intimate contact with the applications of light.

The extent of the lighting field is generally recognized. The annual expenditure for artificial light in this country alone, runs into hundreds of millions of dollars and probably in no case of utilization is the ignorance of the ways and means for accomplishing good results so marked as in that of lighting. The number and variety of interests represented by those who have more or less to do with the applications of light is indicated to some extent by the many sided interests of the membership in the Illuminating Engineering Society, which includes architects; decorators; engineers both gas and electric; opthalmologists; physicists; physiologists; psychologists; the medical profession; employees of lighting companies; managers and salesmen of the lamp and fixture manufacturing companies; managers of buildings, stores, offices, and industrial organizations; technical journalists; faculty members in scientific schools and universities; and municipal and public service commission representatives. This diversity of membership is in itself a very significant indication of the almost universal interest attached to illumination in its various aspects.

The Illuminating Engineering Society

It follows that in a field of such diverse interests there are more than the ordinary reasons for the existence of a national society, and at the same time the nature of its membership introduces additional factors in the actual conduct of its affairs which render them somewhat more difficult than in the case of the national societies of electrical, mechanical and civil engineers.

The Illuminating Engineering Society was formed ten years ago in New York as a national organization for the express purpose of advancing the theory and practise of illuminating engineering and for spreading information related thereto among those constituting this exceptionally wide field of interests. In its original plans, therefore, the society committed itself to educational ideals. Since its organization, the society has gained strength both in numbers and in influence, and it is to-day recognized as the central authority in matters pertaining to light and illumination. In a peculiar manner, the work of this society has benefited the lighting industry as well as the public welfare, and there is no question as to the widespread effect of its educational and co-operative efforts in promoting a better understanding and a more intelligent appreciation of the advantages of good illumination, as evidenced for example by the higher standards in illumination which are found throughout the country to-day in contrast to those of ten years ago.

When the society was organized in 1906 the production and applications of light had of course already become subjects of more or less scientific study, although there were even at that time evidences of many problems in this field which were beginning to be recognized as deserving of special study and investigation. At about the same time and during the years immediately following, new lamps of higher efficiencies became available, and while there was an increasing fund of published information concerning lamps and their use, this information was not co-ordinated and it tended to be fragmentary, because the relations existing between the various phases of this information had not been established so as to unify it and to reduce it to a working basis. In this respect the society has filled an important place by its provision of a common ground for the presentation and discussion of ideas on the best ways and means for the correction of bad illumination practise and for handling given cases in new and hitherto unthought of ways. From a great variety of sources the society has thus brought together into its transactions a wealth of information which forms in the annual volumes a noteworthy series of reference books on the subject.

Activities of the Society

Aside from the transactions, an idea of the work of almost any society may be gained from the activities of its committees. In this respect the Illuminating Engineering Society holds a pre-eminent position. As an illustration, its committee on *Lighting Legislation* has been the medium of assistance to three of the leading states in this country, in the formulation of state rules and regulations covering industrial lighting. The Commissioner of Labor of one of these states made the public statement only a few months ago, that as far as his experience had gone, the Illuminating Engineering Society has been the first national organization in this country to be of professional aid in the practical drafting of such engineering rules. Work of this kind has been conducted by the society for some five or more years.

In an educational way the committee on *Education* has not only made a complete survey of the attention which is being devoted to light and illumination in the high schools and universities, but has drafted our courses of study for the guidance of technical schools, and methods of conducting class work in the elementary institutions. Further, in the matter of popular education, the committee on *Popular Lectures* has done important work in the preparation of authoritative lectures suitable for popular audiences. Other notable activities include the work of the committee on *Glare*, which has made an extended study into methods for avoiding the harmful effects on the eye produced by glare, or misdirected light; the committee on *Research*, which has served in a co-operative manner with individuals and organizations in connection with research work either in contemplation or in progress, which has special features of interest and value in relation to the work of the society; the committee on *Nomenclature and Standards*, which seeks to promote agreement and standardization in the units and terminology of the subject.

Another unique indication of the educational aims of the society was the publication several years ago of a pamphlet entitled: "*Light: Its Use and Misuse.*" Within three years the society published seven editions of this pamphlet involving more than 250,000 copies. This pamphlet is of special interest in its relation to the ideals of the society because it was the result of the work of a special committee rather than an individual, appointed to produce a primer on illumination, and moreover because of its impartial presentation of the elementary principles of illumination. Its widespread acceptance by the public, by manufacturing companies, and by domestic and foreign journals, is an indication of the great need for information of this kind in such form as to be readily understood by the average user of light.

The 1910 Lecture Course

From October 26 to November 8, 1910, the first lecture course held by the society was given at the Johns Hopkins University in Baltimore. The scheme was an entirely new venture. In its original form, the plan was to encourage the establishment of a course of lectures on the general subject of illuminating engineering at one of the technical schools, because the facilities in the educational field available for specialized instruction in illumination were looked upon by the society as inadequate. In the original announcements of the 1910 course, the idea was advanced that such a course would be most appropriately given at one of the universities where graduate instruction is emphasized, and further that as the Johns Hopkins university had regularly offered courses by non-resident lecturers as a part of its system of instruction, the arrangements were readily made whereby the lectures could be given at that institution under the joint auspices of the university and of the society. In this course, the subjects and the scope of the lectures were proposed by the society and approved by the university, and the lecturers were invited by the university upon the advice of the society.

In the 1910 plans, three objects were made the basis for the course (1) to indicate the proper co-ordination of those arts and sciences which constitute illuminating engineering; (2) to furnish a condensed outline of study suitable for elaboration into an under-graduate schools; and (3) to give practising engineers an opportunity to obtain a conception of the science and art of illuminating engineering as a whole. These lectures were eminently successful, particularly in the co-ordination of the arts and sciences which constitute illuminating engineering as outlined in item (1), and in affording the practising engineer opportunities to grasp the various phases of the field as outlined in item (3). The lectures were attended by about 250 men from different parts of the country, many of them from engineering schools and universities as well as from gas and electric central operating companies and from manufacturing companies. Many of those in attendance also followed the excellent laboratory course which was arranged to accompany the lectures.

Subsequent to the course of lectures, the lectures themselves were published in two volumes of about 500 pages each, and the hope expressed by those responsible for the earlier event that these volumes would serve to advance the knowledge of this new and important branch of engineering has since materialized. In its scope and general importance the 1910 lecture course has always been regarded as a most ambitious and eventful undertaking.

A review of the lectures shows that the greater emphasis was placed on the science rather than on the art of illumination. In the six years following, many developments in the lighting field have taken place, typified by new types of lamps and new methods of lighting. Much of the material in the 1910 course may be classed as fundamental theory and hence the usefulness of these earlier volumes has practically not been impaired due to obsolescence other than in the changes in lamps and in those features falling within the scope of illumination as an art.

The Forthcoming 1916 Lecture Course

As a fitting close to his presidential administration of the society's affairs, Dr. Charles P. Steinmetz has planned the new series of lectures for September of this year. This new course is not to be a duplication of the 1910 course, but may rather be looked upon as a supplementary series of lectures dealing more especially with illumination as an art, and covering the many applications of illumination in which much important work has been done since 1906.

The emphasis which is to be placed in this new course on the practical aspects of the subject is not to be construed as a tendency towards a decreasing appreciation of the value and importance of the scientific features of illumination. It has, however, seemed to the committee on whom the responsibility of the new course has been placed, that the greatest need at the present time is for a well balanced presentation of the practical methods of solving modern illumination problems. The lectures will be divided into three general classes: General, Interior Illumination, and Exterior Illumination. The subjects to be treated, classified according to these three divisions, are as follows:

General: (1) The Principles of Interior Illumination; (2) The Principles of Exterior Illumination; (3) Color in Lighting; (4) Architectural and Decorative Aspects of Lighting; (5) Recent Developments in Electric Lighting Appliances; (6) Recent Developments in Gas Lighting Appliances; (7) Modern Lighting Accessories.

Special Lectures on Interior Illumination: (8) The Lighting of Factories, Mills and Workshops; (9) The Lighting of Offices, Stores and Show Windows; (10) The Lighting of Schools, Auditoriums and Libraries; (11) The Lighting of Churches; (12) Theater Lighting (including Stage Lighting) and the Lighting of Art Museums; (13) The Lighting of the Home; (14) Train Lighting.

Special Lectures on Exterior Illumination: (15) Street Lighting; (16) The Lighting of Yards, Docks and Other Outside Works; (17) Headlights, Searchlights and Projectors; (18) Sign Lighting; (19) Building Exterior, Exposition and Pageant Lighting.

The committee on lectures, in charge of the subjects and scope of the lectures, is as follows: E. P. Hyde, Chairman; W. H. Gartley, L. B. Marks, Louis Bell, W. D. Weaver, C. H. Sharp, Secretary.

The administrative committee on lectures having in hand the details of the arrangements is as follows: P. S. Millar, Chairman; C. O. Bond, J. D. Israel, W. J. Serrill, C. E. Clewell, C. L. Law, H. K. Mohr, F. H. Gale, A. S. McAllister, G. H. Stickney.

The university committee representing the University of Pennsylvania in the general arrangements of the lecture course is as follows: Harold Pender, Electrical Engineering; W. T. Taggart, Organic Chemistry; C. E.

Clewell, Electrical Engineering; R. H. Fernald, Mechanical Engineering; G. E. de-Schweinitz, Opthalmology; A. W. Goodspeed, Physics; W. P. Laird, Architecture; and E. B. Twitmyer, Psychology.

A most important feature of the new course is to be the exhibits of lighting appliances and methods, forming a distinct part of the plans, and to be staged in one of the large rooms immediately adjoining the lecture hall in the engineering building of the University of Pennsylvania. The price of tickets for the lecture course has been fixed at $25.00 which includes admission to all lectures and functions connected with the lecture course and reprints of the lectures in the form of a bound volume to be issued subsequent to the course itself. It should be noted in conclusion that this lecture course follows immediately after the general convention of the society, which is to be held this year in Philadelphia. Additional information regarding the details of the lecture course is obtainable from Mr. C. L. Law, Chairman of the Sub-committee on Sales; and from Mr. H. K. Mohr, Chairman of the Sub-committee on Publicity. Mr. Law may be addressed in care of the New York Edison Company at 15th St. and Irving Place, New York City; and Mr. Mohr at 1000 Chestnut Street, Philadelphia, Pa.

A REVIEW OF THE N. E. L. A. LAMP COMMITTEE REPORT

By G. F. Morrison

Edison Lamp Works, Harrison, N. J.

The lamp committee report of the N.E.L.A. always contains most valuable data concerning the present status of the lamp industry and the advances made during the previous year. Mr. Morrison has made an interesting review of this report which, we trust, will be of value to many of our readers.—Editor.

The Annual Report of the Lamp Committee, the publication of which is awaited each year with interest by the members of the lighting business, has grown to be not only an index of the advances in lamp manufacture and distribution, but also a record of good practice in lamp equipment and application.

The 1916 Report is drawn along lines similar to those of the preceding years, which it brings up to date. It contains 50 pages, with numerous illustrations, tables and diagrams. An introduction, briefly reviewing the Committee's work, is followed by a chapter on lamp sales, in which the growth and trend of the lamp business are analyzed. Last year's report indicated a falling off in the number of lamps sold in 1914, as compared to 1913. Owing to the volume of business in the latter part of the year, the 1915 sales not only made up for the deficiency but established a new figure of over 110, 000,000 lamps, 10 per cent above that of 1913. The percentage distribution of the lamps among the Mazda, Gem and carbon, establishes more firmly than ever the pre-eminence of the Mazda, in which class fell nearly 79 per cent of all the lamps sold, "or almost four times the total sales of all other types of lamps combined. It may, therefore, be said that the higher efficiency lamps now practically dominate the field, the sale of carbon lamps having dropped to 5.43 per cent while the sales of the Gem lamp have fallen from 31.41 to 15.68 per cent during the last two years." (See Fig. 1.)

A table (page 729) shows the distribution of sales among the various sizes of multiple and series Mazda lamps. The 25 and 40-watt lamps are the most popular of the multiple class, being followed by the 60-watt, while the 60 and 100-c-p. lamps lead among the series.

"It will be noted that the largest relative gains among the multiple lamps are for the 200 and 300-watt sizes, and that the 20-watt size represents but 2 per cent of the total number of Mazda B lamps sold during the year. In the street series lamps, the sales of sizes below 100 c-p. have declined, while the Mazda C lamps, in sizes above 100 watt. except the 1000 c-p., show relative gains."

A tabulation of the average candle-power and wattage of all Mazda lamps sold for each year since 1907 shows, "that for 1915 there was a considerable rise in candle-power with a slight fall in wattage, the average wattage for 1915 being a little in excess of that for 1913. "It is also interesting to note that the average candle-power of lamps sold during 1915 was 42.23, or nearly two and one-half times the average candle-power represented by the sales during 1907. Dividing this candle-power by the wattage shows the average efficiency to be approximately 0.892 candles per watt, which is an increase over

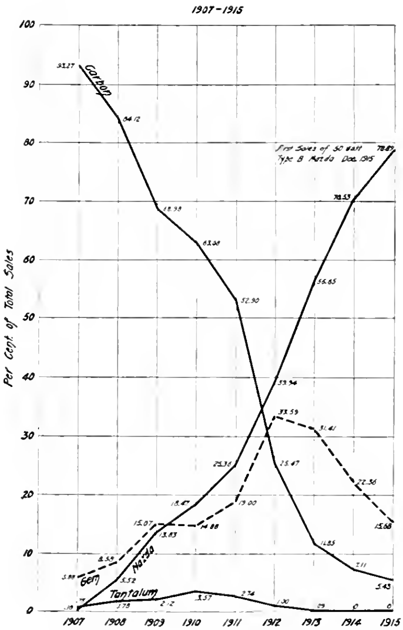


Fig. 1 Curves showing Approximate Distribution of Domestic Incandescent Lamp Sales, 1907 to 1915

1914 of about 10 per cent." Excluding the Mazda C lamps, the candle-power and watts for 1915 are respectively 35.4 and 42.7.

The change in efficiency of each size of multiple (105–125-volt) Mazda C lamps since its introduction, forms an interesting tabular comparison. Such efficiencies are now expressed in mean spherical candle-power per watt, whereas formerly they were expressed in mean horizontal candle-power per watt. Both values are given for the earlier efficiencies so as to be more readily comparable. Another table gives the physical dimensions of lamps standardized during the year.

In the past, the miniature lamps have been considered relatively unimportant from the central station standpoint. However, their use is very rapidly increasing for special decorative effects, imitation candles, etc. Since over 1,000,000 candelabra lamps were sold for such purposes during 1915, it is apparent that they have become a factor of sufficient importance to merit active consideration as a means of service and as a source of revenue. Fig. 2, reprinted from the report, shows the principal forms of Mazda candelabra lamps.

While no startling developments are reported, a large number of minor developments have been made, resulting in considerable improvement of the Mazda C lamps, especially as regards uniformity. The focus type lamps, in which the filament approximates a "point source" have been the recipients of much engineering attention. Such lamps, which have special advantages in the projection of light by lenses and parabolic reflectors, are finding a wide variety of uses in connection with floodlighting equipments, stereopticons, headlights, searchlights, etc. In addition, the application on commercial circuits and the rapid application of electric lighting to automobiles, since the advent of the Mazda lamps, is noted. "It is estimated that 1,500,000 automobiles are now lighted by electricity, while practically all machines made in 1916 are being so equipped."

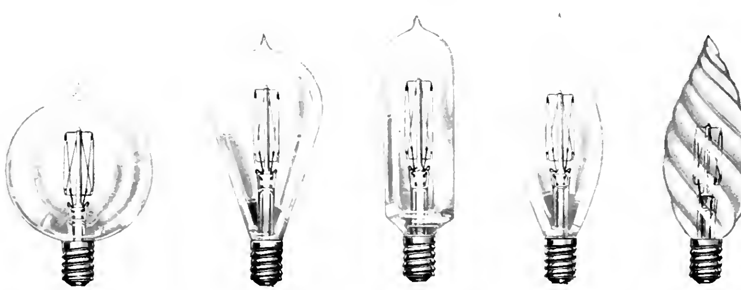


Fig. 2 Principal Forms of Mazda Candelabra Lamps

A very promising application of the focus type Mazda C lamp is for moving picture projection, concerning which it is reported as follows:

"The convenience and safety of the incandescent lamp has brought about a demand for the development of lamps suitable for moving picture projection. In the past the limitation of brilliancy and concentration of light source has rendered it impracticable. The Mazda C lamp, however, greatly increased the possibilities in this direction and ever since it became available the manufacturers have been experimenting and endeavoring to adapt it to this service. Special lamps, reflectors, lenses and other accessories have been developed and while no lamp has yet been standardized, pending the perfection of certain details, practical equipments have been produced which are equivalent in power to the ordinary arc projections, used in the average moving picture theater. As the lamp is of a high current and low voltage, it will have particular advantage on alternating current circuits."

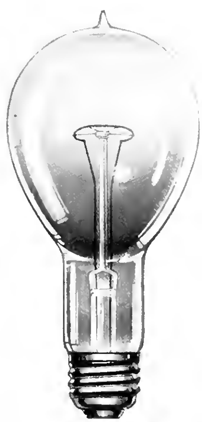


Fig. 3. New 75-Watt Mazda C Lamp

New lamps for regular service developed during the year, include:

(1) 75-watt, 105–125-volt, Mazda C lamp.
(2) 50-watt, 105–125-volt, Mazda B lamp.
(3) 200- to 1000-watt, 220–250-volt, Mazda C line.

The 75-watt lamp, shown in Fig. 3, extends the regular line of Mazda C lamps one step lower. The 50-watt lamp, Fig. 4, meets important central station conditions and is referred to later on.

The subject of fixtures having been fully treated in last year's report, a brief section calls attention to the improvements during the year and the desirability of so locating

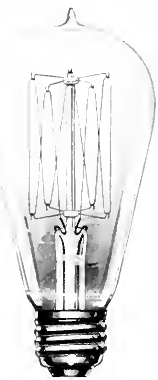


Fig. 4. New Unit 50-Watt Mazda

the filaments in indirect types of fixtures as to avoid circles of light on the ceiling.

In the chapter on applications, central stations are urged to secure proper use of the incandescent lamp, which is now an almost universal illuminant. Attention is called to the large number of improper and inefficient installations, especially of the Mazda C lamps, to be seen on every hand; also to the great improvements that can be secured by the application of illuminating engineering principles. Illustrations show a number of instances of proper installation, while one shows an improper equipment, resulting in disagreeable glare.

Industrial lighting, stage lighting and outdoor sports are fields deserving of special effort. Attention is called to campaigns on industrial lighting by a number of member companies, and to the "Lighting Sales Bureau Report on Industrial and Yard Lighting." The "Safety First" movement and the recent industrial activity have shown the importance of factory lighting. These problems are engaging the attention of government authorities, and regulations are likely to be made on this subject in the near future.

Floodlighting, which has become very prominent during the year, presents many possibilities as suggested by the beautiful

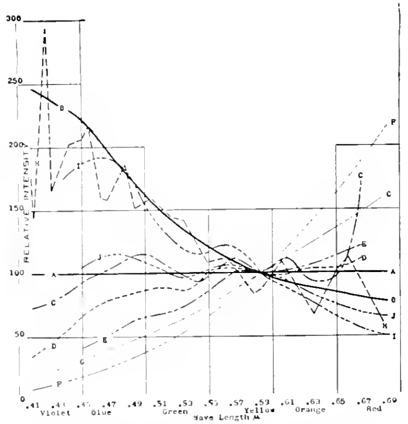


Fig. 5 Spectrophotometric Curves of Color Characteristics Natural light, Artificial Daylight Equipments, and Mazda Lamps

(A) "Black body" at 5000 degrees absolute (equivalent to noon sunlight)
(B) Blue sky (Ives) I.E.S. Transactions, 1910, page 208
(C) Daylight glass with Mazda C lamp (Bradk) I.E.S. Transactions, 1914, page 592
(D) Bluish glass with Mazda C lamp (Sharp) I.E.S. Transactions, 1915, page 220
(E) Blue bulb Mazda C lamp
(F) Mazda B lamp (7.9 lumens per watt)
(G) Mazda C lamp (20 lumens per watt)
(H) Moore tube (Moore) Transactions I.E.S. 1916, page 192
(I) Trutint glass (Luckiesh) I.E.S. Transactions, 1914
(J) Trutint glass (Luckiesh) I.E.S. Transactions, 1914

lighting effects of the Panama-Pacific Industrial Exposition. Two types of reflectors illustrated, take 500 and 250-watt focus type Mazda C lamps, while a third takes the 1000-watt regular lamp. As examples, the lighting of the State House, in Boston, and the Woolworth Tower, in New York, are illustrated, while the following fields of application are listed:

- Athletic fields
- Bathing beaches
- Billboards
- Docks and grain elevators
- Drill halls
- Fire fighting
- Flags
- Freight piers
- Loading and unloading ships
- Logging operations
- Painted signs
- Patrol duty
- Public buildings
- Signalling
- Stages
- Statues
- Trap shooting

The Mazda C lamp has made incandescent lighting practicable for photographic purposes. Many portrait studios are now rendered independent of daylight. An installation of 400 and 500-watt lamps, equipped with angle steel reflectors and placed behind a thin diffusing cloth screen, is shown. A few moving picture studios have been lighted, though in the majority of cases the incandescent lamp has been used in conjunction with more actinic mercury vapor lamps. Some lamps for photographic purposes have been made with photographic blue tinted bulbs, which reduce the apparent brilliancy about 40 per cent. without materially affecting the photographic efficiency.

Under "Artificial Daylight" the production of "white light" for accurate color matching is discussed. While the Moore carbon dioxide tube gives the closest approximation of the traditional north skylight, very fair approximations of average daylight are secured from the Mazda C lamps by the use of color screens, as shown in the spectrophotometric curves in Fig. 5, which is reproduced herewith.

"It is believed that the field for artificial daylight equipments is an important one and that in cultivating it member companies may find new employment for lighting, and at the same time render useful service in promoting certain forms of industry which heretofore have suffered from the lack of such daylight equivalents."

A chapter is devoted to the Bureau of Standards (U.S.). It refers to the coopera-

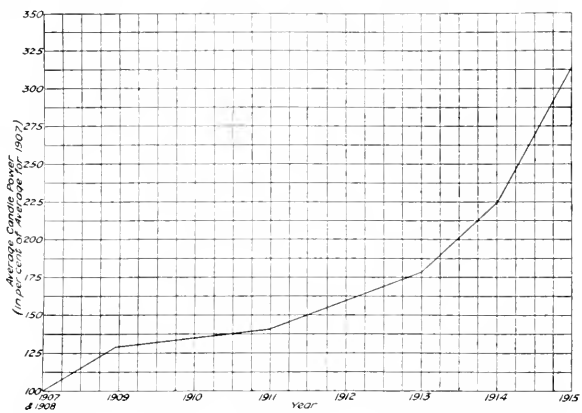


Fig. 6. Average Candle-power Curve of Mazda Street Series Lamps. (All Amperes included)

tion of the Committee with the Bureau and the revision of the "Standard Specifications for Incandescent Lamps."

The proposal to rate lamps in lumens instead of candle-power is rather fully treated. While it has long been recognized that the mean horizontal candle-power was not scientifically correct, as a measure of light output, it was not until the advent of the Mazda C lamp rendered it an inaccurate measure, that a change seemed practically necessary. Either the mean spherical candle-power or the lumen (12.57 or 4π lumens is equivalent to 1 m.s.c.p.) is a correct unit of measurement, approved by scientific and engineering societies. Besides being less liable to confusion, "it has the advantage that it is applicable, in common, to the light produced by a lamp and to the light delivered upon a plane which is illuminated." "When lamps are rated in lumens, a natural and proper expression of the efficiency is the lumens per watt. When the efficiency is increased the lumens per watt proper are increased." The watts per candle, commonly used, is a reciprocal expression of efficiency and decreases numerically with increase in efficiency.

"The lamp manufacturers have abandoned the old method as the basis of rating all Mazda lamps. The Standard Specifications for Incandescent Lamps employ the former method only as an indication of the total light produced, which latter is adopted as the basis of comparison and is obsolete in testing laboratory practice. Accordingly, your Lamp Committee desires to place itself on record as favoring in principle the universal adoption of the lumen as the unit of light flux for lamp rating purposes."

In regard to voltage standardization, the Committee recommends further consideration and the appointment of a special committee to deal with the situation, so as to take care of the interests of the central station companies, the lamp manufacturers, and other manufacturers of current-consuming devices. Various technical meetings and a committee of the Ohio Electric Light Association have been giving attention to this subject. The lamp manufacturers are arranging the publication of a pamphlet giving the central station voltages in various communities, endeavoring to facilitate the selection of lamps of proper voltage.

Colored, or dipped lamps, have been investigated, with the object of finding a practical means of reducing intrinsic brilliancy and producing soft and pleasing light effects. Experiments have been made with white, amber and other colors; one member company having supplied some 60 and 50-watt opalescent-dipped Mazda lamps under free renewals. Such colorings, of course, reduce life and light output of lamps. With opalescent or white dips the light is said to be reduced approximately 9 per cent; and with amber about 18 per cent.

In municipal street lighting, "the year past has witnessed an even more rapid extension" of incandescent lighting than 1915. "The Mazda C lamp continues to replace other illuminants, especially the enclosed arc lamp." "While the majority of the lamps for street lighting are of the series type, an increasing number of multiple lamps are being used, especially in central, well-lighted districts."

A series of questions submitted to members brought out some interesting information. A year ago the Committee recommended that higher candle-power lamps be adopted where possible. This tendency is indicated by answers received and confirmed by the candle-power curve in Fig. 6. A general summary of the answers is as follows:

1st. Mazda lamps are being used very extensively in approximately all street lighting installations.
2nd. Where no Mazda lamps are at present being used a large number of member companies are considering changing to this type.
3rd. In a large percentage of installations Mazda lamps are used exclusively.
4th. The introduction of Mazda lamps for street lighting has been very pronounced during the past year.
5th. A majority of the companies installing Mazda lamps during the past year for street lighting have applied the new equipment in substitution of other illuminants.
6th. In a majority of the installations made during the past year both for new lighting and on account of replacing other illuminants the Type C lamp has been used.
7th. More carbon arc lamps have been replaced than any other type of illuminant.
8th. The Type B (series lamp) has been replaced by the Type C very generally.
9th. In a majority of cases where the Type B lamp has been replaced by the Type C the candle-power has been increased. (See Fig. 6 above referred to).

The replacement of enclosed arc and gas lamps in the thoroughfares and side streets of New York City, by multiple Mazda C lamps of various sizes, is described. Arc lighting is now practically eliminated in the city. "During the latter part of 1915, the authorities decided to replace such gas and naphtha lamps as could conveniently be reached from the electric mains of the lighting companies with Mazda C lamps." The magnitude of the replacements, sizes of lamps used, spacings, heights, etc., is given. Nearly 60,000 Mazda lamps are being installed in the various boroughs, the 100-c-p. size being the smallest used.

Chicago was one of the first municipalities to appreciate the possibilities of the Mazda C series lamp. Reference is made to the various types of ornamental equipment. It is expected that the installation, in the course of a few months, will include approximately 16,000 600-c-p. Mazda C lamps, "and that the future will see the replacement of gasoline, gas and carbon enclosed lamps."

purchase of lamps, are accepted in part payment of the lighting bills. (Electrical World, Vol. 67, No. 18, p-990).

Under ruling of the Public Service Commission, the New York Edison and United Electric Light & Power Companies, in New York, have discontinued free renewals, furnishing initial lamps and renewals for an extra charge of half a cent per kw-hr. Since the 50-watt Mazda B lamp became available, the use of Gem lamps has been entirely discontinued.

"The 50-watt Mazda B lamp was decided upon by these companies after very careful consideration and it is reported that the

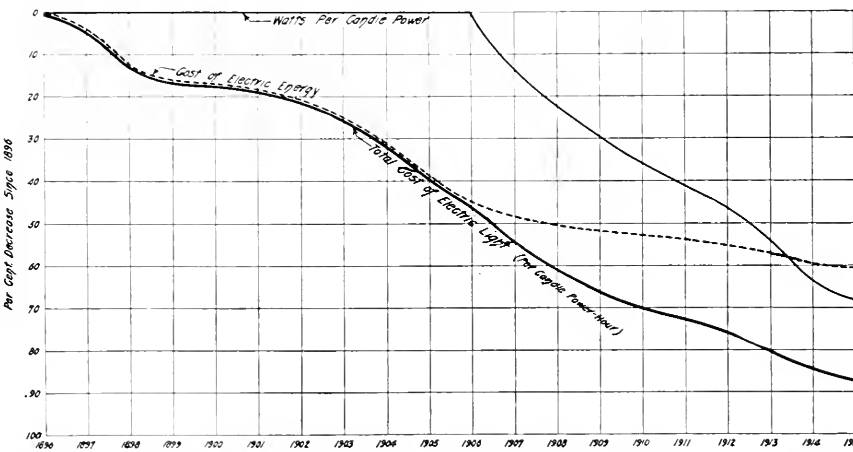


Fig. 7. Curves showing Decrease in Cost of Electric Energy and Electric Light

Company lamp policy is one of the most important questions to which the Committee has directed its attention, but lack of space precludes detailed presentation. Enormous quantities of printed matter, circulated among customers and the public generally, keep them informed regarding the progress with modern illuminants.

A few changes have occurred in the methods of exploiting lamps. "Free renewals have been discontinued in some cases, while in others it has been newly adopted." While some companies are going out of the lamp business, others consider active distribution, on a purely merchandizing basis, the best method. One company has inaugurated a plan by which coupons, issued with the

new lamp has been received with entire satisfaction and that customers are well pleased with the additional illumination and higher efficiency, and the lamp is in popular demand. For the three months ended April 1, 1916, the companies referred to report having supplied to their customers upwards of 300,000 of these lamps."

A canvas indicated that 5 per cent of the member companies had already adopted the 50-watt Mazda B lamp, while a large number, including Philadelphia and other large cities, have the matter under consideration. Chicago has included it in the free renewal list; Boston announced its adoption as of July 1st. "It is felt that this new unit will meet with general adoption and that it eventually will replace the 40- and possibly the 60-watt sizes." In all probability some of the present sizes of multiple Mazda lamps, including the 20-watt, will ultimately be discontinued. Further discussion of lamps to constitute the line is suggested.

In illustrating the cost of illumination, the curve given in last year's report is extended for the current year, Fig. 7, and shows the continuation of the downward tendency, quite in contrast to most other commodities.

In conclusion the Committee acknowledges assistance from many sources, both in connection with the work throughout the year, and in the preparation of the report.

The various sections of the Report deserve a much fuller study and analysis than can be included in a general review and is recommended to the careful attention of those interested in any phase of the lighting business.

TABLE I

Type and Size Reg. Mult.	PER CENT OF TOTAL MAZDA SALES 1913	1914	1915	PER CENT OF MAZDA MULTIPLE SALES ONLY 1914	1915
2½-watt	3.760	2.459	1.458	2.538	1.482
5 -watt	. . . . .	. . . . .		. . . . .	. . . . .
7½-watt	. . . . .	. .	0.420	. . . . .	0.428
10 -watt	2.761	5.091	5.658	5.257	5.763
15 -watt	6.300	5.704	5.663	5.891	5.768
20 -watt	2.592	1.817	2.056	1.988	2.101
25 -watt	29.340	26.780	25.623	27.659	26.062
40 -watt	27.110	26.323	27.833	27.189	28.312
50 -watt	. . . . .	. . . . .	0.816	. . . . .	0.830
60 -watt	15.085	16.724	16.103	17.271	16.384
100 -watt	5.722	5.799	6.648	5.973	6.779
150 -watt	1.093	0.870	0.555	0.899	0.567
200 -watt	. . . .	0.272	0.724	0.275	0.736
250 -watt	0.897	0.662	0.505	0.674	0.515
300 -watt	. . . . .	0.163	0.331	0.168	0.336
400 -watt	0.094	0.179	0.265	0.183	0.271
500 -watt	0.157	0.203	0.257	0.211	0.263
750 -watt	. . . .	0.133	0.052	0.139	0.054
1000 -watt	. . . . .	0.082	0.041	0.085	0.043

Type and Size Series Burning	PER CENT OF TOTAL MAZDA SALES 1913	1914	1915	PER CENT OF MAZDA MULTIPLE SALES ONLY 1914	1915
23-watt	2.340	2.815	2.516	2.910	2.558
36-watt	0.545	0.666	0.738	0.686	0.748
			Total Multiple	100.00	100.000

St. Series				PER CENT OF MAZDA ST. SERIES ONLY	
32-c-p.	0.410	0.258	0.252	14.611	14.700
40-c-p.	0.497	0.279	0.225	15.855	13.596
60-c-p.	0.652	0.479	0.357	27.165	21.430
80-c-p.	0.222	0.285	0.200	16.155	12.054
100-c-p.	0.135	0.254	0.343	14.430	20.666
200-watt	0.091	0.065	0.013	3.559	0.825
250-c-p.	. . . . .	0.072	0.106	4.052	6.359
350-c-p.	0.015	0.001	0.001	0.507	0.061
400-c-p.	. . . . .	0.030	0.077	1.464	4.705
600-c-p.	. . .	0.033	0.083	1.846	5.128
1000-c-p.	. . .	0.001	0.081	0.300	0.476
			Total St. Series	100.00	100.000
Misc.	1.82	1.501			
	100.000	100.000	100.000		

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

METAL SPRAY PROCESS

By means of the Schoop process, electro-positive metals may be deposited on iron, steel and many other coherent bodies whether metallic or not. The coating metal adheres to the object chiefly by mechanical union. The metal is discharged in hot particles moving at a high velocity and these, when directed upon the object which has previously been cleaned by subjecting it to the action of a sand blast, penetrate the pores of the latter, while the spray is still plastic. Thus the coating dovetails itself into the pores of the object in the presence of a reducing gas which prevents oxidation at the junction of the metal. Experiments extending over a period of a year seem to indicate that the action of the spray is purely mechanical except in a few cases where the impact metals have a chemical affinity.

Any metal wire can be sprayed but a hard metal, such as copper, can not be applied with the same degree of adherence upon a solid copper object as it would be upon a more porous cast iron object or upon a softer metal such as lead or zinc. These coatings may be polished or buffed like any ordinary metal but usually the finishing process makes such procedure uneconomical. In spraying where the softer metal forms the object, the body of it as well as its pores, will be penetrated by the harder metal and its projectile action. However, when the condition is reversed the softer spraying metal will fill the open pores of the harder object and key itself into the former on cooling. The penetrating action is entirely absent in this case. Thus, it is important to choose the proper metal where stress, wear and chemical action are involved even though an adherent coating may be obtained in any case. Hence, sprayed coatings used for protective purposes rather than for finish or decoration are restricted to lead for resisting acid, to lead, tin and zinc for resisting air, moisture, sea water and ordinary atmospheric action and to aluminum for resisting high temperature. However, where oxidation of the coating is of no importance copper and its alloys can be freely used.

With symmetrical pieces which can be arranged so as to revolve very uniform coatings may be obtained, while with other pieces which do not lend themselves readily to this procedure the operator's eye must be relied on for uniformity. The usual thickness of coatings is from 0.001 to 0.002 in. However, where greater thicknesses are desired two or more additional coats may be applied as required.

In general the applications of the process may be divided into five classes.

1. Protective Coatings.
2. Bonding or Junction Coatings.
3. Electrical Coatings.
4. Decorative Coatings.
5. Detachable Coatings.

There are numerous special applications in the industrial world but in the electrical industry probably the protective and electrical coatings are of most importance. Protective coatings are valuable where the usual methods can not be applied, the object being too bulky or the requirements such that the protection could not be applied until the apparatus was assembled. Electrical coatings may be used for conducting purposes such as lead on glass for condenser units. Heating units may be produced by spraying resistance wire on a suitable non-conducting material such as porcelain. Contact resistance of various metals may greatly be reduced by copper at the junction point.

H. 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.

INDUCTION WATTHOUR METER: PREVENTION OF CREEPING

(171) Please explain why an induction watthour meter is prevented from creeping by the holes in its disk.

The holes prevent creeping by decreasing the induced current in the disk, and consequently reducing the torque, when the disk is revolved to that position which brings a hole under the motor element of the meter, so that creeping will be checked within one-half revolution of the disk (light-load adjustment). In the modern type of meter two holes are used.

In some of the earlier types there were no holes in the disk. One of these types employed an iron wire near the shaft; this wire could be bent into such a position that it would be affected by the direct action of the damping magnets, and when carefully adjusted to give just the correct degree of attraction would prevent creeping. L.T.R.

TRANSMISSION LINE: GUY WIRE INSULATORS

(172) What is the recommended practice concerning the use or omission of insulators in guy wires on wooden-pole transmission lines?

While some wooden-pole lines have been erected without insulators in the guy wires, it is nevertheless considered to be the best practice to place insulators in the guy wires regardless of what may be the voltage of the transmission circuit. Adherence to this recommended practice will, in general, avoid injury to linemen when working on the poles near the conductors, especially in case there is a partial leakage to ground caused by slightly defective transmission insulators. The standard location for insulators in guy wires is indicated in the following extract from the specifications of one of the large transmission companies:

"All guy wires shall be insulated by the insertion of two strain insulators; the upper of these insulators being inserted in the guy so as to be at least six feet (in a horizontal direction) from the pole itself, or at least six feet below the lowest line wire; and the second strain insulator being inserted in the guy so as to be between six feet and eight feet from the lower end of the guy, and at least eight feet from the ground. In short guys, in which the two insulators here required would be located at the same point or near each other, the two insulators may be coupled in series and put into the guy together." T.A.W.

COMMUTATING-POLE MOTOR: HUNTING

(173) Experience shows that a commutating-pole motor having its brushes set slightly off neutral displays a decided tendency to hunt when driving a fluctuating load. What is the explanation?

The hunting of a commutating-pole motor operating under the above conditions is caused by the magnetomotive forces set up by the current in the armature winding. When the brushes of a machine are shifted off neutral, all the armature conductors embraced by double the angle of shift set up a magnetomotive force which is either in the same direction or directly opposed to that of the main exciting field, depending upon the direction of the shift.

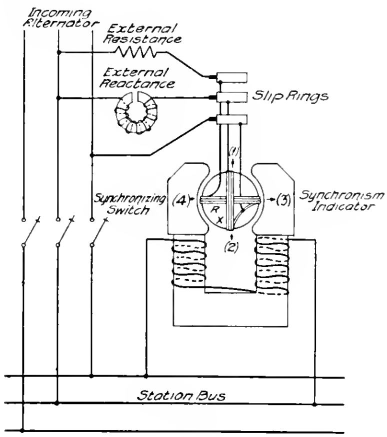
With a forward brush shift, the effective magnetic field in which the armature rotates is strengthened by an increase of load, for the armature ampere-turns lying between the double angle of shift have a magnetizing effect upon the field. Consequently, the motor speed drops.

With a backward brush shift, the effective magnetic field is weakened by an increase of load, for the ampere-turns referred to tend to demagnetize the field. Therefore, the speed rises. An excessive amount of backward shift will cause the motor to run away, or to draw a sufficient current from the line to open protective devices. While a lesser amount of backward shift than this may not cause the machine to be in danger of self-destruction, the degree of hunting that can result on fluctuating load may be intolerable. P.O.N.

SYNCHRONISM INDICATOR: CONSTRUCTION AND OPERATION

(174) Describe the synchronism indicator's internal construction, connections and theory of operation.

A synchronism indicator is essentially like a small bipolar two-phase synchronous motor. Its component parts are: an electromagnet stator; a rotor; an external resistance; and an external reactance. These are laid out diagrammatically in Fig. 1. The stator is built up of laminated iron and is excited by a continuous winding supplied with a single-phase current from the station bus. The rotor is mounted on ball bearings, in order that it shall be sufficiently responsive and smooth in operation. It carries two windings separated from each other approximately 90 degrees and joined together at one end only. The "outside" end of each coil and the junction of the "inside" ends are connected to slip rings. Connections made through brushes bearing on these rings connect the junction of the rotor coils directly to one line of the incoming alternator, connect the outside end of one rotor coil through the external resistance to a second line of the alternator, and connect the outside end of the other rotor coil through the external reactance to the same second line of the alternator. These connections are shown in Fig. 1 in which it will be seen that they span the synchronizing switch and that the indicator leads are tapped to the same phase on both sides of the switch.



(174) **Fig. 1**

When in operation the stator sets up an alternating field around the rotor. This flux lags about 90 degrees behind the e.m.f. of the bus, because the exciting current has that lag due to the comparatively high inductance of the field winding. The windings R and X of the rotor each set up a field also. That generated by the coil R (which is in series with the external resistance) is practically in phase with the e.m.f. of the incoming alternator, because the impedance of that circuit is principally pure resistance. That generated by the coil X (which is in series with the external reactance) lags practically 90 degrees behind the e.m.f. of the incoming alternator, because the impedance of that circuit is largely reactive. (These two rotor fields of course combine but for the purpose of analysis the two will be considered individually.)

The operation of the indicator under different conditions is as follows:

(1) Assume the case wherein the incoming alternator frequency is the same as that of the bus and also that the e.m.f's. of both are in phase (i.e., the synchronizing switch can be closed, provided the two voltages are equal). The stator flux is 90 degrees behind the e.m.f.; the coil X flux is also 90 degrees behind the e.m.f., therefore in phase with the stator flux; and the coil R flux is in phase with the e.m.f., therefore 90 degrees ahead of and out of phase with the stator flux and that of coil X. Under this condition the rotor takes a set position, that illustrated in Fig. 1, because the stator exerts a torque on coil X but not on coil R. When the rotor is in this position the dial pointer points vertically upward.

(2) Assume the case wherein the incoming alternator frequency is the same as that of the bus and the e.m.f. of the two are 180 degrees out of phase. Under this condition the explanation of the action between the stator and coil R is identical with that given in Case (1). The change of e.m.f's. from "in phase" to "180 degrees out of phase" changes the relative direction of current flow through coil X and consequently its relative polarity, which reverses the direction of the torque exerted on it by the stator with the result that the rotor takes up a set position 180 degrees from that shown in Fig. 1. When the rotor is in this position the pointer points vertically downward.

(3) Assume the case wherein the incoming alternator frequency is the same as that of the bus and also that the alternator e.m.f. is 90 degrees ahead of the bus e.m.f. The stator flux is 90 degrees behind the bus e.m.f.; the coil X flux is 90 degrees behind the alternator e.m.f. (which was already assumed to be 90 degrees ahead of the bus flux), therefore 90 degrees ahead of and out of phase with the stator flux; and the coil R flux is in phase with the alternator e.m.f., therefore in phase with the stator flux. Under this condition the stator exerts a torque on coil R but not on coil X and the rotor takes a set position 90 degrees away from that illustrated in Fig. 1, say, for example, in a clockwise direction. When the rotor is in this position the dial pointer points horizontally to the right.

(4) Assume the case wherein the incoming alternator frequency is the same as that of the bus and also that the alternator e.m.f. is 90 deg. behind that of the bus e.m.f. The explanation given in Case (3) will similarly apply to this case when cognizance is taken of the fact that the polarity of coil R is reversed relative to the stator. This feature of dissimilarity results in the direction of the torque exerted by the stator on coil R being reversed, and the rotor takes a set position 90 degrees counter-clockwise from that illustrated in Fig. 1. When the rotor is in this position the dial pointer points horizontally to the left.

(5) Assume the only remaining case wherein the frequency of the alternator is changing and consequently the alternator e.m.f. and bus e.m.f. are coming into and going out of phase in a cyclic manner. This case is merely a sequence of the preceding cases in cyclic rotation. If the alternator frequency is greater than the bus frequency the cases recur in one order; say, (1), (3), (2), (4), (1) and so on: If the alternator frequency is less than the bus frequency the cases recur in the contrary order; i.e., (1), (4), (2), (3), (1) and so on. The rotor, in responding to the influences of these cases in succession, revolves and carries with it the dial pointer. Synchronism indicators are customarily marked to indicate over-speed of the incoming alternator when the pointer rotates in the clockwise direction and under-speed of the alternator when the pointer rotates counter-clockwise. The greater the difference in the two frequencies, the higher the rotational speed of the pointer.

E.C.S.

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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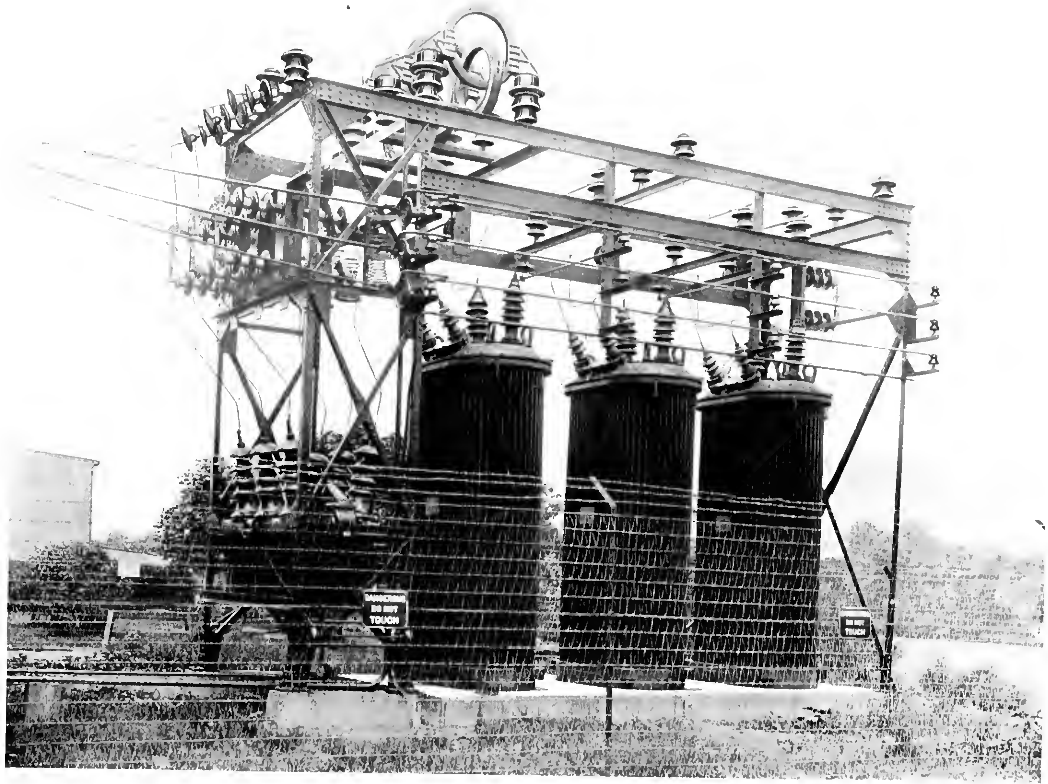

OUTDOOR TRANSFORMER SUBSTATION WIRED WITH "JITNEY" BUSSES

See page 755)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

In our last editorial we touched, very briefly, it is true, on the difficulties of modern technical education. With the kaleidoscopic changes in industrial conditions brought about by advances in scientific knowledge and the dictates of commercial competition, each year it is becoming increasingly more difficult for our educational institutions to prepare young men for the work that lies ahead of them.

Educational methods that are but a few years old are out of date—how rapidly we are discarding what formerly seemed satisfactory can best be realized by contemplating how hopelessly inadequate the old form of apprenticeship, with its three to seven years at the bench, unaided by subsequent training, would be to meet our present day requirements. The time available for special education for scientific, technical, and commercial occupations over and above the absolutely necessary general education is limited, the best way of spending this limited time is becoming one of the great problems of industrial preparedness for the immediate future.

Whatever trend future educational methods may take one thing seems certain, namely, that we must have the closest kind of cooperation between our educational institutions and our industrial institutions.

With the constant increase in the demand for specialists in well defined lines of activities, the tasks of educating men to meet the requirements seem to be falling more and more to the lot of the manufacturer.

That many manufacturing concerns are fully alive to the situation and are doing wonderfully successful work along these lines is gratifying, but at the same time our educational institutions have a most difficult problem in determining the make of up a curriculum that will give the young man the most desirable gound work before he reaches the manufacturing establishment.

It is in determining the nature that this ground work shall take that we see the great field for co-operation between the educational institution and the manfacturer.

The increased degree of specialization demanded by modern industry would seem to be met most effectively in the colleges by less, rather than more, specialization in technical education; by devoting more time to general mental training and less to imparting specific knowledge. No practical curriculum could be made sufficiently comprehensive or exhaustive to produce the many kinds of specialists required. The time is too short, the teaching staff would need be far too numerous, and the effort might after all be largely in vain, for the graduate might, by choice or force of circumstance, change his occupation so that a specialization would be imposed on him quite different from that arduously acquired in college. The knowledge and skill of the industrial specialist is now, and probably will continue to be, gained chiefly by experience in his chosen occupation. That part of his education the industrial concern can better impart than the college. What should be acquired in college is a mental training,—logical thinking, scientific attitude, accuracy in method and in observation, resourcefulness, sense of proportion, clarity of expression; these mental habits coupled with a thorough grounding in fundamental principles and a knowledge of where to turn for specific information, would probably be a far better equipment for the average engineering graduate than specific knowledge of a number of branches of engineering study, knowledge which was acquired in time necessarily taken from general mental training, and much of which will probably prove useless and soon forgotten in his specialized life work. It is the mental habit that the college can best teach, for habits, for good or ill, are formed early and endure.

THEORIES OF MAGNETISM

Part III

By Saul Dushman

Research Laboratory, General Electric Company

The observed relations between magnetic susceptibility and temperature have led to some interesting speculations upon the nature of magnetism. These theories are the subject of discussion in the following installment.—Editor.

Electron Theory of Magnetism

The relations between magnetic susceptibility and temperature which have been mentioned in the second part of this paper have led to certain interesting mentioned speculations regarding the nature of magnetism, which can quite properly be discussed in this connection.

As has already been stated, we have every reason to believe that the magnetism of any magnetized substance is due to the resultant effect of an infinitely large number of elementary or molecular magnets. In order to obtain a physical image, as it were, of the origin of these elementary magnets Ampere assumed the existence of currents traveling in circular orbits within the molecules themselves; but it has been only within the past two decades that this assumption has received a much firmer foundation by the postulation of the electron theory.

According to the present views of the constitution of matter, there are a number of reasons for believing that every atom has a number of negatively charged corpuscles or electrons revolving in closed orbits about its center, with frequencies ranging around that of ordinary or visible light. As was first shown by Rowland, the net effect of an electron revolving in this manner would be to make one face of the orbit a south pole and the other a north pole. Knowing the frequency ν, of revolution, the radius, r, of the orbit, and the charge, ϵ, of the electron, it is possible to calculate $\mathbf{M}$ the moment of the resulting elementary magnet. [1]

The magnetic moment of a circuit of area A carrying a current i is given by

$$\mathbf{M} = A\, i$$

In the case of an electronic orbit,

$$A = \pi\, r^2$$
$$i = \nu\, \epsilon$$

Hence,

$$\mathbf{M} = \epsilon\, \nu\, \pi\, r^2 \qquad (17)$$

Denoting the velocity of the electron in its orbit by v, it follows, since

$$v = 2\, \pi\, \nu\, r$$

that

$$\mathbf{M} = \frac{\epsilon\, v\, r}{2} \qquad (18)$$

That these equations are at least plausible can be shown from the following quantitative considerations.

The value of the maximum intensity of magnetization I_m, for iron, has been given in Table V, Part I, as 1850. It follows that the intensity of magnetization or total magnetic moment per gram atom (J_A) is 13,200.[2]

Assuming that the number of orbits per gram-atom is the same as the number of atoms, that is, 6.062×10^{23},[3] the value of the magnetic moment of the elementary magnet of iron is calculated to be

$$\mathbf{M} = \frac{13{,}200}{6.06} \times 10^{-23} = 2.178.10^{-20}$$

The radius of the iron atom is probably very close to 1.5×10^{-8} cm., while the most accurate value of ϵ is 1.591×10^{-20} e.m.u. Substituting these values in equations (17) and (18) it follows that

$$\nu = 1.936 \times 10^{14} \text{ sec.}^{-1}$$
$$v = 1.825 \times 10^{7} \text{ cm. sec.}^{-1}$$

This frequency corresponds to a radiation having a wave-length of 15.5×10^{-5} cm., that is, in the infra-red region; also the velocity calculated is approximately the same as actually observed for the slowest moving electrons emitted by incandescent metals.

A closer study, however, of electronic orbits, such as postulated above, has shown that this simple theory cannot account for the phenomena of dia- and paramagnetism,

(1) E. H. Williams, The Electron Theory of Magnetism, pp. 9–10.

(2) $1850 \times \frac{\text{Atomic Weight}}{\text{Density}} = \frac{1850 \times 55.8}{7.8} = 13{,}227.$

(3) See the writer's paper on "The Kinetic Theory of Gases, General Electric Review, Dec., 1915.

and it remained for P. Langevin to suggest a theory which has proven to be exceedingly useful in attempting to obtain a further insight into the actual mechanism of magnetic phenomena.

The starting point of Langevin's theory is the observation that, in general, diamagnetic susceptibility is independent of temperature while paramagnetic susceptibility decreases with increase in temperature in accordance with Curie's law, as has already been mentioned in the previous section. "From these observations Langevin concluded that *there exists a fundamental difference between diamagnetic and paramagnetic properties.* In Langevin's theory the diamagnetism is a characteristic property of each atom which contains a certain number of revolving electrons. If the resultant magnetic moment of these electrons in an atom is zero, then the body is diamagnetic; the action of an external magnetic field consists in a change of the orbit, the diamagnetic modification of the atom. If the revolving electrons possess a resultant magnetic moment, the body is paramagnetic. *Matter in all its forms is diamagnetic; paramagnetism, whenever it appears, covers, as it were, the diamagnetism without transition between the two groups.*"(4)

Zeeman Effect

In order to explain these remarks, it is necessary to refer, in this connection, to a remarkable discovery made by Zeeman in 1896. He observed that the character of the lines emitted in any spectrum suffer a radical

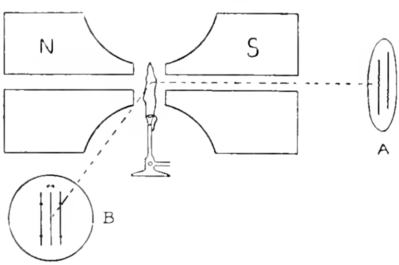

Fig. 9

change when the source emitting this light is placed in a strong magnetic field. Fig. 9 illustrates diagrammatically the arrangement of apparatus and results observed. A Bunsen flame containing common salt (to produce the yellow light of sodium) was placed between the poles of a strong electromagnet and the light focussed on a spectrometer so arranged as to bring out sharply the D-lines of sodium. On exciting the magnetic field and viewing the source along the lines of magnetic force, each of the lines appeared double, while on

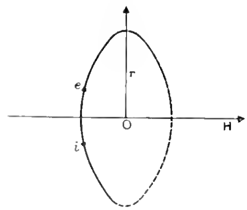

Fig. 10

viewing it at right angles to the lines of force, each line appeared treble. In other words, the frequency of the radiation appeared to be altered by the magnetic field.

An explanation of this phenomenon was offered by Lorentz in terms of the electron theory as follows:

Each line in the spectrum of any luminous source is due to vibrations of electrons about positive atoms. Consider in any atom an electron of mass m and charge ϵ (see Fig. 10) moving with velocity v in an orbit of radius r, the plane of which is perpendicular to a magnetic field of intensity H. When the magnetic field is not acting, the centrifugal force is balanced by an elastic force, which is directed toward the center and which we will assume is proportional to the radius, r. Then

$$\frac{m\,v^2}{r} = f\,r \tag{19}$$

where f is the force of attraction towards the center when $r = 1$.

On applying the magnetic field, the electron becomes subjected to a force at right angles to the field and to the direction of its motion, that is, along the radius of its orbit. The magnitude of this force, as found by applying the fundamental laws of electromagnetism, is,

$$F = H\,\epsilon\,v \tag{20}$$

With the electron rotating in the direction indicated by the arrow at e and the magnetic field acting in the direction H (see Fig. 10) this force will be directed outwards along the radius, while if the electron is rotating in the direction i, the force will be directed inwards

(4) J. Kunz, On the Present Theory of Magnetism and the Periodic System of Chemical Elements. Eighth International Congress of App. Chem., *22*, 187 (1912).

along the radius. Fig. 11([5]) illustrates the application of these considerations to the hypothetical case of a rotating positively charged corpuscle. For the case of an electron, the direction of the force as indicated by the arrow would be in the opposite direction.

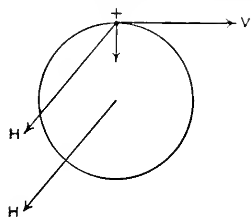

Fig. 11

Since the electromagnetic forces acting on the electron are perpendicular to the direction of its motion, the magnitude of its velocity v is unchanged, but the radius of the orbit is altered.

Thus the effect observed will be to decrease the radius of the orbit in the case of one set of electrons and to increase it in the case of another set, while in the case of those electronic orbits whose planes are parallel to the direction of the lines of magnetic force, the effect will be nil. Since it is only the orbits whose planes are at right angles to the line of vision that affect the eye, it is possible in this manner to account for the doubling of the line in one case and the trebling in the other case as observed by Zeeman.

Denoting the frequencies of the altered orbits by ν_1 and ν_2 and the radii of these orbits by r_1 and r_2 respectively, it evidently follows that

$$\frac{m\,v^2}{r_1}=f\,r_1-H\,\epsilon\,v \qquad (21)$$

$$\frac{m\,v^2}{r_2}=f\,r_2+H\,\epsilon\,v \qquad (22)$$

Hence

$$v\left(\frac{1}{r_2}-\frac{1}{r_1}\right)=\frac{H\,\epsilon}{m}$$

Since

$$v=2\,\pi\,\nu\,r$$

it follows that

$$\nu_2-\nu_1=\frac{H\,\epsilon}{2\,\pi\,m} \qquad (23a)$$

and similarly it can be shown that

$$\left.\begin{aligned}\nu_1-\nu&=-\frac{H\,\epsilon}{4\,\pi\,m}\\ \text{while}\quad \nu_2-\nu&=\frac{H\,\epsilon}{4\,\pi\,m}\end{aligned}\right\} \qquad (23b)$$

These equations enable us to calculate from the observed change of frequency in the magnetic field, the value of ϵ/m for the electron. The results obtained are in splendid accord with other methods for calculating this important magnitude and in fact even exceed these in degree of accuracy, so that the values of ϵ/m obtained from investigation of the Zeeman effect are considered by many physicists as the most accurate available.([6])

Langevin's Theory of Diamagnetism

So much for the Zeeman effect. Now let us see in what manner Langevin has applied similar arguments in deriving a theory of diamagnetism.

Let us consider the result of placing a diamagnetic substance in a magnetic field. The argument is quite similar to that used in the case of the Zeeman effect. Every electronic orbit will be influenced by the magnetic field so that the radius is either increased or decreased and the frequency altered correspondingly. In deducing the equation given above for the Zeeman effect, it was assumed that the plane of the electronic orbit is at right angles to the direction of the field. If, however, the latter makes an angle Θ with the perpendicular to the plane of the orbit, then the magnetic intensity at right angles to the orbit becomes $H\cos\Theta$, and the change in frequency is therefore equal to

$$\nu_1-\nu=-\frac{H\,\epsilon\cos\Theta}{4\,\pi\,m} \qquad (23c)$$

It has already been shown in referring to Fig 10 that if the electron is rotating in the direction indicated by the arrow at ϵ, and the magnetic field acts in the direction of H, that the force acting on the electron will be outwards and consequently the frequency will be decreased. Furthermore, with the electron traveling in the direction indicated by the arrow (so that the positive current is traveling counter-clockwise with respect to the direction of the field) the side of the orbit towards H will be a north seeking pole.

With the orbit making an angle Θ with the direction of H, the change in magnetic moment

$$d\,\mathbf{M}=\pi\,\epsilon\cos\Theta\,(r^2\,\nu-r_1^2\,\nu_1)$$
$$=\frac{\pi\,\epsilon\cos\Theta\,v^2}{4\,\pi^2\,\nu^2}(\nu_1-\nu)$$

([5]) Zeeman, Magneto-Optics, p. 32.

([6]) Kaye & Laby, Physical Constants. For a popular discussion of the Zeeman effect, the reader is referred to Fournier d' Albe's, The Electron Theory, Chapter XIII. In his book on Magneto-Optics, Zeeman deals with the Phenomenon at grent length.

from this equation and (23c) it follows that

$$d\,\mathbf{M} = -\frac{H\,\epsilon^2\,r^2\,cos^2\,\Theta}{4\,m} \qquad (24)$$

If there are n_o orbits *per unit mass* and if the axes are uniformly distributed in all directions, the average value of $cos^2\,\Theta$ is 1/3(7), and the total change in magnetic moment is

$$J = -\frac{H\,\epsilon^2\,r^2\,n_o}{12\,m}$$

But by definition

$$J = \chi\,H$$

Hence

$$\chi = -\frac{\epsilon^2\,r^2\,n_o}{12\,m} \qquad (25)$$

Since all the terms on the right hand side of this equation are necessarily positive, it follows that χ is negative, that is, the body is diamagnetic.

In non-mathematical language the argument is simply this: the external field tends to make the electronic orbit develop a polarity which is opposed to that of the field, that is, a north pole tends to develop on that face which is towards the north pole of the exciting field and a south pole on the other side.(8)

Weber's Theory of Diamagnetism

The relation given above may also be deduced in another manner which is quite independent of any consideration of the Zeeman effect.(9) Let us assume that there are non-revolving electrons present, which begin to revolve as soon as the magnetic field is excited and continue to revolve as long as this external field is applied. That is, we shall assume that the magnetic field induces a current in a resistanceless orbit whose radius is of the same magnitude as that of the atom. If L is the self-inductance of this orbit and i the current circulating in it, then it follows from ordinary laws of electromagnetism that

$$\frac{d\,Li}{d\,t} = -\frac{d\,H\,\pi\,r^2}{d\,t}cos\,\Theta$$

Hence,

$$Li = -H\,\pi\,r^2\,cos\,\Theta \qquad (26)$$

If we assume that the magnetic energy is stored up in this circuit as electromagnetic inertia of the electron, it is seen that

$$\frac{1}{2}\,Li^2 = \frac{1}{2}m\,v^2 \qquad (27)$$

where v is the velocity and m the mass of the electron.

Substituting the relations

$$i = \epsilon\,\nu$$
$$v = 2\,\pi\,r\,\nu$$

it follows that

$$L = \frac{4\,\pi^2\,m\,r^2}{\epsilon^2} \qquad (28)$$

and

$$i = -\frac{H\,cos\,\Theta\,\epsilon^2}{4\,\pi\,m} \qquad (29)$$

The consequent change in magnetic moment is equal to

$$d\,\mathbf{M} = i\,.\,\pi\,r^2\,cos\,\Theta$$

Substituting from equation (29),

$$d\,\mathbf{M} = -\frac{H\,\epsilon^2\,r^2\,cos^2\,\Theta}{4\,m}$$

Summing up the moments for all the n_o atoms per unit mass and taking into account the fact that the axes of these orbits are uniformly distributed in all directions, we conclude as above that

$$\chi = -\frac{n_o\,\epsilon^2\,r^2}{12\,m} \qquad (25)$$

Application to the Calculation of the Radius of Electronic Orbits

How far is this equation in accordance with the actual values of χ? In view of our ignorance regarding both n_o and r it is difficult to check the relation quantitatively, but it can be shown that it is at least quite plausible.

For the sake of argument, we shall assume that n_o is the same as the number of atoms per unit mass, so that $n_o\times$atomic weight $= 6.062\times10^{13}$.(10)

Hence,

$$r^2 = \frac{\chi\,.\,A\,.\,12\,m}{\epsilon^2\times6.062\times10^{23}} \qquad (30a)$$

where A = atomic weight.

In the case of chemical compounds, we can calculate in a similar manner an average value of r for all the atoms by means of the equation

$$r^2 = \frac{\chi\,.\,M\;\;12\,m}{\epsilon^2\times6.062\times10^{23}\times Z} \qquad (30b)$$

where M = molecular weight.

and Z = number of atoms per molecule.

(7) Clerk Maxwell, Treatise on Electricity and Magnetism, Vol. 2, p. 475.

(8) A popular exposition of Langevin's theory of diamagnetism will be found in Stradling's "Modern Theories of Magnetism," J. Franklin Inst. *180*, 173, Aug., 1915.

(9) The method given in this section was originally worked out by Weber, long before electrons were ever thought of, and is given in Clerk Maxwell's Treatise on Electricity, Vol. 2, p. 475.

(10) It is quite probable that n_o is much greater than the number of atoms. Hence the values of r calculated below are to be regarded as upper limits only.

Table XII gives values of r calculated in this manner for a number of substances. The values of $\chi.M$ for all the organic substances are taken from Pascal's published data([11]), while the other values are taken from Landolt and Bornstein's Tabellen.

TABLE XII

RADIUS OF ELECTRICITY ORBIT CALCULATED FROM DIAMAGNETIC SUSCEPTIBILITY

Substance	$\chi.M\times10^6$ (or $\chi.A\times10^6$)	Z	$r\times10^8$ calc. from χ	$r\times10^8$ Calculated from Atomic Volume
H_2O	12.96	3	0.58	1.54
$BaCl_2$	85.4	3	1.50	2.27
SO_2 (liquid)	18.3	3	0.69	1.28
NH_3 "	18.3	4	0.60	1.59
CH_3Cl	32.0	5	0.71	1.53
$PbCl_2$	66.7	3	1.32	2.00
Pb	24.8	1	1.40	(1.75)
C	6.0	1	0.69	(1.0)
CH_3OH	22.1	6	0.54	
C_2H_5OH	34.6	9	0.55	
C_3H_7OH	46.	12	0.55	
$C_8H_{17}OH$	105.	27	0.55	
CH_3CHO	22.1	7	0.50	0.96
C_2H_5CHO	34.0	10	0.52	1.39
C_3H_7CHO	45.8	13	0.53	1.38
$C_5H_{13}CHO$	81.5	21	0.55	
C_6H_6	55.4	12	0.60	1.29
$C_6H_5CH_3$	67.2	15	0.59	1.29
$C_6H_5NH_2$	62.5	14	0.59	1.32

A comparison of the values thus derived for the atomic radius with those obtained from other considerations is interesting. In the case of carbon and lead a direct comparison may be made by using the published values of the atomic volumes. Assuming that the atoms of lead and carbon are arranged in the form of a center face cubic lattice it can be shown that

$$2\,r_1=\frac{1}{\sqrt{2}}\sqrt[3]{\frac{4\,V}{6.062\times10^{23}}}\qquad(31)$$

where V = atomic volume.

In Table XIII the values of r_1 for some of the elements have been calculated by means of this formula, while in the case of most of the other elements, the following equation has been used

$$r_2=\sqrt[3]{\frac{3}{4\pi}\cdot\frac{V}{N}}\qquad(32)$$

As will be seen from the table, the values of the atomic radius calculated by means of either equations are not very different. By means of these values, the average values of r given in the last column of Table XII have been calculated for a number of compounds. In these calculations it has been assumed that the atomic radius of carbon in the combined form has the same value as for diamond (*i.e.* $r=1$). The values of V have been taken from the table published recently by W. D. Harkins and R. E. Hall.([12])

Comparing the values of r calculated from the diamagnetic susceptibilities and those calculated from the atomic volumes, it will be seen that there is quite a parallelism, and that the electronic orbit is uniformly smaller in radius than that of the atom, as we would expect to be the case.

TABLE XIII

ATOMIC RADIUS AND AVERAGE RADIUS OF ATOMS IN COMPOUNDS

Calculated from the Atomic Volumes

Element	V	$r_1\times10^8$	$r_2\times10^8$
C (diamond)	3.4	1.	1.10
C (graphite)	5.3	1.16	1.28
Ba	36.3	2.19	2.43
Bb	18.2	1.75	1.93
Cl	21.4		2.04
H	9.2		1.54
N	13.7		1.76
O	11.2		1.64
S	15.5		1.83

From the equation for the diamagnetic susceptibility, it is seen that if the diameters of the electronic orbits and their number is independent of the temperature, then the diamagnetic susceptibility ought to be also independent of the temperature. The fact that the lines of the spectrum of any substance are unaffected by temperature is in accord with this assumption. Nevertheless, we must also take into account that there are a number of diamagnetic substances whose susceptibility does vary with temperature. It is evident that for these cases the simple theory given above is quite inadequate.

Langevin's Theory of Paramagnetism.

"We have seen that in all cases the creation of an exterior magnetic field modifies the electronic orbits by polarizing diamagnetically all the molecules. This phenomenon is manifested only in the case where the resultant

([11]) Annales de Chimie et de Physique, *19*, 5 (1910). His values have been corrected for the difference in the value of the magnetic susceptibility of water used by him (0.75×10^{-6}) and the value recognized as more accurate at present which is 0.72×10^{-6}.

([12]) Journ. Am. Chem. Soc. *38*, 169 (1916).

moment of the electronic orbits is zero, when the matter is diamagnetic in the ordinary sense of the word.

"If the resultant moment is not zero, upon the diamagnetic phenomena is superimposed another phenomenon due to the orientation of the molecular magnets by the external field. The substance is then paramagnetic if the mutual action between molecular magnets is negligible, as in the case of gases and of solutions, and ferromagnetic in the case where the mutual actions play the essential role. As soon as the paramagnetism appears it is, as a rule, enormous in comparison with the diamagnetism and therefore completely conceals it. This explains the absence of continuity between paramagnetism and diamagnetism; paramagnetism may not exist; but if it exists, it hides completely the diamagnetism.

"Therefore, substances whose atoms have their electrons in revolution in such a way that their effects are additive, are paramagnetic. The atoms of such substances may be looked upon as elementary magnets."[13]

As the simplest case, we shall consider the action of a magnetic field upon a paramagnetic substance in the gaseous state. The molecules will tend to arrange themselves in a direction parallel to that of the field, but, we know from the kinetic theory of gases that the molecules of a gas are constantly colliding and rearranging their mutual orientations. There is thus set up a state of equilibrium between the magnetic force tending to line up the molecules and the force of thermal agitation which tends to disturb any such orderly arrangement. It is very simple by following up these considerations to show in what manner the paramagnetic susceptibility ought to vary with the temperature. For, let us suppose that the gas is at absolute zero. Under those conditions there is no thermal rotation whatever and all the molecules will tend to line up with even the weakest magnetic field, that is, the susceptibility will be infinitely great. As the temperature is increased, some of the atoms will get out of alignment and a stronger magnetic field will be required to bring them back into line. That is, the susceptibility will be lower at the higher temperature, a conclusion which, as we have already noted, is quite in accord with Curie's law.

Before we give Langevin's derivation of this law, it will, however, be best to discuss rather breifly a much simpler case so as to illustrate the application of some results deduced from the kinetic theory of gases.

According to this theory, the molecules of a gas are in constant motion with velocities which increase with the temperature according to the fundamental equation,

$$\frac{1}{2} m v^2 = \frac{3}{2} kT \qquad (33a)$$

where m denotes the mass and v the mean velocity of the molecules at the absolute

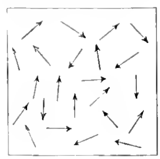

Fig. 12

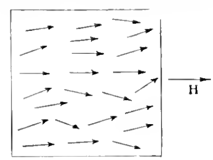

Fig. 13

temperature T. The constant k is known as Boltzmann's gas constant and is derived from the gas equation

$$p = knT \qquad (33b)$$

where n denotes the number of molecules per unit volume at the absolute temperature T and pressure p.

Let us now consider the same gas at two different pressures p_1 and p_2. In transferring a given mass from one pressure to the other, work will be gained or lost, and if the operation is carried out at constant temperature, heat will be absorbed or given out. The work done against external forces (work gained) in expanding the volume of n molecules from the higher pressure p_1 to the lower pressure p_2 is given by the equation

$$W_1 = nkT \log_e \frac{p_1}{p_2}$$

In order to maintain the temperature constant, the heat equivalent to this work has to be supplied by some constant temperature reservoir.

The result deduced above may also be expressed in the following more general form: The ratio of the densities of a gas in two points between which the work available by transferring gas from one point to the other is $\frac{W_1}{n} = W$ per molecule, is equal to

$$e^{\frac{W}{kT}}$$

where e is the basis of the natural system of logarithms.

[13] Williams, loc. cit.

Now consider a paramagnetic gas such as oxygen. In absence of a magnetic field, the molecules will be oriented in all possible positions, as shown in Fig. 12, but on applying a magnetic field of intensity H, they will assume some such arrangement as that shown in Fig. 13.

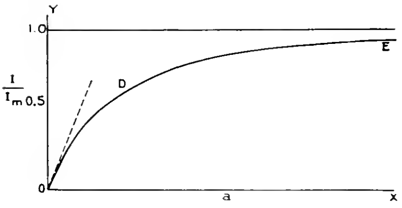

Fig. 14

Let α be the angle that any given molecular magnet makes with the magnetic field H. The work done by a molecule when rotated from the given position to that in which it is in line with H is

$$W = -MH \cos \alpha$$

where M is the elementary magnetic moment. That is, the potential energy of the elementary magnets is increased. It is also evident that during this process the average rotational energy will be decreased and will appear as an increase in temperature of the gas.

From this it follows that if one considers the distribution of the magnetic axes between the various directions, the density per unit solid angle will vary from one direction to the other proportional to

$$e^{\frac{\mathbf{M}H \cos \alpha}{kT}}$$

all directions being equally probable if $\mathbf{M}$ or $H=0$.

This result enables us to calculate the value of the intensity of magnetization, I, at the temperature T. For the details of the derivation, the reader must refer to other sources, but the resulting equation is

$$\left.\begin{aligned} I &= \mathbf{M}n\left(\coth a - \frac{1}{a}\right) \\ \text{where} \quad a &= \frac{\mathbf{M}H}{kT} \end{aligned}\right| \qquad (34)$$

and n = number of molecules per unit volume.

As H is increased indefinitely or the temperature decreased towards absolute zero, the expression in brackets tends towards unity, and the intensity of magnetization approached the maximum value $I_m = \mathbf{M}n$ which corresponds to saturation, that is, the condition when all the molecular magnets are oriented parallel to the magnetic field.

The equation

$$\left.\begin{aligned} \frac{I}{I_m} &= \coth a - \frac{1}{a} \\ &= f\left(\frac{H}{T}\right) \end{aligned}\right\} \qquad (35a)$$

is represented by a curve such as that shown in Fig. 14.

For small values of a (that is, for small values of $\frac{H}{T}$),

$$\frac{I}{I_m} = \frac{\mathbf{M}H}{3kT} \qquad (35b)$$

or

$$I = \frac{\mathbf{M}^2 n H}{3kT} = \kappa H \qquad (35c)$$

Hence

$$\kappa = \frac{\mathbf{M}^2 n}{3kT} \qquad (36)$$

that is, the paramagnetic susceptibility per unit volume is inversely proportional to the absolute temperature, which agrees with the rule obtained experimentally by Curie (equation (14) Part II).

Denoting the number of atoms per units mass by n_o, it is seen that the specific susceptibility

$$\chi = \frac{\mathbf{M}^2 n_o}{3kT} = \frac{C}{T} \qquad (37)$$

where C is Curie's constant per unit mass.[14]

Equation (37) may be interpreted physically thus: When a paramagnetic gas is subjected to a magnetic field, the equilibrium state of the gas is such that the average fraction of the total number of molecules oriented with their axes in the magnetic field is given by the ratio $\frac{\mathbf{M}H}{3kT}$. It will be obsereved that both $\mathbf{M}H$ and kT represent quantities of energy, the former denoting the magnetic energy stored up in the field when a magnet of moment $\mathbf{M}$ is acted upon by a field of strength H, while kT coresponds to the rotational energy of a molecule capable of orientation about its axis of rotation.

[14] Langevin's theory has been given by him in Ann. de Chimie et de Phys. [8], 4, 70 (1905) and Journ. de Physique [4], 4, 678 (1905). The reader can also consult the references already given for the theory of diamagnetism.

In the case of gases it is more convenient to express equation (36) in the following form:

$$\kappa = \frac{\mathbf{M}^2 n^2}{3\,k\,n\,T} = \frac{I^2{}_m}{3\,p} \qquad (38)$$

p being the pressure of the gas at which κ is measured.

According to Curie for oxygen at the pressure 10^6 bar and 0° Cent.,

$$\kappa = 1.43 \times 10^{-7}$$

Hence

$$I_m = 0.65$$

Substituting the value $n = 2.67 \times 10^{19}$, we find for the elementary magnetic moment of the oxygen molecule the value

$$\mathbf{M} = 2.43 \times 10^{-20},$$

a result which is remarkably close to that already deduced above for the magnetic moment of the iron molecule.

That $a = \dfrac{\mathbf{M}H}{3\,k\,T}$ is very small under all ordinary conditions may be shown from the following considerations:

The value of the constant k as deduced from the kinetic theory of gases is equal to 1.372×10^{-16} *erg*/deg.[15] Using the value already derived for the magnetic moment of the oxygen molecule and substituting in the equation for a when $T = 273$, we obtain the relation,

$$a = 0.65 \times 10^{-6}\,H$$

which shows that even in a field of 100,000 gauss (about the maximum field strength attainable in practice) a is still considerably smaller than unity.

Modifications of Langevin's Theory

The application of equation (37) to the calculation of the elementary magnetic moment will be discussed in another section. It is well, however, to bear in mind distinctly the assumptions from which the above equation has been deduced. It has been assumed that the gas laws are valid for the substance under consideration. Hence the law can only be applied to the case of gases and dilute solutions (for which the ordinary gas laws are valid). To the case of solids and liquids the law cannot be applied without some modification. According to Langevin's theory the resultant magnetic moment per unit volume of a paramagnetic body depends only upon the directing power of the field and on the "scattering" power of the thermal agitation. The equilibrium between these two tendencies leads to Curie's law. As Kunz has pointed out[16], in the case of solids and liquids, the molecules will exert attractive or repelling forces upon each other and this force will be a certain function of the temperature, $f_1\,(T)$, which will tend, in general, to oppose the directing action of the magnetic field in the same manner as the thermal agitation. Consequently the paramagnetic susceptibility will vary with the temperature according to some equation such as

$$\chi = \frac{[\mathbf{M} f_2(T)]^2\, n_o}{3k\,T + f_1(T)} \qquad (38)$$

where $\mathbf{M} f_2(T)$ expresses the additional fact that the magnetic moment itself may vary with the tempeature according to some function of the temperature, $f_2(T)$.

In a recent paper E. A. Holm[17] has attempted in a similar manner to introduce a correction in the equation of Curie and Langevin for intermolecular forces and has by this method been able to account for some of the results obtained by Onnes and Perrier with mixtures of oxygen and nitrogen at extremely low temperatures.

As already mentioned in Part II it has been found that at these low temperatures there occur in the case of all the substances so far investigated, characteristic deviations from Curie's law, so that the specific susceptibility χ increases less with decrease in temperature. Onnes and Perrier found that in a number of cases the susceptibility follows an empirical law of the form

$$C_1 = \chi\sqrt{T}$$

while Oosterhuis has shown that in other cases the modified form of Curie's law

$$C_2 = \chi(T + \triangle) \qquad (16)$$

is in much better accord with the observations.

Each of these equations may be considered as a special case of the more general equation (38) given above. Nevertheless the manner in which Oosterhuis has deduced his equations from theoretical considerations is very interesting.[18]

It will be observed that in deducing equations (36) and (37) it was assumed by Langevin, that the rotational energy of a molecular magnet is equal to kT. But within the past decade or so numerous reasons have arisen for concluding that the rotational energy of a molecule such as an elementary molecular magnet is less than kT

(15) Kinetic theory of gases, table of constants, GENERAL ELECTRIC REVIEW, Dec. 1915.

(16) Phys. Rev. 6, 113 (1915).

(17) Ann. Phys., *47*, 1 (1915).

(18) Proc. Amsterdam Acad. Sciences, *16*, 432 (1913) and Phys. Zeitsch. *14*, 862 (1914).

and approaches this value only at very high temperatures. Thus, at very low temperatures the specific heat of all substances seems to decrease much more rapidly than is to be expected from ordinary considerations, and since the specific heat is a measure of the total kinetic and rotational energy of the molecule we must conclude that the expression kT is not an accurate measure of the rotational energy. The Planck-Einstein theory of energy quanta attempts to explain this observation (together with a number of other phenomena observed at low temperatures) by "the assumption that at very low temperatures in the neighborhood of the absolute zero the molecules gradually lose their mobility and a given substance at absolute zero is a real solid body, as it were one large molecule, where the molecular mobility has disappeared."[19] According to this theory the rotational energy of a molecular magnet would be expressed as

$$\frac{h\nu}{2}+\frac{h\nu}{\epsilon^{\frac{h\nu}{kT}}-1}$$

where h denotes the so-called quantum constant and ν corresponds to the frequency of rotation.[20] By substituting this expression for kT in equations (36) and (37) Oosterhuis derives a relation of the form given in equation (16) and shows that both crystallised and anhydrous manganese sulphate as well as gadolinium sulphate and platinum follow this relation quite accurately. Kunz's interpretation of the above equation is worth quoting. "It means that the influence of the temperature agitation of the individual elementary magnets becomes weaker and weaker and that we cannot even define the molecular magnet, because the whole system of magnets is as it were solidified, so that even at the absolute zero saturation of a substance is impossible and that the influence of temperature becomes smaller and smaller or the paramagnetic susceptibility becomes constant."[21]

In the next issue we shall discuss the extension of Langevin's theory to ferromagnetic substances and the interpretation of all these theories in the light of the relations between susceptibility and chemical composition.

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(19) Kunz, los. cit. p. 118.

(20) See the writer's article on The Absolute Zero, GENERAL ELECTRIC REVIEW April, 1915.

(21) Loc. cit. p. 118.

INDUSTRIAL CONTROL

Part III

MAGNETIC CONTROL FOR STEEL MILLS

By G. E. Stack

Industrial Control Department, General Electric Company

The two preceding parts of this series on "Industrial Control" appeared in the July and August issues of the Review respectively. The description of "Magnetic Control for Steel Mills" has been divided into three parts of which the following article constitutes the first:—"Applications to Alternating-Current Motors." The other two parts will follow covering "Applications to Speed-Regulating Sets" and "Applications to Direct-Current Motors."—Editor.

APPLICATIONS TO ALTERNATING-CURRENT MOTORS

General Remarks

The purpose of this article is to discuss some of the more important details of magnetic control as it is now being supplied to steel mills; particularly those details which the designer takes into consideration when laying out the various equipments, as well as those points which are so essential to the steel-mill engineer in enabling him to obtain the best efficiency and maximum protection of his motors. It is desired that these remarks will also serve to answer the majority of questions which confront those who only occasionally come in contact with this type of apparatus.

Advantages of Magnetic Control

In determining the control equipment that will be suitable for the various motors used in this class of work, the first question to be answered is, whether it will be of the magnetic type or simply a hand-operated drum controller or other similar hand-operated device. In order to answer this question correctly, it is necessary to know the limiting features of each system.

As the drum controller is in such common use, is generally so well understood, and does not rightly come within the scope of this article, it will be considered that the limitations of that type of controller are understood and no attempt will be made to explain its operation except in those cases where magnetically operated switches or contactors introduced to augment its capacity.

Magnetic control lends itself to so many conditions that no one reason can be given for its adoption in all cases. The determining factor in one instance may be entirely absent in another and therefore a number of these are determining factors will be cited.

(1) *Capacity.* The amount of current and voltage (or energy) to be handled by the control, in the absence of other factors, often determines immediately the type of control. For instance, a 10-h.p., 220-volt motor to be started once a day would require only a hand-operated compensator, starting box, or drum controller for its control; but a 2000-h.p., 2200-volt motor would demand control apparatus of far greater capacity than it would be possible to furnish in a simple hand-control device. It would be necessary in this case to employ a small master controller which, in turn, would control magnetic switches of suitable capacity for handling the large currents and high voltages.

(2) *Duty.* The severity of the service is probably one of the most common as well as important factors which determine the use of magnetic instead of drum control, both from the standpoint of the operator and the control device itself. For example, a comparatively small motor operating on a duty-cycle requiring very frequent starting and more especially frequent "jogging" (in which the full-line voltage is ruptured many times in rapid succession in order to "inch" the motor along) would require contacts and arcing tips that are of more rugged construction than the segments and fingers of a drum controller to withstand the continual arcing. The requisite requirements are secured in the magnetic control by the use of the magnetic switches, or contactors, which have their arcing tips so placed as to allow the arc to travel directly upward. The combination of the magnetic blowout and the draught of air set up by the heated gases make the arrangement ideal for rupturing circuits of this nature. The panel on which the contactors are mounted can be placed at a distance from the operator and also far from any other apparatus which the arc might injure. In the case of a larger equipment than the one just cited, it might be assumed that the drum controller would stand up under the duty-cycle but the controller itself would require so much effort from the operator when worked in conjunction

with other devices that it would be necessary to change operators frequently. Under these conditions it would be advisable to use a magnetic control operated by a small master controller, which the operator could easily handle all day without fatigue.

(3) *Automatic Features.* When automatic control is desired, that is, when the acceleration of the motor is made independent of the operator and this acceleration so governed to prevent injury to the motor due to too rapid acceleration, magnetic control is installed in almost all instances, with the few exceptional cases of motor-operated drum controllers, etc.

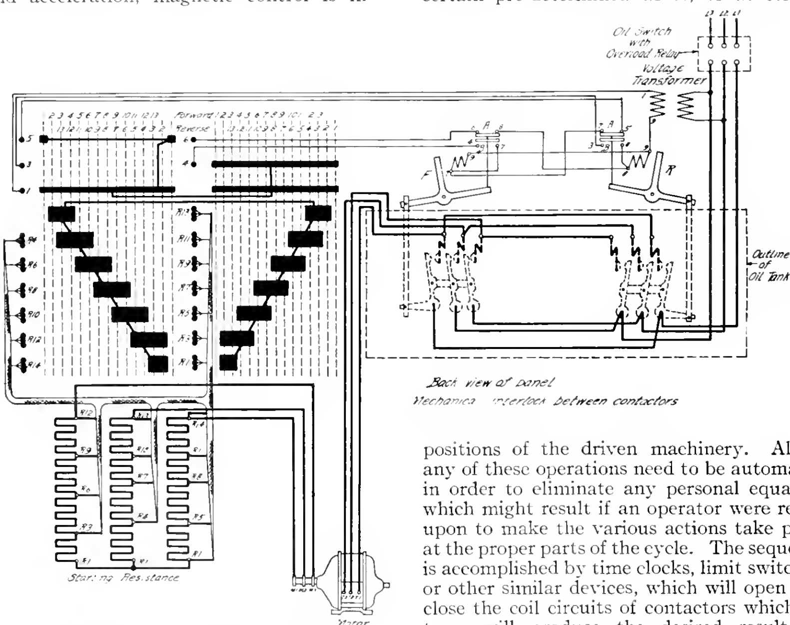


Fig. 1. Connection and Development of a Drum Controller Modified with Contactors for Reversing the Primary of a 2200-Volt Three-Phase Induction Motor

Under this same heading is included a number of other features which may determine the control, such as operating a motor on a duty-cycle requiring starting, stopping, and reversing in which overloads on the motor are very frequent. The magnetic control in this case is provided with overload relays which disconnect the motor from the line when the overload occurs; and as soon as the master controller is brought back to the off position, the overload relay is reset and the equipment is again ready to operate almost instantly, without the necessity of the operator leaving his position to close a circuit-breaker or to make any movements other than simply turning the master controller to the off position.

Very frequently it is desired to have motors start up, slow down, and stop, at certain pre-determined times, or at certain positions of the driven machinery. All or any of these operations need to be automatic, in order to eliminate any personal equation which might result if an operator were relied upon to make the various actions take place at the proper parts of the cycle. The sequence is accomplished by time clocks, limit switches, or other similar devices, which will open and close the coil circuits of contactors which, in turn, will produce the desired result by changing the motor circuits.

Cyclic control, which is a system involving a number of motors that are to be stopped and started in a certain sequence, is accomplished with magnetic control by the use of auxiliary switches or interlocks on the running contactors of the various control panels. This arrangement prevents the succeeding motor from starting until the preceding one is well under way.

It is possible to give a much larger number of general conditions in which it can be shown that magnetic control is far superior to hand-operated devices and in a great many of the cases magnetic control would be indispensible.

Applications

The simplest application of contactors is that in which a single contactor is used to throw a motor on and off the line, or to open and close any electrical circuit at a distance, or a high-voltage or large-current circuit near at hand. The contactor itself is operated by opening and closing its coil circuit. This coil circuit, or control circuit as it is more commonly called, can be operated by hand or by any other convenient method.

A practical application of controllers is represented in Fig. 1 which shows a reversing control equipment for a 2200-volt induction motor. The contactors are used in conjunction with a drum controller which has segments and fingers suitable for handling the secondary circuits of the motor direct, as well as for the control circuit of the two oil-immersed primary reversing contactors. These contactors in this instance take the place of primary contacts in the controller itself, which would be very difficult to include in the controller due to the high voltages and currents to be handled. This provides an equipment with no automatic features except overload and no-voltage protection. It will be noted from the diagram that the no-voltage-release feature is obtained by means of the auxiliary switches, or interlocks, *A* and *B* on the contactors themselves. With the drum controller on the first point in the forward direction, the control circuit from the voltage transformer (which supplies 220 volts for the contactor coils) passes to finger *1* on the drum controller, through the segments to finger *5*, through the interlock *A* on contactor *R*, through the coil on contactor *F*, and back to the other side of the transformer. When contactor *F* has closed, its main contacts close the motor primary circuits. It also opens interlock *A* which makes it impossible to energize the coil on contactor *R* as long as contactor *F* remains closed, and it also closes interlock *B* thereby establishing a

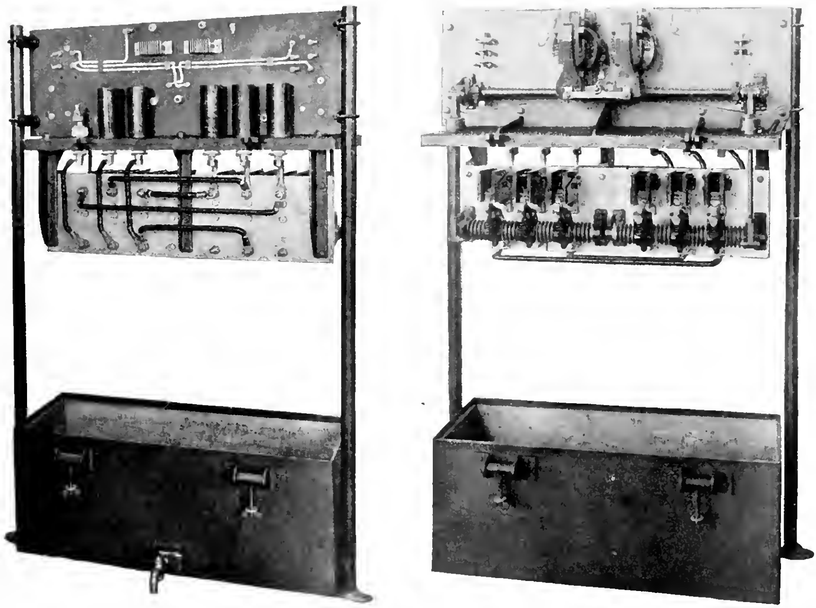


Fig. 2. Oil Immersed High-voltage Reversing Primary Contactors

holding circuit through interlock *B* back to finger *3* on the controller. Finger *5* makes contact only on point *1*, in which position all the resistance is in circuit in the motor secondary. Should the power fail when the master controller is in any position other than the first point, the contactor will drop out, thus disconnecting the motor from the line, also opening its own coil circuit. Therefore should the voltage be restored to the line the motor would not again start until the controller is brought back to the first point. This prevents the motor from being thrown on the line with all the secondary resistance short circuited, which would probably result in serious damage either to the motor or to the driven machinery. The same cycle of operation is also obtained when the controller is turned in the reverse direction, except that in this case the reversing contactor *R* closes driving the motor in the opposite direction.

Contactors capable of handling currents up to 1500 amperes at voltages up to 2200, and smaller currents up to 300 amperes at voltages up to 6600, are obtainable for this class of work. But, as the size of the motors increases the secondary current increases, and the limit of the drum controller is soon reached in this direction. It is then necessary to use contactors to handle the secondary as well as the primary circuits.

Fig. 3 represents a control for a three-speed motor in which oil switches are used in the primary circuits for both line and pole-changing switches. The secondary resistance during starting is cut out by means of drum controllers which are operated in connection with three contactors that select the proper secondary winding to correspond with the primary used and with three others that short circuit all of the resistance and the drum controller on the last point.

This equipment is a good example of contactors used for both increasing the capacity of the controller and obtaining other automatic features. As shown in Fig. 3, three oil switches are used, one for each speed. Each oil switch is provided with an auxiliary switch which is opened when the oil switch is opened and is operated with it. These auxiliary switches handle the control circuit for the contactors in the secondary circuit. For instance, if it is desired to operate at the low speed, the low-speed oil switch is closed, which makes the proper primary circuit connections to the motor. The auxiliary switch marked *G* also closes and establishes a circuit from *L-3* through the contacts *11* and *4* to the auxiliary switch on the controller marked *J*. If this controller is in the off position, the current will pass through the upper disk *N*, then through the coils on contactors *A* and *B* to *L-2*. The contactors *A* and *B* would close and establish a holding circuit for themselves through the auxiliary switch *L* on contactor *A* and back to *L-3* through the auxiliary switch *G*. As the starting resistance is cut out, by operating controller *J*, the auxiliary switch *N* is opened as soon as the controller is moved away from the off position; and when the controller reaches the last point, the auxiliary switch *P* closes, establishing a circuit through the auxiliary switch *M* on contactor *A* for contactors *C* and *D* which close and short circuit the secondary rings of the motor, effectually shunting the controller. In case of overload or no voltage, or when the equipment is reversed by operating the reversing oil switches, it is necessary to turn the controller to the off position before the secondary circuits can again be established, thus providing the same protective feature as explained for Fig. 1. The high speed and low speed of this motor uses the same secondary controller and resistance, and both of them provide the same features. The intermediate speed, however, which is a separate winding on both primary and secondary, requires different resistances and another controller, and consequently other contactors. These contactors in turn, provide the same features as the ones just described.

The equipment just described provides a maximum amount of protection with the minimum control apparatus, and is suitable for a great many mill devices.

Fig. 5 shows a typical wiring diagram of a control equipment for high-voltage rolling-mill motors of large capacity. This equipment consists of a small master controller that has a number of points which control only the coil circuits of the oil-immersed primary-reversing contactors and the secondary contactors. It is unlike the previously mentioned equipments in that all the motor circuits are handled by the contactors and none come to the controller.

The primary reversing contactors are both electrically and mechanically interlocked against each other to prevent both closing simultaneously and short-circuiting the line. They are also provided with interlocks *A*, which make circuit after the main motor circuits are completed. These interlocks establish a circuit for the secondary con-

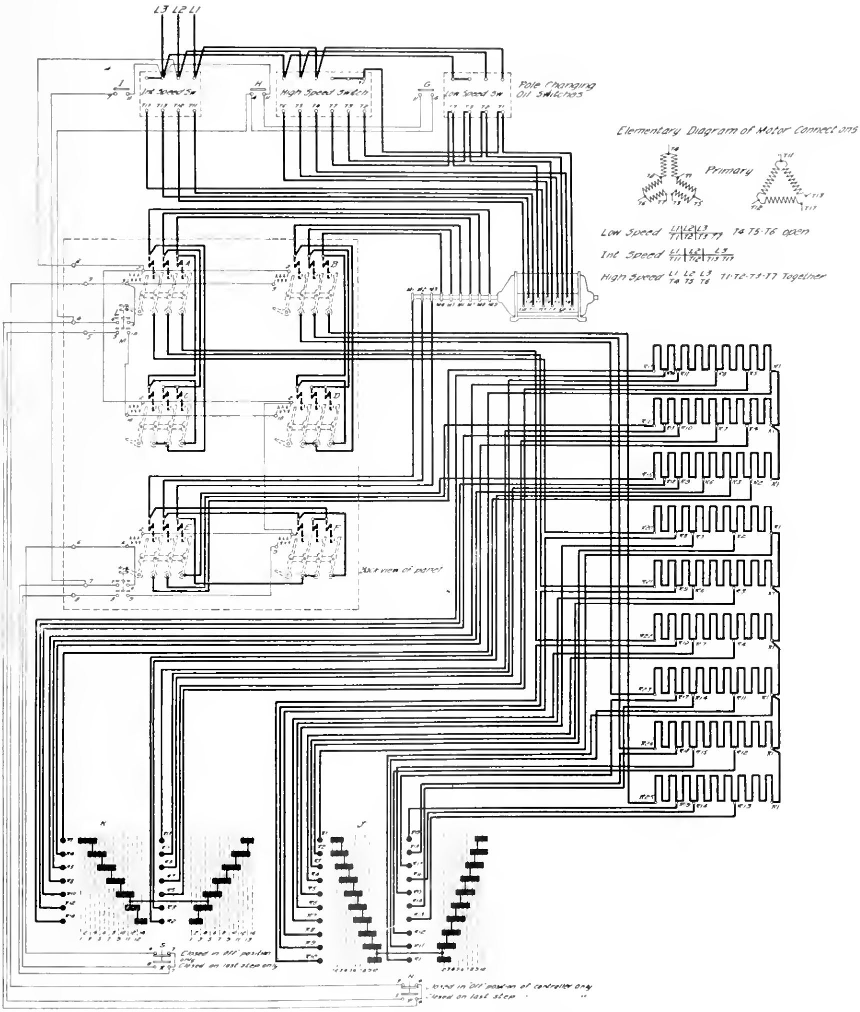


Fig. 3. Connections of Drum Control Equipment for 12-16 H.P., 800/600/400-600/400/300 R.P.M., 500-Volt Induction Motor with Controller Short-Circuited by Contactor on Last Step

tactors, thus preventing the contactors from closing until after the primary circuit is closed and the series coils of the accelerating relays are energized.

The small double-pole contactor *9* is closed by the controller in the off position only. The control circuit for all the contactors is wired through the contacts of this contactor, and it is so wired that it establishes a holding circuit for itself independent of the controller. This contactor provides protection against accidental starting of the motor when voltage is restored to the line after its failure, in case the master controller has been left on one of the running positions. This is the same protection as secured in the two previously mentioned equipments.

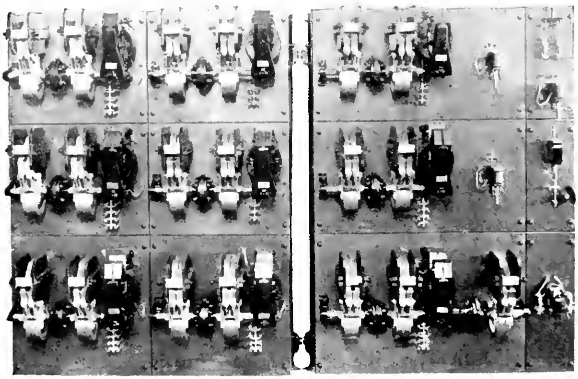


Fig. 4. Secondary Control Panel with Plugging Relay for Use with the Primary Panel of Fig. 2

The secondary contactors, although controlled manually from the master controller, are also dependent upon the current-limit relays which, in turn, are dependent upon the amount of current being drawn from the line. It will be noted from Fig. 5 that the coil of contactor *3* is energized by the current passing from finger *6* on the controller through the coil through contacts *13* and *14* on interlock, through the voltage coil on the plugging relay to the other side of the line. The impedence of the coil of the relay is sufficient to limit the current to such a value that it will pick up the relay plunger, but is insufficient to close the contactor. If the current, which is already flowing in the series coil of the relay, is above the calibrated value, the disk *G* will stay in the open position until this current falls to the calibrated value; then the disk drops and short circuits the voltage coil of the relay, thus throwing the coil of the contactor directly across the line. This closes the contactor which, in turn, short circuits a part of the starting resistance and at the same time operates the three-disk interlock. These three disks are adjusted to operate in a definite sequence which is very essential to successful operation. The sequence when the contactor is in the act of closing is—first, for disk *D* to bridge contacts *13* and *15;* second, for disk *C* to break the circuits of contacts *13* and *14*; and third, for disk *E* to bridge the contacts *16* and *17*, which must also happen after the main contacts of the contactor have short circuited the resistance, thus causing a rise in current in the line. When disk *C* bridges contacts *13* and *15*, the contactor establishes a holding circuit for itself independent of the relay. Disk *C* disconnects the contactor from the relay so that it can be used for succeeding contactors if desired; and disk *E* establishes a pick-up circuit for the succeeding contactor through the succeeding relay which operates in a manner similar to that just described. The position of disk *E* in the sequence is such that the current in the current coils of the relays has risen due to the short circuiting of the resistance before the voltage coil of the relay is energized; otherwise, the relay would fail to function because it would not obtain current enough to be picked up after it had started to drop.

It will be noted that there are three of these accelerating relays. The first one to operate is known as the plugging relay and is adjusted to current limit only when the motor is plugged (reversed when running at full speed). The other two relays are used for current limit acceleration during both starting from rest and plugging.

In connection with the equipment just described, the resistances of sections *G*, *H*, *I*, *J*, *K* and *L* are laid out with sufficient ohms that, when full-line voltage is applied to the primary when the motor is at rest, they will allow a predetermined amount of current to flow

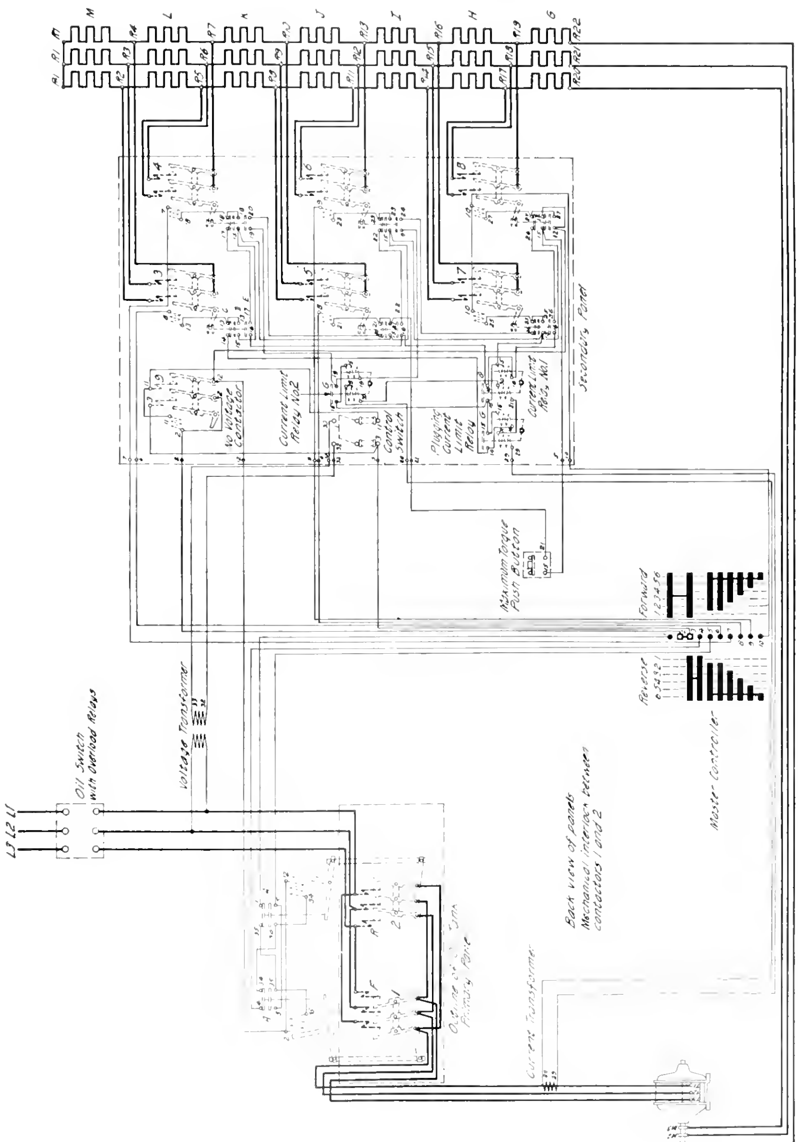


Fig. 5. Typical Wiring Diagram of a Control Equipment for High-voltage Rolling-mill Motors of Large Capacity

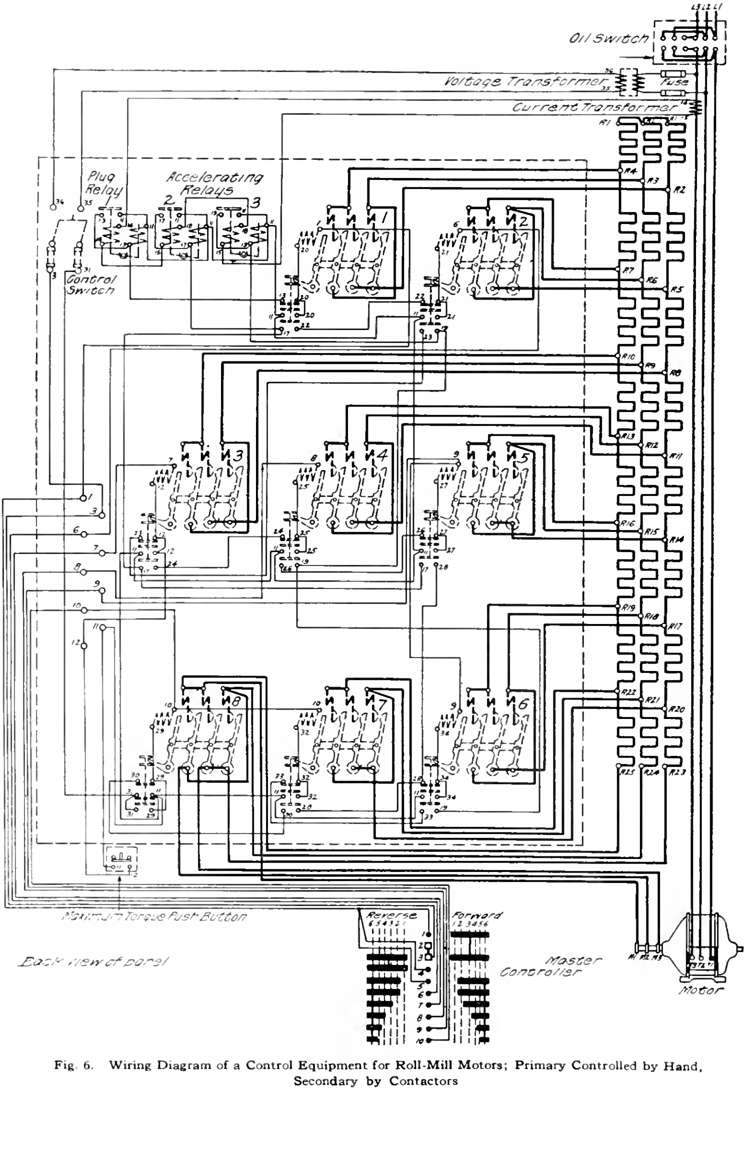


Fig. 6. Wiring Diagram of a Control Equipment for Roll-Mill Motors; Primary Controlled by Hand, Secondary by Contactors

in the main circuits, which in this class of work is approximately 125 per cent of full-load current. Section *M* has a resistance equal to the total of all the other sections. When starting from rest, all the resistance is in circuit; and, when the primary contactor closes, only one-half of the predetermined accelerating current flows for the first instant. The plugging relay, however, is adjusted to drop out at a current value a trifle greater than one-half, therefore it immediately drops, allowing contactor *3* to close which raises the current to the accelerating value. Contactor *4*, however, cannot close until the current has dropped to the calibrated value of current-limit relay *1*. *The resistances are so proportioned and the relays so calibrated that approximately equal peaks of current are obtained on every point for the remainder of the acceleration. In case the motor is plugged after it has come up to speed, double voltage and frequency will be impressed across the secondary resistance. This excess voltage is sufficient to force the maximum accelerating current through the entire resistance, and the plugging relay will therefore prevent contactor *3* from closing until the current has dropped to approximately one-half the maximum value, which is the instant at which the motor is at standstill. After it closes, the remainder of the acceleration continues as described.

The section of resistance marked *G* is never cut out of circuit. This resistance is used to give a series characteristic to an induction motor which is supplied with a flywheel when driving a mill having very intermittent high-peak loads. This resistance is sufficient to give from 5 to 10 per cent slip at full-load, which allows the flywheel to give up its stored energy without drawing more than full-load current from the line, until after the motor has slowed down more than the slip-resistance value. In some cases where it is desired to have the flywheel give up a great deal of its energy and at the same time operate at a higher motor efficiency than the preceding scheme permits, a notching-back relay is supplied which inserts resistance by opening secondary contactors when the peak-load comes on and cuts this resistance out of circuit again after the load has subsided.

Equipments of this type are rarely ever started under heavy load; consequently, it is possible, as previously stated, to limit the accelerating peaks to a reasonably low value. To take care of starting under load, or with

* See "A Short Method for Calculating the Starting Resistance for Shunt, Induction and Series Motors," by B. W. Jones, GENERAL ELECTRIC REVIEW, February, 1915, p. 131.

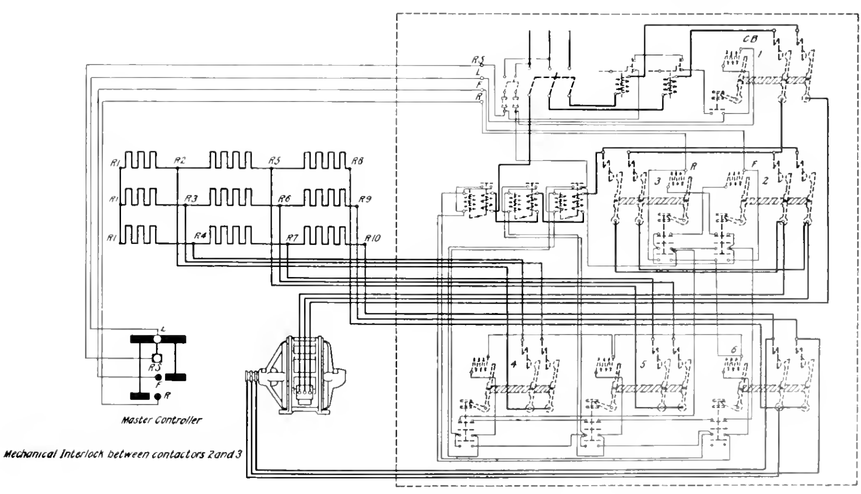


Fig. 7. Wiring Diagram of Magnetic Control Equipment for Motors Driving Table Rolls

metal in the rolls, which occasionally may be necessary, a maximum torque push button is provided; this will shunt the current-limit relays and close the proper secondary contactor to give this maximum torque condition.

Fig. 6 shows the wiring diagram for an equipment driving a roll mill in which the primary is controlled by hand-operated oil switches and the secondary by contactors. The overload and no-voltage protective features in this case are on the oil switch. The control circuit for the contactors is taken from inside the oil switch. This results in a very effective interlocking system. In starting from rest or in reversing, the master controller can be placed in the full running position and complete control obtained by operating the oil switches. The contactors will drop out when the oil switches are opened and will start to close in the proper sequence subject to the current limit relays when the oil switches are closed.

Fig. 7 shows the wiring diagram of an equipment for operating 220- and 440-volt motors driving table rolls or other machinery requiring substantially the same type of control. This equipment is provided with forward and reverse contactors, current-limit relays to govern the closing of the accelerating contactors, line switches, and control switches. These motors vary in size from 25- to 75-h.p., and as it is not necessary to use an oil switch with each motor, all the protective features including the disconnecting line switch, overload relays, and no-voltage release or circuit-breaker contactor are supplied directly on the control panel. The two overload relays, one in each of two phases, are gravity reset, and trip out the circuit-breaker contactor on overload. This contactor also will open on failure of voltage, and the wiring is such that it is necessary to return the master controller to the off position before the circuit-breaker contactor can again be closed. These equipments are suitable for rapid reversing drives and provide the maximum amount of protection to the motor, at the same time requiring the minimum amount of manual labor to reestablish the normal operating conditions. If the motor be subjected to an overload, the overload relays will trip out the circuit-breaker contactor and the motor will stop. The operator simply turns the controller to the off position which resets the circuit-breaker contactor, and he is again ready to operate.

The equipments described represent the type of magnetic control that is used for controlling alternating-current motors driving rolling mill machinery of the more common type. There are a larger number of motors in steel mills driving pumps, fans, blowers, etc. which have not been discussed because they are not limited to steel mills but are used generally in industrial plants.

JITNEY BUSSES

By George P. Roux

Consulting Engineer, Philadelphia, Pa.

The making of mechanically and electrically reliable connections to a high-tension polyphase overhead line frequently taxes one's ingenuity. In the following article, the author describes a general scheme which has been developed to reduce the often complex design of such connections, to simplify their construction, and to increase the assurance of continuous service.—Editor.

Although it is not the intention to discuss in this article the matter of transportation, as might be supposed, the title is not irrelevant, inasmuch as we propose to deal with the transportation or transmission of electric power, where the question of "bus" is involved. It is specially appropriate for those cases where taps and connections have to be made, as from transmission lines and in power houses and substations where the use of auxiliary busses greatly facilitate the solution of certain wiring problems. Such requirements are met in a practical way with what are termed "jitney busses," that is, small and short busses, to differentiate this system from larger ones known simply as "busses."

In connecting high tension apparatus it very frequently occurs that the wiring presents difficulties owing to the location of the apparatus with respect to the lines, requiring complicated turns with intermediate supports. These necessarily complicate the layout, and require expensive supporting structures and additional space that is sometimes unavailable. The jitney bus overcomes these difficulties and lends itself to quite a number of applications too numerous to be described in detail. Only a few examples can be illustrated here, and from these the engineer will readily see the possibilities of its adaptation to other cases with equally satisfactory results.

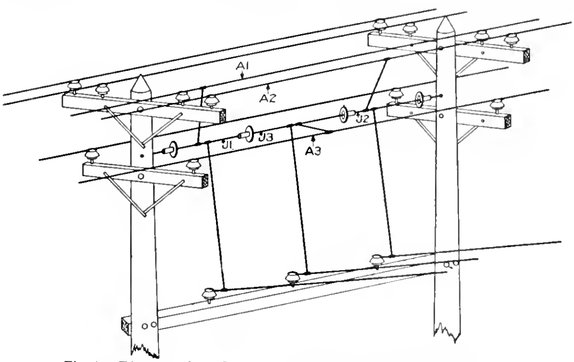


Fig. 1. Diagram of the Jitney Bus Method of Tapping One Circuit of a Two-circuit Three-phase Line of Triangular Arrangement

Tapping a Line

Very often a double-circuit line has to be tapped where the arrangement of the wires and the pole head structure make this task difficult and hazardous with respect to rigidity, safety and spacing. An instance is given in Fig. 1, where a two-circuit three-phase line is shown, the three wires of each circuit being in a triangular position and parallel to each other. One line is to be tapped between two poles set for this purpose at a short distance apart so as to present a rigid support for the line wires across the short span. A jitney bus is installed between the two poles and between the two circuits, and is attached to the poles by means of eye-bolts and suspension insulators, using galvanized guy wire for the bus if it is found advisable to further brace the two poles to add to the stability of the structure. The jitney bus is in three sections, insulated with suspension or strain insulators between sections. To this jitney bus, wire $A1$ is connected to $J1$, wire $A2$ to $J2$ and wire $A3$ to $J3$. Vertical connections are then made from $J1$, $J2$ and $J3$ to the leads of the apparatus or to the service line attached to insulators supported on a cross arm between the two-pole structure, if the tap is to be at right angles, or else to a lower cross arm if the tap is to be parallel with the line.

Fig. 2 shows a similar arrangement for a tap from a single circuit with wires triangularly located. Fig. 3 shows a tap from one line of a double circuit with wires vertically spaced; and Fig. 4 the same tap from the top circuit of a double line with wires horizontally located.

Fig. 5 shows a jitney bus tapping two circuits which could also be dead-ended on the supporting structure and either connected to a service line or to apparatus, or connected with a switch that could be located in an accessible place below the lines.

Nowhere are found such exacting requirements as exist for pole lines or wire supporting structures. These structures are exposed to the action of the elements; furthermore, their construction is subject to restrictions by local ordinances or right-of-way stipulations; and, finally, for obvious reasons it is necessary to reduce the overhead burden to a minimum and to keep certain clearances and spacings to insure mechanical and electrical stability and the reliability of the service.

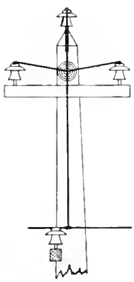


Fig. 2. Single Line Tap

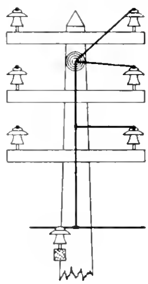


Fig. 3. Vertical Tap

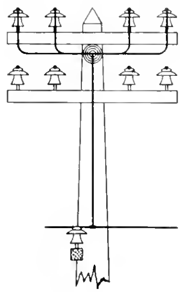


Fig. 4. Horizontal Tap

Various Applications of the Jitney Bus

The jitney bus excellently fulfills these requirements. It provides a short rigid connecting link to which straight and short jumpers can be attached, connecting each section of the bus with its respective line and eliminating the danger of accidental contacts due to long and mechanically weak jumper connections that are subject to the destructive effect of wind, ice and foreign load. The jitney bus also adds to the appearance of the structure and reduces the overhead encumbrance.

Transformer Wiring

In many instances the lack of room or some other circumstance does not permit the installation of transformers immediately under the busses, thus making a direct connection to the busses impossible. Extra long connections with bends and turns that are liable to come in contact and that must be crossed for at least one transformer in a bank of three connected delta are usually necessary.

With the aid of the jitney bus, short, direct and rigid connections can be made, greatly improving the general appearance and adding to the safety of the wiring and facilitating replacement or interchangeability of the apparatus or its reconnection at will.

A common case is shown in Fig. 6 for an outdoor transformer structure, where three transformers are so placed as to offer less resistance to the action of the wind and require less space than if they had been turned 90 degrees around with their leads parallel to the line. In addition, their removal may be more easily effected, a greater space exists between the tanks, making them more accessible, and a more suitable location of the oil gauge, valves and thermometers, if any is possible, all of which facilitate inspection, care and operation.

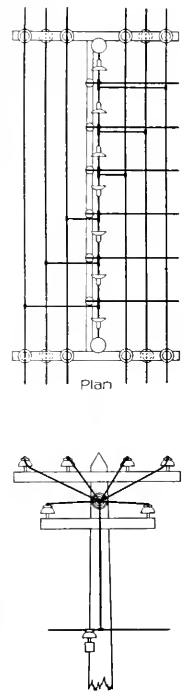


Fig. 5. Tapping Two Lines

The three high-tension line wires forming the main busses are installed above the structure. Under and at right angles to them, three jitney busses are provided, with a jumper connecting each one to its respective line above; and then the leads to the transformers below are clamped thereon. For the secondary connections three similar jitney busses are installed below the primary jitney busses and are suspended from insulators hanging under the supporting struts. The three transformers of Fig. 6 are shown with their primaries connected star and secondaries delta. Where they are connected delta-delta, a fourth high and low tension jitney bus is provided which obviates crossing the leads of one transformer.

All connections to primary and secondary lines and busses and to the neutral wire are made with clamps, thus permitting a rapid change from one style of connection to another in case of replacement or accident. For large installation copper tubing is preferable for the busses on account of its rigidity and neatness. The installation of jitney busses can be made just as well with suspension insulators throughout.

Connections between switching apparatus, lightning arresters, etc., can also be made with jitney busses with great simplicity, increased reliability, and an improved appearance.

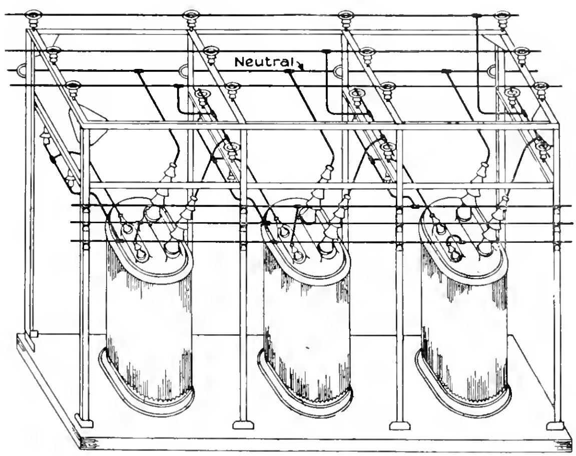


Fig. 6. Outdoor Transformer Substation Wired with "Jitney" Busses

EFFICIENCY IN CAR OPERATION

By J. F. Layng

Railway Engineering and Traction Dept., General Electric Company

The increase in the cost of materials and labor has forced electric railway companies to the greatest economy of operation. The following article points out several factors in connection with the operation of electric railways whereby economies may be effected, and the illustrations and discussions bring out these points forcibly.—Editor.

There are certain fundamental economies that can be obtained in the operation of motor cars. These are dependent upon the running time, stops per mile, length of stop, rate of acceleration and deceleration, and equipment weights. A careful study of each of these elements is necessary to determine if any road is operated at the minimum cost, or at the maximum efficiency. The points which will be brought out can be demonstrated by the efficiency engineer in the same way as are other items of expense that are entered on the books of a railway company. The increase in the cost of producing transportation will cause the future successful management to thoroughly study the conditions of operation of each particular division comprising a property.

It is a regretable fact that the number of stops per mile and the length of stop is a phase of operation that has received but scant consideration. How many managers know how many stops their cars make per mile? As a matter of record I am sorry to say that during an investigation of requirements for the purchase of new equipments the manufacturers find that the answers to the requests for these data from managers of properties sometimes vary 100 per cent from the actual conditions. It is almost invariably the belief that a car makes more stops than is shown by actual check.

In order to show just what these points mean in service a number of calculations have been made and the results plotted in the form of curves. These calculations have been made on the fundamental laws of gravity, speed, and time, from which there is no appeal. This discussion is not based on a theory; it is a condition which, if we accept, leads into truly scientific management. The curves show energy consumption for different rates of acceleration, braking, and length of stops when maintaining the same schedule, extending coasting with allowable increase in schedule speeds, effect of length of stops on schedule speeds, and effect of stops per mile on schedule speeds and power consumption.

Since the early days of electric railroads it has been well known that on test runs there are great differences in the power used, even when the service conditions are the same. With a given car over a given route, with the same number and length of stops, the power consumption will vary more than 30 per cent when operated by different motormen. This emphasizes the differences which it is possible to obtain by operating the car at different rates of acceleration and deceleration; the difference being, of course, in the amount of coasting which is obtained by the different methods of operation. A few years ago a number of investigations were made to determine some systematic method of securing the maximum amount of coasting at all times, and as a result the coasting clock was designed. In other instances wattmeters and amperehour meters were used, the idea being to obtain in each case the maximum amount of coasting, which necessarily will give the minimum of energy consumption .

To illustrate these points, calculations and curves have been made on cars weighing 18 tons complete with load, and equipped with two motors. It is assumed throughout the calculations that the car is geared to have a free running speed of 22 m.p.h., a 1000 ft. run schedule speed of 10.65 m.p.h., 7-second stops and 20 lb. per ton friction.

Fig. 1 shows the car accelerating at ¾, 1, 1¼, 1½ and 2 m.p.h.p.s. The watthours per ton mile obtained with these different rates of acceleration are 110, 90, 83, 79 and 76, respectively. From this it can be seen that the percentage of difference of energy used from 110 to 90 watthours per ton mile is 18 per cent while the saving between 90, 83, 79 and 76 will be 7½, 5½ and 3.8 per cent, respectively. This analysis shows that low rates of acceleration are exceedingly wasteful and inefficient, and the difference in power consumption at the higher rates of acceleration, while material, are not nearly so great. It will be noted that the total difference in power consumption of 110 watthours per ton mile for accelerating at ¾ m.p.h.p.s. and 76 watthours per ton mile for accelerating at 2 m.p.h.p.s. is 31 per cent. This is a larger figure than can be obtained in normal operation, and this point will be explained later.

In reviewing these figures, it will readily be appreciated that a control, automatic in operation, will enable the management to select a predetermined economical rate of acceleration that will always be maintained in service.

The next thing which we have to consider is different rates of braking. Fig. 2 shows curves braking at 0.825, 1, 1½ and 2½ m.p.h.p.s. With these values and under the same conditions as are outlined for acceleration at 1½ m.p.h.p.s., the power consumption will be 100, 85, 79 and 76 watthours per ton mile, respectively. The percentage of differences between these figures is 15, 7 and 4 per cent, and the total difference between 100 watthours per ton mile and 76 watthours per ton mile obtained with the maximum and the minimum braking is 24 per cent. It will be well to explain that the savings shown by these two sets of curves for different rates of acceleration and braking are not additive in every case, but it is possible to obtain either of the savings separately. With the lowest rate of braking and accelerating there is a point

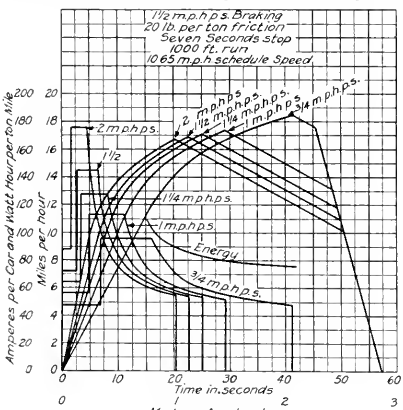


Fig. 1. Chart Showing Decrease in Energy as Rate of Acceleration is Increased

where the lines cross, which would make it impossible to keep the schedules as outlined.

With a given car there are two other features which enter into the question of power consumption, viz., the effect of the length of stops, and also the question of extending the running time. In Fig. 3 is illustrated the effect of power on lengthening the stop from 7 to 10.9 and 12.3 seconds, and still maintain the same schedule. With the 7-second stop the energy required will be 74 watthours per ton mile, and with the 10.9-

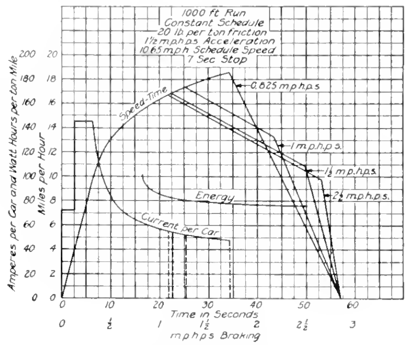


Fig. 2. Showing Decrease in Energy Consumption as Rate of Braking is Increased

second stops it will be increased to 81 watthours; with a 12.3-second stop the energy will be increased to 105 watthours per ton mile. These figures indicate the advisability of doing everything possible to facilitate the rapid loading and unloading of the passengers, and it brings in the consideration of the method of fare collection, low step and general efficiency of the trainmen.

Fig. 4 illustrates the amount of energy which may be saved by extending a given schedule. This curve, while interesting, shows savings in power which will in all probability be offset by the greater expenditure for platform wages. The tendency among all progressive operators has been to do everything possible to facilitate the making of high schedule speeds, and the analysis shows that in nearly every case it is advisable to sacrifice power and maintenance savings for platform wages, since the platform wages represent such a large portion of the operating ratio. However, there are lines operating that have large leeway in the schedules, but conditions are such that changes in running time and service conditions will not allow a reduction in the cars to give required service. In this case the maximum amount of coasting can be procured effectively.

One of our problems is to determine how to secure the maximum number of car miles per hour. In order to establish a ready check as to what schedule speeds are possible with a given number of stops per mile, and also the general effect on power consumption, curves 5, 6 and 7 are presented.

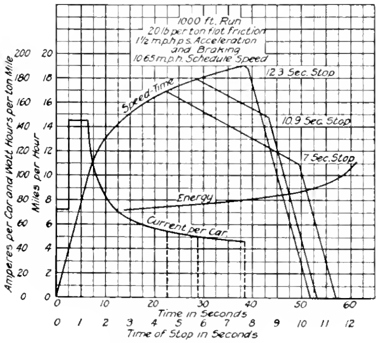


Fig. 3. Showing Increase of Energy Consumption for a Given Run and Schedule as the Time of Stop is Increased

Length of stops has a great influence on the general efficiency of a system. In securing data for new equipments, it is found in different cities that the average length of stop varies from 5 to 10 seconds. The importance of shortening the stop to a minimum, from a power consumption standpoint, is shown in Fig. 3 for different lengths of stop when the same schedule is to be maintained. However, there are conditions where instead of maintaining the schedule the running time is extended. To explain this latter condition the curves shown in Fig. 5 are given. With a car geared to a free running speed of 25 m.p.h., making 7 stops per mile, it will be noted that it is possible to make a schedule speed of 10 m.p.h. with 10-second stops, while with 5-second stops the schedule speed will be increased to 11.2 m.p.h., or 11.2 per cent.

Fig. 6 shows a 20-ton car geared for a free running speed of 15, 20, 25 and 30 m.p.h., and the watthours per ton mile at the car are also shown with each of these variables. Curve 7 gives the same information for a 40-ton interurban car, geared for 30, 40, 50 and 60 m.p.h., free running speed. It is interesting to note the effect of stops per mile on schudule speed and power consumption. Take a 20-ton car, geared for a free running speed of 25 m.p.h., and comparing the services of 7 and 9 stops per mile, it will be noted that with 7 stops per mile it is possible to make 11.2 m.p.h. schedule, and that the power consumption will be 2.52 watthours per car mile, while with 9 stops per mile a schedule of 9.8 m.p.h. can be made, and the power consumption will be increased to 2.88 kw. hours per car-mile. When comparing the 7 and 9-stop per mile services it should be noted that with 9 stops per mile the energy has been increased 14.25 per cent, and what is more important the schedule speed has been decreased practically 10 per cent.

An example of the power and schedule savings that can be made will be illustrated by a car making 40,000 car-miles per year. Assuming that the power costs one cent per kilowatt hour delivered at the car, the difference between 7 and 9 stops per mile would mean a saving of $144 per year per car in power. On the assumption that the car makes 40,000 miles per year and maintains a schedule speed of 11.2 m.p.h., the car would be in operation 3571 car-hours, while if making a schedule speed of 9.8 m.p.h., the car would be in service 4081 car-hours. These figures illustrate the advisability of cutting down and eliminating all useless stops, and show the necessity of inaugurating skip-stop, nearside

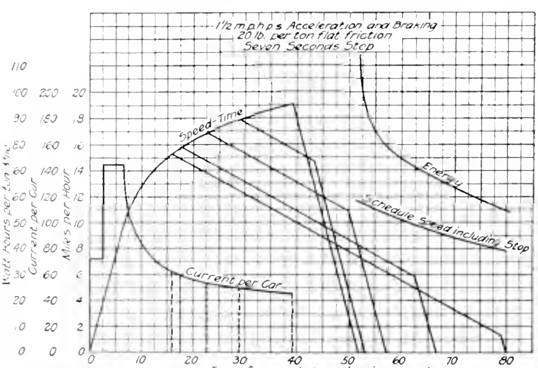


Fig. 4. Chart Showing Decrease in Energy Consumption, Current Input, and Schedule Speed by Increasing the Coasting in a 1000-Ft. Run

stop, and every other means which we have at hand to reduce the number of stops per mile. It may be said that on some lines, even though the schedule speed were increased from 5 per cent to 10 per cent, it would not be possible to decrease the number of cars actually required for the service, but still there are a larger number of other cases where it is possible to take the full advantage of the savings which are obtained by operating at the maximum schedule speed.

The advantages accruing from reducing the number of stops and thereby increasing schedule speeds is not by any means all with the railway company, but is also shared in even larger proportion by the patrons. Assume that operating conditions have been changed so that it is possible to shorten a schedule five minutes, and that the car carries 50 passengers, it is reasonable to assume that at least half of these passengers benefit to the full extent of the saved time. On this basis the total time saved for half of the passengers would be 125 minutes. The total aggregate time saved to a community would be stupendous. Some of the large progressive companies have different schedule speeds to economically meet the varying conditions of traffic. I know of one company that operates four different schedules, which apply to the morning rush, midday service, evening rush and the evening service. During the non-rush hours schedules are speeded up and every possible advantage taken to decrease the number of cars needed, and to speed up the remaining cars so as to give the proper interval between cars.

In using curves 6 and 7, it should be borne in mind that they apply only to tangent level track, without curves, and do not include any traffic delays. In ordinary practice, adding 10 per cent to the schedule speed will enable the theoretical values to be applied to actual conditions.

So far we have been discussing the savings which it is possible to obtain in operation.

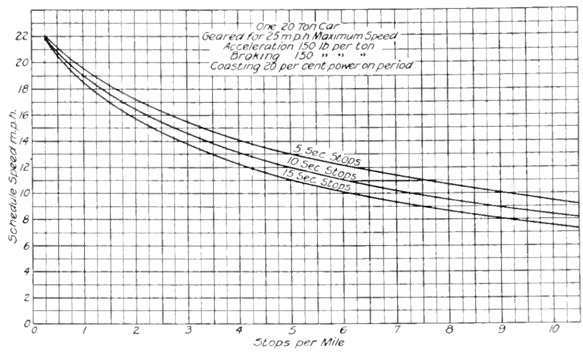


Fig. 5. Typical Schedule Speeds for One-Ton Car

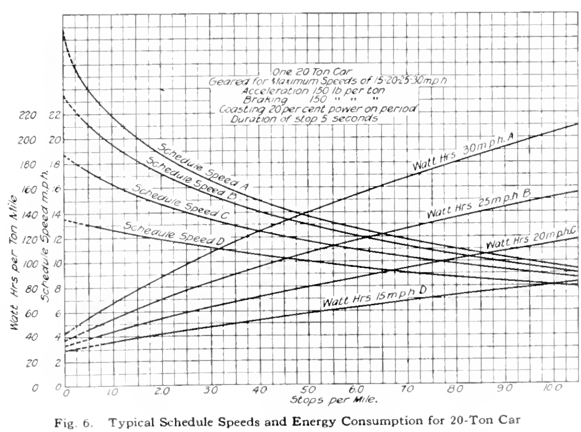


Fig. 6. Typical Schedule Speeds and Energy Consumption for 20-Ton Car

There is one other feature which was recently called very strongly to our attention, that is, the substituting of trucks and motors arranged for 24 in. wheels where 33 in. wheels are now used. In the particular case to which I refer a pair of trucks for these cars weigh 14,000 lb., the cars being equipped with two motors weighing 3370 lb. each. By substituting four motors which weigh 900 lb. each, the total weigh savings when substituting four small motors for the two large motors was 3140 lb. The saving in weight by substituting 24 in. wheel trucks was a further weight saving of 5400 lb., making a total reduction in car weight of 8540 lb. This weight reduction amounted to 20 per cent of the weight of the car, and the figures show that it much more than pays for the investment.

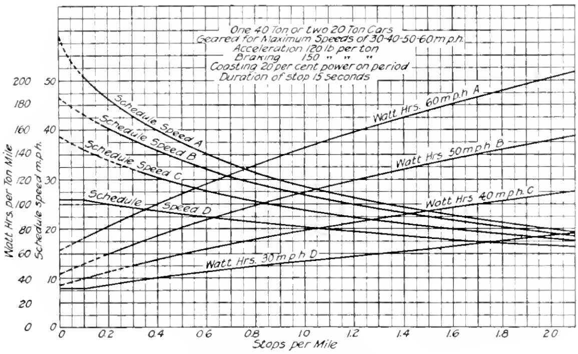


Fig. 7. Typical Schedule Speeds and Energy Consumption Curves for One 40-Ton or Two 20-Ton Cars

There are other substitutions on the car body and car equipment which can frequently be made to considerable advantage. In nearly all cars which were built sometime ago there are certain elements which are extremely heavy, and lighter weight material could be substituted at a small cost. Recently the new management of a road were discussing why it was necessary to have large heavy drawbars on the cars, which were never used. This is merely taken as an illustration to show that there are many cases where there is apparatus on a car having considerable weight, which is being hauled around year after year, when the weight could easily be saved and the power expense and other expenses incident thereto eliminated to advantage.

During the past year there has been a large growing tendency to apply light weight, one-man cars to many services. This feeling is not confined to any particular district, but is growing more and more general. On nearly every property which I have visited recently there has been a tendency to place small light weight one-man cars in stub-end service. An analysis of the number of passengers carried throughout the day in many instances shows that a car having a seating capacity of approximately 30 passengers would be sufficient for practically all needs.

In analyzing the traffic on city lines, there are usually found several cases where the receipts per car mile are far below normal. These lines are the ones which drain the net earnings and are a necessary evil. The small car in many cases will transform a deficit to an earning.

Recently we had occasion to analyze a service where two cars were required. At the present time cars weighing 56,500 lb. operated by two men are employed. This particular company buys power, paying two cents per kilowatt-hour for current. In going over the conductors' reports it was found that with the exception of one trip a day never more than fifteen passengers were carried. However, these cars were used to transport the workmen of a particular factory, which always closed at a particular hour, and at this period eighty passengers would have to be carried. During the remainder of the day the load would vary from two to fifteen passengers. The management of this company have practically decided to purchase four 10,000-lb. one-man cars seating 30 passengers. The power will be reduced to approximately one-fifth of that which is now being obtained, and the labor saving will be reduced to slightly more than half.

One of the most progressive managements that I know of is at present analyzing the service of a large representative city to determine just what can be done with extremely light weight one-man cars. Their preliminary analysis shows that there will be 1st, a saving of wages; 2nd. a saving in power; 3rd. a saving in maintenance; 4th the development of traffic, due to more frequent service; and 5th a reduction in accidents. Of course, it is not intended that these light weight, one-man cars shall be substituted for every class of service. There are certain classes of work, such as the congestion in the down town city streets, which would make it inadvisable to ever attempt, or even seriously consider, the use of small cars. However, there are certain lines which can be picked out in every city, where the small car can be substituted for the large car, and enormous savings made. From present indications it would seem that a large number of places can be found where the installation of the small cars would pay 50 per cent or more on the investment.

The small one-man car should be equipped with all possible safety and time-saving devices, which should include air brakes, control with dead man's release which automatically cuts off power, applies brakes, sands track and opens car door. When these features are properly applied they are time savers, and in case of accident put the railway in the position of having provided the greatest possible protection.

With the rising cost of producing transportation, and the increased competition of the privately owned automobile, it is apparent that it will be necessary to introduce the new forms of light weight one-man cars for many places, and it will merely be a question of analysis to determine just how many applications can be made of this recent addition to transportation.

AUTOMATIC OPERATION OF MINE HOISTS AS EXEMPLIFIED BY THE NEW ELECTRIC HOISTS FOR THE INSPIRATION CONSOLIDATED COPPER COMPANY

By H. Kenyon Burch
Chief Engineer, Inspiration Consolidated Copper Company, Miami, Ariz.
M. A. Whiting
Power and Mining Engineering Department, General Electric Company

In the composition of this article the authors have not restricted themselves simply to a description of the automatic hoist installation at the Inspiration Consolidated Copper Company's mines but have, in the introduction and at other pertinent points, impartially stated the operating conditions under which automatic control or hand control produces the best results. The greater portion of the article, however, they have devoted to a general description of the automatic hoist equipment located at the Inspiration Mines. The principal features covered are the arrangement of the hoists, the automatic cycle, the hand control, the protective devices, and the adjustments. This article appeared in the Bulletin of the American Institute of Mining Engineers, March 1916, and will be presented as a paper at the Arizona meeting of the A.I.M.E., September 1916.—Editor.

One of the advantages presented by electric drive in many classes of work is the ease with which the electric motor can be controlled automatically. In a large number of cases certain features of the control are automatic—for example, the rate of acceleration may be limited automatically or the equipment may be stopped automatically at the limit of travel—but the equipment is started and ordinarily is stopped by hand. In other cases the motion of the machinery is utilized to start, control the speed, and stop the motor automatically, independently of any operator.

A considerable proportion of the large mine hoists now in use have certain automatic features, particularly protective devices against overwinding, and, in some classes of electric hoists, devices for preventing excessive acceleration or retardation. The large automatic hoists discussed in this paper, however, are completely automatic, i.e., capable of making their trips without the presence of an operator at the control levers.

According to circumstances, various advantages may be obtained by automatic control, chief of which are decreased power consumption, increased precision and safety of operation, and decreased cost of attendance. The first step in the analysis of a prospective automatic mine hoist is to determine whether automatic operation is feasible at all. If men are to be hoisted, or levels changed, the attention of an operator is required for these purposes; but under some conditions it may be entirely practicable and advantageous to build the equipment so that, while provision is made for hoisting men or changing levels, ore can be hoisted automatically from any one level. If, however, an operator's attention is required every few minutes for changing levels, handling men or drills, or for other work requiring hand control, it is obvious that automatic operation between times will not be of any practical benefit.

SPEED CONDITIONS REQUIRED FOR AUTOMATIC HOISTING

For a very slow hoisting speed it may be possible for the skip or cage to pass through the dump at full speed, and a sufficiently accurate stop may possibly be obtained automatically by cutting off power and applying the brakes at full speed. In this case, either a shunt-wound direct-current motor or an induction motor may be used. A number of slow-speed automatic hoists are arranged in this manner and are driven by induction motors. One equipment of this type used in mining work is the inclined hoist for handling concentrates at one of the mills of the Arizona

Copper Co., described by H. L. Hall in the *Mining and Engineering World* for Apr. 10, 1915. This hoist has a rope speed of approximately 275 ft. per minute.

For higher rope speeds, at least for speeds over 400 ft. per minute, it is necessary to consider carefully the speed characteristics obtainable from the type of drive proposed. For these higher rope speeds, it is necessary to slow down before entering the dumping horns. Furthermore, the speed about midway in the dump must usually be reduced below the maximum safe speed entering the dump. A reasonably accurate stop is always required; in some cases a total variation of 2 or 3 ft. might not prove prohibitive, but in other cases the stop must be more accurate. For reliable operation, it is nearly always imperative that the automatic-control system shall act in like manner irrespective of load, i.e., that the rate of retardation and the position of stopping be nearly the same whether the skip comes up loaded or empty.

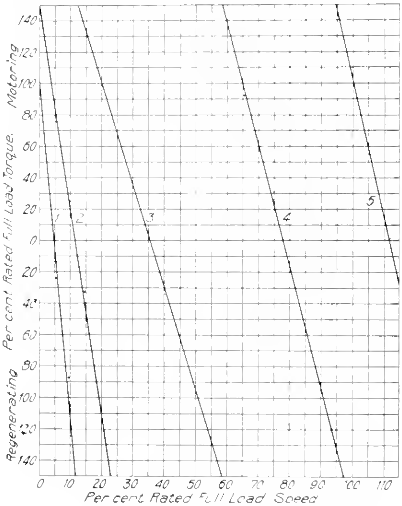


Fig. 1. Typical Speed-Torque Curves for Direct-Current Mine Hoist with Generator Field Control

There is only one class of motive power which is inherently suited for automatic operation at high rope speeds, viz., the direct-current shunt-wound motor with voltage control. The speed-torque characteristics for an equipment of this character are represented in Fig. 1. These curves are typical of this class of equipment, although the exact slope of the curves will vary slightly in individual cases. Curve 1 shows the characteristics on the lowest, and curve 5 the characteristic on the highest, speed position of the controller for the case selected. The intermediate curves represent three controller points arbitrarily selected out of a total of 30 or more. It will be observed that these curves are nearly, but not quite, parallel. That is to say, the increase in speed in passing from full load to no load is approximately, but not exactly, the same for the various positions of the controller. The deviation from parallelism is due to the effect of armature reactions in the generator and hoist motor, and may be somewhat different for different cases; but its effect is negligible.

The net advantages (for the purpose of automatic hoisting) obtained by this system of drive are as follows:

As the hoist controller is moved back toward the off position the hoist is retarded. In case the net rope pull is sufficient and the stored energy of the moving system is not too great, the hoist motor simply drops back in speed to correspond to the reduced generator voltage obtained on the intermediate

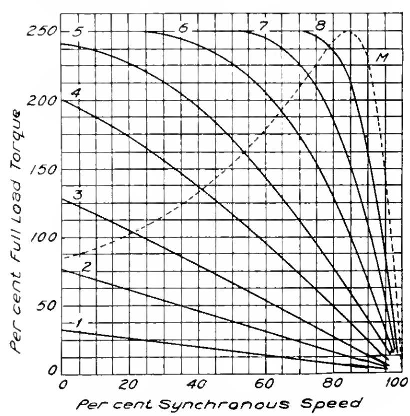


Fig. 2. Typical Speed-Torque Curves for Induction-Motor-Driven Mine Hoist

position of the controller. If, however, the net rope pull is very low (particularly with empty skips in balance), and if the stored energy of the moving system is high, the hoist motor will invert, momentarily, and will act as a generator, returning power to the motor-generator set. This effect is represented in Fig. 1 by the extension of the curves below zero torque. In this manner, if the controller is moved toward the off position more rapidly than the hoist tends to come to rest under the influence of the load, the hoist motor forcibly retards the hoist. If the controller is moved back at the same rate in both cases, the hoist will be retarded to nearly the same speed, and in nearly the same time, irrespective of load in the skip.

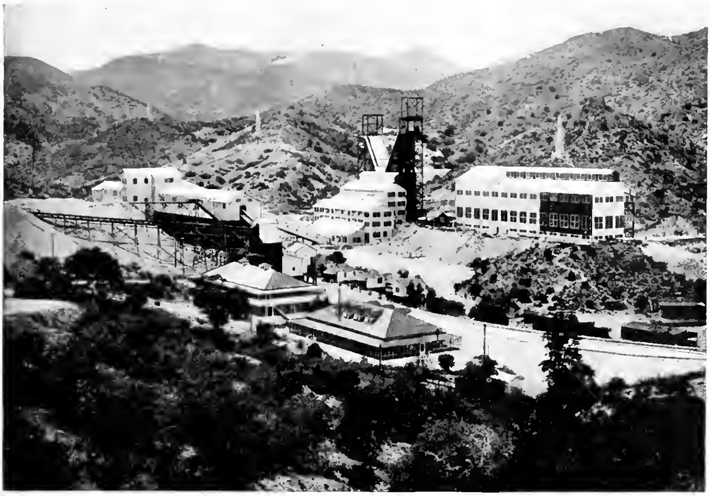


Fig. 4. Main Shafts, Compressor House, Coarse-Crushing Plant and Storage Bins, Inspiration Consolidated Copper Co., Miami, Ariz., During Construction Period

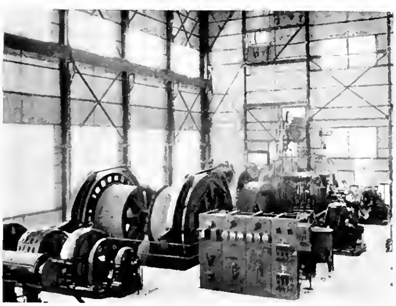


Fig. 3. Main Hoists, Inspiration Consolidated Copper Co.

It is fairly obvious that the steam hoist is unable to approach very closely the speed conditions just described. The steam hoist, of course, is capable of retarding a load by working against the steam or compression, but the vital points in relation to automatic hoisting are: (1) for the same throttle opening and cutoff, the speed will vary widely with variation in load; and (2) if the throttle is partly closed or the cutoff advanced to a point at which the skip will enter the dump at a suitable reduced speed, the engine will exert only a slight retarding torque (if any) to help retard from full speed to the reduced speed at which the engine tends to continue. Most of the retardation must therefore come from the load, which is variable, or may even be negative. Furthermore, with a partly closed throttle the final speed at which the engine tends to continue will vary widely with variation in load.

The induction-motor hoist, in its relation to automatic hoisting, has somewhat the same characteristics as the steam hoist. Fig. 2 represents the speed-torque characteristics of a typical mine-hoist induction motor. In a direct-current hoist, a given retardation can be accomplished in a certain time and distance by the same manipulation of the control, irrespective of the load hoisted. In a steam or air hoist or an induction-motor hoist, a like retardation of different loads requires different manipulation of the control.

These characteristics indicate, and their further consideration confirms, the conclusion that high-speed mine hoists which are to be operated automatically must be, in almost all cases, driven by direct current.

THE AUTOMATIC HOISTS OF THE INSPIRATION CONSOLIDATED COPPER CO.

When the layout of their main shafts was under consideration by the Inspiration Consolidated Copper Co. a concurrence of several conditions indicated the possibility of effecting a saving by hoisting the ore automatically. These conditions were as follows: (1) A direct-current equipment was necessary in any case, as a motor-generator set was required for the flywheel equalization as provided in the power contract with the Reclamation Service. (2) The ore was all to be hoisted from one level. (3) Drills, timbers, supplies and waste were to be handled through a drift opening. (4) Men were to be handled on a separate hoist exclusively. (5) On account of the moderate depth and rope speed only a moderate retardation effort would be required.

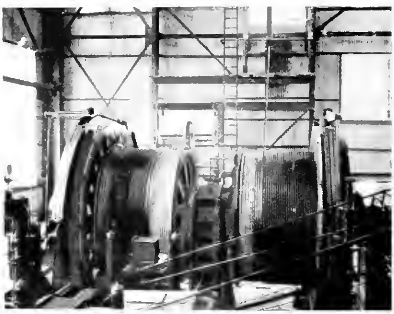


Fig. 5. Drums and Brakes of One Main Hoist

General Arrangement of Hoists

Two three-compartment shafts have been sunk, for two independent balanced hoists, each hoist being adequate in an emergency to keep the concentrator operating at practically full capacity. The third compartment of one shaft contains a double-deck man cage, operating against a counterbalance weight, and the third compartment in the other shaft carries this counterweight, together with air lines, electrical cables, etc. Skips carrying 12½ tons are used, and the ordinary hoisting schedule for which the equipment was designed called for an output of 10,000 tons, with a maximum capacity of 14,000 tons, in 14 hr. The hoists are located in one end of the compressor house. No. 2 hoist, in the background in Fig. 3, handles the skips in the East shaft, which is nearest the compressor house. No. 1 hoist, in the foreground, handles the skips in the West shaft, the ropes from No. 1 passing above No. 2 hoist over idler sheaves on the upper deck of the East headframe, thence over the sheaves on the West headframe. Fig. 4 shows the arrangement of shafts and headframes in relation to the compressor house.

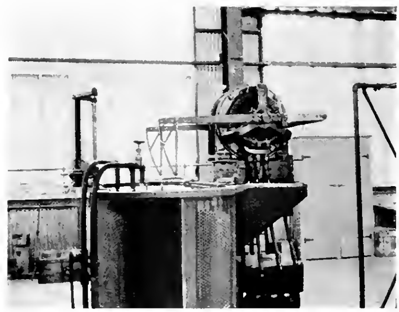


Fig. 6. Liquid Slip Regulator for Regulation of Input to Flywheel Set

The hoists are duplicates, each consisting of one fixed and one clutched drum, each 10 ft. diameter by 65-in. face, grooved for 1,000 ft. of 1¾-in. rope in one layer. The brakes and clutches are air operated with oil cataracts and floating levers, and the automatic control system was so designed that the brake engines could be made practically standard (Fig. 5.) The hoists were designed and built by the Nordberg Manufacturing Co. and the electrical equipment by the General Electric Co.

Each hoist is driven by a 580-h.p., 575-volt, 264-r.p.m. shunt-wound motor through a flexible coupling and Falk gears. Power is supplied to the hoists by a 750-r.p.m. flywheel motor-generator set, consisting of one 850-

h.p., 2,300-volt, 25-cycle induction motor, two 500-kw., 575-volt generators, one 20-kw., 125-volt exciter and a 19,700-lb. 112-in. diameter steel-plate flywheel. Each hoist motor is connected separately to one of the generators and controlled by varying the field of its generator. The flywheel is not in any way necessary to the control or automatic operation of the hoists. Its function is to eliminate the peakloads from the power system. The control for equalization of the power demand follows along standard lines, using a liquid slip-regulator for varying the speed of the flywheel set by varying the resistance in the secondary circuit of the induction motor (Fig. 6).

The depth, from the dump to the chairs under the loading pockets, is 630 ft. in each shaft; from the collar to the chairs, 557 ft. The rope speed is approximately 750 ft. per minute.

Description of Automatic Cycle

Before beginning automatic operation it is necessary, of course, that each hoist be properly clutched-in for the loading level, with one skip in each shaft resting on the chairs below its loading chute. It is not important which skips are on the chairs, provided, of course, that the operator obtains a "release" of skips in both shafts before starting the automatic operation. He then introduces the automatic control by closing two small control switches and locking in two levers, all on the operating-platform. This does not, of itself, start the automatic operation, so that the hoists may be left standing in this manner indefinitely. To start the automatic operation, a master controller is thrown to the automatic running position, and left there as long as automatic hoisting continues. According to the positions in which the skips have been resting, one hoist or the other will start. Say, for example, No. 1 hoist starts, hoisting its South skip. The closing of the master controller just mentioned energizes a small pilot motor which moves No. 1 hoist controller gradually to the full-speed position in one direction. As No. 1 controller starts away from the off position, it simultaneously energizes No. 1 generator field and actuates a pilot device which releases the brakes on No. 1 hoist. As the controller moves farther toward the full-speed position, it gradually builds up the generator voltage, thereby accelerating the hoist to full speed.

Toward the end of its trip the travel of No. 1 hoist actuates a pilot motor which moves No. 2 hoist controller gradually to the full-speed position in one direction, thereby accelerating No. 2 hoist in a similar manner, to hoist its North skip. Shortly before its skip enters the dumping horns, the travel of No. 1 hoist, by means of cams, one of which

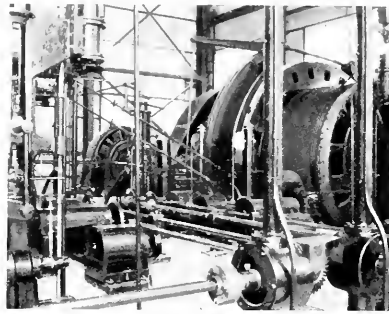


Fig. 7. Depth Indicators and Automatic-control System for Main Hoists

is geared to each drum, moves No. 1 controller gradually toward the off position. This gradually decreases No. 1 generator voltage, thereby retarding No. 1 hoist, and just as its North skip is about to land on the chairs, No. 1 controller comes into the off position. This completes the retardation and automatically applies the brakes. No. 1 hoist stands at rest while No. 2 is hoisting its North skip. Toward the end of its trip, No. 2 hoist energizes the pilot motor for No. 1 controller so as to start No. 1 hoist in the opposite direction, i.e., to hoist its North skip. No. 2 hoist comes to rest in the manner described for No. 1, and rests while No. 1 is hoisting its North skip. Toward the end of its trip, No. 1 hoist energizes the pilot control to start No. 2 in the opposite direction, i.e., to hoist its South skip. The sequence continues in this manner until stopped by the operator, as described later.

A loading system is used underground by which the skips are automatically loaded with a predetermined weight of ore per trip. The reduction of the attendance required at the foot of the shaft contributes materially to the advantages of automatic hoisting. The automatic loading system can be thrown out of engagement in either shaft so that the hoists may be operated either automatically or by hand, for purposes of inspection or adjustment, without hoisting any ore.

Variation in Rate of Automatic Hoisting

To obtain a more rapid operation of the hoists, i.e., a greater number of trips per hour, when operating automatically a control switch may be thrown, by which each hoist will be started earlier in the trip of the other hoist, thus overlapping to a greater extent the trips of the two. If it is desired to run the hoists automatically at fewer trips per hour than normal, this is done by introducing resistance permanently in each generator field circuit, to give a rope speed lower than normal.

Hand Control

When the details of design were first considered, one of the chief problems was the arrangement of the control so that the transition from hand to automatic operation, and more especially the transition from automatic to hand operation, might be made without risk or delay, and in a manner easily remembered by any operator acquainted with the equipment. To this end the levers on the operating platform which operate the hoist controllers and brakes for hand control are not disconnected from the controllers or brake engines when running automatically. Consequently, when the automatic pilot devices are cut in, and the hoists are operating automatically, these levers move back and forth, as if the hoists were being controlled by hand by invisible operators. When, therefore, the transition from automatic to hand operation is made during a trip, the brake and controller levers of both hoists are in the correct positions and properly in engagement for hand control.

The automatic operation can be interrupted at any time during a trip. This is done most easily by throwing the master controller for automatic operation to the off position, which causes any trip which is under way at the time to be completed automatically, dumping in the usual manner, but prevents the next trip from starting. If the hoists are then left standing, and not operated by hand, all that is necessary to start automatic hoisting again is to throw the master controller to the automatic running position (Fig. 7).

Before the construction work at the foot of the shafts and in the bins in the tipple had been completed in all details, it was necessary occasionally to stop an automatic trip without letting it dump. In such an event, or when necessary for any reason to transfer to hand control before completing a trip, the master controller for automatic hoisting is thrown to the off position. Without disconnecting or unhooking any other parts the controller lever of the hoist which is running may then be pulled back to the off position by hand, and as the controller comes into the off position the brakes will set automatically. It is now possible to leave the pilot control of the brakes connected in service, so that the brakes will release and set automatically, as the controller is moved by hand from or to the off position. Or, if necessary on account of the character of hoisting to be done, the automatic pilot control of the brakes can be cut out, in which case brakes and controller will be controlled separately by hand.

Under all conditions (except when making adjustments in the manner described later), the cams on each hoist controller remain connected mechanically to the hoist drums. This cam mechanism thus serves two purposes: (1) in automatic operation it provides the automatic slowdown and stop; and (2) in hand operation, if the operator does not begin retardation at the proper point, this mechanism will retard the hoist in practically the same manner as when hoisting automatically, thus providing protection against overwinding when operating by hand.

Protective Devices

The protective system resembles those of a considerable number of large direct-current mine hoists, of the same general type (except the automatic operation) as the Inspiration hoists. In the latter, as has just been noted, the automatic control system provides against overwinding in hand operation. An additional set of emergency-limit switches is used, which gives similar protection in case of failure of the automatic control. During hand operation there are effective, therefore, two complete sets of protective devices against overwinding. For each hoist a hand-operated emergency switch is provided on the operating platform, and a similar emergency switch is located at the foot of the corresponding shaft, by means of which either or both hoists may be stopped quickly from the operating platform, or the foot. Without appreciable complication, additional emergency switches may be installed at other points, if desired.

The operation of any one or more of these emergency devices cuts off power from the hoist and makes an emergency application of the brakes. An emergency, which affects one hoist only, acts on the power and brakes of that hoist only. The failure of excitation or alternating-current power, which affects both hoists, cuts off power and makes an emergency application of the brakes simultaneously on both hoists.

Adjustments in Service

When unclutching for changing levels, and when taking up stretch of ropes, the adjustments are taken care of as follows:

On the Inspiration hoists it has been the custom, whenever the hoists are to be idle an entire shift, to bring both skips to the collar of the shaft, in order to save rusting of the ropes. This is done by unclutching just as in any ordinary hoist with one fixed and one clutched drum. If desirable for any reason, either hoist may be run by hand control either out of balance or clutched in for balance to operate from other levels than the regular loading level. When clutching or unclutching, the adjustments of the automatic control system are not touched.

If the shafts are sunk to the ultimate depth contemplated, and the present loading stations abandoned, the control can be readjusted to operate automatically from the increased depth. Without changing the adjustment of the control equipment, it is not possible to operate automatically from levels differing considerably from the normal level for which adjustment has been made, but the system is capable of modification so as to hoist automatically in balance from any level to the dump, without readjustment, all the adjustments being taken care of automatically by clutching in at the desired level.

Stretch of ropes is taken up in a simple manner which itself is semi-automatic and does not require any measurements. The first time it was necessary, the stretch was taken up on both ropes of one hoist in about 15 min., at the end of which all adjustments were in shape for hand or automatic operation. The method is as follows:

The hoist is run into an automatic stop with the skip on the clutched side resting on the chairs. (This is effected by the cam which is geared to the clutched drum.) The controller and cams are now in the proper position for an automatic stop on this side but the rope on this side has unwound farther than normal by an amount equal to the stretch or slack which it is intended to take up. This cam is now uncoupled, but the other cam is left coupled. The hoist is now moved by hand control just far enough to wind up the estimated amount of slack, and the cam on this side is then coupled up to the clutched drum. This operation takes up the slack on the clutched side and transfers it to the fixed side. The hoist is now run, in balance, into an automatic stop on the fixed drum side, which lands the skip on the fixed drum side on the chairs, and brings the skip on the clutched side into the dump. The cam on the fixed side is now uncoupled, and before moving the hoist to take up slack, the other drum is unclutched, so as to leave its skip in the normal position in the dump. The fixed drum is then moved sufficiently to take up all the slack on that side, i.e., the stretch of rope on that side plus the slack transferred to that side by taking up the stretch on the clutched drum side just previously. The cam is then coupled up to the fixed drum and the other drum is clutched-in, which completes the adjustment of both ropes and cams and leaves the hoist ready for operation. It is necessary, of course, not only to take up stretch on each side, but also to clutch-in at the proper level. During the foregoing procedure, after unclutching one drum as described, the same movement of the other drum which takes up the slack also makes the necessary correction for level.

General Observations on Operation

The East shaft was ready for operation before the construction work had been completed in the West shaft. The ropes were put on No. 2 hoist, and for purposes of test and for a thorough tryout of the system, both hoists were operated automatically, No. 1 hoist running automatically as if in actual service, but without any ropes on the drums.

Both ropes were on No. 2 hoist and both skips were hung in the East shaft by the morning of July 25, 1915. During one shift on that day, after marking the ropes and the drum flanges, we coupled up the automatic control and the depth indicators to the drums, checked up the shaft and tipple clearances, and the adjustment of the cams for automatic retardation and stop, and hoisted 18 skips of ore by hand control, using the cams for automatic retardation but not using complete automatic operation. The following day, between 8 a.m. and noon, we made adjustments for complete automatic operation, and hoisted automatically 44 loaded skips. The adjustments were refined somewhat at a later date, but those made during the first three-quarters of an hour of automatic operation worked well.

The same morning in which the equipment first operated automatically, the accuracy of stop was observed for 12 consecutive trips, i.e., six trips each way. The total variation between maximum and minimum was 4 in. of rope travel. After a few weeks of intermittent operation, similar observations were taken. In 20 consecutive trips (10 each way), the total variation between maximum and minimum was only 1.5 in. of rope travel in one direction and 1.25 in the other. During this time the ore hung back in the loading pockets on one side, so that six of the trips included in the above figures were made empty. It is significant that this variation of 1.5 in. is only 1 per cent. of the distance traveled per second at full speed of the hoist.

Attendance

To operate two hand-controlled hoists, either steam or electric, of the size and importance of these, would require at least two operators per shift; and according to practice in some localities, an oiler would be employed in addition to the two operators.

For the operation of these two automatic hoists there is required only one operator, who is able to attend to the oiling and to whatever hand operation of either hoist may be necessary on his shift.

GENERAL CONCLUSIONS

In the section of the paper dealing particularly with the Inspiration hoists, it is our purpose principally to describe the operating features and the results accomplished by the system, as it would expand this paper to an excessive length to describe fully the essential details of design of the control equipment by which these results were attained. It would enlarge the paper still more to enter into the reasons in accordance with which the methods were selected for performing the several necessary functions of this control system. When the design of the equipment was undertaken several engineers worked, at first independently and then in consultation, in order to give due consideration to all practicable methods of operation of the various details, and as a result several arrangements were studied and discarded before settling on the one finally adopted. It was this thorough preliminary study of the entire situation which made it possible to begin practical automatic operation promptly, after the skips were hung in the shaft.

Differences in operating conditions will naturally require different methods of control, so that it is to be expected that for large automatic mine hoists which may be built in the future the control system will differ from the Inspiration system in several respects. However, the exhaustive investigation of the subject which preceded this installation, and the experience gained in the adjustment and starting of the Inspiration equipment, make it possible to determine readily the feasibility of other proposed automatic hoists for different conditions of operation. The experience thus gained makes it practicable, moreover, to build equipment for greater depths, higher speeds, or other exacting conditions for which, without this experience, it would be impossible to make designs with reasonable certainty of success.

The application of automatic mine hoists will always be limited by the fact that operation cannot be truly automatic, except where the conditions of hoisting are reasonably uniform. In other words, where, under prevailing conditions, the attendance of an operator is required practically continuously throughout the shift in order to change levels, hoist or lower loads out of balance, or handle men, it is impossible to realize any practical advantages by operating automatically during the short periods of hoisting ore regularly from any one level. On the other hand, entire uniformity is not necessary in order to make automatic operation practicable. As an illustration, consider the case of a main hoist serving a few levels, and an auxiliary hoist in the same hoist house handling all men, timbers, supplies, waste, etc., for all the levels served by the main hoist. Conditions of operation may possibly be sufficiently favorable so that if the main hoist is arranged for automatic operation (or for semi-automatic control from the level stations by the skip tender), the operator for the auxiliary hoist will be able to take care of the hand operation required on the main hoist.

It may reasonably be anticipated that from time to time various mine-hoisting projects will come up for consideration in which the possibilities offered by automatic hoisting should by no means be dismissed without investigation.

THE PLIOTRON OSCILLATOR FOR EXTREME FREQUENCIES

By William C. White

Research Laboratory, General Electric Company

Hot-cathode tubes have been in practical use a number of years for the reception of the extremely small currents in radio telegraphy and telephony. However, the electrical properties of such tubes find applications in other fields when, as in the case of the pliotron, they are capable of handling larger amounts of energy and at higher voltages. One such application is taken up in the following article which is a description of the use of the pliotron for the production of alternating currents. First, is given an explanation of the general principles involved and then two arrangements are described: one, for the production of a frequency of only one-half cycle per second, and, the other, for the production of a frequency of fifty million cycles per second.—Editor.

It has been common practice during the last few years to utilize hot cathode vacuum tubes of the relay type, such as the pliotron,* for the production of a few watts of alternating current energy of audible, or radio, frequency.

A type of pliotron has been developed in the Research Laboratory at Schenectady having an output of high frequency current sufficient for transmission purposes in practical radio telegraphy and telephony. In the light of this development it is of interest to determine to how high and to how low a frequency this tube will oscillate, and what factors prevent a further increase, or decrease. It is also desirable to know what quantities of energy could be obtained at extreme frequencies. The following article has therefore been prepared to show some of the possibilities of the pliotron oscillator in these directions.

Fig. 1. Filament and Grid Element of Pliotron

Fig. 2. Pliotron Tube Complete

THE PLIOTRON

The type of pliotron referred to has the usual three elements; filament, grid and plate, all enclosed in an evacuated globe. The tungsten filament is about 10 inches long and is W shaped, the four spans lying in the same plane. The grid surrounds the filament and consists of a mesh of very small tungsten

* For the electron theory of the pliotron see "The Pure Electron Discharge and its Applications in Radio Telegraphy and Telephony," General Electric Review, May, 1915.

wires lying in two planes, one on each side of, and parallel to, the plane of the filament. This is made by winding the tungsten wire for the grid on a rectangular frame. The planes of the grid wires are each about 1/8 inch distant from the plane of the filament.

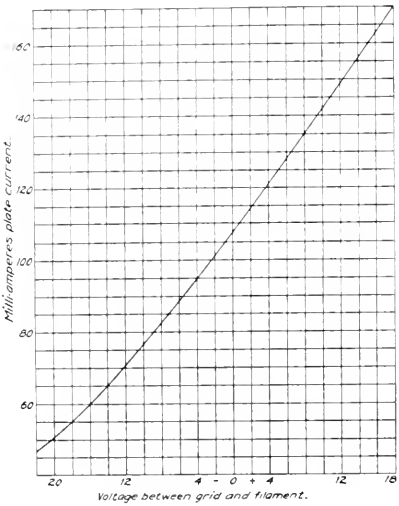


Fig. 3. Curve Showing Control Characteristics of Pliotron

The plate consists of two rectangular sheets of thin tungsten about 1¾ by 2½ inches, and these sheets are spaced parallel to each other about ½ inch apart; these are held in the bulb so as to be parallel to the planes of the grid and filament and, therefore, each one is spaced about ¼ inch from the filament.

The grid and filament element is shown in Fig. 1 and the complete pliotron tube in Fig. 2.

These pliotron tubes are evacuated to a high degree and the metal of the grid and the plate is freed from gas.

In operation the filament is made incandescent as in a lamp, and if then a positive potential, with respect to the filament, is applied to the anode a current will flow between the two, due to the passage of electrons from the filament to the plate.

Providing the filament is emitting sufficient electrons, the number of electrons reaching the plate per unit of time (and thus the current between filament and plate) depends upon the potential gradient, and, therefore, this current increases with the plate voltage.

Now the electrons in their passage must pass through the mesh of the grid. Any change in potential of the grid with respect to the filament changes the electric force distribution between filament and plate, and therefore, the electron current. If the grid is made positive with respect to the filament the electrons are accelerated and the current increases; if negative, their acceleration is retarded and the current decreases.

When constructed in a certain manner there exists an almost linear relation between grid potential and plate current through a wide range. Such a relation is shown in the characteristic curve, Fig. 3. The plate current will follow faithfully, and without lag or phase difference, and variation in the potential of the grid.

THE PLIOTRON OSCILLATOR

Suppose an arrangement as shown in Fig. 4. Then F represents the filament, G the grid, P the plate of a pliotron and D is the source of direct current in the plate circuit. A transformer, one coil of which is in the plate circuit is represented by T and A is an alternator supplying an alternating potential to the grid G.

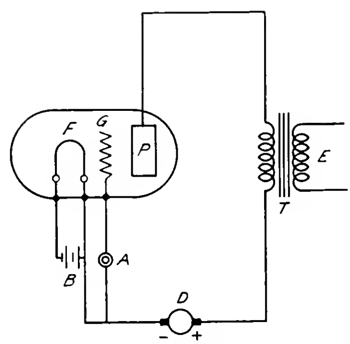


Fig. 4. Diagram of Connections to Illustrate the Principle of the Pliotron Oscillator

During one half of the cycle of the alternator potential the grid is positive with respect to the filament and during the other half it is negative. Since the plate current is controlled by the grid potential the former will also vary, following the sine wave of the alternator, periodically varying between a minimum and a maximum, but never reversing in direction. However, from E, the secondary of the transformer, a real alternating current may be obtained.

The energy of this alternating current obtained at E is drawn from the direct current source D and is of exactly the same character as that supplied by the alternator A, but of much greater energy because very little energy is required to vary the potential of the grid G. Suppose one watt is supplied at A and ten watts of the same character alternating current is obtained at E, it should then be perfectly possible to utilize one watt of the ten then obtained at E to supply the grid, in place of using the alternator and thus make the system self exciting. Such an arrangement as just described constitutes a pliotron oscillator system.

In a steam or gasoline engine a small part of the power obtained is used to operate the valves and it is very important that the opening and closing of these valves be correctly timed. In a similar way, with the pliotron operating as an oscillator, it is very important that the potential returned to the grid for excitation has the correct amplitude and phase relation with respect to the plate current. The frequency of the alternating current which a self exciting system of this type

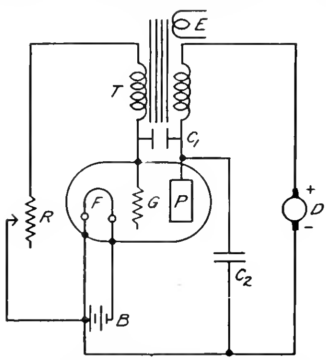


Fig. 5. Diagram of Connections for Very Low Frequency Pliotron Oscillator

generates will, of course, depend on the electrical constants of the circuits.

There have been many connections devised by various workers in this line to accomplish this necessary self-excitation, and for any particular purpose and set of conditions there will be a best arrangement.

In practice, either one of two general methods is employed, or a combination of the two: that is, sufficient energy is supplied the grid to keep the system oscillating either by electromagnetic or electrostatic coupling.

PRODUCTION OF CURRENTS OF VERY LOW FREQUENCY

For the production of very low frequencies it is necessary to have very large inductances and capacities. For instance, an inductance of 101 henries and 25 microfarads has a natural period of one second. Such an inductance, to be of a reasonable size, should have a closed iron core and will have many thousand turns of wire. A capacity of the order of 25 microfarads is most practical in the form of a number of units of tinfoil-paraffine-paper condensers connected in parallel.

Owing to the fact that inductive effects and capacity charging currents are very small at a frequency of the order of one cycle per second, it is usually advisable to provide for both electromagnetic and electrostatic coupling between the grid and plate circuits.

Such a connection for the production of very low frequencies from the pliotron is shown in Fig. 5.

Here the elements of the pliotron are represented as before, and T is a transformer acting as an inductance and also is used for transferring energy back into the grid circuit. The condenser C_1 forms an electrostatic coupling between the circuits and aids the electromagnetic coupling in supplying energy back into the grid circuit for excitation. The condenser C_2 is a capacity added to increase the period of the oscillations, and R is a resistance which is placed in circuit for some tests described in a later paragraph. As in the previous figure the pliotron filament is made incandescent from a battery B and the energy to produce the alternating current is derived from a direct current generator D. Alternating current energy may be withdrawn from the system by a third coil E on the transformer T.

It has been possible by such an arrangement to produce an alternating current of a frequency as low as one half cycle per second. Lower frequency than this may be obtained if suitable inductances or capacities of higher value are available.

Experiments at a Frequency of One Half Cycle Per Second

For measurements at this frequency zero center direct current instruments are used.

the swing of the pointers being slow enough that readings at the peak of the wave may be obtained, and the phase relations between the various currents and voltages noted.

By means of small magnetic needles as indicators the magnetic flux actions in the transformer may be studied.

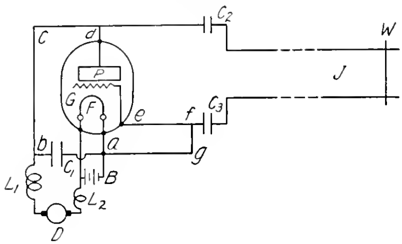


Fig. 6. Diagram of Connections for Very High Frequency Pliotron Oscillator

If, while this pliotron oscillating system is operating, resistance is introduced at the point R in Fig. 5, the amplitude of the oscillations will be decreased, and if sufficient resistance is added enough energy can not be supplied to the grid circuit to both excite the system and supply the losses in this resistance, and therefore the oscillations will die down and finally cease. The value of this resistance can be readily adjusted so that five to ten seconds, or even longer, will be required for the oscillations to slowly decrease in amplitude and finally die out.

This effect can be watched by means of the direct current meters in the circuit and thus the damping factor determined or a curve drawing instrument employed giving a permanent record of the train of oscillations. There will be a certain critical resistance at which the system will just continue to oscillate, but at a reduced amplitude, any increase now in the resistance will cause the oscillations to die out, and the rate of decrement is definitely controlled by the amount of additional resistance added, and can be watched on the direct current instruments.

This procedure may be reversed; that is, if the system is at rest with the value of R higher than the critical value, the oscillations will build up when R is lowered, the rate of building up being under control. If B and D are very steady sources of supply, the value of R can often be made below the critical point, and still the system will not oscillate, being in an unstable equilibrium. However, a momentary opening and closing of the circuit at R will usually supply just enough of a shock to the circuits to overcome this equilibrium and allow oscillations to start building up.

By proper values of inductance and capacity, the system may be given a frequency of just one cycle per second and then a relay in one of the circuits will tick off seconds, thus forming a real electrical clock.

It is possible that some electrochemical reactions may best be brought about by a current of very low frequency.

The amount of low frequency energy obtainable is dependent upon the voltage of the source D, but even with this at only 110 volts sufficient energy can be obtained for the experiments mentioned in the preceding paragraphs.

THE PRODUCTION OF VERY HIGH FREQUENCIES

For the production of very high frequencies it is necessary to reduce the inductance and capacity of the circuits to a minimum; in fact, the natural capacity between the elements inside the pliotron bulb is more than sufficient to supply electrostatic coupling between the plate and grid circuits. Also, the conductors of the circuits must be carefully laid out so as to be of a minimum inductance, yet of correct relative value.

For the determination of frequencies above ten million cycles per second direct measurement of the length of the electrical waves set up is the best method to employ. Electric wave impulses travel at a velocity of approximately 186,000 miles per second, or 3×10^8 meters per second.

Now, in any wave motion through a medium, the velocity of propagation is equal to the product of the frequency and the wave length or distance from crest to crest. Therefore, for a frequency of fifty million cycles per second, the wave length will be 6 meters, or about 19.6 feet.

If one end of a rope is tied to a wall and the other end moved rapidly and periodically up and down, waves will travel out along the rope toward the fixed end, and if the length of the rope bears a certain relation to the frequency of the up and down movement the waves reflected from the fixed end will reinforce the incident waves and a series of stationary waves along the rope will result.

In a similar way, if a very high frequency current is made to pass along a straight parallel pair of wires of a length which is a multiple of the wave length of the high frequency current employed, stationary electrical waves will result. This means that at intervals along the wires half a wave length apart there will be points at which the voltage between wires will be a maximum, while at intermediate points half way between the voltage from wire to wire will be zero.

If no energy is being drawn from these wires they constitute a resonant circuit, and therefore the voltage and current will be practically 90 deg. apart in phase and at the points of maximum voltage the current will be zero, and vice versa.

The actual arrangement of apparatus used to produce these high frequencies is shown in Fig. 6.

Here the pliotron elements, filament heating battery, and direct current energy source are represented as in previous figures. The inductances L_1, L_2 and the capacity C_1 are used to prevent the very high frequency currents from passing through the direct current source D. The oscillating inductance in the plate circuit consists solely of the connecting wire b, c, d, between filament and plate, and in the grid circuit of e, f, g, a, between filament and grid. Each of these wires is only a few inches long.

The voltage for charging the parallel wires is obtained by connecting them to grid and plate, but through very small capacities, C_2 and C_3, which reduce the effect of the capacity of the wires on the oscillating system and also insulate the wires from the supply sources B or D as far as direct current is concerned.

As previously mentioned, it is necessary that the parallel wires J have a length which is a multiple of the wave length set up by the oscillator. This is accomplished by sliding the short circuiting bridge W along the wires until this condition is obtained.

Experiments with a Frequency of 50 Million Cycles

By means of a special bridge slider that does not make metallic contact with the wires, but draws current from them through a small capacity used in connection with a sensitive hot wire milliammeter, the voltage distribution along the wire may be found and the wave shape plotted in the form of a sine curve. The frequency may thus be accurately determined and the presence of any current of a harmonic frequency detected.

It will be found that a maximum of voltage occurs at a point a quarter of a wave length from the short circuiting bridge, thus showing the right angle phase relation between current and voltage in a resonant circuit.

A current flows through the short circuiting bridge located at a minimum of potential and maximum of current, which can be shown by bringing up close to it one side of a rectangular loop of wire, the loop having in circuit a small tungsten lamp with short filament of small diameter wire.

If, with a lamp burning in such a manner, one of the wires is touched with the hand at a point where there is a maximum of potential, the lamp will go out, whereas if touched at a potential minimum there will be no effect. If one of the wires is touched at some intermediate point the lamp will dim more or less, depending on the distance of the point touched from a potential maximum or minimum.

With the direct current source of voltage at 600, ten watts of energy, at a frequency of 50 million cycles, which is a wave length of 6 meters, may readily be obtained.

A frequency higher than this is difficult to obtain with the type of pliotron employed, because the capacity between the elements inside the tube and the inductance of a length of wire connecting the terminals from these elements outside the tube imposes a limitation very close to the frequency value of 50 million given above. By a special design of pliotron tube, higher frequencies may be obtained.

In the past it has been customary to produce very high frequency currents from a Hertzian spark gap oscillator. Such an arrangement sets up successive trains of damped waves for which corrections must be made for quantitative work.

The pliotron method of producing continuous high frequency currents of considerable energy should prove a valuable tool in the solution of many electrical and physical problems.

The pliotron, being a high vacuum tube with gas free electrodes and operating on the pure electron discharge principle, gives constant results, which is such an essential feature in investigation work.

ELECTRICITY IN COAL MINE HAULAGE

Part II

By William P. Little

Power and Mining Department, General Electric Company

The first part of this article gave a thorough discussion of the mechanical and electrical features of locomotives for coal mine service. The present installment includes a few fundamental calculations that may be employed to determine the haulage requirements of a locomotive; and recommendations covering the installation of the trolley system, bonding of rails, selection of substation equipment, the operation and care of locomotives, and the equipment for making inspections and reapirs.—Editor.

Haulage Calculations

Upon the ability of a locomotive to handle the load required of it depends to a great extent the total output of the mine. For this reason, much thought and study should be given to this problem before purchasing a locomotive, to determine whether it will perform the required duty and to make certain that the most economical size of locomotive is selected. The following information is necessary to determine accurately the size and type of locomotive best adapted for any particular service:

Length of track—single—double
Number of turnouts
Number of sidings
Aggregate length of track
Weight of rail per yard
Length of rail
Gauge, measured from inside of one rail to inside of other
Minimum radius of curves
Condition of track
Maximum grade against load and length.
Maximum grade with load and length
Required location of trolley (left, middle, right)
Maximum and minimum height
Speed of locomotive
Characteristics of electric power supply
Maximum allowable width for locomotive
Maximum allowable height for locomotive
Number of cars to be handled per hour
Number of cars per trip
Weight of car empty
Weight of car loaded
Wheel base of cars
Are car wheels self-oiling?

A map and profile of the track give much of the above information and whenever possible should be furnished the manufacturers when building or submitting quotations on locomotives for a particular duty. It is also necessary to specify, when placing an order, the style of end frame required and whether the locomotive is to be equipped with draw-hook, draw-eye, or double draw-eye; also the height of the center of the draw-hook, draw-eye or pocket above the rail. If other than standard end frames are required a drawing or dimension sketch of the mine car should be furnished. Cases have been known where a customer specified certain end frames which were subsequently found to be unsuited for his mine car bumpers.

The amount of work or capacity of a locomotive is dependent upon its speed and drawbar pull. The drawbar pull is the force exerted at the drawbar of the coupling and differs from the tractive effort, which is the force exerted at the wheel treads, by the amount consumed in the friction losses of the locomotive. Therefore drawbar pull (DBP) is a variable quantity and dependent upon operating conditions. For calculation, this friction loss is assumed to be 20 lb. per ton. Thus a 10-ton locomotive would consume 200 lb. tractive effort to overcome the friction of the locomotives; that is, if a locomotive is running light with zero drawbar pull, it would be developing 200 lb. tractive effort.

Locomotives equipped with chilled iron wheels have a rated or running drawbar pull equal to 20 per cent of the rated weight in pounds and a maximum starting tractive effort equal to 25 per cent, while with steel tired wheels these figures may be increased 5 per cent.

The maximum pull a locomotive will develop at the drawbar or coupling is governed by the weight on the wheels, by the adhesion between the wheel treads and the rail, and to a slight extent by the ratio of the wheel-base to the height of the coupling. This latter effect, however, need not be considered unless the wheel-base is very short and the coupling high. Therefore locomotives of equal weight, under the same conditions, will pull equally no matter what the name plate stamping may read.

Obviously then the drawbar pull rating of a locomotive is of no particular importance insofar as the actual hauling capacity of the locomotive is concerned. It is only through a custom of long standing that manufacturers stamp the rating on the name plates of the locomotives. About the only practical value of this rating is that it establishes a definite point on the load curve of the motor equipment at which the speed rating is taken. Manufacturers do not guarantee the drawbar pull as stamped on the name plate, because it depends upon local conditions entirely. If the rails are too light or slippery, or the track otherwise in bad condition, the values given cannot be realized. All that they do guarantee is the weight of the locomotive and the ability of the motor equipment to readily slip the wheels.

The problem of determining the size of a locomotive to haul a given load does not admit an exact mathematical solution. The reason for this is that no definite figures can be set for the train resistance nor for the adhesion between the locomotive driving wheels and the track. The best that can be done is to make an estimate, and base this estimate on values of train resistance and adhesion that experience in actual practice has shown to be correct for average conditions.

Train resistance consists of friction of the car journals, the rolling friction between the wheel treads and flanges and the rails, and the resistance due to grade. With light, poorly laid rails and bad journals the train resistance on the level may be as high as 50 lb. per ton or more: with heavy, well laid rails and well lubricated car journals, it may be as low as 18 or 20 lb. per ton. The generally accepted figure for average mine conditions is 30 lb. per ton for straight level track. Curves, of course, set up considerable flange friction. In railway practice, resistance due to curves is generally assumed at ½ lb. per ton for each degree of curvature. The curvature in degrees is equal to 5750 divided by the radius of the curve in feet. Owing to the careless manner in which mine tracks are laid this figure is subject to wide variations. The resistance due to grades has an exact value and is 20 lb. per ton for each per cent grade: then a 2 per cent grade would cause a resistance of 2×20 or 40 lb. per ton for grade alone. To this must be added the car friction, which at 30 lb. per ton would make a total train resistance of $40+30=70$ lb. per ton for 2 per cent grade.

Upon track conditions depend entirely the adhesion between the tread of the locomotive driving wheels and the rail head. With light rails and poor track it may be as low as 15 per cent; that is, the maximum tractive effort of say a 5-ton locomotive would be $10{,}000\times0.15=1500$ lb. On the other hand with clean heavy rails it might be as high as 35 per cent. The commonly accepted figure for this value, as stated before, is 25 per cent for chilled iron wheels and 30 per cent for steel tired or rolled steel wheels.

To estimate the size of a locomotive to haul a given load, the following formula offers a convenient method:

$$W=\frac{L\times R}{400-R}$$

W = weight of locomotive in tons.
R = The train resistance in lb. per ton.
L = The weight of the trailing load in tons.

Example:

What size locomotive will be required to haul a 45-ton trailing load up a 2 per cent grade, assuming car friction 30 lb. per ton?

Train resistance R = resistance due to grade + car resistance.

$R=(2\times20)+30=70$ lb. per ton.

$L=45$.

$W=\frac{45\times70}{400-70}=9.55$ tons, or a 10-ton locomotive will be required for the above service.

This formula is based on working the locomotive at 20 per cent tractive effort, that is, when hauling this load the 10-ton locomotive will be developing 4000 lb. tractive effort. Therefore, if the track conditions permit a maximum adhesion of 25 per cent, there is a margin of 1000 lb. tractive effort left for bad spots on the rail, curves, and other emergency conditions.

If the grade is comparatively short so that the entire train is not on it for more than 30 seconds or so, the momentum of the train will assist to some extent and the locomotive may be worked at 25 per cent tractive effort. The formula then becomes

$$W=\frac{L\times R}{500-R}$$

In considering the horse power rating of any traction motor it is most convenient to deal with it in terms of tractive effort and speed. Expressed in these terms

$$\text{h.p.}=\frac{T_e\times S}{375}$$

Where Te = tractive effort in lb.
S = speed in miles per hour.

Since horse power is directly proportional to the product of these two factors it follows that a given motor may have a large horse power rating and yet not be as good for a certain service as one of lower rating. For example: a certain motor rates 30 h.p. at the axles and develops at this rating 1320 lb. tractive effort at 8.5 miles per hour. Another motor rating 25 h.p. develops 1560 lb. tractive effort at 6 miles per hour. Throughout the load curve the same proportional difference holds true.

Due to track or other local conditions at some particular mine the speed of the 30-h.p. motor may be too high and the motorman would run on resistance points a large part of the time to keep the speed within the safe limits; whereas with the 25-h.p. motor the speed may be slow enough so that the motorman need not run on resistance, and on account of its higher tractive effort would run cooler. Therefore despite its lower horse power rating, it would in reality be the better motor for the service.

It can be readily seen then that the horse power is not always a true measure of the service capacity of a locomotive. If it has low tractive effort and high speed, and local conditions at the mine are such that slow speed is required, then the high speed characteristics of the motor are of no value and a locomotive of lower speed but higher tractive effort rating would give much better service.

The capacity of the motor equipments with which locomotives are equipped should be such that in general they will operate satisfactorily and not develop troubles due to overheating. The size of these equipments is not, however, based on any exact determination, but is merely the result of long experience with many locomotives operating under various conditions.

Thus it can be readily seen that the size of a locomotive to perform a certain duty is dependent upon many variables, and the majority of those variables is determined entirely by local conditions. Therefore, when a mine operator requests recommendations from a manufacturer for locomotives or places an order, he should furnish them with all the information possible regarding the local conditions under which the locomotive will be obliged to operate and the duty required of them.

Locomotives used for gathering service in coal mines are subject to very intermittent loads and the service conditions are apt to change from time to time as the working faces recede. Consequently, it is difficult to obtain service data for this class of work, but generally a lighter duty is imposed upon this type of locomotive because of the short run and intermittent service than is the case with the main haulage type. From the experience obtained by observing the present motor equipments on gathering locomotives, it can be stated that there is practically no danger of overheating, providing the service is restricted to gathering work only.

Mine operators usually request recommendations on locomotives of a certain weight and seldom specify in detail the service for which they are intended, and the manufacturers, of course, recommend standard equipments if possible. As a result the motor equipments now in service are operating under widely varying conditions. While this practice has only developed a few cases of overheating, still there is always present the chance of putting a locomotive on a service schedule that is too severe for the motor equipment. Unless all the details and data relative to the service required of the locomotive are known, manufacturers cannot calculate with any degree of accuracy the size best suited for this service.

Trolley System

Current is usually fed to the locomotive by means of an overhead trolley, the rail forming the return circuit to the source of supply, and if the workings are at all extensive it is necessary to install feeder circuits tapping in on the trolley line at points where the voltage has been reduced by resistance of the line or load. Experience has proved that 0000 trolley wire has considerable advantage over smaller sizes, unless there are only a couple of locomotives operating in the mine, because the number of feeders is reduced.

The size of the feeders depends on the length of haul and distribution of load, the amount of current required and the allowable voltage drop. Excessive drop is a very common cause for complaint, because low voltage at the motors makes it difficult to maintain schedule and gives rise to motor troubles, to say nothing of the cost of power loss. As an approximate rule the voltage of supply to any locomotive should be kept within 20 per cent. Therefore it always pays to put sufficient copper in the feeders and trolley line to prevent the voltage from dropping to too low a value at the locomotive.

As the rails form the return circuit for the electric current, it follows that they must necessarily be considered in connection with voltage drop. Many mine operators are very careless regarding this point and give little attention to the proper bonding of the rails, the consequence being that even though their feeder system and trolley wire are of ample size for the load, still they experience excessive drop at the locomotive in distant sections of the mine. The rail itself, on account of its large cross section, has a large current-carrying capacity, and the bonding should be done so that no appreciable drop will occur between the joints.

The bonds now used in many mines consist of channel pins and short lengths of copper wire. Upon inspection and testing they are frequently found to be in such poor condition and of such high resistance that the return current leaves the rails and follows the adjacent pipe lines and streams of water on its way back to the power house.

The channel pin bonding when first installed offers little resistance and test readings equivalent to 6 to 8 feet of solid rail can be obtained; but, as the contact between the pin and rail is open to moisture, corrosion soon starts and the resistance steadily increases until it reaches a point where the value of the bond is entirely lost. The solid wire ordinarily used with channel pins has no flexibility and the vibration caused by trips passing over the joints has a constant tendency to loosen it in the pins. Numerous tests of these channel pin bonds under the varying conditions encountered in mine work have been made by manufacturers and they have proven conclusively that this type of bond does not fulfil the requirements of efficiency and that it is reponsible for a large per cent of the troubles incident to electric haulage, such as low voltage and armature and field burnouts. Besides this it causes an unnecessary load on the generating plant. These tests have proven that over 50 per cent of the channel pin bonds, six months after installation, have a resistance greater than that of an entire length of rail, and the remainder of the joints have an average resistance equaling about two-thirds that of a rail length. It is impossible to obtain anything like efficient operation of a locomotive over tracks bonded in this way.

To take the place of the inefficient channel pin bonds compressed terminal bonds should be used. By their use the joint resistance may be reduced from one-sixth to one-tenth of a rail length. This immediately improves voltage conditions with a resulting decrease in motor troubles from burnouts, etc. More cars per trip can be handled and the increased efficiency of the generator plant will easily offset the increased cost of this type of bond. Compressed terminal bonds properly installed show no material increase in joint resistance after four or five years of service under ordinary mine conditions. Thus the saving in maintenance alone justifies the higher cost of installation.

Substations

Unless each separate mine has its own direct current generating station, the power is generally furnished to the mines by some power company or central power plant, the supply being alternating current at high potential. At the mine it is transformed to direct current by motor-generator sets or rotaries and fed into the direct-current system. Where the direct-current system is large there may be several of the substations; sometimes above ground feeding into the system through bore holes, or underground, the alternating current power being supplied to the substation through bore holes. Where the bore hole is necessarily deep the latter method has the advantage in that the drop between the station and the system is negligible, the transforming station being located and feeding into the desired point with practically no voltage drop. However, upon local conditions depends the advisability of an underground substation. The alternating current voltage has to be stepped down at the point of entering the bore hole, inasmuch as most states require that current cannot be brought into a mine at high potential. Where rotaries are used this necessitates again stepping the voltage down at the substation to the required rotary alternating-current pressure, for it is generally advisable to bring the current to the substation at the maximum allowable voltage, thus giving the minimum voltage drop and loss.

In some cases it is most decidedly advisable to install rotary converters for transforming from alternating current to direct current, while in other cases the motor-generator set offers so many advantages that its slightly lower efficiency of transformation is usually more than offset. It is safe to say that the rotary converter together with its transformer will have approximately five per cent better efficiency throughout the entire range of load than will the motor-generator set.

On the other hand, if the source of power is a system whose voltage is variable, these variations will be transmitted immediately to the direct current voltage of the rotary and then to the mine, and it must be remembered that a 10 per cent reduction in voltage means practically a reduction of 10 per cent in speed of all locomotives in the mine driven from the rotary converter, which in turn, of course, means a considerable reduction in output. The rotary converter has practically no ability to rectify power-factor. It can operate at unity power-factor itself but has little or no corrective power. The motor-generator set, on the other hand, will operate at 80 per cent leading power-factor, which tends to correct the bad effect produced by induction motors and other inductive loads. Some power companies offer a bonus discount to their customers for the use of synchronous motor-generator sets on their lines, and in such cases the discount is usually large enough to more than offset the benefits which would be derived by the use of rotary converters as far as power consumption and better efficiency is concerned.

The transformers for use with rotary converters have a secondary voltage which is hardly applicable to the other motors about the mine and must therefore be considered more or less special. If transformers are necessary for the motor-generator sets they can be arranged for such a voltage that other motors can be operated from them. The motor-generator sets can be compounded from about 250 volts to 275 volts and the generator commutators are as a rule more easily kept in good condition than those of converter. This is particularly true of 60-cycle apparatus. This, however, is not an important point in favor of the motor-generator set because 60-cycle rotaries of modern design should give little or no commutator trouble. The comparative costs of either equipment are practically the same and their choice depends almost entirely on the characteristics of the alternating-current distribution system and local conditions.

Locomotive Troubles and Remedies

Before a locomotive is put into operation it should be given a very thorough inspection to see that no connections are broken or short circuited, that the parts are assembled correctly, and bolts and nuts tight, and that everything is in proper condition for operation. All journals and bearings should be well oiled and the gears and pinions well lubricated with clean heavy grease. The sand boxes should be filled with dry sand and the levers tried to see if they operate without sticking and when shut that no sand issues from the sand pipes. The breaks should be operated to see that they are properly adjusted and that when the brake wheel is turned tight the brakeshoes are exerting a pressure against the wheel and also when released to see that the shoes are clear of the wheel flanges. The controller should be in the "off" position before the trolley is put on the wire.

When starting, the current should be thrown into the locomotive gradually, taking into account the load which the locomotive is called upon to start. It of course takes more pull to start a load from rest than to keep it moving, even up a slight grade; therefore, if the wheels begin to slip the locomotive should be reversed, slacking up the couplings. This will relieve the starting conditions, because then it is only necessary to start one car at a time and not the whole load simultaneously. In advancing the controller from one notch to another it should be done quickly, allowing it to remain on each point until the locomotive has attained the speed corresponding to this point. If, however, the controller has been advanced too rapidly and the wheels begin to slip, move the controller back quickly to the "off" position and advance again in the usual manner. By moving the controller back slowly arcing at the finger tip is the result and may cause burning or blistering of the contact surfaces.

The controller is only intended for starting duty and should not be used as a speed control by running on an intermediate position, as this is liable to cause a burnout of the resistance. If the locomotive runs too fast with the controller in the "on" position and the motors in parallel, run the motors on the series point of the control, or else throw the controller "on" for a time and then "off" allowing the locomotive to coast.

Before applying the brakes the controller should always be thrown to the "off" position and never should braking be accomplished by reversing the motors except in case of emergency. This practice of reversing the motors is often resorted to, but it imposes a very severe duty on the motors, controllers, and in fact on the whole equipment. Reversing the motors when running at full speed is apt to break the gears and spring the armature shaft.

When a locomotive fails to start, the trouble is generally a broken connection in the motor circuit, the trolley circuit, the return circuit, the controller, the resistance, or else the circuit breaker is open. If the open circuit is in the motors, the defective machine can be located by raising the brushes of one motor and then the other and throwing the controller to the multiple position. Of course, the defective machine is the one that will not start with the brushes down. If, however, it is found that neither motor will operate under these conditions the open circuit is somewhere between the motor and the trolley, unless (as in very rare cases) there should be an open circuit in both motors. An examination to determine this is best made by the use of a bank of lamps, one side of which is attached to the trolley wire and the other applied to different parts of the circuit, beginning at the trolley harp and continuing throughout the circuit until the open is passed. This, of course, will be noted by the lighting up of the lamps.

If the open circuit is found to be in the field coils of one of the motors it often becomes necessary to cut this motor out by raising the brushes from the armature or, better, removing them, and drive the locomotive with the other motor. In doing this, however, it must be borne in mind that the locomotive only has half its hauling capacity and only half the load customarily hauled should be connected to it; however, the locomotive will to a great extent protect itself by slipping the driving wheels and this will determine the amount of load which it will handle.

Another fault which might prevent the locomotive from starting is wrong connections, causing the motors to buck each other. This will cause a heavy current and blow the protective fuse or circuit breaker. Reversing the brush leads of one motor will correct this. A ground may also prevent the locomotive from starting, as also will mechanical troubles, such as brakes not released, broken gears, and bearings stuck or "frozen."

Short circuits in the starting resistance, or open connections in the controller, will cause the locomotive to jump when the controller is thrown from point to point, instead of starting smoothly. This condition might also arise from having too little or too much resistance between the controller points.

A common cause of excessive heating is overloading the locomotive, and this trouble can only be remedied by reducing the load or providing a heavier locomotive for the service. On the other hand, the locomotive may be large enough, but due to low voltage cannot develop its rated power, and therefore the heating effect is the same as if it were running on overload. Besides causing excessive heating, low voltage also slows down the speed and causes commutator troubles. This low voltgae may be the result of insufficient copper in the feeder circuit, poor bonding of the rails, poor connections, or insufficient capacity of the generators at the power plant.

A short circuit of an armature turn will cause a heavy current to flow through it, resulting in excessive heating at this particular place. This current is induced in the short-circuited coil by the field as originally given. The trouble can be detected by the smell of burning insulation, or by feeling the armature, the short circuited coil being warmer than the rest of the armature. This can be temporarily remedied by disconnecting the short-circuited coils at the commutator and bridging the gap by connecting together the points in question on the commutator.

Excessive heating may also be due to short-circuited turns in the field coils, causing the motor in question to speed up, specially on light load. The motor takes heavy current, which causes over-heating of the motor armature. The short-circuited field coil can readily be detected, because it will be cooler than the others. This is due to decreased resistance of the field coil by the amount of the short-circuited turns, and consequently decreased heat loss. When a field coil has so many turns short circuited that the operation of the motor is materially affected, the coil should be removed and replaced by a new one.

If the armature bearings have been worn to such an extent that the armature is let down on the pole faces excessive heating and burnouts will result. The remedy for this, of course, is to give more careful attention to the wear of the bearings by frequently checking the air gap with a gauge, and replacing the worn linings when the armature is getting dangerously near the pole, and also by keeping the bearings well lubricated. When motors are equipped with ball bearings this trouble is not experienced.

The commutator of a motor is subject to very severe service, and unless properly taken care of will give an endless amount of trouble and have short life. With sparkless commutation, however, the life of the commutator is dependent only upon the wear from the brushes; but this is scarcely ever realized with traction motors, because of the dirt and grit which is bound to get on the commutator, and the continual vibration of the motors. However, excessive sparking at the commutator is indicative of some condition which can be obviated and it should be remedied immediately.

Excessive sparking at the brushes is frequently caused by an open circuit in the armature winding, which causes a higher potential difference between the two live segments than can be commutated without sparking. This often becomes so violent as to cause the motor to flash over at the commutator. The faulty coil is indicated by the blackened and slightly burned segments between which it is located. If this is not remedied at once it will cause a flat spot on the commutator, and in a short time the commutator will have to be turned down. Temporary relief can be obtained by bridging the gap between the coil at the commutator.

Short-circuited field turns, if a large number are affected, will also cause excessive sparking at the brushes, because the field is distorted and the neutral point changed. The defective coil should be removed and replaced by a new one.

Dirty commutators are also a common cause for sparking; they should be kept free from oil and dirt. If they become rough, they should be smoothed down with sandpaper, for the sparking will continue to roughen them more and more, and eventually re-turning will be necessary. By touching up occasionally with sandpaper this may be delayed and often avoided, and the life of the commutator lengthened.

Much of the trouble with commutators is caused by careless handling of the locomotive by the motorman, such as operating it with defective controller or resistance. When a resistance is broken the common remedy is to short-circuit the broken grid by inserting a nail or copper wire. This, however, should not be allowed, except in case of emergency, and then only as a temporary relief; for a large per cent of the resistance may be cut out of one or more of the steps, causing the motors to take excessive current when this point of the controller is reached. This causes the locomotive to start with a jerk and might result in burning the commutator or brushes, to say nothing of breaking gears and other mechanical parts. Therefore the safest and least expensive remedy is to replace any broken grids by new ones as soon as possible.

When a ground occurs in a motor, whether armature, field, or commutator, the fuse or breaker will blow and it will not be possible to keep the breakers in without holding, which should never be done.

Sometimes motors show a ground when tested with a voltmeter or a bank of lamps, and yet operate satisfactorily. This leakage might be caused by dirt, coal, etc., and a thorough inspection should be made and the ground removed, else in a short time a permanent ground will be established.

When a ground occurs the motor containing it should be cut out of service and the locomotive operated on one motor until such time as the ground can be located and remedied.

Operating Hints

To get the best results from electric locomotives, it is essential that they be given proper attention and that adequate equipment be provided for repairing them and changing parts. Some mine operators require the motorman to stay an hour after "all over" every day to give the locomotive a thorough inspection, blowing out the motors with a hand bellows, if compressed air is not available, and "oiling up." A report is then made out by the motorman and handed in to the mine electrician, making note of the exact condition of the locomotive. In this way the electrician has a record of all troubles, the wear of the bearings, the condition of the armature, wheels and controller. He is then able to remedy troubles before the locomotive is actually disabled and can divide his work so as to give the proper attention to every locomotive at periodic intervals and when the locomotive is not in operation. When the armature bearings are worn so as to let the armature down dangerously near the pole pieces, the linings can be replaced before actual trouble is experienced. If the commutator is getting rough and developing flat places these can be removed and turned down. Wheels can be replaced when worn down dangerously. In this way the locomotive can be kept almost constantly in service and all the troubles remedied and repairs made when it is idle. This method greatly increases the efficiency of the locomotive and more than pays for what additional expense it may entail with the greater efficiency and larger amount of work that can be obtained from each locomotive. It also greatly decreases the possibility of trouble occurring during working hours.

Along with this inspection by the motormen, specially with companies operating a number of mines, a chief inspector who is absolutely familiar with locomotives and their operation and trouble has been found a good investment. His duty is to visit the mines at unexpected times and see that all instructions regarding their operation and care are adhered to. Also in some mines it is his duty to instruct the motormen and to examine them to see that they are capable of operating the locomotives properly; that they know the functions and duties of the different parts and can make the necessary minor repairs on the road, and thus hold up work the least possible time.

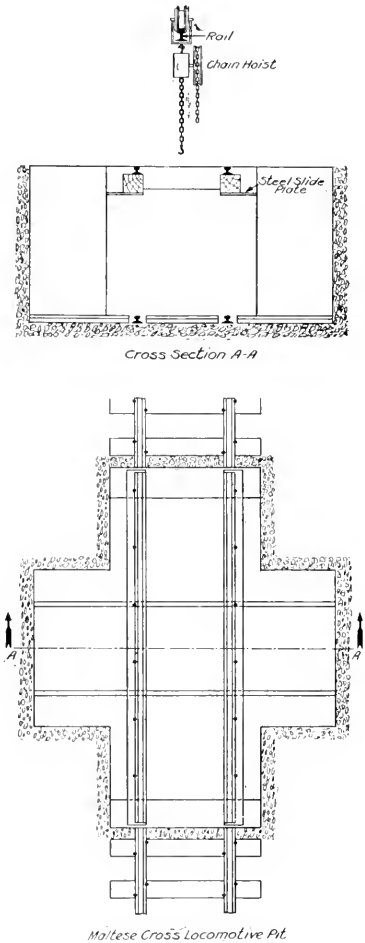


Fig. 16

Repair Equipment

A pit should be provided at different sections in the mine, to serve the greatest number of locomotives. and at a place where these locomotives can be run onto it without much loss of time. Best results are obtained by having the pits electrically lighted and well ventilated. This feature in many mines is often never considered, the object being to build a pit with the least expense possible; the result being that the men working on the locomotives are obliged to use mine lamps for illumination, which are very inadequate, and besides fill the place with smoke and foul the air. Of course, the best results can never be obtained and the chances are that the time required for the work is considerably longer than would be required if the ventilating and lighting conditions were good.

The maltese cross construction of pits gives bests results, and specially in changing wheels is this construction most advantageous. The pit should be made of concrete and free from water. Rails along the bottom allow quick handling of wheels when changing. The rails across the top should be mounted on large timbers which can be knocked out to the side with a sledge after the locomotive has been blocked up. This leaves the wheels free to be dropped down to the bottom of the pit by means of a chain hoist. With the new wheels on the rails at the other end of the pit, the old wheels can be rolled into one of the cross places out of the way, and the new ones rolled under the motor and hoisted into place. With this method wheels can be very quickly and easily changed.

The chain hoist should be of ample capacity to lift up one end of the heaviest locomotive that the pit serves and should be mounted over the center line of the pit parallel to the rails and suspended from a trolley which rolls along on a rail the length of the pit. The hoist then can be suspended over any portion of the main pit.

Each pit should have a work bench and a complete set of wrenches, etc., to fit any locomotive which might be brought into the pit. In this way much time can be saved in going from the pit to the shop to get the proper tools to work with.

A supply of spare parts should always be kept on hand so that replacements can be made without holding up the locomotive in waiting for parts from the factory. A list of parts which are most apt to need replacement is as follows:

Motor armature
Armature coils (in case the operator winds his own armatures)
Field coils
Brushes
Brush-holders
Main and reverse controller fingers
Main and reverse controller segments
Brakeshoes
Wheels and axles
Axle linings for both wheels and armature, in case the latter is not ball bearings
Gears and pinions
Journal boxes
Journal springs
Trolley harp
Trolley poles
Rheostat grids

It is both desirable and economical to have at all times such a stock of parts that any material interference with the operation of the locomotive will be impossible.

In conclusion the writer would point out a few things which are essential for the successful and continued operation of electric locomotives for coal mine haulage.

The locomotive must not be required to haul a load greater than its hauling capacity. Just because it is an inanimate object there is no reason for abusing it.

Give the locomotive at least reasonable attention. A mule is fed and cleaned, why not the locomotive?

Daily inspection and "greasing up" by the motorman should be required, and also periodic inspection by some one thoroughly familiar with the locomotive.

Daily report sheets on the condition and operation of the locomotive should be required of the motorman.

Feeders should be of ample size and so distributed as to give sufficient voltage to all locomotives for their efficient operation.

Rails should be well bonded and always kept in first class condition, specially on main haulage roads.

The generating station should be of ample capacity to maintain the voltage of the trolley system at all points when properly fed.

Adequate facilities and tools should be provided so as to make repairs and replacements to locomotives with the minimum hold-up from service.

Ample stock of spare parts most liable to need replacement should be kept to facilitate repairs.

Motorman should be instructed as to the proper method of operation and care of a locomotive.

Electricians should be instructed as to the proper care and methods of making repairs and locating troubles.

Pits should be well ventilated and electrically lighted.

If these few points are given due consideration, the mine operators will find that electric locomotives offer by far the cheapest, most efficient and dependable method of haulage that can be obtained at the present time.

THE FUNDAMENTALS OF LIGHTING

By M. Luckiesh

Nela Research Laboratory, National Lamp Works of General Electric Company

The author emphasizes the importance of studying light, shade and color both separately and collectively in any scheme of lighting where the best results of light are desired. The selection of the proper quality of light and the determination of its correct distribution are the prime requisites.—Editor.

The analysis of human consciousness reveals two kinds of visual sensations, namely, chromatic and achromatic sensations. No masterpiece of painted or sculptured art, no beautiful landscape, no office or factory operation, so far as the visual sense is concerned, consists of more than an arrangement or sequence of varied colors and brightnesses. In other words, vision is accomplished through the ability to distinguish differences in light, shade, and color. If the image of any scene, which is focussed upon the retina, could be examined it would appear as a miniature map of varied colors and brightnesses similar to that seen on the focussing screen of a camera. However, there are important differences between the records made by the eye and by the camera. In the case of the eye, only that portion of the image near the optical axis is seen in true focus, but the camera faithfully focusses the images of objects included in a relatively large solid angle. The differences between the two records are further accentuated by the presence of physiological and psychological phenomena in the human visual process. In fact, the latter are the vast unknowns in lighting.

It is not generally enough recognized that the fundamentals of lighting are light, shade and color. It is the variation of these factors that models and paints an object or an interior. A thorough grasp of the art and science of lighting will not be obtained without a painstaking study of light, shade, and color as related to the appearances of objects, to the physiological processes involved in vision, and to the psychological phenomena associated with visual impressions. Any portion of this study is stupendous, but fortunately the lighting problems appeal to such varied interests that the work is well distributed. However, the lighting expert must not only keep in touch with the progress made in these various studies but should be an analytical observer.

It is not generally enough recognized that light, shade, and color are the fundamentals of lighting notwithstanding the experimental demonstrations that are everywhere present. No art or science is more readily studied than lighting because experiments are always awaiting the observer. In general, color plays a minor part in vision relative to light and shade. The magical drapery of color, which is omnipresent but usually unnoticed, would disappear in the absence of color-vision. Indeed color-vision appears to be a gift—the Creator's full measure—because color-blind persons progress almost unhampered excepting in certain fields where man has called upon color to serve him in a special manner. Differences in hue are less conspicuous than differences in brightness; in other words, light and shade provide the skeleton and body of a scene and the hues supply the drapery. It is not the intention to depreciate the importance of color in vision because it is recognized that the presence of colors and the physiology and psychology of color-vision are of extreme importance in our daily life. It is merely unfortunate that the lack of development of observation and appreciation of color by the human race, as a whole, has forced color to play a minor role in ordinary vision, notwithstanding it is ever ready to furnish pleasure and interest by its continued variation about us. Nevertheless, color in lighting represents a large and almost uncultivated field for the lighting expert.

The problem of lighting, from the viewpoint of the fundamental factors—light, shade, and color—can be divided into two parts, namely, quality and distribution of light. In other words, the light of the proper quality, or spectral character, should first be chosen and then the proper distribution should be determined. At the present time practically any desired quality of light can be obtained. Where daylight color-values must be maintained, artificial daylight of various kinds is available. That which is chosen will depend upon the requirements. For æsthetic purposes a knowledge of the science of color will readily supply the desired quality of light. The artificial illuminants which are available furnish a variety of qualities of light especially for lightings of such magnitude as were recently carried out so well by W. D'A. Ryan at the Panama-Pacific Exposition. Developments are in progress which will eventually appease many other demands for special qualities of light for aesthetic and spectacular lighting. The physics of color, as related to lighting, has been fairly well explored but relatively little is accurately known regarding the physiological and psychological aspects of color in lighting.

In regard to the appearances of colors as affected by different illuminants it must be recognized that, in general, no colored object can appear the same under two different illuminants. It is not generally enough realized that the color of the surroundings is as much a part of a lighting problem as the color of the illuminant. The surroundings can greatly alter the quality of light which reaches a working-plane and can play a large part in the appearance of a completed installation. For instance, with indirect and semi-indirect lighting systems a yellow tint in the ceiling and walls can alter the color of the light from a Mazda C gas-filled lamp to that emitted by the old carbon filament incandescent lamp. Again, when it is essential to display colored objects at night in their true daylight appearances, any objections to the "coldness" of the artificial daylight used for this purpose can be obviated by having the immediate surroundings, upon which the eye normally rests, tinted in "warmer" colors. When considering the æsthetic side of lighting it must be remembered that this is an indeterminate problem. Tastes are as different as individuals and their varied past experiences. In fact, taste is a product of the past and in dealing with this side of a lighting problem the *client's* taste must be given due consideration. Color in lighting is just beginning to receive proper attention but throughout its development let the lighting expert remember that light is the master painter.

Lighting is also the master sculptor. The distribution of light determines the brightness distribution upon the object and thereby models its form. Not always is this true but so generally that no difficulties will be encountered if this be accepted as a fundamental axiom. The appearance of a shadow is determined by three factors. The position of the light source determines the direction of the cast shadow, the character of the shadow's edge is influenced by the solid angle subtended by the light source, and the brightness of the shadow is determined by the relative amount of diffused or scattered light reaching the shadow which depends upon the distribution of light and the reflection coefficients of the surroundings. In dealing with the lighting problem from the fundamental viewpoint of light, shade, and color it is essential to inquire beyond the blue-print and to consider the nature of the operation involved. If it be a factory operation, for instance the winding of hair-like filaments upon the support in an incandescent lamp, it is essential to note whether the filaments are best seen as bright streaks against a dark background or vice versa. In such operations the optimum relation of the two brightnesses should be sought for. If the problem be one of street-lighting, the brightness sensibility of the retina must be considered for the particular environment. For instance, at ordinary conditions of adaptation, the brightness difference that can be perceived under ideal conditions is somewhat less than two per cent although a considerable factor of safety should be allowed for readily perceiving objects under ordinary conditions. Under the conditions of adaptation outdoors at night the brightness difference that is readily perceptible is ten per cent or more. It is a fact that computations are seldom incorporated in the design of lighting systems which show before-hand the brightness differences that the eye is called upon to distinguish. Computations and measurements show that, for instance, the brightness difference between two successive steps of a stairway at some distance from a street lamp is less than the eye can possibly distinguish outdoors under many street-lighting conditions. It is thus seen that light and shade can be considered from various viewpoints and even with our scanty knowledge of lighting conditions as related to vision we have more knowledge than is made use of in the consideration of lighting problems.

Lighting is not generally enough considered in relation to the architectural and decorative schemes of interiors. Study should be given to this phase of the subject by lighting experts with the aim to meet the architect and decorator upon the common ground where architecture, decoration, and lighting intermingle. Architecture and decoration are arts of light, shade, and color. The lighting effects should intimately harmonize with the architectural and decorative areas and patterns. When symmetry is a keynote of decoration, the lighting consideration should not stop when symmetry of outlets has been attained. Surely it does not demand a lighting expert to place the outlets symmetrically upon a blue-print. Symmetry of *lighting effects* is the result to be attained. For instance, assume a large room crossed by beams projecting below the ceiling. In the center of the square area enclosed by crossing beams is a recessed square of fair size. A natural place for an outlet is in the middle of this recessed square which is a recurring element in the assumed interior. Surely it is not the best general solution of the problem to hang from this outlet a unit which gives a circular spot of light upon the square designs in the ceiling. Such a procedure is common yet it evidences no consideration on the part of the lighting expert for the architect's conception. A moderate shadow on the under side of the beams provides the impression of supporting ability in a very simple manner. Uniform lighting is sometimes undesirable and the possibilities of non-uniform distribution of light on large areas are not often recognized.

The discussion of light, shade, and color as fundamentals of lighting could be prolonged considerably without exhausting the subject. Only a few points have been chosen at random to demonstrate that these factors are intricately interwoven in lighting. The writer has for several years been applying such a diagnosis to the consideration of many problems of lighting and vision and believes that this is the fundamental procedure. Ordinary engineering data, catalogues, and blueprints are indispensible but should only follow the fundamental analysis of the problem. Definite progress will only arise from persistent analytical consideration of the relation of lighting and vision and it is believed that no more fundamental starting point than the consideration of light, shade and color exists.

INTERIOR ILLUMINATION WITH MAZDA C LAMPS

By A. L. Powell

Edison Lamp Works, General Electric Company

This article presents a bird's-eye view of the different classes of lighting. The cited references to other articles set forth in more detail the methods of designing installations and the features to be taken into account. It is hoped that this outline, with its illustrations, will serve as indicative of the progress of incandescent electric lighting.—Editor.

Lighting practice with incandescent lamps has gradually become fairly well standardized. There is no field of illumination to which these lamps are not well suited. The vacuum tungsten filament lamp had become the almost universal electric illuminant. On the introduction of the Mazda C lamp there arose many problems which required solution. It is not practical to take a new illuminant and say offhand where and how it can best be used; some experimentation is required to find out the most suitable means of applying a new lamp. A gradual evolution in lighting practice takes place. These new lamps have been on the market for over two years; the transitory period is over. The methods of applying them having been fairly well worked out, it will be well to set forth in outline a few of the points which have received attention.

The author has previously described[1] the general principles to be observed in designing interior lighting layouts, and has discussed the various systems—direct, semi-indirect, and totally indirect—so that there should be no need for repetition. It is therefore most satisfactory to present the subject by analyzing each class of service separately and viewing the problems which arise.

Armories and Gymnasiums[2]

These rooms usually have lofty ceilings with few overhead obstructions, a condition which makes high candle-power light sources with fairly wide spacing economical. A few years ago arc lamps were practically the standard illuminant, the few installations of small incandescent lamps arranged in huge clusters being the exceptions. The remarkable efficiency, simplicity of operation, and low maintenance cost of the Mazda C lamp has caused it, almost without exception, to supplant all other illuminants in this field. The great difference in efficiency between it and the old form of enclosed carbon arc lamps warranted scrapping these latter and installing a completely new equipment. The ease of maintenance in comparison with flame carbon arc lamps has also led to the adoption

[1] "Interior Illumination" General Electric Review, March 1914, page 318.

[2] A very complete summary of this field of lighting is to be found in a paper by A. L. Powell and A. B. Oday, entitled, "Present Practise in the Lighting of Armories and Gymnasiums with Tungsten Filament Lamps," Transactions Illuminating Engineering Society, Vol. 10, No. 8, page 746, Nov 20, 1915

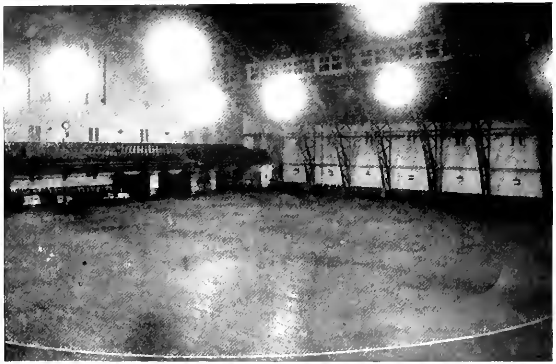


Fig. 1 Night view in the 8th Regiment Armory, N. G. N. Y., Lighted by eight 1000-watt Mazda C lamps in G. E. Novalux Form 1 Fixtures with Opalescent Enclosing Globes.

Fig. 2. Artistic Semi-indirect Lighting with Mazda C Lamps in the Grace M. E. Church, New York City. The Design of the Fixtures Harmonizes with the Architecture of the Structure

Fig. 3. An Indoor Tennis Court Illuminated by Mazda C Lamps. A Combination of Totally Indirect and Well-diffused Direct Lighting is Used, Seven Lamps on Each Side.

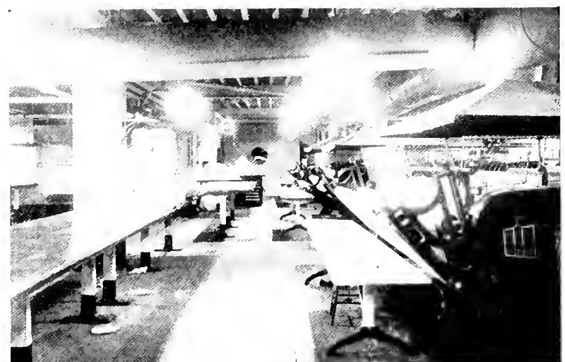


Fig. 4. A very well Illuminated Steam Laundry. Bowl-frosted, 100-watt Mazda C Lamps in Enameled Steel Reflectors are Localized with Reference to the Folding Tables, Mangles, and Other Pieces of Apparatus

of the Mazda C lamps. The work of installing these incandescent lamps in all the armories of New York State is now almost completed, and similar installations are being made in other parts of the country.

Due to the fact that the ceilings are usually dark, or broken by framing, direct lighting is most suitable. The following types of auxiliaries have proven satisfactory; prismatic enclosing units (realites), opalescent enclosing globes (with and without external reflectors), deep bowl dense opal reflectors and deep bowl porcelain enamel steel reflectors. These devices are all standard and relatively inexpensive. In armories 300- to 1000-watt lamps are used; while in smaller sized gymnasiums lamps from 100 watts up are employed, depending on the spacing conditions.

Churches and Auditoriums[3]

The glare in churches, which is the result of a multiplicity of small poorly diffused light sources in the field of view, is gradually becoming a thing of the past. There is an awakening of the public to demand more comfortable and artistic meeting places. The indirect systems are proving very popular. In those interiors where direct lighting must be used care is taken in locating the fixtures and in selecting the diffusing equipment. A few large light sources hung high are much less glaring than a number of small lamps hung low or placed on brackets.

There has been such a gain in efficiency, due to the Mazda C construction, that the less efficient light distribution systems are now within the purse of the congregation. More light can be wasted to secure a desired decorative effect. For example, one progressive church has recently installed a system wherein the lamps are placed in deep boxes located along the front of the balcony, thus there are no fixtures to mar the beautiful colonial simplicity of the structure.

More and better designs of fixtures are becoming standard so that there is now very little necessity to have special equipment designed to fit a particular architectural treatment. Indirect fixtures are listed of Gothic, Renaissance, Georgian and like periods; direct-lighting enclosed globes, small reflectors or shades and semi-indirect dishes of various shapes and sizes are available with pressed and etched decorations of all styles. Many of these are tinted and appear very attractive unlighted and when illuminated show the ornamentation and give good diffusion to the light.

The direct bearing of the Mazda C lamp on this situation is that it has awakened an interest on the part of the lay public in the subject of better lighting. With the wide range of sizes, the various conditions which arise can be met skilfully and in a satisfactory manner.

Indoor Tennis Courts, Squash Courts, Etc.[4]

These areas require a high intensity of evenly distributed illumination with the light sources arranged so that they will not annoy the players or distract their attention. The light must be steady. The high efficiency of the Mazda C lamp is the first factor in its favor. Another point of importance is the fact that the rather concentrated light source lends itself readily to reflectors for accurately controlling the distribution. Some particular problems, for instance, require that the light be emitted in a definite angle. After tests and experimenting had shown the possibilities, many satisfactory installations of Mazda C lamps were made. Tournaments and practise games are carried on very successfully by artificial illumination.

Industrial Plants[5]

The management of a well conducted factory is constantly on the alert for a means of improving the overall efficiency of its plant. Good lighting is a most important element. Many of the first installations of Mazda C lamps were made in this class of service. As the high-wattage multiple lamps (750 and 1000 watts) appeared first they were best suited for large high erecting shops and foundries. On the introduction of the smaller sizes, the Mazda C lamp was used in the same manner as the Mazda B lamps for all kinds of factory lighting. In many cases the type C lamps replaced less efficient illuminants, there by increasing the intensity of illumination rather than decreasing the power consumption. Higher standards of illumination are to be seen on every hand, on account of the night shifts caused by the unprecedented amount of manufacturing which has been taking place.

There has been a little anxiety on the part of those interested in lighting as it was feared

[3]The principles of Church Lighting were outlined by A. L. Powell in the GENERAL ELECTRIC REVIEW February 1914, page 142.

[4]A bulletin, now in the course of preparation by the Edison Lamp Works, gives recommendations covering in detail this class of service.

[5]More detailed information on this field of lighting will be found in the following articles:
"Mazda C Lamps in Industrial Service," A. B. Oday, Lighting Journal, Vol. 3, No. 4, page 71, April 1915.
"High Candle-power Mazda Lamps for Steel Mill Lighting," G. H. Stickney, GENERAL ELECTRIC REVIEW, May 1915.

that the increased brilliancy of the Mazda C lamp might be harmful to the eyes of the workmen. Experience has proven, however, that if proper attention is given to the location of outlets and to reflector equipment this feature is not objectionable. For example, where rather shallow reflectors are used on low hangings, lamps should always be bowl-frosted.

Fig. 5. Mazda C Lamps of 200- and 300-watts in Semi-indirect Dishes Provide Evenly Distributed Lighting of High Intensity in this Executive Office

Very complete lines of angle, deep bowl and shallow dome reflectors, in both porcelain enamel and aluminum finishes, are standard. These are used in accordance with rules which have been set forth in the technical press many times.

The improved color of light is a factor in some instances. In a laundry installation white light enables the operators to detect stains or spots on the linen much more readily than with other kinds of light. Where accurate color discriminations are necessary, enclosing globes of specially determined blue glass are used in conjunction with the regular Mazda C lamps, or the filament is mounted in the blue glass bulb of the same general character. Experience and tests have shown that these special equipments are extremely satisfactory for supplying artificial daylight.

Offices and Drafting Rooms[6]

In offices and drafting rooms semi-indirect lighting, employing dense opal, and totally indirect units, is now widely used and results in better conditions for the eye. The dense glass, although reducing the measured efficiency of the system a slight amount, is much more preferable to the very light density bowls so often employed as the surface brightness is much lower. In changing from efficient direct lighting to semi-indirect the power consumption is somewhat increased, but the increased efficiency of the Mazda C lamp has made this change more practical. When using indirect systems fewer outlets of somewhat larger capacity are required. The good properties of this form of lighting are so well known that they need not be discussed.

One point is of importance, when Mazda C lamps are used indirectly, the fixture or hanger employed should be of that certain length and the socket in that relative position to the bowl that the light is thrown to the ceiling in such a manner as to evenly illuminate this. Many cases are to be observed where the rather concentrated filament of the Mazda C lamp is placed too low in the dish, thereby concentrating the emitted light into a fairly narrow angle with the result of a ring or circle of very bright illumination on the ceiling above the unit and the spaces between the units comparatively dark. In other cases, to get rid of this effect the lamp is raised so high that from some parts of the room the filament becomes visible, thereby introducing glare. Shadows from the supporting chains are sometimes quite objectionable and may be eliminated to a considerable extent by having the upper half of the lamp etched or frosted, which introduces some diffusion to the upward light.

Schools and Hospitals[7]

This group of buildings so important from the humanitarian standpoint is receiving

[6]Some calculations and tests of various illuminating systems useful to office lighting are found in two papers by A. L. Powell. The first is entitled "Modern Office Lighting" appearing in the Real Estate Bulletin, October 1915, and the second, "Choice of a Semi-Indirect Unit for Office Lighting" was published in the Lighting Journal, Vol. 4, No. 5, page 98, May 1916.

[7]An interesting paper by Mr. M. Luckiesh on this subject, entitled "Safeguarding the Eyesight of School Children," is found in the Transactions of the Illuminating Engineering Society, Vol. 10, No. 2, page 181.

Fig. 6. The Lunch Room in an Modern High School where 100-watt Mazda C Lamps Furnish Adequate Lighting. Inexpensive Fixtures are made of Bowl-shaped Opalescent Glass Reflectors Inverted by Means of a Special Holder

Fig. 7. An Illustration of the Simplicity of Stage Lighting with Mazda C Lamps. A Few Medium-size Units in Angle Steel Reflectors are Used as Border Lights while the Apron or Front of the Stage is Flooded by a 1000-watt Angle Type Unit Properly Placed

Fig 8. This Large Department Store is Made Very Attractive by 100- and 200-watt Mazda C Lamps in One-piece Diffusing Globes. These Being of Simple Design are Neat and Inconspicuous

Fig. 9. This Display Window is Made to Stand out Prominently at Night by 100-watt Mazda C Lamps in Mirrored Glass Reflectors Properly Placed from View by the Valance or Drapery

more and more attention in regard to the lighting. The attempt has been made by the Illuminating Engineering Society and others to instruct the authorities of schools and hospitals in the principles of eye protection and comfort. They have been warned to avoid glazed surfaces which produce glare, to place the lamps in such positions that they are not annoying, and to install those systems which give good diffusion to the light. The practice in lighting school rooms is becoming standardized; the size and number of lamps desirable for the average room has been quite accurately determined; a number of inexpensive fixtures which meet the requirements are on the market. The general data already given in regard to the use of semi-indirect lighting with Mazda C lamps in offices applies with even more force to this class of interior.

Show Windows[8]

Any device which will make a display window stand out prominently is welcomed by the merchant. The distinctive color and increased illumination for the same wattage possible through the use of Mazda C lamps made them immediately popular. As a result of a vigorous educational campaign, the present-day window lighting is a marked contrast to the inefficient and glaring methods employed a few years ago. Now lamps are placed in the upper front edge of the window, giving the correct direction of light, rather than being scattered haphazardly over the ceiling and located around the edges of the plate glass. Effective reflectors are utilized which direct the light on the merchandise instead of allowing it to escape in all directions. Not only is the lamp hidden by means of the reflector, but even these are concealed from the view of persons on the sidewalk. "Light on the object and not in the eye" is the rule rather than the exception. More attention is paid to the background and light colored matt finishes are installed in the most up-to-date windows, replacing the dark polished wood variety which always appeared dull and gave annoying reflections.

Well designed asymmetrical prismatic and mirrored glass reflectors are standard for the lamps most suited to the show window, namely, the 75- and 100-watt sizes. Some striking installations of artificial daylight lamps (known as Mazda C_2, mentioned under "Industrial Lighting"), are to be seen in various parts of the country and this type of lighting is gradually increasing.

Stores[9]

The stores of most recent construction indicate that the intensity of illumination is increasing by rapid strides. The improved color value of the Mazda C lamp was an important factor in its hearty reception. The increased brilliancy caused persons to give more attention to the proper diffusion of light. High-grade stores have always paid a great deal of attention to color value; and many investigators have been working on suitable tinted enclosing units, which modify the light from the Mazda lamp making it a very close approximation to daylight. The Mazda C_2 lamp is also utilized for the same purpose and is very much better than any previous commercial form of light suitable for general illumination. The decorative effect of the lighting unit is receiving consideration; and the better stores are choosing lighting devices which harmonize with some particular treatment, so that the modern lighting equipment is artistic and part of the room furnishing rather than ungainly pieces of mechanism suspended from the ceiling for the sole purpose of supplying light.

Stage Lighting[10]

Incandescent electric lighting of the stage is most flexible, but previous to the introduction of the high candle-power Mazda C lamp it was necessary to supplement this with light from hand-fed open arc lamps. These are now rapidly disappearing on account of the convenience of control of the Mazda C lamp and its greater safety. Now an operator is not necessary for each group of spot lamps for these can be handled direct from the switchboard. The concentrated filament lends itself to use in devices which give special distributions of light and many startling and novel effects have been secured. The standard industrial reflectors are very useful in stage lighting and are being employed more and more. The relation between the color of light and the dyeing of the scenery has been given a great deal of attention, and elaborate investigations along these lines have been reported.

[8] Those desiring more detailed information are referred to an article by A. L. Powell, "A Few Points on Modern Window Lighting" which appeared in Signs of the Times, August 1915.

[9] "Store Lighting with High Efficiency Mazda Lamps" is discussed in the Lighting Journal, Vol. 2, No. 8, page 166, Aug. 1914.

[10] See "The Use of Mazda C Lamps for Stage Lighting" by A. L. Powell and L. W. Cook, Lighting Journal, Vol. 4, No. 1, page 3, January 1916.

*THEORY OF ELECTRIC WAVES IN TRANSMISSION LINES

Part IV

By J. Murray Weed

Transformer Engineering Department, General Electric Company

In the present contribution, the author considers the waves and oscillations that are produced when an uncharged line or section of line is switched onto another line or section which is charged. The switch, assumed to be located at the generator end of the line in previous installments, is here assumed to be located at some point between the generator end of the line and the receiver end.—Editor.

If an uncharged line or section of line is suddenly switched onto another line or section of line which is charged, a charging wave, of reduced voltage, will enter the uncharged line, and a wave of partial discharge will travel back into the line which was charged. For the charging wave, in accordance with equation (16), we have

$$E_{ch} = I_{ch} Z_2 \tag{109}$$

and for the wave of discharge,

$$E_{dis} = -I_{dis} Z_1 \tag{110}$$

where Z_1 and Z_2 are the wave impedances of the discharging line and the line which is being charged, respectively. In order to make the treatment general, these impedances are assumed to be different. The minus sign appears in the second member of equation (110), because the voltage of the discharge wave is negative while its current is positive.

Before the switch is closed, connecting the two lines, their voltages are E_o and zero

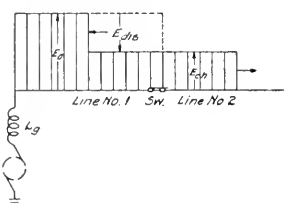


Fig. 15

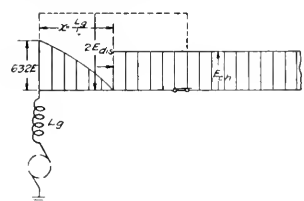


Fig. 15a

respectively, while the current is zero in both lines. After closing the switch, both voltage and current will be the same in the two lines, i.e., on both sides of the switch. Thus,

$$I_{ch} = I_{dis} \tag{111}$$

and

$$E_{ch} = E_0 + E_{dis} \tag{112}$$

From equations (109) to (112) we find

$$I_{ch} = \frac{1}{Z_1 + Z_2} E_0 \tag{113}$$

$$I_{dis} = \frac{1}{Z_1 + Z_2} E_0 \tag{114}$$

$$E_{ch} = \frac{Z_2}{Z_1 + Z_2} E_0 \tag{115}$$

and

$$E_{dis} = -\frac{Z_1}{Z_1 + Z_2} E_0 \tag{116}$$

If the wave impedance Z_1 and Z_2 are equal, the voltages of the charging wave and the wave of discharge will be equal numerically but of opposite sign. Thus,

$$\left.\begin{array}{l} \text{For } Z_1 = Z_2 \\ E_{ch} = \tfrac{1}{2} E_0 \text{ and} \\ E_{dis} = -\tfrac{1}{2} E_0 \end{array}\right\} \tag{117}$$

The waves of charge and of discharge corresponding to this condition are illustrated in Fig. 15.

In Fig. 16, the condition is that of $Z_2 = 8\ Z_1$, as when an uncharged overhead line is thrown onto a charged cable. In Fig. 17, $Z_1 = 8\ Z_2$, as when an uncharged cable is thrown onto a charged overhead line.

When the wave of discharge reaches the generator end of the line, assuming that there is no appreciable concentrated capacity, the wave front will be reflected by the inductance of the generator in the same manner as from the open end of a line. The voltage at the terminals of the generator will change suddenly from E_0 to $E_0 + 2\ E_{dis}$. For $Z_1 = Z_2$, in accordance with equation (117), the

* Previous installments of this article appeared in the issues of December, 1915, and February and March, 1916.

inherent sign of E_{dis} being negative, this reflection of the wave of discharge leaves the line completely discharged, and a charging wave similar to that of Fig. 12 begins to grow in the line through the inductance of the generator. Such a charging wave, corres-

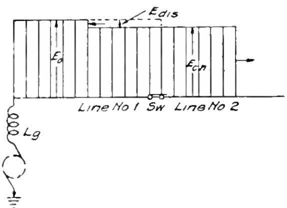


Fig. 16

ponding to the voltage $(-2\ E_{dis})$, will grow in any case. This is illustrated in Figs. 15a, 16a and 17a for the relative values of Z_1 and Z_2 used in Figs. 15, 16 and 17, respectively.

If the wave impedances of the two sections of the line are not equal, the reflected wave, upon its return to the junction point, will be only partially transmitted to line No. 2, and will be partially reflected. The portion which is transmitted and that which is reflected may be determined by the application of Kirchhoff's laws to currents and voltages at the junction point. Thus, for any wave traversing line No. 1 and impinging upon the junction point, the voltage of the original wave plus the voltage of the reflected wave in line

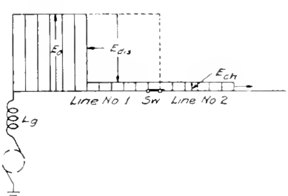


Fig. 17

No. 1 is equal to the voltage of the transmitted wave in line No. 2. These conditions are represented by the equations,

$$E_1+E_1'=E_2 \tag{118}$$

and

$$I_1+I_1'=I_2 \tag{119}$$

We also have

$$E_1'=-I_1'\,Z_1 \tag{120}$$

and

$$E_2=I_2\,Z_2 \tag{121}$$

where E_1 and I_1, E_1' and I_1' and E_2 and I_2 are respectively the voltages and currents

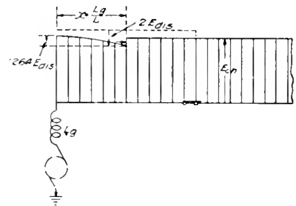


Fig. 16a

of the original wave, the reflected wave and the transmitted wave. From these equations we get

$$I_2=\frac{2}{Z_1+Z_2}E_1 \tag{122}$$

and

$$E_2=\frac{2\,Z_2}{Z_1+Z_2}E_1 \tag{123}$$

Also

$$E_1'=\frac{Z_2-Z_1}{Z_1+Z_2}E_1 \tag{124}$$

and

$$I_1'=-\frac{Z_2-Z_1}{Z_1\,(Z_1+Z_2)}E_1 \tag{125}$$

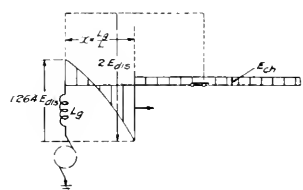


Fig. 17a

From these equations we have

$$\left.\begin{aligned} &\text{For } Z_1=Z_2,\\ &E_1'=0, \qquad I_1'=0,\\ &E_2=E_1 \text{ and } I_2=I_1 \end{aligned}\right\} \tag{126}$$

This expresses the fact that for the particular case $Z_1=Z_2$ no reflection occurs.

Applying equation (124) to the case in hand, we find that of the wave of voltage E_{dis}, returning from the generator end of the line, the voltage of the reflected portion is

$$\frac{Z_2-Z_1}{Z_1+Z_2}E_{dis} \tag{127}$$

This wave returns to the generator, is reflected with full value as before, and when it again reaches the junction point it is partially reflected with voltage,

$$\left(\frac{Z_2-Z_1}{Z_1+Z_2}\right)^2 E_{dis} \tag{128}$$

This process of reflection and partial reflection will continue indefinitely for the theoretical line of zero losses which we are considering, the voltage (and current) of each reflection being superposed upon that previously existing in the line, and upon that which grows in the line through the inductance of the generator. Reflections of the charging waves returning from the farther end of line No. 2, which will be partially reflected at the junction point and partially transmitted into line No. 1, will also be included in the general summation of voltage (and current).

If the switching point is located near the generator end of the line (line No. 1 short as compared with line No. 2), a considerable number of waves of reflection and partial reflection will travel back and forth between this point and the generator before any reflections return from the receiver end in line No. 2. If Z_2 is larger than Z_1, as with a cable for line No. 1, line No. 2 being an overhead line, the result is a step by step reduction in voltage at the generator and at the switch. On the other hand, if Z_2 is smaller than Z_1, line No. 1 being the overhead line and line No. 2 the cable, the voltages at the generator and at the switch oscillate with alternately positive and negative values. The frequency is,

$$n=\frac{1}{4\,X_1\sqrt{L_1\,C_1}} \tag{129}$$

X_1 being the distance from the generator to the junction point. The successive values of voltage at the generator are,

$$\left.\begin{array}{l}
E_0 \\
E_0+2\,E_{dis} \\
E_0+2\,E_{dis}+2\dfrac{Z_2-Z_1}{Z_1+Z_2}E_{dis} \\
E_0+2\,E_{dis}+2\dfrac{Z_2-Z_1}{Z_1+Z_2}E_{dis}+2\left(\dfrac{Z_2-Z_1}{Z_1+Z_2}\right)^2 E_{dis}
\end{array}\right\} \tag{130}$$

etc.

Substituting the value of E_{dis} from equation (116) and writing

$$\triangle=\frac{Z_2-Z_1}{Z_1+Z_2} \tag{131}$$

these expressions for voltage reduce to

$$\left.\begin{array}{r}
E_0 \\
\triangle\ E_0 \\
\triangle^2\,E_0 \\
\triangle^3\,E_0 \\
\text{etc.}
\end{array}\right\} \tag{132}$$

Whether this is an oscillatory voltage or a step by step voltage depends upon the inherent sign of $\triangle$; that is, as stated above, it depends upon whether Z_2 is larger or smaller than Z_1.

The successive values of voltage at the junction of line No. 1 and line No. 2, under the conditions which give the voltages of (132) at the generator, as found by equations (112) and (123), are

$$\left.\begin{array}{l}
0 \\
E_0+E_{dis} \\
E_0+E_{dis}+\dfrac{2\,Z_2}{Z_1+Z_2}E_{dis} \\
E_0+E_{dis}+\dfrac{2\,Z_2}{Z_1+Z_2}E_{dis}+\dfrac{2\,Z_2}{Z_1+Z_2}\cdot\dfrac{Z_2-Z_1}{Z_1+Z_2}E_{dis} \\
E_0+E_{dis}+\dfrac{2\,Z_2}{Z_1+Z_2}E_{dis}+\dfrac{2\,Z_2}{Z_1+Z_2}\,\dfrac{Z_2-Z_1}{Z_1+Z_2}E_{dis}+ \\
\qquad\qquad \dfrac{2\,Z_2}{Z_1+Z_2}\left(\dfrac{Z_2-Z_1}{Z_1+Z_2}\right)E_{dis}
\end{array}\right\} \tag{133}$$

etc.

Introducing E_{ch} instead of E_{dis}, and substituting $\triangle$, these expressions reduce to

$$\left.\begin{array}{r}
O \\
E_{ch} \\
\triangle\ E_{ch} \\
\triangle^2\,E_{ch} \\
\triangle^3\,E_{ch} \\
\text{etc.}
\end{array}\right\} \tag{134}$$

The oscillatory or step voltages at the generator and at the switch or junction point, in accordance with (132) and (134), are illustrated in Figs. 18 and 19 for the relative values of Z_1 and Z_2 used in Figs. 16 and 17 respectively.

The charging waves entering the line from the generator, as illustrated in Figs. 15a, 16a and 17a, are not taken into account in expressions (132) and (134) and Figs. 18 and 19. These voltages are superposed upon those of the waves entering the line from the generator. Since the voltage of the generator is $E=E_o$, the final voltage of the line will be E_o, and the oscillating or step voltages, instead of approaching zero for

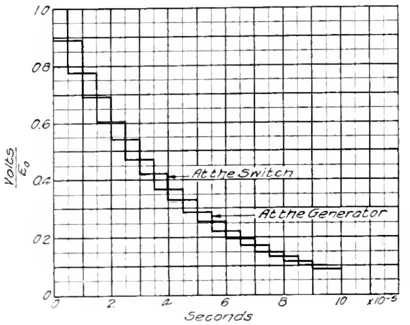


Fig. 18

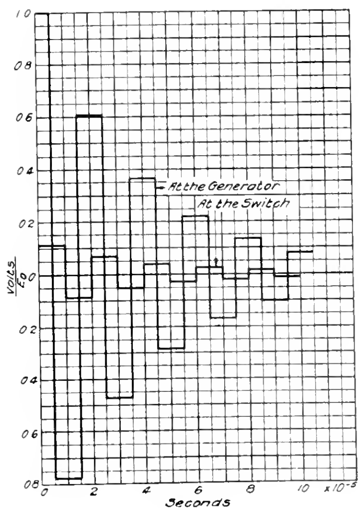


Fig. 19

final value, approach the gradually growing voltage whose final value is E_o. The rate of growth of the voltage of the wave entering the line from the generator is affected, however, by each successive change in voltage at the generator terminlas due to the reflections, since the rate of growth of current in the generator depends upon the difference

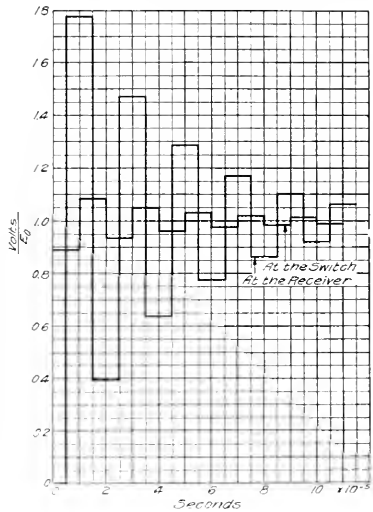


Fig. 20

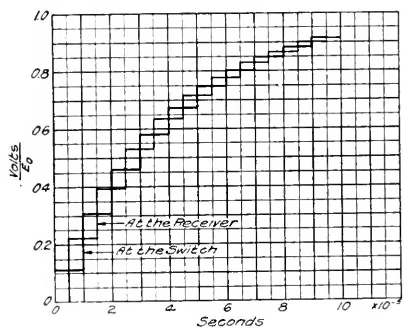


Fig. 21

between the generator voltage and the voltage in the line at its terminals.

If the switching point, instead of being located near the generator end of the line, is located near the receiver end, a considerable number of reflections will travel back and forth between this point and the receiver before any reflections return from the generator. If the receiver end of the line is open, the successive values of voltage at the end of the line are

$$\left.\begin{array}{l} 0 \\ 2\,E_{ch} \\ 2\,E_{ch}+2\,\dfrac{Z_1-Z_2}{Z_1+Z_2}\,E_{ch} \\ 2\,E_{ch}+2\,\dfrac{Z_1-Z_2}{Z_1+Z_2}E_{ch}+2\left(\dfrac{Z_1-Z_2}{Z_1+Z_2}\right)^2 E_{ch} \end{array}\right\} \qquad (135)$$

etc.

These expressions reduce to

$$\left.\begin{array}{l} O \\ E_0+\triangle\ E_0 \\ E_0-\triangle^2\,E_0 \\ E_0+\triangle^3\,E_0 \end{array}\right\} \qquad (136)$$

etc.

The successive values of voltage at the junction point are,

$$\left.\begin{array}{l} E_0 \\ E_{ch} \\ E_{ch}+\dfrac{2\,Z_1}{Z_1+Z_2}E_{ch} \\ E_{ch}+\dfrac{2\,Z_1}{Z_1+Z_2}E_{ch}+\dfrac{2\,Z_1}{Z_1+Z_2}\dfrac{Z_1-Z_2}{Z_1+Z_2}E_{ch} \\ E_{ch}+\dfrac{2\,Z_1}{Z_1+Z_2}E_{ch}+\dfrac{2\,Z_1}{Z_1+Z_2}\dfrac{Z_1-Z_2}{Z_1+Z_2}E_{ch}+ \\ \qquad\qquad \dfrac{2\,Z_1}{Z_1+Z_2}\left(\dfrac{Z_1-Z_2}{Z_1+Z_2}\right)^2 E_{ch} \end{array}\right\} \qquad (137)$$

etc.

These expressions reduce to

$$\left.\begin{array}{l} E_0 \\ E_0+\qquad E_{dis} \\ E_0-\triangle\ \ E_{dis} \\ E_0+\triangle^2\,E_{dis} \\ E_0-\triangle^3\,E_{dis} \\ \quad \text{etc.} \end{array}\right\} \qquad (138)$$

The voltages of (136) and (138) are plotted in Figs. 20 and 21 for the relative values of Z_1 and Z_2 used in Figs. 16 and 17 and in Figs. 18 and 19.

If an inductive receiver is connected to the end of the line the reflections will be the same as those described above, but the voltages of (136) and (138) will be superposed upon those of the discharge waves entering the line through the receiver. These waves will be similar to the charging waves entering the line through the generator, except that the voltage of these waves of discharge will be negative, and their direction of travel negative.

The application of the principles developed above will be extended if it is understood that when several uncharged lines are simultaneously switched onto a charged line, at a common junction point, the result is the same as that produced when a single line, of wave impedance equivalent to the parallel combination of the individual wave impedances of all of the lines is switched on. Also, if a single uncharged line is switched onto several charged lines at their junction point, the result will be the same as though it were switched onto a single line of wave impedance equivalent to the parallel combination of the individual wave impedances of the charged lines. When a branch line is switched onto a main line at some mid-point, the two ends of the main line will figure as distinct lines meeting at the point where the branch line is switched on.

The equivalent impedance of several parallel wave impedances is found by the same rule that is employed for finding the equivalent resistance of several parallel ohmic resistances.

INCANDESCENT STREET LIGHTING REGULATING APPARATUS

By H. H. Reeves

Supply Department, General Electric Company

This article outlines briefly the fundamental theory of those regulators which are designed to control constant-current series circuits. The effect of different kinds of loads on the regulation of the circuit and the operation of the transformers is also pointed out. A knowledge of the theory and operating characteristics of constant-current transformers will help in selecting the most efficient and desirable system for series street lighting.—Editor.

There are two systems of electrical distribution, series and multiple. The series system is, at present, almost universal for street lighting. In this system as the name implies the lamps are connected in series; i.e., the same current passes from the controlling apparatus through all the lamps in one group or circuit and back to the controlling apparatus. This current must be held approximately constant at the value for which the lamps are built. As alternating current is generally supplied at constant potential the regulating apparatus must transform the constant potential to constant current over a certain range in load, which is generally from full rated capacity to zero load.

There are two distinct types of regulators for controlling constant-current series circuits—the movable coil type and the stationary coil type.

In the movable coil type, a series reactance is provided which changes with the change in load in such a manner as to keep the total impedance, and consequently the current, constant. In the stationary type, a fixed reactance is provided of the proper value to give the current regulation desired.

There are two styles of movable coil type regulators, one combining transforming and regulating features in one device, while in the other the regulating coil and transformer are separate mechanisms.

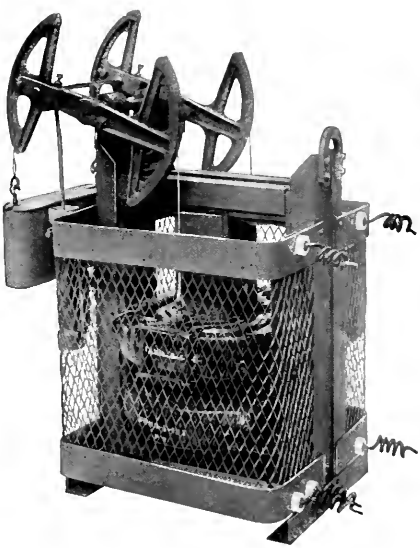


Fig. 1. One Type of Movable Coil Constant-current Transformer

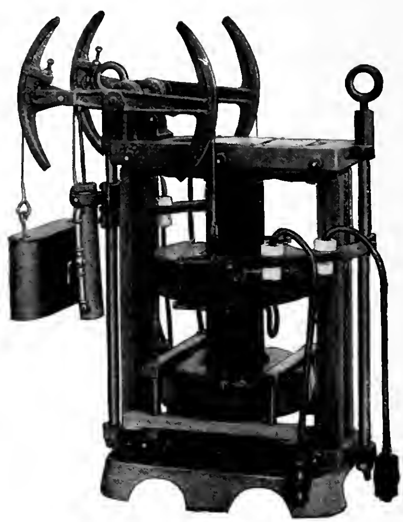


Fig. 2 Another Type of Movable Coil Constant-current Transformer

Movable Coil Regulator, transforming and regulating features combined

The variable reactance in this type is obtained by means of two coils, movable with respect to each other. One coil is stationary, while the other is suspended from a rocker arm to the other end of which weights are attached. These weights, together with the magnetic repulsion between the coils, counterbalance the weight of the movable coil. At full load the coils should be about 2 inches apart, and as the load falls off the tendency for the current to rise, due to the decreased resistance of the secondary circuit, is offset by the separation of the coils. The separation is caused by the greater repulsion of the increased magnetic flux, due to the momentarily increased current in the secondary coil. With the coils farther apart more of the magnetic lines of force from the primary coil go out between the coils as leakage flux and the e.m.f. induced in the secondary is decreased in proportion to the fall in the secondary load, thus maintaining the current at a constant value.

These transformers are designed so that the coils will separate sufficiently to maintain constant current, even when all of the lamps are cut out of the circuit; in other words, they regulate from full load to no load maintaining constant current on the secondary within 1 per cent on either side of normal. The center of curvature of the weight sector arm is adjustable, as is also the amount of balancing weight.

Figs. 1 and 2 illustrate this type of transformer and Fig. 3 indicates the diagrammatic circuit connections.

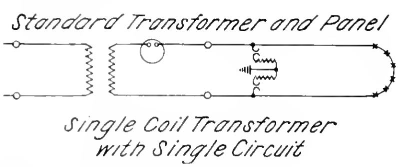


Fig. 3. Diagrammatic Circuit Connections of the Transformers Shown in Figs. 1 and 2

The vector diagram for this type of transformer is shown in Fig. 4, where

ϕ = magnetic flux
i_m = exciting current
E = primary impressed e.m.f.
E_o = component of primary e.m.f. consumed by e_1
e_1 = primary counter-generated e.m.f.
ir = primary e.m.f. of resistance
ix = primary e.m.f. of reactance
i_p = primary current total
i = primary current load
e_o = secondary induced e.m.f.
IR = secondary e.m.f. of resistance
IX = secondary e.m.f. of reactance
I = secondary load current
e = e.m.f. available for load

The effects of loads of varying power-factor upon the voltage available for load can be

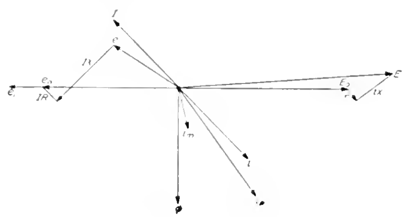


Fig. 4. Vector Diagram for a Constant-current Transformer

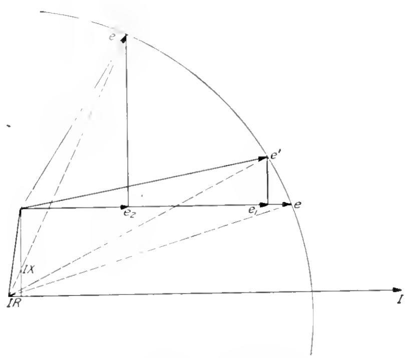


Fig. 5. Vector Diagram Showing Effects of Different Power-factors on Voltage

seen from Fig. 5, where the dotted line represents the impressed circuit voltage.

I = current
IR = transformer e.m.f. of resistance
IX = transformer e.m.f. of reactance
e = terminal voltage available for load with a load of unity power-factor
e' = terminal voltage available with load of 0.98 power-factor
e_1 = voltage available for load with load of 0.98 power-factor
e'' = terminal voltage available with load of 0.86 power-factor

e_2 = voltage available for load with load of 0.86 power-factor

If a transformer is carrying a load of unity power-factor and various portions of the load become short circuited, this diagram can be used to show the result as in Fig. 6, where

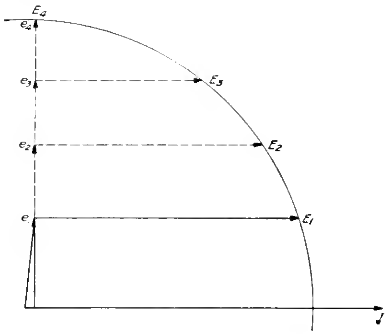


Fig. 6. Vector Diagram Showing Effect of Load on Voltage

e_1, e_2, e_3, and e_4 are the e.m.f.'s in the various conditions of load consumed by reactance in the transformer and E_1, E_2, E_3 and E_4 are the corresponding load voltages. E_4 is zero and illustrates the condition of short circuit on the transformer.

It should be stated that these vectors represent the permanent conditions which maintain after equilibrium of the moving elements has been established. Momentarily, there is a surge of current resulting from the fact that it takes an appreciable interval of time to overcome the inertia of the coil and weight. By oscillographic test this surge may be even 2.5 times the normal value of current and may last from two to four cycles.

Fig. 7 shows the equivalent electric circuits of a 1 to 1 ratio transformer where r_p and x_p are the primary resistance and local leakage reactance, while r_s and x_s are the secondary resistance and local leakage reactance, x_m and r_c the shunted inductive and non-inductive circuits carrying the magnetizing current and core loss current respectively. If the primary has n times as many turns as the secondary, then the same equivalent circuits may be used to represent the transformer, if the actual secondary resistance and local leakage reactance be multiplied by n^2 to obtain the values to be used in the equivalent circuits, and the real secondary load current be divided by n. R is the resistance and X the reactance of the load and r_L and x_L are the resistance and reactance of the line. The generated voltage may then be represented by e_o. As this is constant and the current i_1 of the load is held constant as explained below, I_o or the total (or primary) current must also be constant. This means that Z_o the total impedance must be constant.* The quantities r_p, r_s, r_L, are constant, R and X vary and the remaining quantities must also vary to maintain Z_o constant.

An expression for Z_o may be obtained by the use of complex quantities as follows:

The admittance of branch (1)

$$y_1 = \frac{1}{Z_1} = \frac{1}{r_s + R - j\,(x_s + X)}$$

$$= \frac{r_s + R + j(x_s + X)}{(r_s + R)^2 + (x_s + X)^2} = A + jB$$

where

$$A = \frac{r_s + R}{(r_s + R)^2 + (x_s + X)^2}$$

and

$$B = \frac{x_s + X}{(r_s + R)^2 + (x_s + X)^2}$$

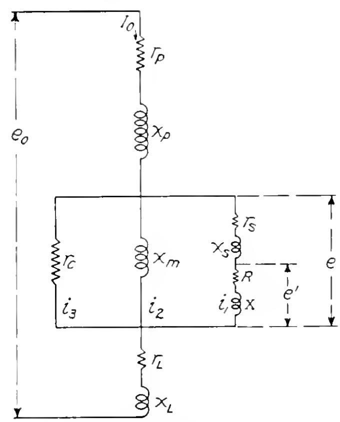


Fig. 7. Diagram Showing Equivalent Electric Circuits of a Constant-current Transformer

The admittance of branch (2)

$$y_2 = \frac{1}{Z_2} = \frac{1}{o + jx_2} = \frac{o + jx_2}{o + x_2^2} = jC \text{ where } C = \frac{1}{x_2}$$

* As a matter of fact, in practice the load current i_1 will vary from one to two per cent either side of normal and the variation of the primary current I_o will be slightly greater than this due to the variation in the excitation losses.

Fig. 8. Regulating Apparatus Used in Conjunction with the Transformers Shown in Figs. 9 and 10

The admittance of branch (3)

$$y_3=\frac{1}{Z_3}=\frac{1}{r-jo}=\frac{r_2+jo}{r_2^2}=\frac{1}{r_2}=D$$

The admittance of (1), (2) and (3) in parallel

$$y=y_1+y_2+y_3=A+jB+jC+D=F+jG$$

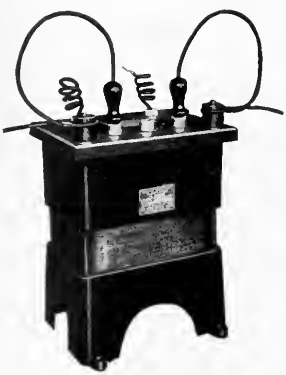


Fig. 10. Transformer Used in Conjunction with the Regulating Apparatus Shown in Fig. 8

where

$$F=A+D \text{ and } G=B+C$$

The impedance of (1), (2) and (3) in parallel

$$Z=\frac{1}{y}=\frac{1}{F+jG}=\frac{F-jG}{F^2+G^2}=H-jK$$

Fig. 9. Transformer Used in Conjunction with the Regulating Apparatus Shown in Fig. 8

where

$$H=\frac{F}{F^2+G^2} \text{ and } K=\frac{G}{F^2+G^2}$$

The impedance of the rest of the circuit

$$Z^1=r_p+r_L-j(x_p+x_L)=L-jM$$

where

$$L=r_p+r_L \text{ and } M=x_p+x_L$$

$$Z_o=Z+Z^1=H+L-j(K+M)=N-jO$$

where

$$N=H+L \text{ and } O=K+M$$

The relation between generated electromotive force and secondary load voltage may be expressed as follows:

$$e = c^1 + i_1(r_s - jx_s)$$
$$e_o = c + I_oZ^1$$
$$e_o = c^1 + i_1(r_s - jx_s) + I_oZ^1$$
$$e_o = c^1 + i_1(r_s + jx_s) + I_o[(r_p + r_L) - j(x_p + x_L)]$$

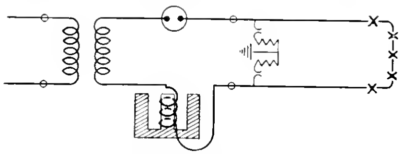


Fig. 11. Diagrammatic Circuit Connections of Regulating Apparatus Shown in Figs. 8, 9 and 10

This equation shows the relation between the impressed voltage, the voltage required by the load and that consumed as impedance drop in the transformer. Under varying loads this impedance drop of the transformer varies from approximately 5 to 100 per cent of the impressed voltage. This does not mean that there is a corresponding loss of energy as the I^2R and core loss vary but slightly with change of load.

Movable Coil Regulator, transforming and regulating features separate

The variable reactance in the second style of movable coil regulator is obtained by means of an iron core and coil which move with respect to each other.

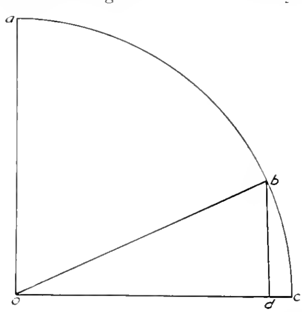


Fig. 12. Diagram Showing Effect of Reactance on Voltage

On open circuit, the coil and core hang apart, the weight of the core on its lever arm overbalancing the coil on the opposite end of the same lever. When the circuit is closed, the current flowing through the line (this being a series circuit, the same current flows through the coil of the regulator) attracts the coil and core. The coil moving down over the iron core adds the reactance of the regulator to the resistance of the incandescent lamps until such a point is reached that the attractive force of the coil and core balance, at which point normal current is flowing in the line. Should the current decrease slightly, the coil moves up reducing the reactance added to the circuit and thus increasing the current. Should the current increase slightly, the coil moves down over the core increasing the reactance added to the circuit and bringing the current back to normal value.

Fig. 8 shows the regulator and Figs. 9 and 10 illustrate the two types of transformers used with this regulator. Fig. 11 indicates the diagrammatic circuit connections. The regulator could be used directly on the line providing the total voltage of the lamps plus the line loss and drop in the regulator equalled the circuit voltage. This practice is not recommended, however, as there is no provision for insulating the series lamp circuit from the main distributing system and burnouts would be more apt to take place.

Electrically we can assume the regulator and transformer to be a unit and then apply the vector diagrams as drawn for the unit type transformers.

Stationary Coil Regulator

In any transformer with fixed reactance the current regulation between full load and short circuit depends upon the impedance. If the transformer has an impedance of 4 per cent at full load current, then the short circuit current will be approximately 25 times the full load current. By increasing the impedance at full load, the current at short circuit is reduced, therefore, if we provide a fixed reactance of the proper value we may obtain any current regulation desired. It is obvious from Fig. 12 where *oa* represents the open circuit voltage, *od* the reactance voltage at

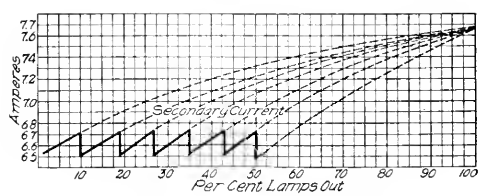


Fig. 13. Curves of Current Regulation of Stationary-coil Constant-current Transformers

full load, *oc* the reactance voltage at short circuit and *bd* the full load voltage that the more nearly we approach 100 per cent reactance the closer the current will be maintained to a given value. It is impractical, however, from a commercial standpoint to lower the power-factor too much by inserting reactance and a compromise is effected in the design of the transformer. The standard transformer has a reactance of 0.866 with a corresponding power-factor of 50 per cent. This gives a current regulation of 18 per cent from full load to zero or 1.16 amperes rise which is below the burning out current of the Type C Mazda lamp. The current does not rise along a straight line as the load falls off but in a curved line as shown in Fig. 13.

Part of the required reactance in the transformer is obtained by displacement of the high and low-voltage windings; the remainder by means of a magnetic shunt. To take care of different loads, taps have been placed in the low-voltage winding. If we change our connection from one tap to another, either adding or subtracting turns, the reactance increases, or decreases, as the square of the number of turns added or subtracted. It is therefore necessary to compensate for this change in reactance.

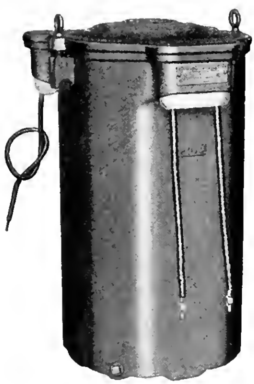


Fig. 14. A Stationary-coil Constant-current Transformer

This is accomplished by means of an auxiliary low-voltage winding, which is interlaced with the high-voltage winding so that it has a very low reactance; then by boosting or bucking the proper number of turns in this coil with those of the main low-voltage winding the desired reactance is obtained on all taps. The current regulation on the different taps is shown by the curves in Fig. 13.

Figs. 14, 15 and 16 illustrate the transformer, while Fig. 17 indicates the diagrammatic circuit connections.

Fig. 15. Installation of a Stationary-coil Constant-current Transformer

The vector diagram for the transformer is shown in Fig. 18, where

ϕ = magnetic flux
i_m = exciting current
E = primary impressed e.m.f.
E_o = component of primary e.m.f. consumed by e_1
e_1 = primary counter-generated e.m.f.
ir = primary e.m.f. of resistance
ix_a = primary e.m.f. of reactance due to auxiliary secondary winding.
ix_m = primary e.m.f. of reactance due to main secondary winding
i_p = primary current total
i = primary current load

e_o = secondary induced e.m.f.
IR_a = secondary e.m.f. of resistance in auxiliary winding
IR_m = secondary e.m.f. of resistance in main winding

Fig. 16. Coils and Core of Transformer Shown in Fig. 14

IX_a = secondary e.m.f. of reactance due to one-half leakage flux in auxiliary secondary winding
IX_m = secondary e.m.f. of reactance due to one-half leakage flux in main secondary winding

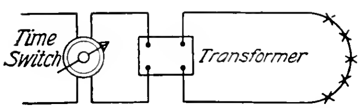


Fig. 17. Diagrammatic Circuit Connections of Transformer Shown in Fig. 14

e = secondary terminal e.m.f.
I = secondary load current

The current regulation of this transformer when operated with a load of series auto-transformers is radically different from the regulation with a straight resistance load as seen in Fig. 19. This shows the current in the lamps when connected across constant potential, also when connected to stationary coil type transformers having different percentages of reactance. These curves apply only

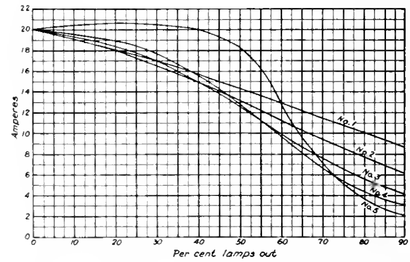


Fig. 19. Curves of Current Regulation of a Stationary-coil Constant-current Transformer Carrying a Load of Auto-transformer Units
Curve 1: 50 per cent Full-load Power-factor
Curve 2: 60 per cent Full-load Power-factor
Curve 3: 75 per cent Full-load Power-factor
Curve 4: 85 per cent Full-load Power-factor
Curve 5: 100 per cent Full-load Power-factor Constant-potential

to changes in load due to broken or removed lamps. If the auto-transformers are short circuited the current will follow more or less closely the curve shown in Fig. 13.

Conclusion

The movable coil and stationary coil regulators supplement each other in the field of street lighting. The movable coil type is preferred in the larger sizes on account of its higher power-factors and closer regulation. It requires station room and an attendant, however, and the stationary coil type requiring neither of these is better adapted to installations in outlying or isolated districts remote from the station. Its low cost, also, makes it attractive to lighting plants where first cost is the determining factor.

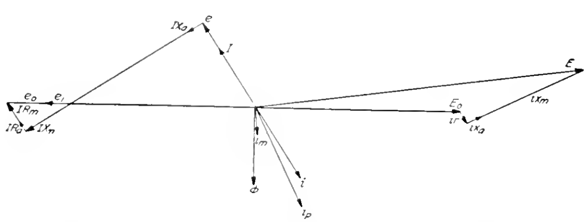


Fig. 18. Vector Diagram of Stationary-coil Constant-current Transformer

A MERCURY-ARC RECTIFIER FOR CHARGING SMALL STORAGE BATTERIES

By C. M. Green

Lynn Works, General Electric Company

This article is descriptive of the mechanical and electrical features of two forms of small portable mercury-arc rectifiers. Curves of regulation, efficiency and power-factor and tables of voltage and current are included.
—Editor.

A small portable mercury-arc rectifier, known as the Form K, has been built in increasing quantities for the past twelve months, during which time over 1000 outfits have been shipped to various parts of this country, Manila, Australia, Cuba, and South America.

With the increased use of storage batteries for ignition, lighting, and starting systems and their various combinations on automobiles and launches, there has arisen a demand on the part of many users for a device whereby the batteries can be conveniently and inexpensively charged from an ordinary lighting circuit.

While the starting and lighting systems of most modern gasolene automobiles are equipped with generators, it is frequently desirable to separately charge the battery. This procedure will aid the generator and also will keep the battery in proper condition during the winter months and at those other times when the battery receives very little charging current from the generator because of no long trips being taken. For charging the battery separately, the mercury-arc rectifier will be found particularly convenient and almost a necessity.

The particular type of rectifier that is designated Type MS Form K will deliver 5 amperes at 7.5 or 15 volts, depending upon the connection, and may be connected to an ordinary lamp socket. It is designed to charge one 3-cell, one 6-cell, or two 3-cell batteries and can be furnished for operation on 25, 30, 40, 50, 60, 125 or 133 cycle, 110-volt circuits.

A later modification of the Form K rectifier is that styled the Form K2. This latter has been designed along improved lines and more attention has been given to making it fool-proof in the hands of the layman. The rectifier consists of a metal case on which are mounted the necessary reactive coils, the rectifier tube, and a suitable holder, all of which are protected by a sheet-metal cover. The device is supplied with an attachment plug that

TABLE I

Input			Output		Cells Battery	Connection	Remarks
Volts	Amperes	Watts	Volts	Amperes			
110	2.35	166	14.85	4.93	6	6	
110	5.2	183	11.30	11.8	6	6	Battery reversed
110	3.15	186	7.55	6.55	3	6	
110	4.50	188	5.50	9.96	3	6	Battery reversed
110	2.50	146	7.45	5.43	3	3	
110	3.5	140	5.55	8.25	3	3	Battery reversed
110	2	130	4.26	4	6	3	
110	4	125	11.50	10.10	6	3	Battery reversed

A three-ampere fuse was placed in the supply line and following tests made on outfit.

Input			Load		Conn.	Cells	Fuse Blew	Remarks
Volts	Amperes	Watts	Volts	Amperes				
110	3.9	195	0	8.1	6	0	No	Short circuit, run 5 minutes
110					6	6	1.2 seconds	Reversed
110					3	6	1.3 seconds	Reversed
110	3.25	160	0	7.3	3	0	No	Short circuit, run 5 minutes
110					3	6	2 seconds	Reversed
110					3	3	6.3 seconds	Reversed

Fig. 1. Rectifier Connected to Battery (Starting

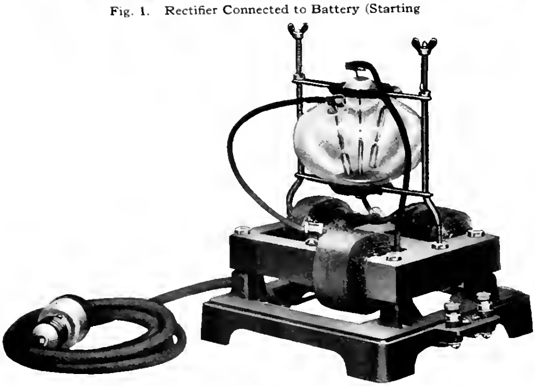


Fig. 2. Rectifier with Cover Removed

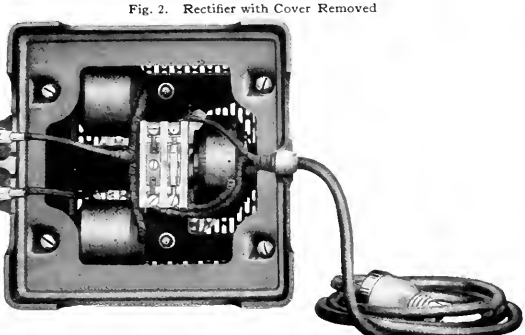


Fig. 3. Rectifier, Bottom View Showing Fuse

may be inserted in a lamp socket and two binding posts, marked + and −, from which wires are run to the battery to be charged. This arrangement makes it unnecessary to remove the battery from the car. In other words, the charging apparatus is ordinarily much lighter and more convenient to move than the battery.

There have been cases where difficulty has been experienced by the reversal of the connecting leads between the battery and the rectifier when making connections for charging. This reversed connection resulted in the battery discharging through the rectifier, thereby materially increasing the current which was usually followed by the loss of the tube. To overcome this difficulty, the Form K2 rectifier has been equipped with a fuse in one side of the supply line. When this fuse blows the battery cannot further discharge and the loss of the rectifier tube by over-heating is prevented. The current values in various parts of the circuit under normal and abnormal conditions (battery reversed) have been investigated and are listed in Table I.

The change in connections from 3-cell to 6-cell load was made in the Form K rectifier by means of transferring the lead from one binding-post connector on the series reactance coil to another, which required the use of a screwdriver. In the Form K2 rectifier this is accomplished by simply transferring the fuse from one side to the other of the double-pole fuse block (see Fig. 3).

The method of holding the cover to the base has also been changed; four small machine screws, which were very liable to get lost, have been replaced by two wing nuts, one on each side of the handle. Spring connectors have been substituted for screw connectors on the leads to the rectifier tube.

The Form K2 rectifier is compact; its outside dimensions being roughly 8 in. wide,

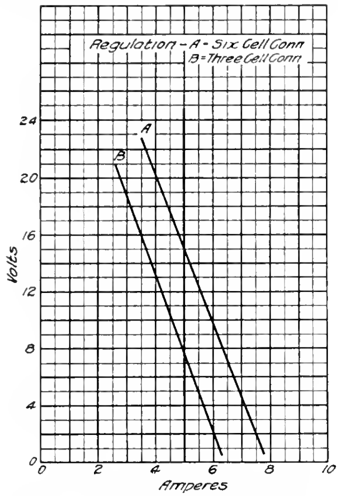


Fig. 4. Curves showing the Mercury-Arc Rectifier Regulation for the 3-cell and the 6-cell Connection

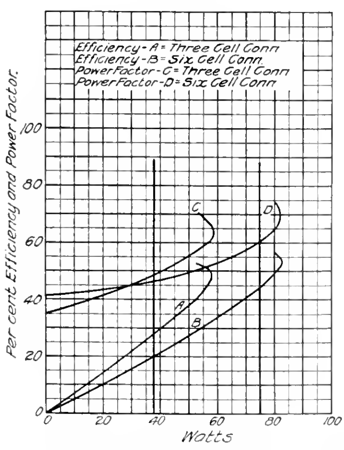


Fig. 5. Curves showing the Mercury-Arc Rectifier Efficiency and Power-factor for the 3-cell and 6-cell Connection

$9\frac{1}{16}$ in. long, and $10\frac{9}{16}$ in. high for 60 cycles and above, and $11\frac{7}{8}$ in. high for 25 to 50 cycles. The net weight of the 60-cycle outfit is approximately 18 lb., which enables it to be readily carried from place to place.

The rectifier tube is spherical and has no pockets in which mercury can be trapped, with the possible result of the tube being broken in shipment. The two anodes and cathode are sealed into the upper part of the

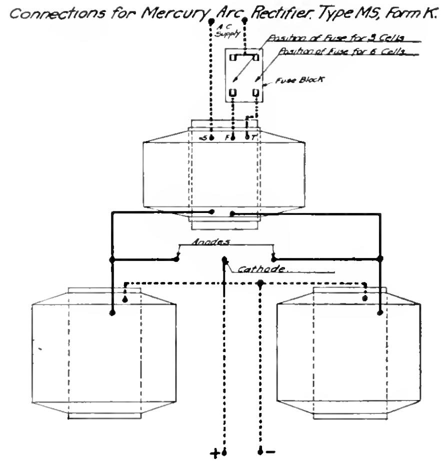


Fig. 6. Connection Diagram

condensing chamber and extend downward into the tube. The tube is $4\frac{1}{2}$ in. in diameter by about 4 in. high, and has bosses top and bottom to prevent it from turning in the holder. Its weight is approximately 8 ounces. The rectifier is shipped with the rectifier tube assembled, so that it is ready for connecting to a battery after being unpacked.

Rectifier tubes, when shipped separately, are packed in excelsior in paper cartons 8 in. by 8 in. by 9 in.; the parcel-post service may be employed. The gross weight is less than 2 lb. This method of packing, together with the rugged construction of the tube, has resulted in very few losses in transportation.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

IS THE INDUCTION GENERATOR PRACTICAL?

The induction generator is fully as practical as the synchronous generator. The only limitation of the induction generator is, that it is difficult to build for very low speeds, such as 100 to 200 r.p.m., and thus at these speeds is expensive and of low power-factor. For speeds of 1800, 1200, and 900 the induction generator is well suited, and for the somewhat larger machines even 720 and 600 revolutions, or the same speeds at which induction motors are economical, may be employed.

The synchronous machine on the system must supply the wattless current of the induction generator and in addition thereto the wattless current of the load. Assuming this to be 50 per cent. with a non-inductive load twice the capacity of the synchronous machine in induction generators could be used. If the load has 90 per cent power-factor, about the same capacity as the synchronous machines, or a little more, in induction generators could be used. It is therefore probably safe to assume that in most cases an induction generator capacity equal to the capacity of all the synchronous machines in the system is permissible.

The output and efficiency of the machine as an induction generator is approximately the same, or rather a little *higher*, than the output and efficiency as an induction motor.

The output is increased approximately proportional to the speed. Thus, if the induction motor delivers 10 h.p. with 10 per cent slip, that is, at 90 per cent of synchronous speed, then as synchronous generator, with 10 per cent speed above synchronism, or at 110 per cent of synchronous speed, it will give $\frac{110}{90} \times 10 = 12.2$ h.p. output. The losses in the machine will be the same, and therefore the efficiency will be higher due to the increased output. If the efficiency as induction motor is 90 per cent, that is, the losses 10 per cent, these losses, at the increase of output by $\frac{110}{90}$, will be only $\frac{90}{110} \times 10 = 8.2$ per cent, and the efficiency therefore 91.8 per cent, approximately. However, the difference is usually much less, as the slip as induction motor is usually much less than 10 per cent—from 1 to 2 per cent.

The most promising and valuable use of the induction generator is in the collection of small water powers, where considerable power is distributed along a moderate sized stream, but nowhere so concentrated as to be collected without excessive hydraulic development. A number of small and cheap dams could be built across the stream at suitable locations, and the water led by canal, flume or pipe to a waterwheel connected to an induction motor, 5 h.p. to 100 h.p., depending on the available power. By step-up transformers all these induction generators would be connected into a moderate voltage transmission line running along the stream. Probably, if the waterwheel speed is low, the power would have to be transmitted to the induction generator by gearing, belt or rope drive.

In these small induction generator stations a cheap kind of waterwheel would be used, without any governor or other speed regulation, and without any attendance in the station except a daily inspection. Nothing could happen: if the belt comes off, the induction generator would continue to spin around idle, as induction motor, and the waterwheel spin at its free running speed; if the induction motor burns out or the transformer gives trouble, the station will cut off by the blowing of the fuses; if the load comes entirely off the system, induction generators and waterwheels will speed up to their free running speed and then spin idly, until the load come on again and pulls them down to the speed above synchronism which carries the load. Somewhere in the system a synchronous machine will be located, and the entire control of the system is effected by this machine. It may be located at the largest water power station, where as generator it will take the power of this station, but be larger than usual, so as to supply the wattless current of the entire system; or the synchronous machine may be located elsewhere, as at the main power consumption place, and then be motor, or merely spin idly on the system. In the latter case, however, some method of starting the synchronous machine is necessary, as the induction generators do not generate until they are connected with the running synchronous machine.

The simplest method of regulation would be a speed governor on the synchronous motor, which connects more or less of a water rheostat across the circuit, and thus throws away the unused excess power by boiling water, and keeps constant load on the system. This may look like a waste of power, but it cheapens installation and operation by making power regulation, and therefore attendance in the induction generator stations, unnecessary; and as the water would probably go to waste over the dam in any case, with no reservoir and water storage provided, it makes no difference.

If the power demand is greater than the available power, and if the location is suitable, a small reservoir above the highest station could be provided, storing the water during the night time. The gates would then be opened in the morning, sufficiently before the power demand begins, to let the water reach the lower station; or at each station, by raising the dam a little, sufficient water storage would be provided for the short time it takes for the water to come down from the next higher station.

In such a system, of a total power not exceeding a few hundred horse-power, low voltage induction machines would be used, and probably 13,200 volts, or even 6,600 volts in the power collecting transmission line. This would allow the use of standard motors and standard transformers, and direct distribution of the power without any step-down substations.

Charles P. Steinmetz

SELF-LUMINOUS PAINT

By W. S. Andrews

Consulting Engineering Department, General Electric Company

The following article, descriptive of self-luminous paint, treats in a very simple and non-technical manner of the properties of this composition, its components, its period of luminous life, and some of its applications.—Editor.

Soon after the discovery of radium by the Curies in 1898 certain fluorescent and phosphorescent mineral compounds were found to be so sensitive to the radio-activity of this element that they show luminescence when only brought near it, actual contact being unnecessary. A fine quality of zinc sulphide known as Sidot's blende proved to be the most responsive.

Sir William Crookes by the invention of his ingenious spinthariscope brought this phenomenon of radio-active luminescence prominently before the public eye. This device consists of a little dark chamber enclosing a disk of cardboard that is coated with zinc sulphide. A small wire is fixed above the disk so that one end of it is very close to the sulphide but not touching it and a microscopic speck of a salt of radium is attached to this end of the wire. When this combination is observed through a magnifying lens of proper power, the zinc sulphide is seen to be perpetually scintillating with innumerable little stars in the vicinity of the radium. This remarkable appearance is caused by the alpha rays that are discharged from the radium with tremendous velocity, some of which bombard the sulphide like atomic cannon balls, every hit producing a flash of light on the target. The accompanying diagram, Fig. 1, shows the construction of this wonderful device in its simplest form.

A next obvious step was to mix a very minute amount of radium salt with finely powdered zinc sulphide so that it might be combined with a suitable adhesive and used as a *self-luminous paint*. For a long time this paint was looked upon only as an interesting scientific curiosity but during recent years it has been applied in various useful ways to make small objects constantly visible in the dark. For example, it is now used extensively on the hands and dials of watches and clocks, making it easy to tell the time in total darkness; also on the pointers of aeroplane and prismatic compasses and other instruments. One of its most recent and convenient applications is on electric switch buttons, drop chain sockets, etc., thereby guiding a person directly to the switch in a dark room.

This radio-active self-luminous paint must not be confounded with an article that has been on the market for many years under the name of "Balmain's luminous paint," which was invented by Prof. Balmain of the London University about the year 1875. The base of the Balmain paint is a special preparation of phosphorescent calcium sulphide, and it requires the excitation of a strong light to make it shine. It absorbs the luminous radiation and then emits it again as a soft phosphorescent glow which gradually fades away so that in the course of a few hours it ceases to be visible until again excited to phosphorescence. The *self-luminous* radioactive paint differs entirely from the above in containing within itself its own exciting power, so that it continues to shine indefinitely even when kept in perpetual darkness.

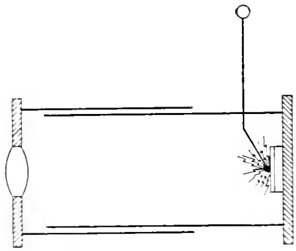


Fig. 1. Diagram of the Spinthariscope

The question is sometimes asked, "How long will the self-luminous compound maintain its brightness?" According to recent research, the "half-period" decay of radium is 1750 years. Based on this assumption, and taking for example one gram of radium to start with, one half of this will disappear by spontaneous decomposition in 1750 years, leaving half a gram. During the next period of 1750 years one half of this remainder will disappear, leaving one quarter gram and so on. It is thus evident that, for all practical purposes, the life of the radium content may be considered unlimited. *Not so, however, with the zinc sulphide,* the quality of which in itself is subject to considerable variation according to its purity and the method of its preparation. There appears to be *a certain amount of luminous quality* locked up, so to speak, in the zinc sulphide. This quantum of light-producing ability may be liberated and used up quickly and with high intensity by strong excitation, or slowly and with a lower intensity by a weaker excitation. Therefore, assuming the use of a uniform quality of zinc sulphide, the useful life of a very bright self-luminous compound will naturally be shorter than that of a compound showing a weaker luminescence, and the intensity of luminescence will depend on the percentage of radium element mixed with the zinc sulphide.

An incandescent lamp may be taken as a familiar illustration of this argument. We may compare the voltage used on the lamp to the radium, and the filament to the zinc sulphide. We all know that an incandescent lamp operated at a voltage well below normal has a very long life and, vice versa, when it is operated at a voltage much higher than normal its life is short. These results are practically parallel with the results which obtain in connection with self-luminous paint. The *normal* voltage for an incandescent lamp is arbitrarily decided by conditions under which it will produce a satisfactory light for a reasonable number of hours, and these same conditions may be applied to the consideration of a proper degree of brightness for self-luminous radium-zinc compounds. If a compound containing, say, 100 micrograms of radium element per gram of zinc sulphide has a useful life of twenty years, it is reasonable to infer that by doubling the radium content the luminescence will be increased about two-fold; but the useful life will be halved, or reduced to ten years.

The satisfactory luminescent intensity of a radio-compound will depend largely on the purpose for which it is used, this also involving the area of the luminous surface employed, so that no fixed standard of light per unit of surface can be adopted. For Army and Navy purposes the United States Government calls for a guarantee on self-luminous paint that it shall maintain an undiminished luminosity for two years. In view of this very moderate demand a high grade quality may be safely used.

It is well known that the phenomenon of radio-activity is not confined to radium. A product of thorium, known as radio-thorium is intensely radio-active, but it has a much shorter life than radium, its half-period of existence being estimated at only three or four years. Meso-thorium, from which radio-thorium is evolved, is a by-product of the incandescent gas mantle industry and on account of its relative cheapness as compared with radium it is now being used extensively either by itself or combined with radium in the production of self-luminous paints.

There is a difference of opinion in regard to the merits of the radio-thorium paint and paint that is energized entirely by radium, but both compounds will probably find their appropriate applications in the future.

PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

Part XIX (Nos. 76 to 78)

By C. E. Parham

Construction Department, General Electric Company

(76) TEMPERATURE EFFECTS ON EQUALIZATION

Operating engineers have noted that lubricating the commutator of one machine that is operating in parallel with another affects the distribution of load between them. This action is caused by a change in the brush contact resistance of one machine only. Also, machines may equalize differently when hot than when cold; this has always been attributed, in a general way, to unequal heating of the machines. It *is* due to unequal heating, but the unequal heating is not always in the same place. For example, the heating of the conductors that form the equalizing circuit may change the load equalization, as may also the heating of the commutator and brushes and hence the brush contacts.

Two very large continuous-current generators would equalize the load when both machines were started, but after operating for a time the loads would become unequal to such an extent that a readjustment of the field rheostats was necessary to bring them into balance again. The same machine always assumed the greater load. After considerable experimenting and adjusting that gave no permanent relief, it was noticed that the commutator of one machine was much warmer than that of the other. There was a good reason for this condition, because one commutator was in line with a cooling draft from a door while the other was in more or less of an air pocket. As it was the machine with the warmer commutator that drew the heavier load, it seemed reasonable to believe that load equalization would be improved by cooling the warmer commutator and heating the cooler one. The soundness of the theory was proved, in a measure, by shifting the brushes of the cooler machine to a position where there was enough sparking to heat the commutator slowly for as the commutator warmed the gradual shifting of the load to that machine could be noticed. The equalization was further improved, temporarily, by shifting the brushes back to their neutral positions. It was further determined that by directing upon the cooler commutator a draft of hot air, the amount of which could be regulated, almost any desired proportionality of equalization could be effected.

This original and effective method of equalizing is not to be considered as a permanent one, but the experiment demonstrated that the failure to equalize was due to the heating of the carbon brushes and of their contacts. The heating was slight at first but the increased current and increased heating were cumulative in effect so that continuous operation caused an appreciable difference in the generator loads. As a permanent relief that proved to be entirely satisfactory, copper line-resistances were installed in series with both machines. Copper was used in order that its positive resistance coefficient might neutralize the negative resistance coefficient of the carbon parts of the circuit.

(77) WRONG TAP SPACING ON CONVERTER

The voltage ratio between the continuous-current end and the alternating-current end of a plain shunt-wound synchronous converter is practically fixed, excepting insofar as the voltage of the continuous-current end may be slightly changed (without changing the voltage of the alternating-current end), by shifting the brushes. The extent to which the brushes may be shifted without producing bad results is limited by the machine's commutation characteristics. The changing of the field excitation has no appreciable effect on the voltage ratio, because such a change affects the power-factor and the resulting reaction of the displaced current on the magnetism of the pole-pieces tends to restore the magnetic conditions that existed before the field change was made. Indeed, unadvised changes in field current are to be avoided. Where such a converter supplies a constant load, the proper method of securing correct voltage at the commutator end is to supply the necessary voltage to the collector end. If the secondary voltage of the supply transformers is too high and the transformers have no taps, the same results may be obtained by connecting reactances between the secondary of the transformers and the collector rings.

A three-phase 240-volt converter was the subject of a complaint on account of sparking. Investigation disclosed that the alternating voltage was too high and that, due to an attempt to lower the continuous voltage by shifting the brushes on the commutator, the brushes had been moved to a position where they sparked. As a movement of the brushes back to the non-sparking point raised the continuous voltage still higher, the operator was compelled to use reactances, for the transformers had no lower taps. The reactances permitted non-sparking operation at approximately the desired continuous voltage, but the converter heated excessively. Furthermore, it was noticed that the heating was practically the same at light loads as at heavier ones. Considerable time was spent in trying to locate the trouble by testing, but this was unproductive. Finally, it was learned that the armature had been repaired at an earlier date. In checking the repair work, it was discovered that when the taps from the rings to the continuous-current winding were replaced, the taps had been spaced incorrectly. Most of the trouble had been due to the cross currents incident to the wrong tap spacing and to the fact that the wrong spacing gave more impedance drop between one phase than between the others.

In this instance, the trouble seekers were called to remedy a minor trouble and they located a major one after considerable delay. If they had known that the armature had been to a repair shop, much time would have been saved.

(93) INSTANCES OF HOT BEARINGS

The test of years in practice has proved that the oil ring method of lubricating bearings is entirely satisfactory. Although it is seemingly obvious that the following precautions should be taken, past experience has shown that it is necessary to call attention to the facts that (1) there must be oil in the oil-well, (2) the oil rings must be installed, and (3) the oil rings must turn.

Complaint was made that the lining in one bearing of a motor armature had melted twice, notwithstanding the fact that the oil had been renewed just as often as had that of the other bearing which had given no trouble. The motor, being started and stopped by means of an automatic panel and being almost inaccessible, was not given daily attention. It would operate for about five days and then the bearing heating would produce a binding effect which would cause the motor circuit-breaker to open. The opening of the breaker was all that prevented the babbitt metal from running out and letting the armature down onto the pole pieces. An inspector, who was sent to locate the trouble, noticed that the floor was much more oily under the trouble giving end of the motor that at the other end. This suggested that the oil flooding could not have been due altogether to careless oiling, for then the flooding at both ends would have been about the same. Inspection of the oil-well showed that there was but little oil in it although the other bearing was nearly normal; both bearings had recently been washed out and refilled. On refilling the oil well and carefully wiping the outside of the box, a crack was discovered through which the oil slowly oozed out. This was stopped by drilling and tapping a hole in the affected area and then screwing in a plug.

In another instance the cause of bearing heating was that the oil ring did not turn, because it had been distorted into an elliptical shape by a crowding which it had received at a time the armature had been reinstalled after having been removed for repair. When an armature shaft is shoved into a bearing, the oil ring should be held up with a screw driver or any other article of suitable shape. Assemblers accomplish the same result by turning an end shield upside down, for then the ring drops out of the way. Some operators lift the rings and rest them on the boss alongside the ring slot; this is not to be recommended as a general practice for the rings may be forgotten and remain raised out of the oil. Indeed, this was found to be the cause of trouble in several instances of bearing heating. In these cases, however, the bearing was so inaccessible that only an experienced hand could locate the ring by feeling for it. Another very similar instance took place when a motor had to be disassembled on account of having been through a flood; in reassembling, the rings were left out entirely.

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.

CURRENT TRANSFORMER: REPLACEMENT

(175) When it is necessary to replace a watthour meter current transformer by one of higher capacity (because of an increased current in the line) must the meter be replaced also?

If the rated secondary current of the new transformer is the same as that of the old, the meter may be retained in service. (Practically all standard current transformers now made in this country have a 5-ampere secondary current rating.) While certainty against meter burnout will be secured if the equal-current rating condition is fulfilled, the new transformer should of course be of the same general quality and ability to carry the secondary connected load as the one it replaces to insure accuracy of indications.

After the change of transformers has been made, the meter readings may be multiplied by the ratio of the primary current rating of the new transformer to that of the old. For example, a 150-amp. transformer replaced a 50-amp. transformer: the ratio which is to be used as a multiplying factor will be $\frac{150}{50}=3$. However, a better way is to change the meter register for one having a different gear ratio so that the dial will be direct reading.

E.C.S.

SYNCHRONOUS CONVERTER: STARTING

(176) What happens in the armature of a synchronous converter when the field flux is reversed during the operation of slipping a pole to correct for reversed polarity on the direct-current side at starting?

When a synchronous converter, or a synchronous motor, is running at synchronism without field excitation, the wattless component of current magnetizes the poles thus producing a flux which, with the energy component of current, gives torque. If the field is excited in the same direction as this armature reaction, the available torque is increased. On the other hand, if the field is reversed, the flux is decreased or even reversed so that the torque of the armature is reduced or reversed. In the case of a synchronous converter with the field connected to the armature in the reverse relation, the torque will be reduced to a value which corresponds to less than the ordinary residual magnetism of the field. This is usually not sufficient to keep the armature rotating in synchronism and therefore it will begin to slip. If the field is kept connected in the reverse direction, the armature will continue slipping. Each time the armature slips a pole the direction of current in the field reverses, so that the field still remains opposed to the armature reaction. Thus it is not possible to build up the flux in the same direction by field excitation as will be built up by armature reaction. This connection of the field corresponds to that of a direct-current generator in which the field current is in the direction that will reduce the residual flux in the fields thereby preventing the generator from building up.

J.L.B.

INSTRUMENT TRANSFORMERS: PHASING CONNECTIONS

(177) In a three-phase line there are two current transformers (one in line *1* and the other in line *3*) and two potential transformers (one between lines *1* and *2*, and the other between lines *2* and *3*). How can the proper secondary leads be identified for connecting up a polyphase wattmeter or watthour meter?

The information that will first be necessary for properly connecting up the meter is the instantaneous polarity of the secondary leads relative to each other. Manufacturers have for some time marked the polarity of their instrument transformers with white paint (some of the earlier units were marked with red paint). The relative instantaneous direction of current will be IN at the marked primary terminal and OUT at the marked secondary terminal.

The direction of relative instantaneous current flow in transformers of General Electric manufacture that were in production prior to the adoption of marking may be determined by the following rule. The instantaneous current flow through the primary and secondary transformer terminals is in the same direction; i.e., the current entering the transformer at a given terminal will figuratively leave it at the "diagonally opposite" terminal. For transformers of other than General Electric make, application should be made to the manufacturer for advice regarding polarity.

The information concerning polarity having been determined, it only remains, first, to connect the leads of the line *1* current transformer and the lines *1* and *2* potential transformer to one element of the meter; and, second, to connect the leads of the line *3* current transformer and the lines *2* and *3* potential transformer to the other element of the meter in the polarity relation exactly corresponding to the first set, in both cases following the connection sketches to obtain the proper direction of current flow through the apparatus.

H.S.E.

SWITCH: PRODUCTION AND ELIMINATION OF SURGES

(178) When energizing a dead high-tension transmission circuit, which is the preferable procedure to follow: (a) Switch the line onto live transformers by means of the high-tension switch; (b) Switch the line onto dead transformers by the high-tension switch and then energize the combination of line and transformers by closing the low-tension switch to the generating source?

Best operating practice strictly recommends that Method (*b*) be employed. This sequence of throwing switches will obviate the production of high-tension surges and consequently will minimize the danger of insulation breakdown.

An idea of the phenomena taking place in both methods of switching can be conceived better from the physical viewpoint than from the mathematical.

(*a*) Consider the live transformer that is about to be switched onto the dead line by high-tension switches:

The energy necessary to excite the line will ultimately, of course, come from the generating system. This transfer, however, will require some time because the energy must first pass through the transformer, being transferred from the low-tension to the high-tension side by means of re-adjustments in the magnetic flux. These readjustments are not instantaneous but, on the contrary, are sluggish.

At the first instant in which the high-tension switch is closed the energy that flows into the line will not come from the generating source, but will come solely from the high-tension winding of the transformer. In other words, the high-tension winding of the transformer (which has a certain capacity, C, a certain voltage, e, and therefore a certain amount of stored energy equal to $\frac{Ce^2}{2}$) will at this first instant discharge into the line. The discharge will be in the form of a wave of very steep front, which will, so to speak, drain the high-tension winding. At this stage the magnetic readjustments that were referred to will take place and the energy coming from the generating system will restore normal conditions in the high-tension winding and in the line.

It is at the first instant when the high-tension winding discharges into the line that the danger to the transformer arises, for at that time the energy which flows into the line must rapidly pass through the inductance and the capacity of the high-tension winding. The danger, therefore, is due to high frequency and not to high current. It is evident that the greater the line capacity the greater will be the disturbance. It is also evident that any arcing in the switch will increase the danger, for the surge phenomenon will be repeated each time the arc is re-established, under which conditions there is a greater likelihood of accumulative oscillations being produced.

(*b*) Consider now the dead transformer connected to the dead line, and both about to be switched onto the generating source by the low-tension switch:

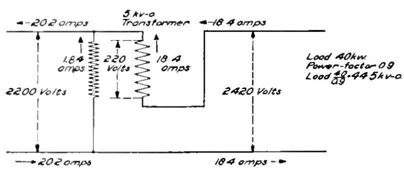
At the first instant the low-tension switch is closed the energy entering the transformer comes from the generating system. This energy is transferred to the high-tension side through the iron of the transformer which interposes such a delay that when the energy ultimately enters the high-tension line it will be in the form of a wave of smooth or slanting front, not with a steep front as in the preceding case (*a*). The high-frequency surges, with their attendant dangers, are therefore absent when this method is applied.

G.F.

TRANSFORMER: BOOSTING OR BUCKING

(179) When boosting the voltage of a feeder by means of an ordinary single-phase transformer, as described in Question and Answer No. 155 in the December, 1915, REVIEW, would not better regulation of service voltage be obtained by increasing the voltage of the generating source above that desired and then lowering the delivered feeder voltage the required amount by the single-phase transformer connected with bucking polarity?

In theory, the scheme outlined above would result in a somewhat better regulation than that outlined in Question and Answer No. 155 and under ideal conditions would furnish a constant service voltage.



(179) Fig. 1

In practice, however, the degree of improvement would be trifling. For example, the regulation of a transformer such as that named in Q. & A. No. 155, a 5-kv-a., 10 to 1 ratio, 60-cycle machine, is about 1.7 per cent. This percentage applies, of course, to the voltage delivered by the transformer, 220 volts. Thus, the effect on the line voltage would be only 0.17 per cent which is entirely too negligible in either the boosting or bucking connection to be of any consequence, or to give the bucking connection a preference over the boosting.

The ideal conditions referred to in the first paragraph are those in which the decreasing amount of buck exerted by the single-phase transformer would be equal to the increased amount of line drop to the transformer, throughout the range from no load to full load. The fulfillment of such conditions in practice is too utopian for consideration. Consideration must also be given to the fact that the feeder circuit in question is likely to be only one of several emanating from the same bus, and that among these others are probably some simple circuits without boosting or bucking transformers. Therefore, the presence of these other feeders would prevent the changing of the generated voltage to suit the feeder circuit under consideration, and would require that the transformer be selected and connected in accordance with the existing bus voltage and the service voltage desired.

E.C.S.

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INDUSTRIAL MULTIPLE RECORDER

(See page 866)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

The short article that we publish this month describing the annual outing of the Quarter Century Club will be of more than passing interest to a great number of our readers, and especially so to those who have been intimately associated with the electrical industry for a number of years.

There is in all probability no body of men that could be better taken as representing the Veterans of that great industrial army which has built up the electrical industry than the members of the Quarter Century Club. Each of its 868 members has served a single firm, whose entire energies have been devoted to the development of the electrical industry, for a period of at least 25 years. This is surely rather an astonishing fact when we remember how apt we are to regard our great industry as only an infant.

It is interesting to note that the total membership of the club represents a period of service equal to 25,000 years, or if we reckon 2400 hours as constituting the average working year, the total hours of service that these veterans alone have given to the electrical world amounts to the astonishing figure of 60,000,000 working hours.

These figures are impressive but they would sink into insignificance if we could compare them with the wealth that these same workers have added directly and indirectly to the country, the comfort that they have added to our daily life and the opportunities they have opened to future generations.

If each of these Veterans could write his reminiscences and they were to be bound in the one volume, they would make one of the most fascinating histories of human effort and human progress that could be produced.

The sum total of human energy represented by the working lives of these men is enormous but of what avail would all this expenditure of energy have been if not so ably directed? An analysis of the results accomplished would bring out in a striking manner the prime factors which led to such phenominal progress as Able Leadership, Staunch Loyalty and Devotion to Duty.

These pioneers of the industry had to exercise considerably more faith in their work than the present generation. We today are working along fairly well defined lines while 25 years ago everything was new and there was no vast accumulation of experience to guide the pioneers in the design of apparatus and in its operation. Things that are well-known to the student today had to be laborously worked out and proved, often at the cost of much experimentation and long labor. The machine tools, instruments, materials and the accumulation of engineering and scientific knowledge that we have at our disposal today make it almost impossible for us to realize the environment of those who were working 25 years ago and make it very hard to fully appreciate the triumph of their accomplishments.

We hope to see the number of members of the Quarter Century Club increase each year, but by the very nature of things their total will always be small when compared with the enormous total of the whole organization; but we feel very strongly that it is in their ranks that we shall always find some of the ablest and soundest men in the industry whose rich store of practical experience will continue to be one of the most valuable assets at our disposal in helping and guiding the army of younger men who are joining our ranks each year.

THEORIES OF MAGNETISM

Part IV

By Saul Dushman

Research Laboratory, General Electric Company

In the present issue the writer discusses Weiss' theory of ferromagnetism and also the relation between chemical composition and magnetic susceptibility.—Editor.

Weiss's Theory of Ferromagnetism

Langevin's theory of paramagnetism described in the previous section has been extended further by P. Weiss to include the case of ferromagnetic substances.

It has already been shown that for paramagnetic substances the relation between the actual intensity of magnetization per unit volume at any temperature and the maximum intensity attainable is given by an equation of the form:

$$I/I_m = \coth a - 1/a \qquad (35a)$$

where $a = \mathbf{M}H/kT$

Weiss now introduces the assumption that in addition to the external field there exists a so-called "intrinsic molecular field" due to the action of the molecules upon each other and that this molecular field (H_i) is in the same direction as the external field and proportional to the actual intensity of magnetization, that is,

$$H_i = KI \qquad (39)$$

The theory that the elementary magnets must exert forces on each other altogether apart from the external field, is not a new one in the history of magnetism. We have already mentioned in Part II that somewhat similar ideas were advanced by Ewing to explain the form of the H-B curve for ferromagnetic substances and the phenomenon of hysteresis. Weiss, however, approaches the problem from a different point of view. At higher temperatures all ferromagnetic substances become paramagnetic and obey Curie's law. Hence any theory of ferromagnetism must involve paramagnetism as a special case and since Langevin has already elaborated a fairly successful theory for the latter, Weiss introduces one more assumption and extends the same arguments to deduce equations which shall apply to the ferromagnetic state.

The relation between the theories of Langevin and Weiss is somewhat similar to that existing between the simple gas laws and the equation of van der Waals. For gases at low temperatures and pressures we have the simple equation

$$PV = RT$$

For gases near the critical condition, that is at relatively higher temperatures and pressures, this equation is found to be no longer adequate. By introducing the assumption that under these conditions the molecules exert attractive forces upon each other, van der Waals was led to derive the more complex equation

$$(P + a/V^2)\,(V - b) = RT$$

which agrees with the observed data very well. In this equation the term a/V^2 expresses the fact that the gas is more compressible than would follow from the more simple equation: in other words, there exists an *inner pressure*, a/V^2, which is added to the external pressure, P. Similarly, according to Weiss, there exists in all ferromagnetic substances, up to the critical temperature, a *spontaneous magnetization*. Under ordinary conditions this field is confined to the immediate neighborhood of each molecule and the resultant effect is nil; as soon, however, as an external field is applied, the

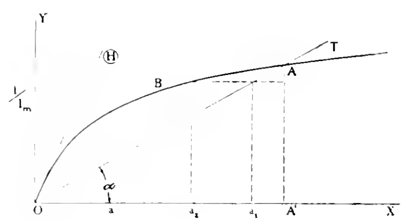


Fig. 15

intermolecular field due to this spontaneous magnetization is allowed to act as well and the result is an increased intensity of magnetization.

Let us now consider with Weiss the effect of this molecular field on the resultant intensity of magnetization. From equation (35a) it follows that

$$I/I_m = \coth a^1 - 1/a^1 \qquad (40)$$

$$\text{where } a^1 = MH_i/kT = MKI/kT \qquad (41)$$

The solution of this equation can be obtained graphically thus: In Fig. 15 let OBA represent the curve giving I/I_m as a function of a. Equation (41) will be represented, at constant temperature, by a straight line such as OAT, whose slope is given by $\tan \alpha = kT/MKI_m$. Evidently the point A, which is the intersection of this straight line with the curve gives the required solution of equation (40), and at the absolute temperature T the ordinate AA^1 represents the saturation value of the intensity of magnetization. It will be observed that in the above considerations the external field has been considered negligible in intensity as compared with the intrinsic or molecular field.

As the temperature is increased, the slope of the line OAT becomes greater and greater until finally it coincides with the tangent to the curve at the origin, that is, the line OH. This evidently occurs at the critical temperature, Θ, at which the spontaneous magnetization decreases rapidly and the substance becomes paramagnetic.

From the observed values for the Currie constant above the critical temperature it is possible as Weiss has shown, to deduce the value of the constant K. At a temperature T just above the critical temperature Θ, we can consider the magnetization as due to both an external field (H) and the intrinsic molecular field. Consequently

$$a = \frac{\mathbf{M}\,(H+KI)}{kT} \qquad (42)$$

Since the magnetization is not very intense, we can also apply the relation

$$\frac{I}{I_m} = \frac{a}{3} = \frac{\mathbf{M}\,(H+KI)}{3kT} \qquad (43)$$

At $T=\Theta$, the internal field first reaches a value which is large in comparison with that of H, hence

$$\frac{I}{I_m} = \frac{\mathbf{M}KI}{3k\Theta} \qquad (44)$$

$$\text{and } K = 3\,k\Theta/\mathbf{M}I_m \qquad (45)$$

Substituting this in equation (43) we derive the relation

$$\frac{I}{H}\,(T-\Theta) = \frac{\mathbf{M}I_m}{3k} = \frac{\mathbf{M}J_m\rho}{3k} \qquad (46a)$$

where ρ = density,

and J_m = Maximum specific intensity of magnetization.

Therefore

$$\frac{J}{H}\,(T-\Theta) = \frac{\mathbf{M}J_m}{3k} = \frac{\mathbf{M}^2 n_o}{3k} \qquad (46b)$$

where n_o = number of elementary magnets per *unit mass*.

Equation (46b) can evidently be written in the form

$$\chi\,(T-\Theta) = C = \frac{\mathbf{M}I_m}{3k\rho} \qquad (46c)$$

where C denotes Currie's constant per unit mass. (See equation (37) Part III.)

[Attention must be drawn in this connection, to the significance of I_m and J_m in the above equations. In Part *I* are given values of "I_m and "J_m" for a number of ferromagnetic substances at ordinary temperatures. These are not, however, the real maximum values of the intesnity of magnetization; they represent only the saturation magnetization at any given temperature. With decrease in temperature this saturation magnetization increases steadily, which is what we would be led to expect from the theories of Langevin and Weiss. It follows that real saturation can be attained only at the absolute zero, where the rotational energy of the elementary magnets has decreased to zero and consequently it is only at this temperature that we can really speak of maximum values of I and J and denote these values by I_m and J_m. For the saturation intensity at any other temperature we shall therefore in the following sections use the symbols I_s and J_s respectively.

In the same manner when using the relations

$$\left.\begin{array}{l} I_m = \mathbf{M}n \\ J_m = \mathbf{M}n_o \end{array}\right\} \qquad (48)$$

in the case of paramagnetic substance, we think of $\mathbf{M}$, n and n_o as constants for the particular metal (and therefore independent of the temperature).]

As has already been mentioned in a previous section (see Part II, equation (15) and Table IX), equation (46c) has been applied by Weiss and Foex to a number of ferromagnetic substances above the Currie point. It is to be noted that the values of Θ given in Table IX are in degrees Centigrade whereas in the above equations Θ is reckoned in degrees absolute.

Eliminating MI_m from equations (45) and and (46c) it follows that

$$K = \frac{\Theta}{C\rho} \qquad (47)$$

It is therefore possible to calculate the magnitude of the intrinsic molecular field for any intensity of magnetization from values of Θ, C, and ρ. From the data given in Table IX and the values of I_s given in Table V we have in this manner derived the values of K, H_i and $(1/2)\,KI^2$ given in Table XIV.[1] It will be observed that the values of H_i thus calculated are extremely large. Thus in the case of magnetite, it is about 17,400,000 gauss, a field strength which is certainly very high as compared with the field strengths attainable in practice. (See note page 357, Part I.)

Specific Heat and Molecular Field of Ferromagnetic Substances

The strongest confirmation of Weiss's assumption regarding the existance of an intermolecular field is furnished by the specific heat data of ferromagnetic substances. It is evident that "If the molecular magnets act upon one another with magnetic forces of this amount, the potential energy due to the molecular magnetic field must have large values." Now the intensity of magnetization decreases continuously as the temperature is increased. It therefore follows that it is necessary to add energy to demagnetize, and the amount of this energy required for complete demagnetization of unit volume is evidently equal to ½ H_iI that is, $(1/2)\,KI^2$. This energy must be added to that ordinarily required to raise the temperature, and therefore, the specific heat ought to be much greater for the magnetized metal.

The quantity $(1/2)\,KI^2$ is given in the last column of the above table. Converting from the absolute (or c. g. s.) units in which it is expressed to calories, we have to divide by the mechanical equivalent of the mean calorie, that is, 4.184×10^7. Thus the *energy of demagnetization per unit mass in calories is*

$$q_m = \frac{KI^2}{2 \times 4.184 \times 10^7 \times \rho} \qquad (49)$$

Taking the case of iron, we find in this manner, $q_m = 17.05$ calories.

The mean specific heat due to change in intensity of magnetization from the temperature at which the value is I to that at which there is complete demagnetization, Θ, is evidently,

$$S_m = \frac{1}{2\,\rho}\,\frac{d\,(KI^2)}{d\,t} \times \frac{1}{4.184 \times 10^7}\ \text{cal.} \qquad (50)$$

which must be added to the ordinary specific heat. The results given in Table XV, taken from the paper by E. H. Williams, were obtained from Currie's experimental data.

[1] The value of I_s for magnetite is that given by Weiss in (Ann. de Physique, 1, 140 (1914). This is more recent than the value given in Table V, Part I, p. 357.)

TABLE XIV

Material	ρ	I	Θ	C	K	$H_i \times 10^{-6}$	$(1/2)\,KI_s^2 \times 10^{-9}$ ergs
Fe	7.86	1850	1017	0.0395	3275	6.060	5.607
Co	8.7	1370	1404	0.0217	7435	10.190	6.977
Ni	8.93	580	637	0.0066	11420	6.622	1.921
Magnetite	5.2	472	854	0.0045	36910	17.400	4.110

TABLE XV

Deg. Centig.	I/ρ	q_m (cal)	$S_m = \frac{\Delta q_m}{\Delta t}$	In the Interval
20	216.3	16.8		
275	207.5	15.5	0.005	20 deg. to 275 deg.
477	189.6	12.9	0.013	275 deg. to 477 deg.
601	164.0	9.7	0.027	477 deg. to 601 deg.
688	127.	5.8	0.045	601 deg. to 688 deg.
720	100.7	3.6	0.068	688 deg. to 720 deg.
740	64.	1.5	0.108	720 deg. to 740 deg.
744.6	50.1	0.9	0.136	740 deg. to 744.6 deg.
753	0.			

The ratio S_m really corresponds to the average slope in each interval of the tangent to the curve giving the intensity of magnetization as a function of the temperature. From the data given in the above table we see that at ordinary temperatures the effect on the ordinary specific heat is negligible, but as the temperature increases, the value of the term due to the molecular field increases until in the neighborhood of Θ it amounts to 0.136 or about two fifths of the total value. The results are represented graphically in Fig. 16, the upper curve A representing the relation between total specific heat and temperature, while the lower curve expresses the relation between S_m and temperature.

The discontinuity thus observed in the specific heat curve therefore furnishes not only a method of determining the Currie or critical point, but also, in consequence of the application of Weiss's theory a method of determining the Currie constant for the paramagnetic substance. Table XVI gives values of Θ and C as determined by both magnetic and calorimetric methods by Weiss and Foex.[2]

The agreement between the two sets of values is to be regarded as an excellent confirmation of Weiss's assumption of the existence of an intrinsic molecular field. What is the nature of the forces between the elementary magnets? Weiss argues that they are neither magnetic nor electrostatic in

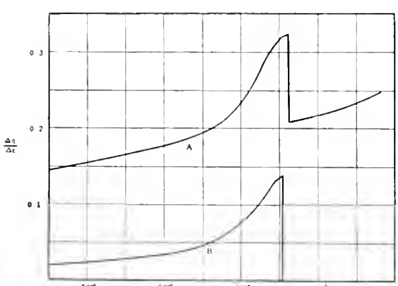


Fig. 16

origin, and from experiments with alloys of iron, nickel and cobalt, he concludes that the force between two molecules must vary conversely as the sixth power of the distance between their centers.[3]

"We are therefore led," he writes, "after considering all phases of the problem, to attribute the phenomenon of the molecular field to the action of forces whose nature is still unknown."

Corresponding States

An interesting deduction can be derived from equation (43) for temperatures *below* the critical point. At these temperatures the external field is negligible in comparison with H_i and therefore

$$T = \frac{3}{a}\frac{I_s}{I_m} \qquad (51)$$

where I_s denotes the saturation intensity at the absolute temperature T, while I_m denotes, as above, the saturation intensity at $T = O$.

For $T = O$, $a = \infty$, and $T/\Theta = 0$, while for $T = \Theta$; $I_s/I_m = 0$. For constant values of T/Θ the values of I_s/I_m will be the same for all ferromagnetic substances. We may therefore regard those temperatures at which T/Θ is the same as corresponding states and the curve giving I_s/I_m as function of T/Θ ought to be the same for all ferromagnetic materials.[4]

This conclusion is found to be in accord with the observations for magnetite, pyrrhotite and Fe_2Ni. On the other hand there is only rough agreement in the case of iron, nickel and cobalt.

In order to account for this discrepancy in Weiss's theory, Keesom has recently suggested a theory which is based on considerations derived from the quantum theory.[5] The argument, is similar to that used by Oosterhuis[6] in explanation of the deviations from Currie's law at extremely low temperatures. Keesom assumes that the energy of rotation of the elementary magnets is not kT (as assumed by Langevin and Weiss) but a more complex function of the frequency (ν) and the quantum constant (h), which approaches kT only at higher temperatures and instead of becoming zero at $T = O$, tends asymptotically towards a constant value as the temperature approaches the absolute zero. That is, he assumes that the elementary magnets possess a certain residual rotational energy even at the absolute zero. This theory leads to calculated values of the intensity of magnetization which are in very good accord with the observed data in the case of nickel. (the only one considered by Keesom). Another interesting conclusion deduced by Keesom is that the elementary magnetic moment instead

(2) Jour. de Phys. 7, 249 (1908).
(3) Ann. de Phys. *1*, 134–62 (1914).
(4) P. Weiss, Phys. Zeitschrift, *12*, 935 (1911).
(5) "On the magnetization of ferromagnetic substances considered in connection with the assumption of a zero point energy." Proc. Amsterdam Academy of Science, *16*, 454 (1913).
(6) Part III of this paper, GEN. ELEC. REVIEW, Sept. 1916.

of being constant (as assumed by Weiss) varies with the temperature, increasing only slowly at ordinary temperatures, but more and more rapidly as the temperature is raised.

This question of the magnitude of the elementary magnetic moment is an exceedingly interesting topic in itself. The attempts to solve the problem have led to at least two interesting theories of the nature of the elementary magnets or *magnetons;* but these speculations can be discussed much better after we have considered the relations between magnetic susceptibility and chemical composition.

RELATION BETWEEN CHEMICAL COMPOSITION AND MAGNETIC SUSCEPTIBILITY

Effect of Chemical Composition on Magnetic Properties of Iron and Steel.

Even a superficial glance over the literature on magnetism shows that an immense number of investigations during the past twenty years deal with the above subject exclusively. Its importance from an engineering standpoint is self-evident, and any investigation which may lead to even the slightest reduction in the weight of iron per kilowatt rating of transformers is a distinct advance in the art when one considers the total amount of iron used in electrical engineering practice. The scope of the present paper will permit us to deal with this subject only briefly. Furthermore this topic has already been dealt with in a comprehensive manner by W. E. Ruder.(7)

Pure Iron

In 1910 Burgess and Aston prepared electrolytic iron containing less than 0.1 per cent of impurities. They tested its magnetic properties under various conditions of heat-treatment and concluded that "while refining commercial steels results in improvement of the magnetic qualities, the amounts of impurities met with in commercial practice do not result in a serious deterioration of the quality."(8)

The problem was again taken up by T. D. Yensen(9). By melting electrolytically refined iron in a vacuum he succeeded in obtaining a metal which showed remarkable magnetic properties, "decidedly superior to those of any grade of iron thus far produced, the maximum permeability obtained being 19,000 at a flux density of 9500 gauss. The average hysteresis loss obtained is less than 50 per cent of that found in the best grades of transformer iron.....While the electrical resistance of the iron thus obtained is very low, this defect may be remedied by the addition of such alloying elements as silicon or aluminum, elements that are known to

(7) Gen. Elec. Review, *18*, 197 (March, 1915)
See also Encyl. Brit. 11th Edition, Vol. XVII, pp 345-346, for a general article on the magnetic properties of the alloys and compounds of iron.
(8) Met. and Chem. Eng. *8*, 191 (1910).
(9) Bulletin *72* Univ. Ill. Exp. Station (1914). Proc. A.I.E.E. Oct. 1915, p 2455.

TABLE XVI

Substance	C		θ	
	Magnetic	Calorimetric	Magnetic	Calorimetric
Iron	0.136	0.112	1026	1031
Nickel	0.025	0.027	649	649
Magnetite	0.048	0.050	861	853

TABLE XVII

SATURATION INTENSITY OF MAGNETIZATION (I_s) OF PURE IRON AT ORDINARY TEMPERATURES

Authority	Material	I_s
Du Bois (1)	"Pure"	1850 ($H > 10{,}000$)
Gumlich (2)	Electrolytic	1725 ($H = 6{,}000$)
Hadfield & Hopkinson (3)	99.88 per cent pure	1680 ($H > 8{,}000$)
Williams (4)	Electrolytic melted in vacuo	1798
Gumlich (5)	"Pure"	1719

(1) Rapports du Congress, 1900 p 465
(2) Electrotechn Zeits *30*, 1065 (1909).
(3) Journ. Inst. Elect. Eng. (London) *46*, 235 1911).
(4) Phys. Rev. *6*, 404 (1915). Table IV, Part I, Gen. Elec. Review, p. 357.
(5) Trans. Far. Soc. *8*, 98 (1912).

increase the electrical resistance very materially without affecting the magnetic quality to any large extent."

The value of I_s for "pure" iron has been determined by different investigators and the data are given in Table XVII.

Steel and Alloys of Iron

Hadfield and Hopkinson[10] have investigated the saturation values of I for a large number of alloys. Their results are summarized as follows:

(1) There is no alloy having a higher value of I_s than that of pure iron.

(2) On the whole the alloys behave as if consisting of a mixture of magnetic and non-magnetic substances, so that *the specific intensity of magnetization is an additive property of the composition.*

(3) The value of I_s for pure iron of density 7.80 is 1680.

(4) "The *effect of carbon is to reduce* the value of I_s by a *percentage equal to six times that of the carbon present.*

(5) "Additions of silicon or aluminum reduce the specific magnetism as if they were inert materials. Silicon seems to neutralize the effect of carbon to some extent."

More recently E. Gumlich[11] has also investigated the effect of addition of carbon on the other magnetic properties of iron, such as coercive force, permeability and hysteresis loss. The maximum permeability for 0.11 per cent carbon is about 3200 at $H = 6000$ and decreases with increases in percentage of carbon.

Next to carbon, *silicon* is the most important addition element in steel and iron. The ferro-silicon alloys were first investigated by Barrett, Brown and Hadfield in 1901–2.[12] who found that alloys containing 2.5 and 5.5 per cent silicon have a higher maximum permeability and lower hysteresis loss than pure iron, combined with a higher electrical resistance. "The heat treatment of these alloys is, however, of importance comparable with that of the silicon content and the practice seems to be annealing at high temperatures".[13]

The value of (I_s) for pure iron is decreased by addition of silicon[14] thus:

Pure iron	1719
1 per cent *Si*	1663
4.5 per cent *Si*	1519

Very recently some remarkable results have been obtained by Yensen on iron-silicon alloys melted in vacuo. The maximum permeability of these alloys was found to be as high as 66,500., while both the coercive force and hysteresis loss are very low.[15] These results show, as Yensen points out, that "no foundation exists any longer for assuming that there is a direct connection between the saturation value of a certain alloy and its properties at low and medium, densities." Thus while silicon lowers the value of I_s for pure iron it increases the permeability and decreases the hysteresis loss. The effect of silicon seems to be primarily that of a purifying agent. It cleanses the metal of oxide and gases; produces larger grain structure and thus helps the permeability. On the other hand, since silicon itself is non-magnetic it diminishes the active cross-section[16] of the iron and therefore the value of I_s.

These conclusions are thus in agreement with the additive law suggested by Hadfield. Results obtained by J. D. Ball[17] with iron-silicon and iron-cobalt alloys, in the course of an investigation on the validity of Kennelly's and Steinmetz's laws, furnish further corroboration of Hadfield's suggestion that each constituent of a heterogeneous material contributes its own magnetic properties. S. W. J. Smith arrives at the same conclusion. "Thermomagnetic measurements make it increasingly evident that the magnetic properties of steels are frequently those of mixtures of magnetic substances, each possessing characteristic properties which contribute in a comparatively definite way to the properties of the material as a whole."[18]

The alloys of iron with *arsenic, tin, antimony*[19] and *copper*[20] have been investigated by Burgess and Aston. A summary of the results will be found in the paper by Ruder.

The magnetic properties of *cobalt*-iron alloys are exceptionally interesting. Attention has already been drawn to the fact discovered by Weiss that the alloy Fe_2Co has a saturation value 10 per cent higher than that of pure iron, thus furnishing the only exception known to Hadfield's conclusion that no alloy of iron

(10) Journ. Inst. Elect. Eng. (London) *46*, 235 (1911).
Also T. D. Yensen, Bull. 72 p. 9.
(11) Trans. Far. Soc. *8*, 98 (1912).
(12) Journ. Inst. Elect. Eng. *31*, 674 (1901–2).
Also T. D. Yensen, Bull. *88*, Univ. Ill. Exp. Station (1915).
(13) Burgess and Aston, Met. & Chem. Eng. *8*, 131 (1910).
(14) Gumlich and Goerens, Trans. Far. Soc. *8*, 111 (1912); also Ruder, loc. cit. Fig. 4.
(15) See Table III, Part I of this paper GEN. ELEC. REVIEW, May 1916.
(16) W. E. Ruder, loc. cit.
(17) Journ. Franklin Inst. April 1916.
GEN. ELEC. REVIEW, May 1916.
(18) Poc. Phys. Soc. *25*, 77–81 (1913).
(19) Trans. Am. Electrochem.
Soc. *15*, 369 (1909).
Met. & Chem. Eng. *7*, (1909)
(20) Met. & Chem. Eng. 79 (1910).

has a higher value of I_s than pure iron. The whole series of iron-cobalt alloys has been investigated by Weiss and Preuss(21) at extremely low temperatures. Their measurements show that the value of I_s for pure iron increases proportionately with the percentage

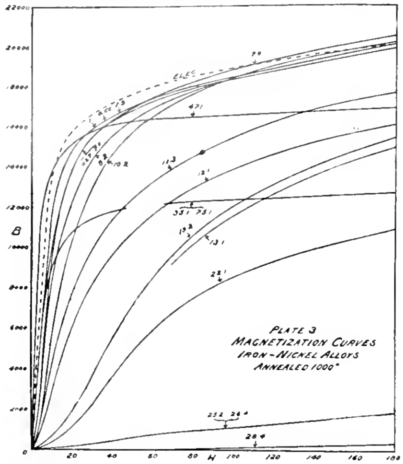


Fig. 17

of cobalt until the composition $Fe_2\,Co$ is reached, and then decreases linearly with decrease in iron content down to pure cobalt. These results indicate that $Fe_2\,Co$ must have a distinct molecular structure of its own which possesses a larger value of the elementary magnetic moment. The discussion of the question must however be postponed to a later section.

The magnetic properties of this alloy have also been investigated very recently by T. D. Yensen.(22) By melting the alloy in vacuo and forging he has obtained values of I_s as high as 2056.(23) The maximum permeability is about 13,000 for $B = 8000$, but in medium fields the permeability is 25 per cent higher than for pure iron or for commercial grades of iron. "The hystersis loss at $B = 10{,}000$ or less is considerably less than for the best grade of commercial transformer iron." At higher densities the hysteresis loss increases rapidly.

The iron-*nickel* alloys have also been investigated in a similar manner by Weiss and Hegg.(24) The value of I_s pure iron decreases linearly with addition of nickel until the alloy $Fe_2\,Ni$ is reached and then decreases at a much greater rate (but still linearly) down to pure nickel.

A most interesting property of these alloys is that a mixture of certain proportions of these two highly magnetic metals results in a practically *non-magnetic* alloy. Fig. 17 taken from a paper by Burgess and Aston(25) gives the H-B curves for different alloys. It will be noted that the alloy containing 28.4 per cent nickel is practically paramagnetic. Even for $H = 100$, B is not noticeably greater than 100 gauss. Unannealled, the alloy is even less magnetic. Similar results were shown by alloys containing 25.2; and 26.4 per cent nickel respectively.

These non-magnetic alloys also show the phenomenon of so-called thermo-magnetic hysteresis of which mention has already been made in Part II of this paper.(26) While non-magnetic at ordinary temperatures, they become strongly magnetic at low temperature and then retain this magnetism for a temperature rise of several hundred degrees.

Manganese steels have been investigated by Hilpert and Mathesius.(27) They observed that according to the heat-treatment used, some of the alloys (e.g. the 20 per cent Mn alloy) could be made magnetic or non-magnetic. Similarly the presence of carbon in a 10 per cent Mn-steel causes the alloy to become non-magnetic when quenched from 900 deg. Thermomagnetic hysteresis phenomena were observed in these alloys similar to those observed in the non-magnetic nickel-iron alloys. Hadfield and Hopkinson(28) have observed in a similar manner that an alloy containing 12 per cent manganese, and 1.25 per cent carbon is almost non-magnetic when quenched from 1000 deg. C. "but when reheated in the neighborhood of 520 deg. C. for about 600 hours, it will acquire a degree of magnetism about 60 per cent of that exhibited by pure iron."

The metals *chromium*, *molybdenum* and *tungsten*, "have the general property of increasing magnetic hardness, that is, they increase the remanence and more particulary the coercive force. These are the properties that are desirable for permanent magnets."(29) The value I_s as well as the maximum per-

(21) Trans. Far. Soc. *8*, 154 (1912).
(22) Proc. A.I.E.E. Oct. 1915, p 2455.
(23) See Part I, Table IV, May 1916.
(24) Trans. Far Soc. *8*, 152 (1912).
(25) Met. and Chem. Eng. *8*, 23 (1910).
(26) GEN. ELEC. REVIEW. Aug. 1916, p. 669.
(27) Zeitsch. fur. Electrochem. *17*, 54 (1912).
(28) Met. & Chem. Eng. *12*, 65 (1914).
(29) Ruder, loc. cit. also Phil. Mag. 44, 738 (1914) and Met Chem. Eng. *8*, 763 (1910).

meability for these alloys is much lower than that of pure iron.

Among the other elements the effects of which on iron have been investigated we may mention *boron*,[30] aluminum,[31] and *titanium*,[32] as well as *sulphur*, *oxygen*, and *phosphorus*. The last three are all deleterious to the magnetic qualities of iron and their removal by other elements always improves the resulting metal. The beneficial effect of vacuum fusing pure iron have recently led Yensen to give the same treatment to pure open hearth iron, with extremely beneficial results.[33] Together with the results previously obtained with Swedish charcoal irons, these results show definitely that it is possible to obtain magnetic properties with commercial grades of iron by vacuum fusion that are comparable with those obtainable with electrolytic iron."

As stated by Ruder, " the effect of this treatment is evidently to remove practically the last traces of impurity notably sulphur and oxygen. The important point about this rule on extremely pure iron is that it shows that the good results obtained by additions of other elements are all secondary, i.e. their effect is one of removing material that is more injurious, magnetically, than the metal added. The additional effects are those of increased resistivity—always at the expense of magnetic quality however and an increase in the size of the grain."

Heusler Alloys

These alloys were discovered by Dr. Heusler in 1898. They are remarkable for the fact that although composed of the essentially non-magnetic metals, copper, manganese and aluminum, they are ferromagnetic. The main constituents appear to be manganese and copper, although an alloy of these two metals alone is not magnetic. But the addition of aluminum, tin, arsenic, antimony, bismuth or boron converts the copper-manganese alloy into a strongly ferromagnetic material. Of these additions aluminum exerts by far the strongest effect, and the proportions of the different elements which have been found to give the best results are approximately 62.5 per cent *Cu*, 23.5 of *Mn* and 14 of *Al*, i.e. *Mn* and *Al* in the proportion of their respective atomic weights.

It is quite natural that a phenomenon apparently so anomalous, should have attracted a large number of investigations and the consequent literature on the subject has, therefore, attained very respectable proportions.

Of the three constituents mentioned above, copper is diamagnetic ($\chi = -0.085 \times 10^{-6}$); aluminum is paramagnetic ($\chi = 0.60 \times 10^{-6}$) and manganese is weakly ferromagnetic or paramagnetic. There seems to be some uncertainty about this point. According to Ihde and Owen, the susceptibility of manganese is of the order of 10×10^{-6}, while Weiss claims to have obtained manganese in a ferromagnetic state. On the other hand the best value of the permeability for Heusler alloys is about 90–100 at a density of 2200 B,[34] which corresponds to a value of χ of about 1.5. The magnetizability of specimens which have been aged by several hours' warming at .110–130 deg. amounts to about two-thirds of that of cast iron.[35] We can therefore not account for the relatively high ferromagnetism of Heusler alloys by ascribing it to any constituent element. Heusler himself has expressed the opinion that manganese enters into *compounds* with all the metals in question (e.g. *Mn Al*), and that the strong magnetism is inherent in these compounds. The copper merely acts as a "solvent" and enables the ferromagnetic property to become apparent.[36] It may also be that the presence of the copper aids in the formation of compounds of the general formula $Al_x(Mn, Cu)_{3x}$ which are the carriers of strong ferromagnetism. Further investigation has shown that the magnetic properties depend in a very pronounced manner upon the thermal history of the specimen, the temperature from which it is quenched and the subsequent rate of cooling. As the latter factor would have a marked influence upon the resulting crystal structure, we are led to the conclusion that in some unknown manner the ferromagnetism of the Heusler alloys is associated with a *definite arrangement of the atoms in the solid state.* E. Take states this conclusion thus: "Various recent researches in the field of ferromagnetic alloys point to the view that ferromagnetism is not a property inherent in *single* molecules at all, but that a *special space-lattice structure is a necessary condition for its appearance.*"[37]

Take has also suggested another explanation based upon Langevin's theory of ferromagnetism:

"Langevin assumes that every molecule of a paramagnetic or a ferromagnetic body has a

(30) T. D. Yensen, Bull. 77, Univ. Ill. Exp. Station

(31) du Bois, Rapports du Congres, *2* p. 475 (1900)

(32) Ruder, loc. cit.

(33) Met. and Chem. Eng. *14*, 585, (May 1916).

(34) W. E. Ruder, loc. cit.

(35) E. Wedekind, Trans. Far Soc. 8, p 161–2.

(36) Trans. Far. Soc. 8, 172 (1912).

(37) Loc. cit p 177. The italics are the writer's.

magnetic moment which differs from zero and which results from the geometrical addition of all the separate magnetic moments produced by the totality of the electrons circulating within the molecular system. The appearance of strong ferromagnetism during ageing might then be conceived as follows: there are present, already before the ageing, in the single, still separated bricks of the elementary magnets, and particularly perhaps in the atoms of manganese, a certain number of rotating electrons; they move in such paths, however, that the magnetic moments of the single bricks of what will afterwards constitute the strongly magnetic elementary magnets only yeild an additive resulting moment which will be very small so far as the exterior is concerned. When the strongly magnetic elementary magnets are being built up, be that by ageing or by slow cooling, the separate orbits of the circulating magnetization-electrons are deformed or mutually displaced by a rearrangement, such that the resulting compound $Al_x\,(Mn,\,Cu)_{3x}$ shows a very large resultant total moment."

It is worth noting in this connection that the Heusler alloys show a definite critical temperature, like the other ferromagnetic substances, at 350 deg. C, and above this temperature they are paramagnetic and vary with temperature according to Curie's law. The microstructure of these alloys has naturally been very thoroughly studied by a large number of investigators.(38) As a result of their observations McTaggart and Robertson have suggested that the magnetic properties of Heusler alloys are to be ascribed to the occurences of manganese in a peculiar crystallized form when dissolved in copper and aluminum; while A. D. Ross, concludes that the magnetic properties are associated with the occurence of solid solutions of varying concentration of the intermetallic compounds $Cu_3\,Al$ and $Mn_3\,Al$.

A. A. Knowlton(39) classifies the different hypotheses into these groups:

"(1) The magnetic units are the molecules of a chemical compound of *Mn* and *Al*, or groups of such molecules.

"(2) The magnetic units consist of manganese molecules or of groups of such molecules.

"(3) The magnetic units are complex groups, which form the structural elements of a certain type of mixed crystal, and contain at least two different kinds of chemical molecules."

The first hypothesis seems to receive a great deal of support from the discovery made by both Heusler and Wedekind that manganese forms ferromagnetic compounds with such diamagnetic elements as *B*, *As*, *Sb*, and *Bi*. The second hypothesis involves the theory that manganese exists in the Heusler alloys in an allotropic form which is ferromagnetic. Since ordinary manganese is paramagnetic, we would expect, if this theory is correct, to find that the metal becomes ferromagnetic at very low temperatures. But the experiments of K. Onnes and Weiss show that even at 14 deg. Abs., manganese is still paramagnetic. The third hypothesis seems to be favored by most of the investigators, but evidently it only replaces the first question by another question as to the cause of ferromagnetism in such crystal structures.

Ferro-magnetic Compounds of Non-magnetic Elements.

The Heusler alloys are, however, not the only illustration of ferromagnetic substances whose constituents are by themselves non-magnetic. Wedekind has drawn attention to the fact that manganese forms ferromagnetic compounds with such highly *diamagnetic* elements as *B*, *P*, *As*, *Sb* and *Bi*. Fig. 18 gives

(38) For Bibliography of investigations see the papers. in Trans. Far. Soc. *8*, pp. 169–207.
(39) Trans. Far. Soc. *8*, pp. 204, (1912).

TABLE XVIII

	Mn P				*Mn B*		
H	B	μ	I	H	B	μ	I
86	202	2.4	9.2	90	498	5.5	33
172	368	2.1	15.6	181	867	4.8	55
747	1235	1.6	38.8	787	2628	3.3	147
	Mn Sb				*Co*		
89	1118	12.6	82	89	2815	31.7	217
178	1959	11.0	142	178	4342	24.4	331
773	5313	6.9	361	773	9154	11.8	667

the H-B curves for some of these compounds and also those of ordinary iron and cobalt for comparison.[40]

The permeability of the phosphide, antimonide and boride for different field strengths is given in Table XVIII.[41]

These compounds also possess definite critical temperatures as follows:

MnP	18–26 deg.
$Mn\ As$	40–45 deg.
$Mn\ Sb$	320–330 deg.
$Mn\ Bi$	360–380 deg.

The magnetizability of the *nitrides* Mn_3N_2, Mn_5N_2, and Mn_7N_2 increases with rise in the manganese content. "The last compound is relatively strongly magnetic, and also exhibits residual magnetism. Of the oxides Mn_3O_4 is the most strongly magnetizable, while MnO is more magnetic than MnO_2.

Similar magnetic properties are possessed by compounds of *vanadium*. While the metal itself is only feebly magnetic ($\chi = 1.5 \times 10^{-6}$), the sub-oxide VO is more strongly magnetic than MnO_2 or Cr_2O_3, and the magnetizability decreases with increasing oxygen content of the different oxides. However, in the case of the sulphides the magnetizability increases with increasing sulphur content. The specific susceptibility of *chromium* metal is about 2.9×10^{-6}, but the oxides Cr_5O_9, and the sulphide Cr_3S_4 are strongly magnetic.

The remarkable fact about all these magnetic compounds is that the essentially non-magnetic elements Mn, Cr and to a lesser degree V, are able to form strongly magnetic compounds with a number of diamagnetic elements, while, on the other hand the addition of the above three elements to ferromagnetic metals like iron, cobalt and nickel decreases the magnetizability of these metals.

The magnetization of a number of alloys as a function of their composition has been investigated by K. Honda.[42]

The observations were extended over all alloys of *Ni-Cr; Co-Cr; Fe-V; Ni-Sn; Ni-Al, Mn-Sb* and *Mn-Sn* and some of the conclusions reached by him are as follows:

1. The ferromagnetism depends upon the concentration and the temperature and is inherent in all cases in a definite crystal structure.

2. The magnetization of a series of alloys which contain two sorts of crystals (whether both are magnetizable or only one), usually varies linearly with the composition of the alloy.

3. In the case of *Mn-Sn* alloys it could be shown that the residual magnetism is inherent in a definite compound Mn_4Sn.

These facts show that ferromagnetism (and probably paramagnetism) is a decidedly non-atomic property; but is *probably associated with a definite arrangement of the atoms in the solid compound*, as has been suggested by Take. To speak of ferromagnetism as a molecular property is apt to be misleading. As Bragg has shown we cannot speak of molecules in the case of solid compounds. All we can state is that the atoms are arranged in some particular form. There is no doubt that an investigation of the arrangement of the atoms in some of the solid alloys described above by the same method as that used by Bragg in investigating the structure of rock-salt, calcite, zinc blende, and other crystals, would be found extremely useful not only in arriving at some explanation for the cause of their magnetizability but also in

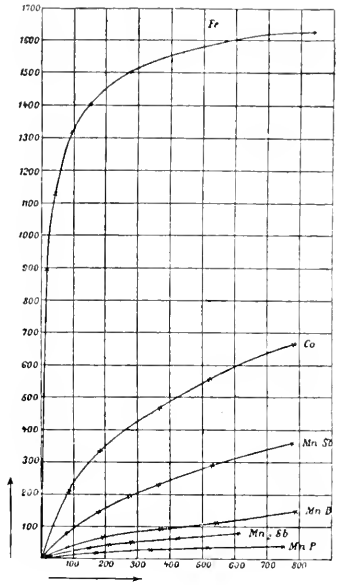


Fig. 18

[40] Trans. Far. Soc. 8 163 (1912).
[41] Wedekind, Zeit. Phys. Chem. 66, 614 (1909).
[42] Ann. d. Phys. 32, 1003 (1910).

TABLE XIX

MAGNETIC SUSCEPTIBILITIES OF THE ELEMENTS

Element	Atomic Weight	Atomic Number	Density	Physical State	$\chi \times 10^6$	$\chi \times A \times 10^6$	$\chi \times A \times 10^6$ (Pascal)
H	1.008	1		Gas			− 2.93
He	3.99	2		Gas		− 42.5	
Li	6.94	3	0.59	Sticks	+ 0.50	+ 3.47	− 4.20
Be	9.1	4	1.93	Regulus*	−1.00	− 9.1	− 8.55
B	11.00	5	2.53	Crystallized	−0.7	− 7.7	− 7.30
C	12.00	6	3.52	Diamond	− 0.49	− 5.9	− 6.00
N	14.01	7					− 5.57
O	16.00	8					− 4.61
F	19.0	9					− 5.95
Na	23.0	11	0.98	Sticks	+ 0.51	+ 11.7	− 9.2
Mg	24.32	12	1.74	Rolled	+ 0.55	+ 13.4	− 10.1
Al	27.1	13	2.58	Cast	+ 0.60	+ 16.3	− 13.2
Si	28.3	14	2.39	Crystallized	− 0.13	− 3.7	− 20.0
P	31.04	15	1.83	White	− 0.90	− 27.94	− 26.3
S	32.07	16	2.07	Rhombic	− 0.49	− 14.6	− 15.0
Cl	35.46	17				− 18.7	− 20.1
Ar	39.9	18				−225	
K	39.10	19	0.86	Sticks	+ 0.40	+ 15.6	− 18.5
Ca	40.07	20	1.58	Electrolytic	+ 1.10	+ 44.1	− 15.9
Ti	48.1	22	4.87	Regulus*	+ 1.2	+ 57.7	
V	51.0	23	5.8	Regulus*	+ 1.50	+ 76.5	
Cr	52.0	24	6.8	Cast	+ 2.9	+150.8	
Mn	54.93	25	7.4	Cast	+ 8.9	+488.9	
Cu	63.57	29	8.95	Electrolytic	− 0.085	− 5.5	*-ous* −18.
Zn	65.37	30	7.13	Granular	− 0.155	−10.14	− 13.5
Ga	69.9	31	5.95	Regulus*	− 0.24	−16.78	− 16.8
Ge	72.5	32	5.47	Regulus*	− 0.12	− 8.70	
As	75.0	33	4.73	Sublimed	− 0.31	− 23.25	− 43.0
Se	79.2	34	4.8	Sublimed	− 0.32	− 25.34	−23.1
Br	79.92	35	3.15	Liquid	− 0.40	− 32.0	− 30.5
Rb	85.45	37	1.52	Regulus*	+ 0.07	+ 6.0	− 27.2
Sr	87.63	38	2.54	Regulus*	− 0.2	− 17.5	− 24.5
Zr	90.6	40	6.4	Crystallized	− 0.45	− 40.8	
Cb	93.5	41	12.7	Regulus*	+ 1.3	+121.6	
Mo	96.0	42	8.6	Powder	+ 0.04	+ 3.8	
Ru	101.7	44	12.3	Regulus*	+ 0.43	+ 43.7	
Rh	102.9	45	12.1	Regulus*	+ 1.1	+113.2	
Pd	106.7	46	11.4	Regulus*	+ 5.2	+554.8	
Ag	107.9	47	10.5	Regulus*	− 0.20	− 21.6	− 31.0
Cd	112.4	48	8.6	Cast	− 0.18	− 20.2	− 20.0
In	114.8	49	7.1	Electrolytic	− 0.11	− 12.6	− 15.0
Sn	119.0	50	7.3	Electrolytic	− 0.02	− 2.4	
			5.8	Gray	− 0.3	− 35.7	*-ic* − 30.3
Sb	120.2	51	6.7	Regulus*	− 0.82	− 98.6	*-ous* −74.0
Te	127.5	52	6.3	Sticks	− 0.32	− 40.8	− 37.5
I	126.9	53	4.95	Crystallized	− 0.36	− 45.7	− 44.6
Cs	132.8	55	1.88	Electrolytic	− 0.10	− 13.3	− 41.0
Ba	137.4	56	3.75	Regulus*	+ 0.9	+123.7	− 38.2
Ce	140.3	58	7.04	Regulus*	+ 15	+2105	
Pr	140.6	59	6.48	Regulus*	+25	+3515	
Nd	144.3	60	6.96	Regulus*	+36	+5195	
Er	167.4	68	4.77	Powder	+22.3	+3733	
Ta	181.5	73	16.6	Sheet	+ 0.8	+145.2	
W	184.0	74	19.1	Regulus*	+0.22	+ 40.5	
Os	190.9	76	22.5	Sublimed	+0.04	+ 7.6	
Ir	193.1	77	22.4	Regulus*	+0.13	+ 25.1	
Pt	195.2	78	21.5	Wire	+0.8	+156.2	
Au	197.2	79	19.32	Sheet	−0.15	− 29.6	− 45.8
Hg	200.6	80	13.56	Liquid	−0.19	− 38.1	*ic-* −33.4
Tl	204.0	81	11.8	Sticks	−0.24	− 48.96	− 40.3
Pb	207.1	82	11.37	Sticks	−0.12	− 24.9	− 45.8
Bi	208.0	83	9.80	Electrolytic	−1.40	−287.2	−192.
Th	232.2	90	11.3	Powder	+0.08	+ 18.6	
U	238.2	92	18.7	Regulus*	+2.6	+619.3	

* Regulus signifies metal obtained in a more or less pure form.

obtaining more definite ideas upon the ultimate nature of ferromagnetism itself.

Magnetic Susceptibilities of the Chemical Elements

The magnetic properties of the elements as a function of their atomic weight has naturally attracted a great deal of attention from a number of investigators. The most recent and no doubt most accurate values of the magnetic susceptibilities up to the present are those of Honda and Owen.[43] Table XIX based largely upon the results given by the latter, gives the specific magnetic susceptibility, χ, and atomic susceptibility ($\chi \times$atomic weight) for all the elements for which data are available.

According to our present views of the structure of matter we consider the atom as built up of a positively charged nucleus whose dimensions are extremely small compared with those of the atom itself, and one or more rings of electrons revolving around this positive nucleus. There are many reasons for believing that all the properties of the elements are intimately dependent upon the total charge carried by the nucleus. If we denote this charge by Ne where e is the unit electric charge (1.591×10^{-20} e.s.u.), the value of N is designated as the atomic number, and it is this number rather than the atomic weight which is the most significant property of any element. It is therefore of interest to consider χ not as a function of the atomic weight but rather as a function of the nuclear charge, N.

Fig. 19 taken from a recent paper by Harkins and Hall[44] gives the specific susceptibility as a function of the atomic number. A few of the values are different from those given in Table XIX but on the whole there is agreement between the data given in the table and those used in the construction of Fig. 19.

It will be found extremely useful to consider the relation between this curve and the periodic arrangement of the elements,[45] such as that shown by Fig. 20 which gives the elements arranged in the form of a logarithmic spiral, so that elements belonging to the same group in the periodic table lie on a straight line radiating from the center of the spiral.

The most striking feature about the curve shown in Fig. 19 is the fact that it apparently bears no resemblance whatever to any of the

(43) K Honda, Ann. d. Phys. *32*, 1027 (1910).
M. Owen, Ann. d. Phys. *37*, 657 (1912).

(44) Journ. Am. Chem. Soc. *38*, 169 (1916).

(45) See the writer's table of the periodic arrangement Gen. Elec. Review, July, 1915.

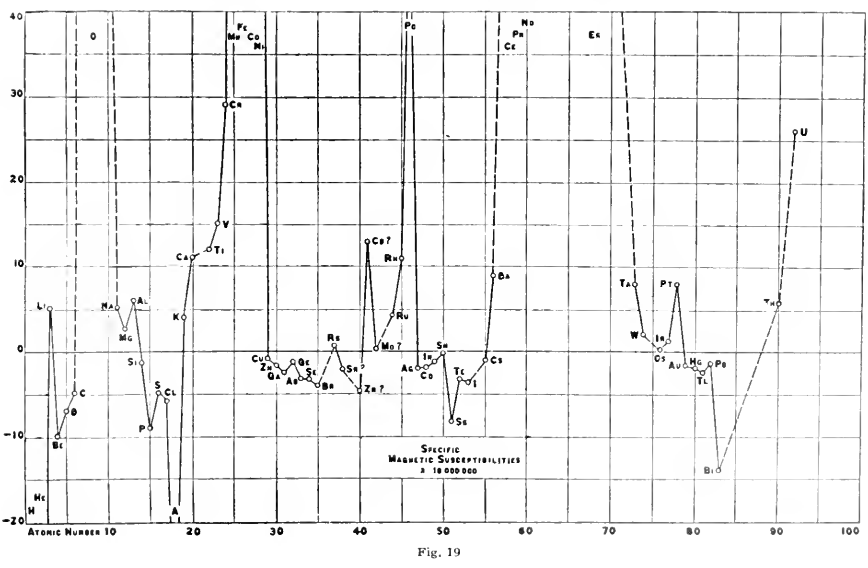


Fig. 19

curves which express other properties of the elements in terms of their atomic numbers.[46] There is therefore *no immediately deduceable relation between magnetic susceptibility and any other* property of the elements. Comparing Fig. 19 and Fig. 20 we see that the elements of Group *O* and group 5 are highly diamagnetic, while in group 8, *Fe*, *Co*, *Ni* are ferromagnetic and the rest of the elements are strongly paramagnetic. It would appear as if the most diamagnetic and most paramagnetic elements are situated at opposite ends of the periodic table, while in between we have a group consisting of *N*, *P*, *As*, *Sb* of the atom we would be led to expect some relation between the diamagnetic susceptibility and the atomic number. However in investigating the susceptibilities of the elements in the free state the natural diamagnetism may often be masked by the paramagnetism inherent in some particular crystal structure. Pascal has therefore attempted to determine the diamagnetic susceptibilities of the atoms themselves by a study of their compounds, and the results which he has obtained so far will no doubt be found to be of great importance in arriving at a definite theory of the nature of magnetism.

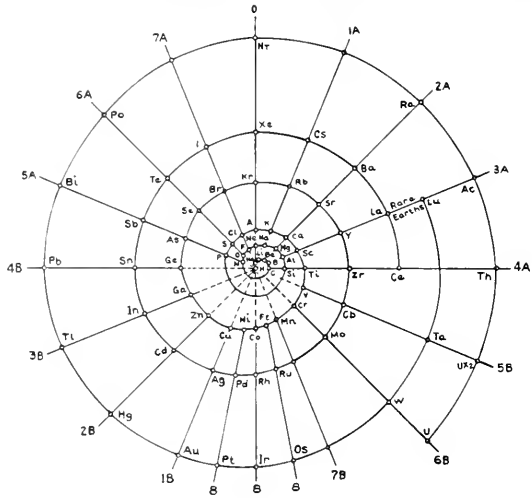


Fig 20

and *Bi* which are diamagnetic, and the rare earth group which is strongly paramagnetic. Regarding the other elements they seem to vary from para- to dia-magnetism in a very irregular manner. Thus, to consider only one case: the alkali metals, *Li*, *Na*, *K* and *Rb*, show a gradual decrease in paramagnetic susceptibility until finally in *Cs* the susceptibility becomes diamagnetic.

From the point of view of Langevin's theory and considering the facts which have been mentioned above about the ferro- and paramagnetism of different compounds it is probably unlikely that there exists any definite relation between magnetic susceptibility in general and atomic numbers; but assuming that diamagnetism is a fundamental property

Pascal[47] assumes that in a diamagnetic substance in which the electronic orbits of the individual atoms are undisturbed, the diamagnetic susceptibility is additively made up of the atomic susceptibilities, that is;

$$\chi_M = \Sigma \, a\chi_A \qquad (52)$$

where

χ_M, the molecular susceptibility, $= \chi \times$ molecular weight,

χ_A, the atomic susceptibility $= \chi \times$ atomic weight

and a denotes the number of atoms of the elements for which χ_A is taken.

[46] See the plot of the Atomic Volume in the writer's article, also the numerous curves given by Harkins and Hall.
[47] Ann. de Chem. et de Phys. *19*, 5 (1910).
Ann. de Chem. et de Phys. *25*, 289 (1912).

In the case of a large number of diamagnetic compounds this relation is not found to hold true because of interatomic forces which distort the electronic orbits of the individual atoms so that

$$\chi_M = \Sigma a \chi_A + \lambda \qquad (53)$$

where λ is a correcting term.

Let us illustrate the significance of these relations by referring to some of Pascal's measurements as given in Table XX.

In each of the groups of similar compounds for which χ_M is given in this table there is a *constant difference* for the addition of $-CH_2$. The average value of this difference as obtained from an investigation of a large number of organic compounds is $10^{-7}\times 123.5$. In a similar manner Pascal finds that for a difference of $(-H)$ the molecular diamagnetic susceptibility decreases by 30.5×10^{-7}. Hence:

χ_A for $C = -10^{-7}\ (123.5-61) = -10^{-7}\times 62.5$.

Now let us apply these results to the calculation of χ_M for hexane and benzene respectively.

For Hexane;

$$\chi_M = -(6\times 62.5+14\times 30.5)\times 10^{-7}$$
$$= -802\times 10^{-7}(\text{observed}=796).$$

For Benzene;

$$\chi_M = -(6\times 62.5+6\times 30.5)\times 10^{-7}$$
$$= -558\times 10^{-7}(\text{observed}=574).$$

The difference between the observed and calculated values in the case of hexane is less than 1 per cent, which is within the experimental errors; on the other hand, in the case of benzene, the difference of 16 is too large to be accounted for experimentally and Pascal therefore ascribes it to the influence of the ring structure of benzene, and this is confirmed by the fact that for all these benzene derivatives he finds in a similar manner that there is a constant difference between observed and calculated values of -15×10^{-7}. That is, for the ring compounds similar to benzene in structure,

$$\chi_M = \Sigma a \chi_A - 15\times 10^{-7}.$$

In a similar manner Pascal determines the values of λ for a large number of different types of organic compounds, and the value of χ_A for most of the elements.[48] These are tabulated in the last column of table XIX, so that they can be readily compared with the atomic susceptibilities of the elements in the free state.

It will be noticed that the values of χ_A in the uncombined and combined states are approximately the same for the following elements:

Be, B, C, P, S, Zn, Ga, Se, Br, Ca, In, Sn, Te, I and the gases *H, N, F* and *Cl* (according to Pascal).

TABLE XX

Compound	Formula	χ_M	Differences
Hexane	C_6H_{14}	796	
Octane..	C_8H_{18}	1037	2x120.5
Decane .	$C_{10}H_{22}$	1297	2x130.
Benzene....	C_6H_6	574	
Toluene ..	$C_6H_5\ CH_3$	699	125
Meta-xylene	$C_6H_4\ (C_3H)_2$	821	122
Formic Acid	$HC\ OOH$	207	
Acetic Acid	$CH_3\ COOH$	329	122
Propionic Acid . . .	$C_2H_5\ COOH$	453	124

The elements which are diamagnetic under both conditions are as folows:—

Si (3.7, 20); *Cu* (5.5, 18); *As* (23, 43); *Sr* (17.5, 24.5); *Ag* (21.6, 31); *Sb* (99, 74 for Sb^{III}); *Cs* (13.3, 41); *Au* (29.6, 45.8); *Hg* (38.1, 33.4 for Hg^{II}); *Tl* (48.96, 40.3); *Pb* (25, 46); and *Bi* (287, 192.)

Oxygen is an interesting case. As a gas (O_2) it is strongly paramagnetic, but combined with *H* (e.g. $H_2\ O$; CH_3OH etc.) it is *diamagnetic*. Combined with carbon as in CH_3COCH_3 where *O* has two bonds united to the same carbon atom it is *paramagnetic*. The determinations of the susceptibilities of the gases *H, N, F* and *Cl* are very uncertain, but according to Pascal the atomic susceptibilities for these gases are the same in the free and combined states.

By plotting the *logarithms* of χ_A as a function of the atomic number we obtain a curve such as that shown in Fig. 22. The values for *He* and *Ar* are based on the measurements made by Tanzler[49], and it has been assumed that the atomic susceptibilities of the other rare gases are probably equally high.

A very remarkable feature about these values of χ_A which is brought out by the above method of plotting, is the fact that similar elements seem to lie on the same straight line, and that these straight lines have

[48] Compt. rend. *158*, 1895 (1914). There seem to be slight differences between the values given in this article and the values which are used in the earlier papers in the Annales de Chimie et de Physique. Thus for C. O. and N. the latter publication gives the values of χ_A as 6.25, -4.8, and -5.8x10-7 respectively.

[49] Ann. d. Phys. *24*, 931 (1907).

approximately the same slope for the different groups. Thus *P*, *As*, *Sb* and *Bi* lie on the dotted line indicated in the figure, similarly *Zn*, *Cd* and *Hg*, (all elements belonging to group 2*B*) lie on another straight line. This fact can be expressed by an equation of the form

$$\chi_a = C_1 \epsilon^{C_2 N} \qquad (54)$$

where C_1 and C_2 are constants

N = atomic number

ϵ = base of natural system of logarithms.

The relation seems to hold splendidly for almost all of the elements whose atomic numbers are over 15. Certainly a relation of this type must have some physical significance. This is, however, as yet undetermined.

The question as to the ultimate nature of diamagnetism is made exceedingly difficult by the existence of a large number of apparently anomalous observations on the magnetic behavior of the different elements under certain conditions. Thus, all the salts of iron are strongly paramagnetic, but $Fe(CO)_5$, and $K_4Fe(CN)_6$ are diamagnetic.(50) Similarly the complex amino-salts of cobalt, and the double chlorides of platinum with potassium and ammonium are diamagnetic although all the other compounds of cobalt and platinum are paramagnetic. Pascal's results show that in a large number of cases the free elements are *paramagnetic* while their *compounds are all diamagnetic*, e.g. *Li*, *Na*, *K*, *Rb*, *Mg*, *Al*, *Ca* and *Ba* (see Table XIX). On the other hand, the *compound* K_2HgI_4 is paramagnetic, while two of its constituent *elements are diamagnetic* and the third (*K*) is paramagnetic only in the metallic states. Similarly *Cu* and $-SO_4$ are diamagnetic while $CuSO_4$ is paramagnetic.

The magnetic behavior of allotropic modifications of the same element has been investigated recently by du Bois and Honda.(51) The differences in magnetic susceptibility are often very large. Thus ordinary or electrolytic tin is only slightly diamagnetic (or even paramagnetic according to some investigators) while the grey modification which is stable

(50) A. E. Oxley, Tables. Ann. *2*, 388.
(51) Mentioned by A. E. Oxley, Phil. Trans. *214*, (A), 109 (1914).

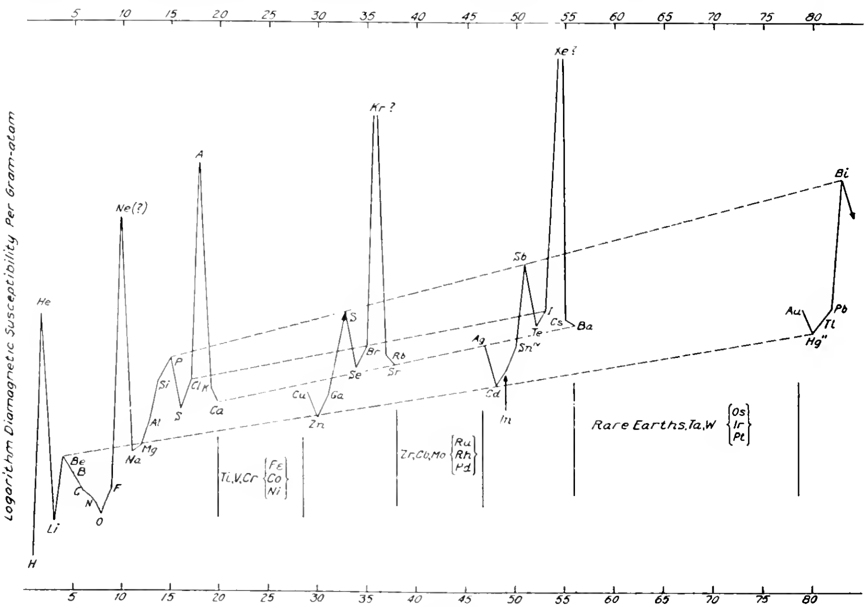


Fig. 21

only at low temperatures is strongly diamagnetic. The different forms of phosphorous show similar differences in susceptibility.

Diamagnetism and Molecular Field

The above facts show that while there is a great deal to justify Langevin's assumption of the fundamental difference between diamagnetism and paramagnetism there yet exist a number of observations which indicate that this broad distinction requires modification in some respects. Thus if diamagnetism is an atomic property why should not the additive relation expressed by equation (52) hold absolutely rigid? Why should the different allotropic forms of the same element exhibit different values of the magnetic susceptibility?

These observations are also similar to a number of observations which have been made by Oxley([52]) and others on the change in diamagnetic susceptibility of various organic compounds when fused. Thus Oxley has observedt hat for most of the substances investigated by him the *liquid state is more diamagnetic than the crystalline*. When the molten substance is supercooled below its crystallization point there is observed no change in the susceptibility as long as the substance remains in the form of a gel, but there is a sudden change when crystallization occurs. He therefore concludes that the diamagnetic susceptibility is not wholly an atomic property. "For the near approach of the molecules which takes place on crystallization is able to modify the susceptibility appreciably." In order to explain these observations Oxley introduces the hypothesis that the *molecular structure is distorted by the near approach of the other molecular structures*, so that the self-induction of the electronic orbits is affected. Thus the molecules must be surrounded by intense molecular fields which in the liquid state neutralize each other; but in the crystalline state the molecules are in fixed positions and are thus able to distort their electronic orbits." The introduction of the idea of a molecular field of the diamagnetic crystalls allows us to neglect the mutual influence of the diamagnetic molecules in exactly the same way as the molecular field of Weiss allows us to express the phenomena of ferromagnetism without bringing into consideration the mutual influences of the molecules. Both the molecular field of Weiss and the molecular field of the diamagnetic crystals are proportional to the intensity of magnetization, in the respective cases and the minimum value of the constant (compare the constant K in Weiss's theory of ferromagnetism) of the latter field is of the same order as that of the ferromagnetic field." In other words while Weiss extends Langevin's theory of paramagnetism to ferromagnetic phenomena by introducing the idea of molecular field, Oxley extends Langevin's theory of diamagnetism by a similar concept. It is of interest to note that just as Weiss finds confirmation of his theory in the departure of the specific heat of iron from the calculated values near the transformation point, so Oxley finds that the specific heat of diamagnetic substances near the temperature of fusion exhibits similar discrepancies from the normal values.

In this manner the latter is also able to account for the anomalous observations, some of which have been mentioned above. "The forces which come into play during the chemical combination we may regard as upsetting the magnetic equilibrium of each component." These conclusions are also in accord with the observed changes in molecular volumes. The discussion of those relations would, however, lead us much beyond the scope of the present paper.

([52]) Phil. Trans. 214 (A) 109 (1914).
Phil. Trans. 215 (A) 79 (1915).

INDUSTRIAL CONTROL

PART IV

In general, controlling devices vary but little in design for different steel mill applications. Perhaps the most complex control, and the one in greatest variance from standard alternating-current controllers, is that of speed regulating sets for induction motors. A description of these types of control, together with a delineation of a few types of starting resistance connections characteristic of steel mill service, comprises the substance of this article.—EDITOR.

(2) MAGNETIC CONTROL FOR STEEL MILLS (Cont'd)

By H. I. SMITH AND G. E. STACK

INDUSTRIAL CONTROL DEPARTMENT, GENERAL ELECTRIC COMPANY

APPLICATIONS TO SPEED-REGULATING SETS

General *

In the control of induction motors with speed-regulating sets, the function of proper sequence of operation is of the greater importance in designing suitable control. If there are several individual machines and much auxiliary equipment in the system, each device must be connected or disconnected at the proper instant to prevent damage resulting to some of the rotating or control apparatus. Therefore, it is generally advisable to provide magnetic control for this easily accomodates the incorporation of interlocking mediums that enforce proper handling of the equipment, even by fairly inexperienced operators. However, hand control with a few auxiliary contactors has been applied to several small motors with good results. Hand control is particularly applicable to cases where the necessity to vary the speed is infrequent, such as in mine fan and pump motor installations where one definite speed reduction is used for some time.

Scherbius System

Consideration will first be given to the Scherbius speed regulating system. Fig. 1 illustrates the complete control connections of a 2300 1300-h.p. 100/65-r.p.m. 6600-volt induction motor having a single-range regulating set capable of reducing the speed of the motor approximately 35 per cent below synchronism. Fig. 4 is an illustration of the contactor panel for the control of this motor. Fig. 2 shows a simplified reduction of the complete connection and the principal circuits which are interlocked to prevent improper operation. Provision is always made in the control of these equipments to permit the main motor being operated either regulating with the set, or non-regulating without the set should trouble develop in any of the circuits external to the main motor. The double-pole double-throw selective control switch *S-2*, Fig. 2, determines the operation; if in the up position, the main motor can be started and run without the regulating set connected to the system, and if in the down position resultant control circuits will connect the regulating set to the motor at the proper time during acceleration. Should it be necessary to vary the main motor speed by rheostatic control because of it being impossible to use the set for any reason, the starting resistance will be good for continuous duty.

When starting the main motor regulating, the interlocking on the control is such that the primary contactors *F* and *R*, Fig. 2, cannot be closed until, first, the regulating set has been started, closing the interlock *ASO* and, second, the field rheostat on the exciter *Re* is in the starting position, closing the interlock *J*. These precautions are necessary to prevent the secondary current of the main motor being thrown on the commutator motor *Rm* when the later is not running, and to assure field rheostat being in such a position that the resultant excitation of the commutator motor will cause it to generate a voltage approximately equal to the slip-ring motor at the speed at which the two are connected, thus limiting the current peak due to difference of potential.

The starting cycle to run regulating is as follows:

(1) The master controller is returned to the off position, and the control switch *S-3* is closed, closing the low-voltage contactor *16*.

(2) The field rheostat *H* is thrown to the starting position, closing the interlock *J*.

(3) The main oil switch is closed and the regulating set started by means of the oil switch *D* and *E*, the induction generator *Rg* acting as an induction motor.

(4) The main motor may then be started on the first point of the master controller and accelerated either by hand or automatically by the current-limit

* In the GENERAL ELECTRIC REVIEW, April, 1916, p. 282, there appeared an article on "Motor Drive for Steel Mills" by F. B. Crosby which constitutes a valuable reference in connection with this article.

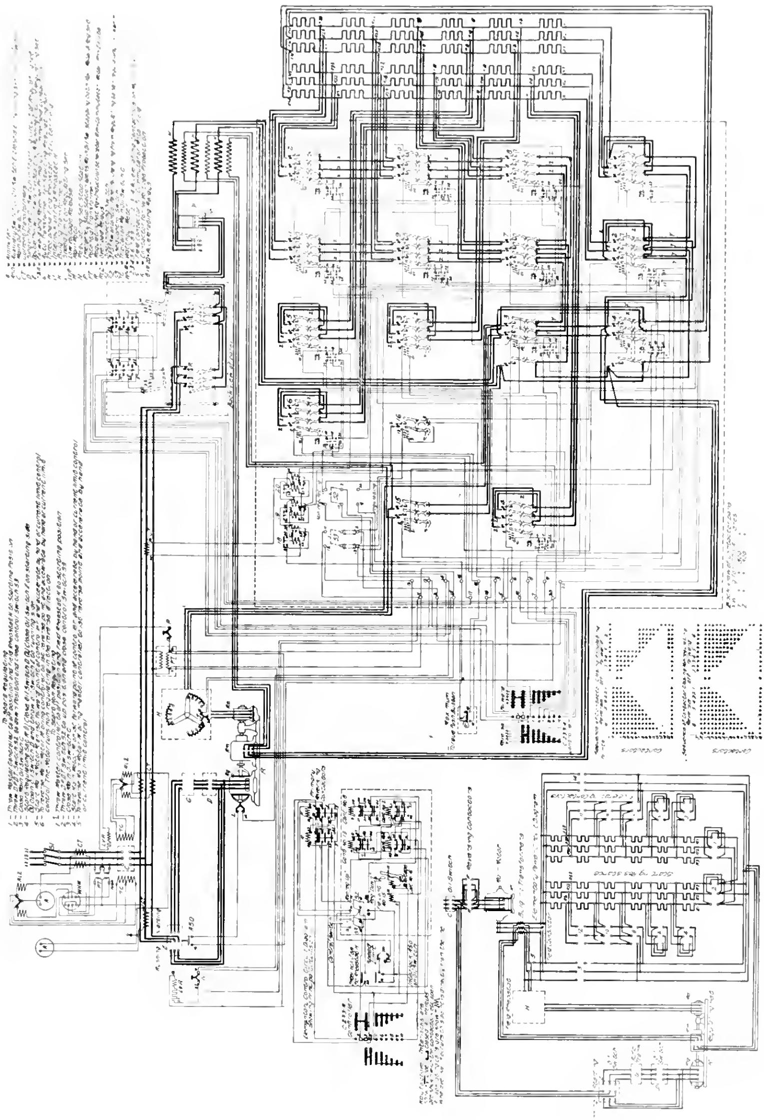


Fig. 1. Complete Connections of Scherbius Speed Regulating System for Controlling a 2300-1300 h.p. Induction Motor. This Single Range Regulating Set is Capable of Reducing the Speed of the Motor Approximately 35 per cent below Synchronism

relays, provided the master controller is on the full-speed position.

It will be seen from Fig. 2 that the short-circuiting contactor *2* is closed in the off position of the controller, thereby short circuiting the commutator motor and forming the Y-point for the starting resistance. The pick-up circuit in the primary contactor *F* may be traced as follows: From terminal *11* on main control switch *S-3*, through interlock *11-21* contactor *14*, through interlock *20-21* contactor *2*, through interlock *J 18-20* on field rheostat *H*, through blade *17-18* on double-throw selective control switch *S-2*, through interlock *ASO 17-19* on oil switch *E*, through speed limit switch *19-14* on the regulating set to one side of the operating coil of the primary contactor *F*; and as the

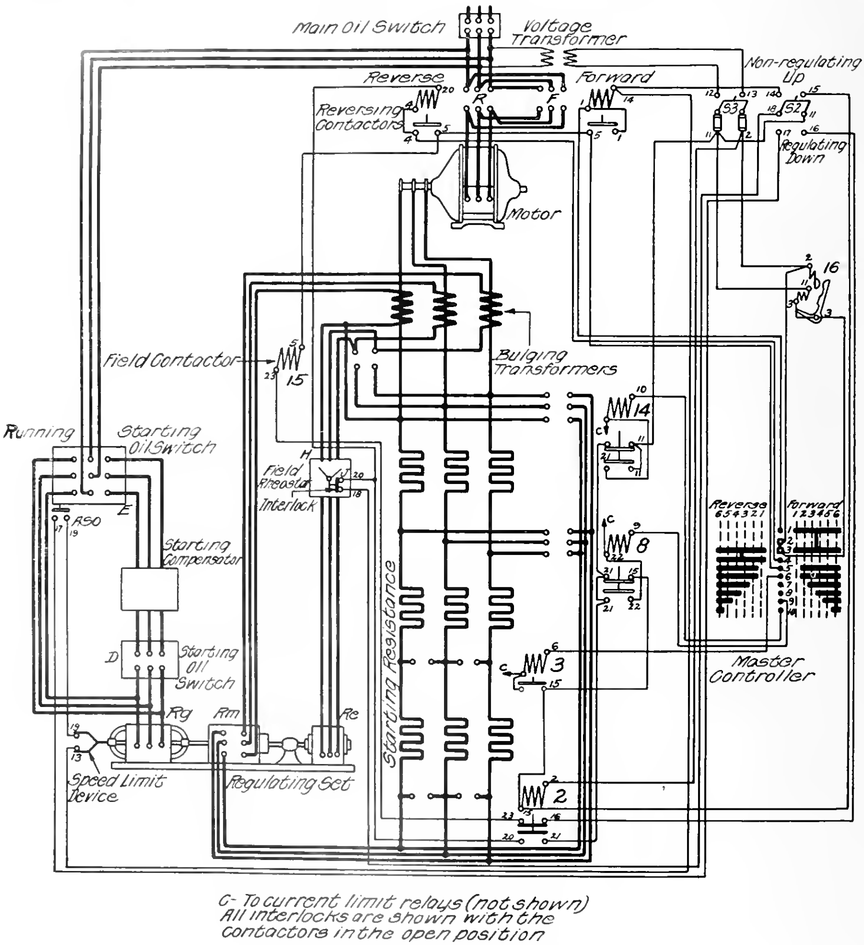
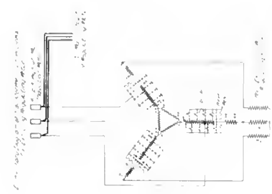


Fig. 2. Simplified Line Diagram of the System Shown in Fig. 1



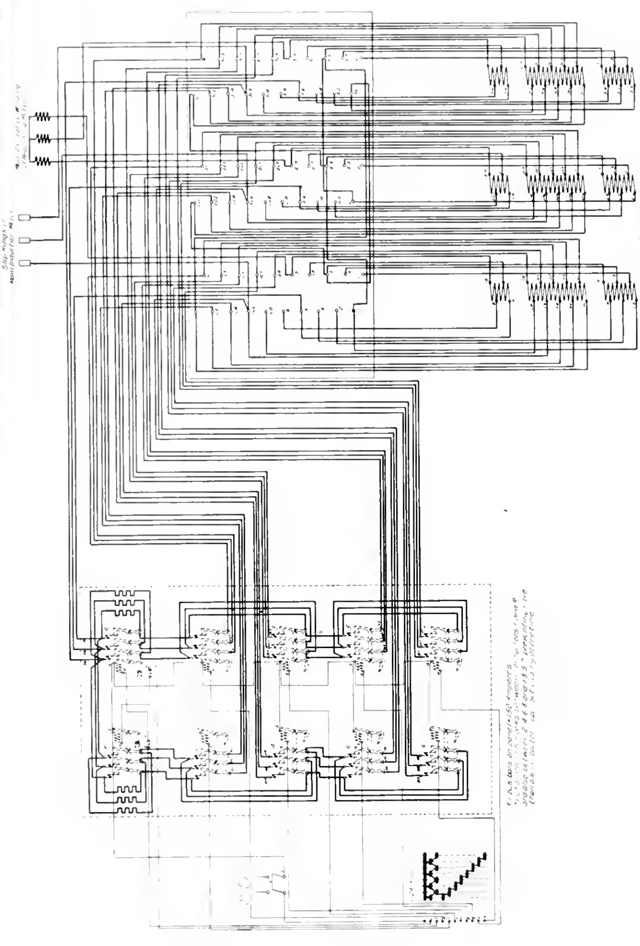


Fig. 3. A Modification of the Scherbius System of Control, Employing Auto-transformer in Place of the Exciter *Re* Shown in Fig. 2.

other side of this coil is connected through the master controller (contacts *1* to *3*) and the low-voltage contactor *16* (contacts *3-2*) to the other side of the line at terminal *2* on the control switch *S-3*, the contactor *F* will close, starting the motor. Only three divisions of starting resistance in a single Y are shown for simplicity, and the three contactors *2*, *8* and *14* correspond to the same contactors on the complete diagram, Fig. 1. Contactor *3*, being closed, short circuits the high resistance divisions used in limiting the current upon reversal, when double the normal slip-ring voltage is induced. When contactor *8* closes, the top disk *15-21* of the interlock drops out the short circuiting contactor *2* and thus allows the secondary current of the main motor to circulate through the commutator motor *Rm*. At the same instant, contactor *2*, upon opening, closes the field contactor *15* through the interlock *16-23*, which later contactor excites both the main excitation winding on the commutator motor and also the field of the exciter. It is imperative that the field contactor *15* be interlocked as described so that it can never be closed when the short circuiting contactor is closed, otherwise the commutator motor would be generating on a short circuit. The remainder of the starting cycle consists of cutting out the remainding starting resistance which is in series with the main winding of the commutator motor. When the last accelerating contactor *14* closes, the interlock *11-21* drops out contactor *8* (by opening the holding circuit through interlock *21-22*.) Now that the main motor is fully accelerated, its speed is controlled entirely by the field rheostat *H*, which changes the excitation of the main commutator motor and thus its generated voltage which opposes the slip-ring voltage of the main motor, thereby varying its speed accordingly. After the primary contactor *F* has once been closed, it forms its own holding circuit through the interlock disk (not shown in Fig. 2) so that it will be possible to open the interlock *J* on the field rheostat *H* without opening the primary contactor. In some cases where only a few definite speeds are desired, an auto-transformer having as many taps as there are different speeds is substituted for the exciter *Re*; the connections of one of these auto-transformers are shown in Fig. 3. The tap connections are shifted for the various speeds by means of the master controller which individually controls each contactor, one for every tap on the auto-transformer. It will be seen from the controller development in Fig. 3 that it is possible to have only one contactor closed at once otherwise the coil on the transformer would be short circuited. The two contactors at the top operate alternately each time the taps are changed, inserting resistance division taps at the instant of change-over; two contactors may be closed for only a short time. For protection against possible short circuits on the coils each of the four contactors in the two vertical rows is mechanically interlocked against every other contactor.

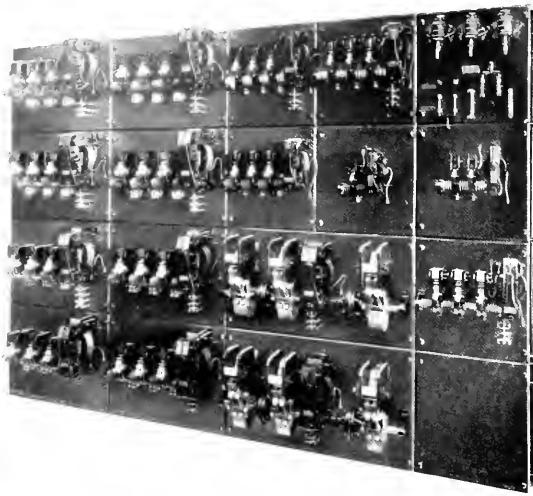


Fig. 4. Contact Panel for Control of 2300-1300 h.p. Induction Motor of Fig. 1

While running regulating there are three safety features in the control interlocking. The functioning of any one of these will automatically stop the motor. The first feature is low-voltage protection; low-voltage contactor *16* (Fig. 2) upon opening due to low voltage stops the motor. Upon return of voltage, it will be impossible to restart again until the master controller has been returned to the off position, when the pick-up circuit of the low voltage contactor is established through the segment *2* of the controller, which makes circuit only in the off position. The second safety feature is the interlock *ASO* on oil switch *E* leading to the regulating set. Should this oil switch be accidentally opened at any time when the commutator motor is connected to the slip rings of the induction motor, the set would accelerate to a dangerous speed due to the rising speed characteristics of the commutator motor, which would be running without load after the induction generator had been disconnected from the line. This interlock, when opened, breaks the control circuit of the primary contactor, and therefore immediately cuts off the power which is tending to make the regulating set accelerate. The third safety feature is the speed limit device on the set, which would stop the main motor in the same manner as does interlock *ASO*, should the set for any reason attain too high a speed.

As reversing the motor is but an emergency condition it is not necessary to operate regulating. Also, as the voltage and frequency upon reversal at full speed are double their normal value, it is best to isolate the commutator motor if it is not designed to stand these excessive values. It will be seen from Fig. 2 that in the reverse direction the pick-up circuit for the contactor *R* is dependent only upon the short circuiting contactor *2* being

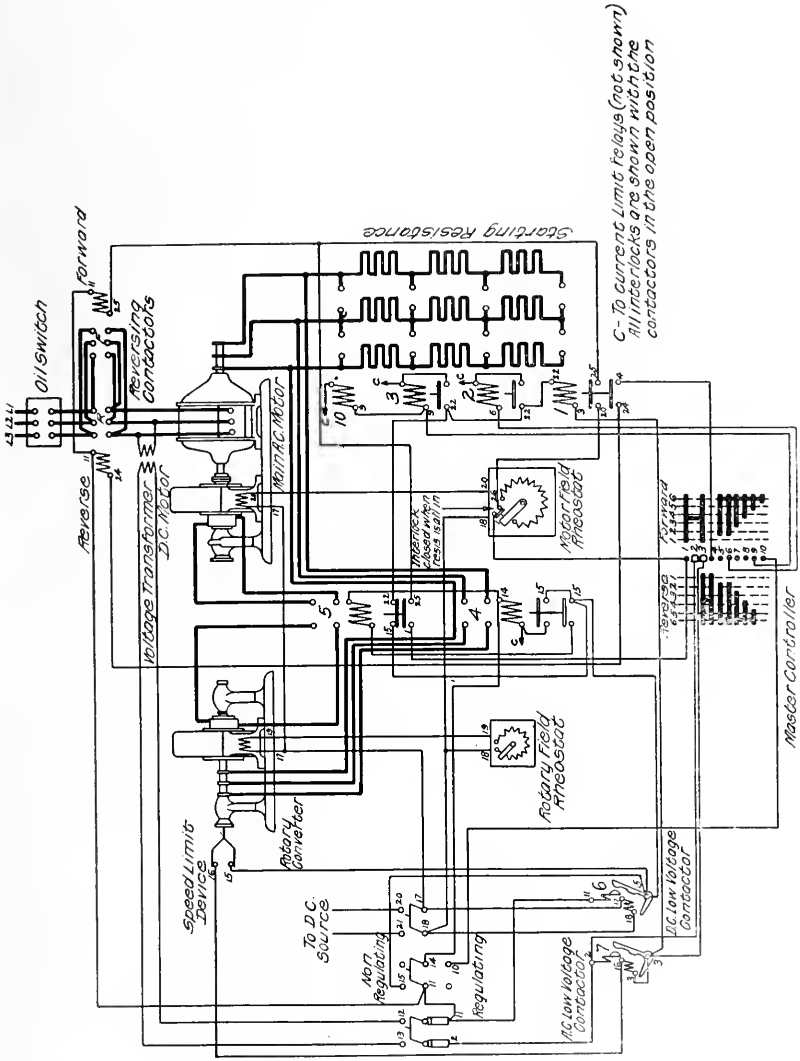


Fig. 5. Elementary Circuit Diagram of Induction Motor Speed Control by Synchronous Converter

closed (interlock *20–21* closed) and therefore will immediately close and reverse the motor when the master controller is thrown to the reverse direction. An interlock on this contactor makes the holding circuit (not shown in Fig. 2) which prevents it from dropping out when contactor *14* closes.

When operating non regulating, the double-pole double-throw selective control switch *S-2*, when in the up position, short circuits all the external interlocking devices such as the speed limit and the interlock *ASO*, so that the motor can be started with the regulating set not running. The accelerating cycle is similar to that described for running regulating, with the exception that the short circuiting contactor 2 is held closed by blade *11–15* on the selective switch *S-2* and the field contactor *15* therefore does not close.

The control for the double-range Scherbius regulating sets, which regulate above and below synchronism, is essentially the same as for the single range. The control features necessary for passing through synchronism are embodied in the field rheostat.

Synchronous Converter System

The general characteristics of the control for the synchronous converter system of speed regulation are not materially different from those described for the Scherbius system. With the synchronous converter system there are separate alternating current and direct current sources of energy, the latter being used for exciting the fields of both the direct current motor and the synchronous converter. Ordinarily a small alternating-current-direct-current exciter set is provided so that the exciting sources will always be available as long as the main alternating-current supply does not fail. In one particular, the cycle of operation varies from that previously given for the Scherbius control. In the Scherbius control, it was necessary that the regulating set be running before the main motor could be started for regulating operation. As the speed of the synchronous converter is directly proportional to the secondary frequency, or slip of the main induction motor, it is necessary that the motor shall have been accelerated to full speed, and consequently small secondary frequency, before the synchronous converter is connected to the slip rings. That is, after the last accelerating contactor has closed, cutting out the remaining portion of the secondary resistance, the contactors connecting the alternating-current end of the converter to the slip rings, also the direct-current end to the direct-current motor, close. The synchronous converter may then be started and it will run at a speed always proportional to the secondary frequency of the induction motor. This secondary frequency, or speed reduction, is varied by means of the direct-current motor field rheostat, which is in the "all in" position at starting. Therefore the direct-current motor armature voltage at starting is very small, and consequently the current inrush when the converter and the direct-current motor are connected to the slip rings of the induction motor is limited by the reactance of this external circuit.

Fig. 5 is an elementary circuit diagram of connections giving the essential details of this equipment. As shown, the direct-current motor is direct connected to the shaft of the induction motor and returns the slip energy of the induction motor to this motor mechanically. A direct-current-alternating-current motor-generator set could as well be used, the direct-current motor driving an induction generator the latter returning the slip energy of the motor to the alternating-current bus.

For simplicity, Fig. 5 shows a starting resistance of only three divisions and only the important interlocking control circuits are included. Separate alternating-current and direct-current control switches, as well as low-voltage contactors, are provided. Before starting regulating, it is necessary that both control switches and both low-voltage contactors be closed. When starting for non-regulating operation, the blade *11–15* of the double-pole double-throw selective switch *S2* short circuits the direct-current low-voltage contactors so that it may be out and still not affect the operation. The field rheostat *H*, in the direct-current motor field, is the one directly affecting the speed control and the field rheostat *K* is used simply to adjust a definite field on the synchronous converter.

The starting cycle to run regulating is as follows:

(1) The main oil switch in the incoming power lines is closed.

(2) Both control switches *S1* and *S3* are closed and double-throw switch *S2* is thrown to the "down" position, which closes the low-voltage contactor *6* immediately and also contactor 7 if the master controller is in the "off" position and the speed limit on the converter is closed.

(3) The motor field rheostat *H* is to the "resistance all in" position which closes the interlocks *J* (*1–26*).

(4) The main motor is started by means of the master controller and is accelerated by hand or automatically by means of the current-limit relays. As soon as contactors *4* and *5* close, connecting both the converter and direct-current motor to the slip rings, all the accelerating contactors are dropped by breaking their holding circuit *22–15* of interlock on contactor *5*.

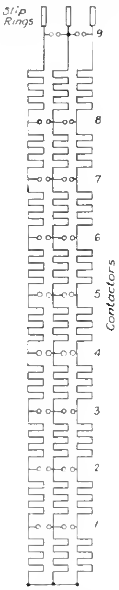


Fig. 6. Single Y Resistance for Secondary of Induction Motor Employing Flywheel for Smoothing out Peak Loads.

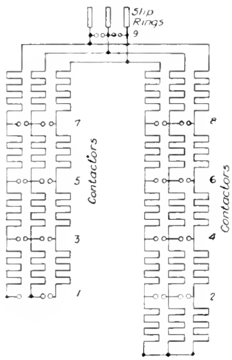


Fig. 7. Double Y Resistance for Secondary of Induction Motor Employing Flywheel for Smoothing out Peak Loads.

The pick-up circuit to the primary contactor *F* may be traced as follows. From terminal *2* of the alternating-current control switch *S3*, through the low-voltage contactor *7* (*2–3*), through the master controller contacts *3–1*, through interlock *J* (*1–26*) on field rheostat *H*, through interlock *26–25* on contactor *1* (closed on "off" position of controller), to one side of contactor *F* coil. As the other side of this coil is connected to terminal *11* on the control switch *S3*, this contactor will close, starting the motor. The holding circuit for *F* contactor is made through interlock *25–1* on contactor *5* so that the field rheostat *H* when operated, opening interlock *J*, will not drop out this contactor. The control is designed for non-regulating operation in the reverse direction which is obtained by altering the cylinder development of the controller on the reverse side so that contact *10* will not be energized and therefore contactors *4* and *5* will not close.

Resistance Connections

The common resistance connection for the secondary of an induction motor is the single Y shown in Fig. 6, in which the resistance is cut out in successive steps in the three legs. Another connection known as the double Y, shown in Fig. 7, is frequently used for starting large motors. Double normal resistance ohms is included in the resistance group which is permanently connected at the Y point; this is used for limiting the current upon reversal to full load. When starting from rest, contactor *1* immediately closes throwing the second group of resistance in multiple with the other group. The remaining steps in starting are obtained by closing the contactors alternately in each group as shown, the final contactor short circuiting the rings. This connection saves no resistance, as it is apparent that in starting a motor a definite amount of energy must be dissapated by the resistance; but the advantage lies in the reduced size of the accelerating contactors and in the wiring from the contactors to the resistance. As each accelerating contactor carries but a portion of the current, which is somewhat unbalanced in the two groups, they need be only approximately 65 per cent of the capacity of the contactors used with a single-Y resistance, as in Fig. 6.

COMPENSATED DYNAMOMETER WATTMETER METHOD OF MEASURING DIELECTRIC ENERGY LOSS

By G. B. Shanklin
Consulting Engineering Department, General Electric Company

An easy and accurate method of measuring dielectric energy loss should prove valuable to engineers interested in high-voltage problems. Although an instrument of the deflecting type is the most logical type to use, very little confidence has heretofore been placed in it because of its inherent phase-angle errors. In this article, the author describes a practical method of correcting for these errors.—Editor.

The measurement of dielectric energy loss has always presented a most difficult problem. The loss is usually quite small, averaging about 10 watts at 30,000 volts in the ordinary test sample. Even at unity power-factor the loss is difficult of accurate measurement. Quite often it is necessary to take measurements at power-factors of one and one-half per cent or less, under which conditions the possibility of errors is greatly increased. Then, too, the loss varies over such a wide range with temperature that it is imperative to run through the datum curves at any specified temperature in the shortest possible time, so that the rise in temperature due to the loss will be negligible.

It is the purpose of this article to describe a recently developed method, of measuring dielectric energy loss, that has given very satisfactory results both in accuracy and ease of operation.

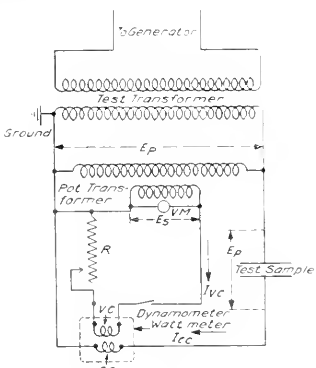


Fig. 1. Ordinary Dynamometer Wattmeter Method

Fig. 1 is a circuit diagram of the ordinary dynamometer wattmeter method of measuring small losses. The deflection of the instrument depends upon the values and phase relation of the currents I_{cc} through the current coil cc and I_{vc} through the voltage coil vc. Assuming that no error occurs in this method of test, Fig. 2 shows the two currents I_{cc} and I_{vc} in their true phase relation when a reading is taken on a sample having a power-factor of $\cos\Theta$. The true loss is then represented by the product of i_{cc} and

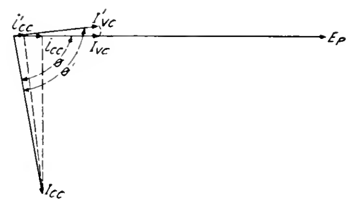


Fig. 2

I_{vc}, where i_{cc} is the component of I_{cc} in phase with I_{vc}.

Due to the phase angle of the potential transformer and also to the self-inductance of the coil vc, the current I_{vc} is never in phase with voltage E_P but lags behind as represented by I'_{vc} in Fig. 2. Under this condition the apparent loss is less than the true loss and is represented by the product of i'_{cc} and I'_{vc}. The error, as can be seen, is quite large.

Under certain conditions the secondary voltage of a potential transformer, and consequently the secondary current when the circuit is only slightly inductive, may lead the primary voltage instead of lagging behind it as shown in Fig. 2. This condition is sometimes met in this test, and since the angle $(\Theta'-\Theta)$ may be either lagging or leading it follows that the apparent watts loss may be either less or greater than the true loss. Fig. 3 shows I'_{ss} leading the voltage E_P. Here, the apparent loss is greater than the true loss.

When the test transformer has an auxiliary voltmeter coil, which is the present practice, this coil is usually connected to the voltage-coil circuit of the dynamometer and the potential transformer shown in Fig. 1 is omitted. A voltmeter coil can be considered as a small tapped-off section of the primary winding at the grounded end.

The phase-angle characteristics are then quite different. When the secondary voltage lags in a potential transformer it leads in the voltmeter coil, at least under the particular

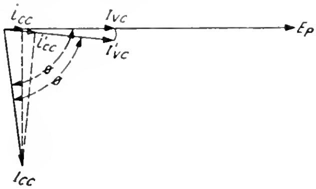


Fig. 3.

conditions here considered. The excitation current of a potential transformer largely determines its phase angle, whereas with a voltmeter coil the phase angle is determined entirely by the leakage reactance between the primary winding and the voltmeter coil.

Exact diagrams of the voltages and currents involved in the two kinds of circuits under discussion cannot be given as the phase angles are so small that it is impossible to represent them clearly. The simplified diagram in Figs. 2 and 3 is sufficient for representing the conditions ordinarily met.

As the angle θ approaches zero, that is, as the power-factor of the test sample approaches unity, the error is correspondingly reduced. Fig. 4 is a diagram of the currents and voltages of a sample having a high power-factor. The error here is practically negligible.

Evidently a method of controlling the current I_{vc}, so that it could be kept exactly in phase with voltage E_P under all conditions of load and voltages, would eliminate the errors of the ordinary method. This control forms the principle of the compensated dynamometer wattmeter method.

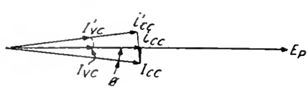


Fig. 4.

Referring to Fig. 5, it can be seen that this method derives its name from the small fixed capacity c (one microfarad) and the small variable resistance r (zero to 200 ohms) which are inserted in the voltage coil circuit. Placing c and r in parallel and varying r results in the effect of a variable capacity. With this compensator it is possible to neutralize the inductance of the voltage coil circuit and to swing current I'_{vc} exactly into phase with voltage E_P. But to do this some

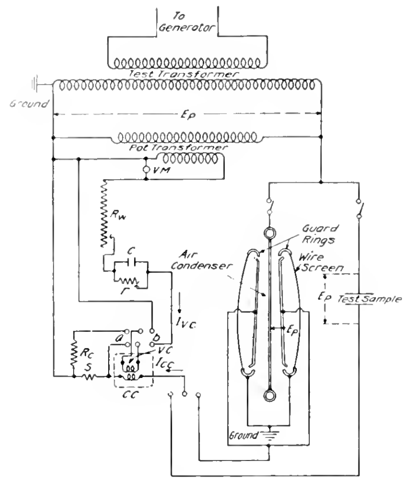


Fig. 5. Compensated Dynamometer Wattmeter Method

standard of reference is necessary, something that can be substituted in place of the test sample and in which the exact value of the angle θ in Fig. 2 is known.

A zero loss condenser having approximately the same capacity as the test sample is the most satisfactory standard of reference. The current I_{cc} then leads the voltage E_P by 90 deg., and it is a simple matter to bring current I'_{vc} into phase with E_P by varying r until the deflection of dynamometer beam is zero. The condenser can then be replaced by the test sample and the true watts loss measured. No further corrections are necessary, excepting, of course, the calibration constants of the instruments and transformation ratio.

It is apparent that the accuracy of the whole test depends upon the standard condenser having a negligible loss over the range of test voltage, zero to 60,000. The greatest difficulty encountered was the design and construction of a condenser for these requirements.

The correction for alternating current watt readings is made separately for each frequency. The measurements are accurate from zero to 100 cycles and possibly much higher.

The same instrument is used for current readings. For currents from zero to 2.5 milliamperes, the coils *cc* and *vc* are thrown in series by switches not shown in Fig. 5. For currents above 2.5 milliamperes, coil *vc* is connected across the non-inductive shunt *S* by closing switch *a*.

All calibrations are made with direct current; the possibility of errors being introduced into alternating-current readings has been carefully investigated and found to be negligible. In measuring alternating current with the coils in series there is no source of error since the same current flows through both coils. When shunt *S* is used, the slight inductance of the voltage coil causes a small angle between the currents through the two coils but a reference to Fig. 3 shows that the error due to this is too small to be measured. A compensator similar to that used in the wattmeter circuit could be inserted in one of the shunt leads for correction if necessary and possibly at higher frequencies it will be used.

The reflecting dynamometer was made especially for this work by the Standardizing Laboratory. It is remarkably steady and reliable considering its extreme sensitivity. Calibration curves taken nine months ago still hold good. In calculating the watts, the following formula is used.

$W = K \times R \times D \times$ ratio.

Wherein

W = watts loss measured.

R = value of resistance in *vc* circuit = 2000 to 20,000 ohms.

D = deflection of beam in millimeters = 0 to 500.

Ratio = ratio of transformation = 300 and 600 to 1.

K = instrument constant = 0.0121 to 0.0127 $\times 10^{-6}$.

These values give an indication of the sensitivity that can be obtained.

The dynamometer is astatic, and consequently there are no errors due to stray magnetic fields. Also, the instrument and its auxiliaries are grounded, and there is no appreciable error due to static, although the apparatus is within ten feet of the high-tension overhead wiring. The wires running from the low-tension plates of the condenser to the dynamometer are protected by wrappings of grounded tinfoil.

Zero Loss Air Condenser

Fig. 6 is a photograph of the air condenser which is used as a standard of reference. The method of connecting it in the circuit is shown in Fig. 5. Fig. 7 is a detail sketch showing the relative positions of the guard ring and plate. The surface curvatures are laid out in such a way as to reduce the concentration of stress to a minimum. Fig. 8 illustrates the method of suspending the high-tension plate from the ceiling with treated sash cord.

The two low-tension plates are placed one on each side of the suspended high-tension plate. In this way the mechanical stresses are balanced and both sides of the high-tension plate can be utilized. Each low-tension plate is supported on a sliding wooden frame-work, and its distance from the high-tension place can be adjusted by the hand-wheel shown in Fig. 6.

Fig. 9 gives the 60-cycle arc-over values of the condenser for different settings of the

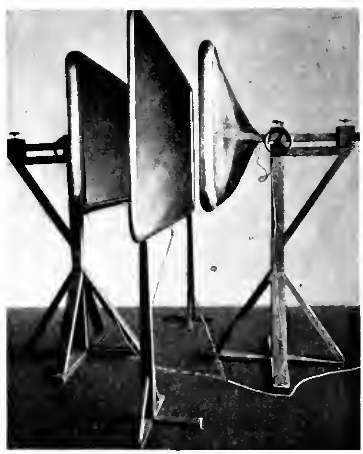


Fig. 6. Zero Loss High-Voltage Air Condenser

two low-tension plates. The plates are not true planes but are warped slightly, about one-fourth inch. The arc-overs always occurred between the two nearest points in preference to the guard rings. The distances given in Fig. 9 are between the nearest points. The fact that the arc-over readings fall on a straight line would indicate that the stress is practically uniform.

The capacity in farads for different settings is given in Fig. 10. Using Karapetoff's value of 0.08842×10^{-12} farads per cm.[3] for air, the points on the dotted curve were calculated. The measured and calculated values agree very closely for settings above four inches. The discrepancy for settings nearer than four inches is due to the slight warping that has been mentioned.

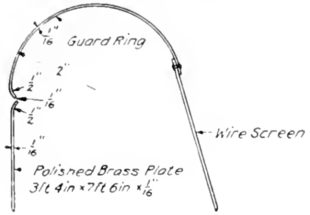


Fig. 7. Showing Arrangement of Guard Ring and Plate

Tests to Determine the Possibility of Loss in the Air Condenser

By referring to Fig. 5 and assuming the condenser switched in the circuit, current I_{cc} consists only of the capacity current flowing between the low- and high-tension plates. All ionization current from the high-tension plate and the over-head wiring is shunted to ground by the guard rings and the wire screen, consequently, it does not flow through the current coil of the dynamometer. If for any reason the angle between I_{cc} and E_P is less than 90 deg., it could only mean that there is a loss in the volume of air between the plates proper.

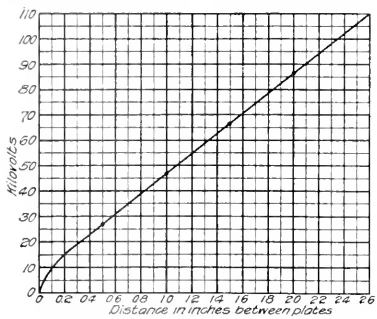


Fig. 9. Sixty Cycle Arc Over of Air Condenser

Assuming that one per cent power-factor, or a phase difference of 34 minutes from 90 degrees, is the smallest likely to be met with in any test sample and allowing an error of one per cent under this condition, which is most conservative, the maximum allowable phase difference of the air condenser is 0.34 minutes or approximately 20 seconds. This would mean that when r is adjusted to give zero deflection of the instrument beam the angle between E_P and I_{vc} would be 20 seconds instead of zero, provided there is no appreciable line leakage.

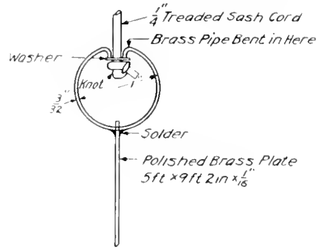


Fig. 8. Showing Method of Suspending High Tension Plate

Fig. 11 gives the maximum allowable watts loss at 60 cycles in the condenser for different settings of the plates, calculated on the basis of 20 seconds phase difference.

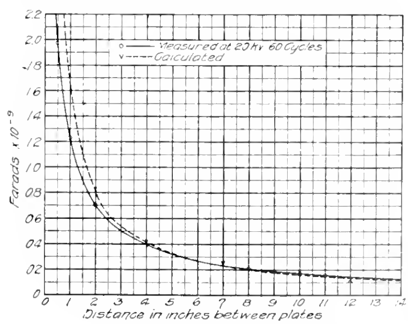


Fig. 10. Capacity of Air Condenser

This loss could be due to:

(a) Natural ionization of the volume of air between the plates.

(b) Ionization of the volume of air by some unknown source of ultra-violet rays, X-rays, or radio-active emanations.

(c) Possible failure of the guard rings and shields to entirely exclude exterior sources of loss.

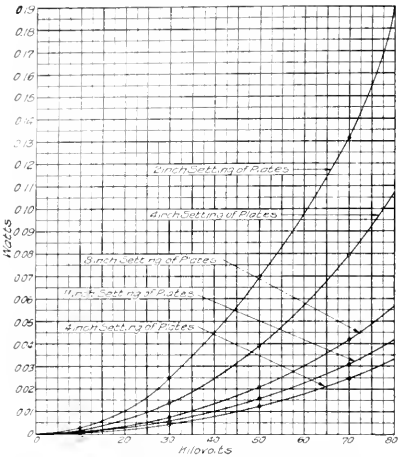


Fig 11. Maximum Allowable Loss in Air Condenser at 60 Cycles Calculated Assuming 20 Seconds Phase Difference or 0.010 per cent Power-factor

(d) Ionization by collision and impact due to over-stressing the air between the plates.

A discussion of these possible sources of loss and of the experiments made to determine the part they play in the accuracy of the test will follow. No attempt will be made to give analytical data concerning ionization phenomena. The point of interest is the determination of whether ionization phenomena in the condenser causes an appreciable error.

(a) *Natural Ionization*

According to Joly, Wilson, and other investigators, 10 ions per cm^3 per second is an average value for the natural ionization of ordinary air.

The total area of the two low-tension plates is 46,000 sq. cm. With a 14-inch setting the total volume of air between the plates is $14\times2.54\times46,000=1,635,000$ cu. cm. The total number of ions per second would then be 16,350,000. The charge on an ion is 10^{-18} coulombs, therefore, the current flowing between the condenser plates would be 0.160×10^{-10} amperes. At 60-kv. this would give a loss of the order of 10^{-6} watts. The allowable loss is 0.01 watts, which eliminates any consideration of the loss which might occur due to natural ions being neutralized at the surface of the condenser plates.

(b) *Ionization by Ultra-Violet Rays, etc.*

To determine what would be the effect of an artificial means of ionizing the air between the plates, the following test was made.

The plates were set at 14 inches and 60 kv. was applied. This caused a positive deflection of the dynamometer beam, giving an apparent loss of 0.2 watts. How much of this was a true loss and how much was due to phase-angle error was unknown at the time but was immaterial so far as the purpose of the test was concerned.

Ultra-violet rays from an iron-arc were then projected between the high-tension plate and one of the low-tension plates, the arc being held within a foot of the condenser. The rays were quite strong as was proved later by the luminescence of a piece of willemite suspended near the center of the plates. Although the ionization must have been many times that due to natural causes there was no noticeable change in the deflection of the instrument. A change of 0.002 watts could have been detected.

This test would also indicate that any appreciable loss due to ionization by impact is not to be expected at stresses below that at which ionization by collision begins; otherwise it could have been detected when the ultra-violet rays were used. The ions generated by these rays must have set free more ions upon impact with the surfaces of the plates; but since the total effect was inappreciable it is reasonable to assume that under normal conditions it would also be inappreciable.

The guard ring and wire screen of the plate nearest the iron arc were then disconnected from ground and short circuited to the plate. When the test was repeated there was a decided change in the deflection. It is evident that the change was caused by ions from the arc itself being drawn into the electric field, since the previous test showed that ultra-violet rays alone do not produce sufficient ionization. In the first test the guard rings shunted out the ions from the arc.

To obtain analytical data concerning the nature of this loss would involve many difficulties, the exact amount of ionization from the arc would have to be under control, etc. As the guard rings are not supposed to be connected to the plates, this test does not effect the true characteristics of the condenser. It does show, however, that the guard rings are effective in shunting out exterior sources of loss.

No experiment was made with X-rays as there could be no likelihood of stray X-rays causing anywhere near the amount of ionization that the ultra-violet rays caused. There is no source of X-rays within 100 feet of the condenser.

A sealed glass tube containing a small amount of radium carbonate was suspended between the plates. It caused no change in the deflection at 60 kv. This was to be expected since the effect of the weak gamma rays must be quite small in comparison with the ultra-violet rays.

There still remains the possibility of radio-active emanations from the surfaces of the plates. The plates were left standing for several weeks until considerably tarnished and coated with dust. Readings of the apparent watts loss were taken and repeated over a period of one hour without a perceptible change. The plates were then thoroughly smeared with a polishing compound and the readings repeated; these agreed exactly with the previous ones. The plates were then given a high polish and the readings taken just afterward also chekced the first.

These tests have been repeated several times and in conjunction with the ultra-violet ray tests would indicate that no appreciable loss is to be expected from radio-active emanations, unless these come from the metal itself which does not seem likely.

(c) *Failure of Guard Rings and Shields*

The possible failure of the guard rings and shields was dealt with, in part, under heading (b). The test with the iron arc proved that the guard rings and wire screen are effective in eliminating external sources of air loss. The only remaining shields are the tinfoil wrappings on the low-tension insulated wiring running across the floor The tinfoil was removed and its absence caused no change in the readings until a voltage of 90,000 was reached, and then only a change of about one per cent.

There is evidence of a slight line leakage, or ordinary surface leakage, between the high- and low-tension wiring. It varies from practically nothing in winter to an appreciable amount in summer when the humidity is high.

(d) *Ionization by Collision*

By elimination, ionization by collision remains as the only possible source of loss. In trying out the other possible sources, the conditions under which the loss was expected were maximized to show that even under these aggravated conditions no loss could be detected. The plates were left at the maximum setting of 14 inches during these tests so as to get a maximum volume of air, for the losses would be expected to vary in proportion to the volume of air at a constant value of volts per centimeter between the plates. Losses due to ionization by collision would, on the other hand, vary with the maximum voltage gradient and would be independent of the volume of air.

Short needles stuck on the surface of the plates would give the desired aggravated effect. A size 2/0 needle, cut to $\frac{1}{2}$ inch length, was stuck in the center of one of the low-tension plates with putty and another opposite it on the high-tension plate.

With a 14-inch setting it was found that ionization at the needle points did not begin until 40 kv. was reached. If this is true of needle points it can safely be assumed that without the needles there will be no ionization by collision in the condenser at the same voltage. At any rate, this gives some basis upon which the greater part of the error due to phase angle can be corrected.

The needles were removed and 40 kv. was held on a 14-inch setting; the resistance r was then varied until zero deflection was obtained. While holding this value of compensation, the data given in Fig. 12 was taken.

The two needles were then replaced in the center of the plates and the curves in Fig. 13 were taken under otherwise exactly the same conditions as those in Fig. 12. There was no change in the current. The increase in watt readings, $W_2 - W_1$, represents the loss due to the needles. In Fig. 14 this is plotted as W. The power-factors at which W was measured are also given in Fig. 14. The data in Figs. 12, 13, and 14 were taken with a value of $R_w = 5000$ ohms.

Referring to Fig. 12, the apparent watts loss W_1 is somewhat greater than the maximum allowable loss in the condenser. Using a value of $R_w = 2000$ ohms, compensation was again made at 40 kv. and 14-inch setting, and the readings shown in Fig. 15 were taken. If W_1 were a true loss, the 5000 and 2000-ohm readings would have checked but there was a difference of almost 100 per cent. This would indicate that at least the greater part of W_1

is phase-angle error, and if any of it at all is a true loss it comes very close to the maximum allowable loss given in Fig. 11. The error was caused by a change in the phase angle of the potential transformer with change in voltage.

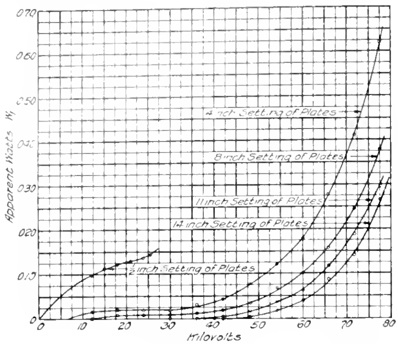


Fig. 12a. Apparent Watts Loss in Air Condenser at 60 Cycles. Compensation made at 40 kv. and 14 inch Setting

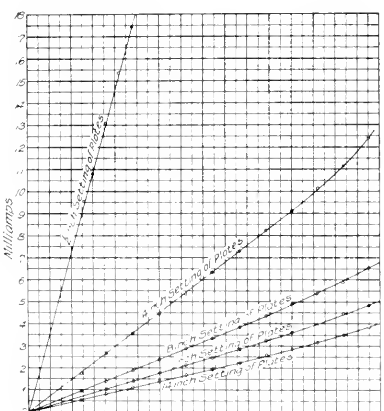


Fig. 12b

The values of W_1 in Fig. 14, are consequently not exactly correct but the error could not be greater than a few per cent.

It is interesting to note that the dielectric field between the plates surrounds the needle points and tends to neutralize the lines of stress radiating from them, thus reducing the maximum voltage gradient. This accounts for the small loss at the needle points and for the high voltage at which ionization begins. Measurements were taken on an ordinary needle-gap without a surrounding dielectric field. At a setting corresponding to 14 inches in Fig. 14, ionization began at 13 kv. and the loss was six times that in Fig. 14.

In the next test the needles were removed; and, using the same values of compensator resistance r and main resistance R_w as were used in Fig. 12, curve I in Fig. 16 (a) was taken. The voltage was held constant at 40 kv.; in this way the error due to the change in phase angle of the potential transformer was eliminated, that is, current I'_{vc} was held constant in value and phase position. Decreasing the distance between the plates increased the current I_{cc} and this caused an increase in the induced voltage across coil vc, due to mutual inductance; but as the current I_{cc} was practically 90 deg. from the current I'_{vc} the induced voltage was in phase with I'_{vc} and acted simply as a small resistance, so small in comparison with R_w that it could be ignored.

The data in curve I were taken during the winter in a dry steam-heated room. No line or surface leakage would be expected under these conditions; and it follows that, since

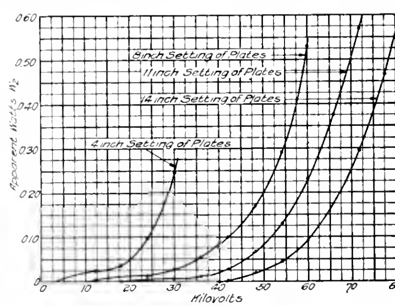


Fig. 13. Apparent Watts Loss in Air Condenser at 60 Cycles with Needles Stuck on Center of Plates. Compensation Made at 40 kv. and 14 inch Setting

there was no possible source of error, the values in curve I represent a true watts loss in the condenser.

Many experimenters have shown that air is much more easily ionized in dry winter weather than in any other season, the ionization being many times that to be expected during damp summer months. This not only applies to natural ionization but to forced ionization as well, since the two are closely related.

The test was repeated this past summer when the humidity was 89 per cent and the data are given as curve *II* in Fig. 16 (a). The deflection of the instrument was negative and this can only be explained by some source of phase-angle error. A true watts loss must read positive.

Measurements made, at the same time curve *I* was taken, to determine the surface leakage of porcelain insulators showed this leakage to be practically nothing, but when these measurements were repeated the day curve *II* was taken the surface leakage was quite large. It would be expected

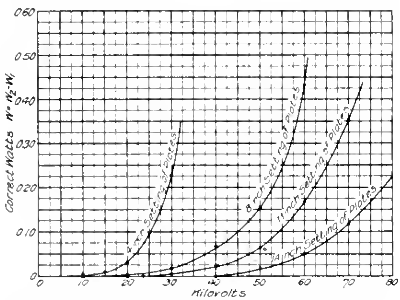


Fig. 14a. Correct Watts Loss Due to Needless $W = W_2 - W_1$ Where W_2 is Watts Loss in Fig. 13 and W_1 the Loss in Fig. 12

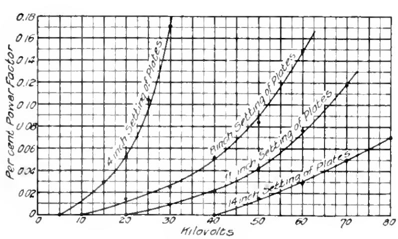


Fig. 14b

that surface leakage between the low and high-tension circuits caused the negative readings noted. This can be explained diagrammatically.

Fig. 16 (b) is a representative diagram of the currents and voltage of curve *I*. It can safely be assumed the line leakage is negligible and also be assumed that at the 14-inch setting current I_{cc} is 90 deg. from voltage E_P. These assumptions can be made on the evidence of the surface leakage tests of porcelain insulators and the needle loss data in

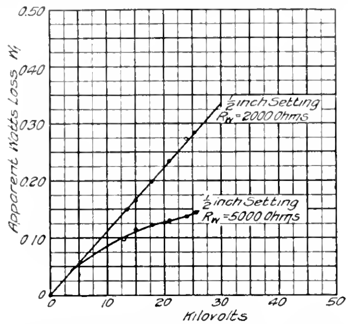


Fig. 15. Apparent Watts Loss in Air Condenser at 60 Cycles Measured with Different Values of R_w. Compensation Made at 40 kv. and 14 inch Setting in Both Cases

Fig. 14. Current I_{vc} is brought into phase with voltage E_P by obtaining zero deflection on the instrument.

When the plates are moved to the 7-inch setting the voltage stress is doubled. Current I_{cc} then takes a position θ instead of remaining 90 deg. from E_P. The product of I_{vc} and i_{cc} represents the true watts loss at the 7-inch setting. Curve *III* in Fig. 16 (a) is plotted from the needle-point data in Fig. 14. Curves *I* and *III* have the same characteristics and it would therefore be expected that the condenser loss as given by curve *I* is due to ionization by collision.

If the room is darkened and the stress increased nearly to the arc-over point, a faint glow is noticeable at several places on the ½-inch radius curvatures of the edges of the plates and guard rings. These curvatures were shaped by hand and it was impossible to make them exactly true, or to assemble the guard rings in exact position. There is a slightly uneven distribution of stress at these defective points, enough to cause some ionization by collision. That it is very slight is evident from the intense brushes visible on the high-tension wiring and on the points of support of the high-tension plate.

Fig. 16 (c) is a representative diagram of the currents and voltage of curve *II*, Fig. 16 (a). The assumptions here are just the reverse of those made for Fig. 16 (b). It is assumed that ionization is negligible and that surface leakage caused the negative readings. At the 14-inch setting current I_{cc} is the vector sum of the condenser current I_c, 90 deg. from E_P, and surface leakage

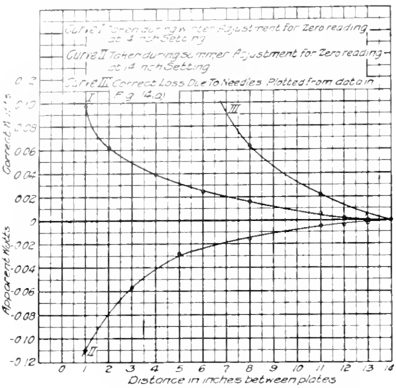


Fig. 16a. Loss in Air Condenser at 40 kv., 60 Cycles

Curve I taken during winter. Adjustment for zero reading at 14-in. setting.
Curve II taken during summer. Adjustment for zero reading at 14-in. setting.
Curve III correct loss due to needles plotted from data in Fig. 14-5.

current I_L, nearly in phase with E_P. When compensation is made, current I'_{vc} is adjusted 90 deg. from current I_{cc} and is consequently $(90° - \theta)$ from voltage E_P instead of being in phase with it.

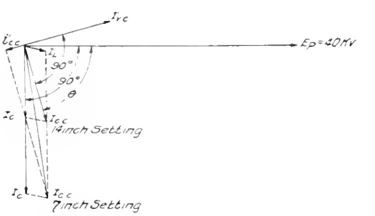


Fig. 16c. Diagram of Currents and Voltage in Curve II Fig. 16a

Now, consider the plates moved to the 7-inch setting. As has been assumed for the sake of simplicity that no ionization takes place, current I_c will still be 90 deg. from E_P. The projection of I_{cc} on I'_{vc} gives i'_{cc} and the apparent negative watts is represented by the product of I'_{vc} and i'_{cc}. No doubt there is slight ionization even in summer time, but surface leakage causes the greater part of the error as is evident by the negative readings.

Curves *I* and *II* represent the two extremes of positive and negative error to be expected throughout the year. Fortunately, ionization and surface leakage vary in opposite directions and when one is a maximum the other is a minimum. The two extremes, curves *I* and *II*, come practically within the maximum allowable watts error as given in Fig. 11. As the amount of error is approximately known, it can be corrected for in the case of samples having a power-factor less than one per cent.

All of these tests and a number of others show that the errors to be expected come within the allowable limits over the whole working range of voltage.

In concluding the discussion of the air condenser, Fig. 17 is given to show the watts loss of the condenser when the guard rings and wire screens are disconnected from the ground and short-circuited to the low-tension plates. Most of the loss comes from ionization on the overhead high-tension wiring and at the points of support of the high-tension plate. The data are further proof of the effectiveness of the guard rings when separately grounded.

Data on Insulating Materials

Energy loss measurements on two or three types of insulation will be given as a check upon the accuracy of the compensated method.

Curves *I* in Fig. 18 give the measurements on transil oil with compensated correction.

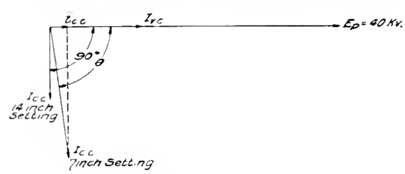


Fig 16b. Diagram of Currents and Voltage in Curve I Fig. 16a

Curves *II* were taken on the same sample using the voltmeter coil of test transformer without compensation. The average error of curves *II* is 25 per cent, the apparent loss being greater than the true loss, that is, current I'_{vc} leads voltage E_P. The interesting

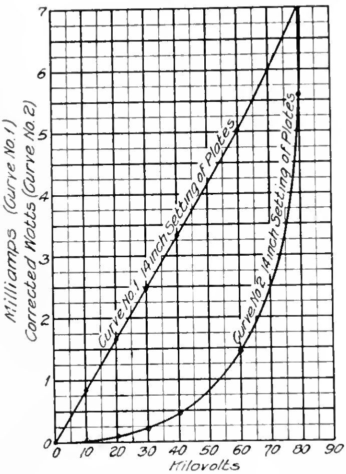


Fig. 17. Watts Loss in Air Condenser at 60 Cycles Guard Rings Connected to Plates

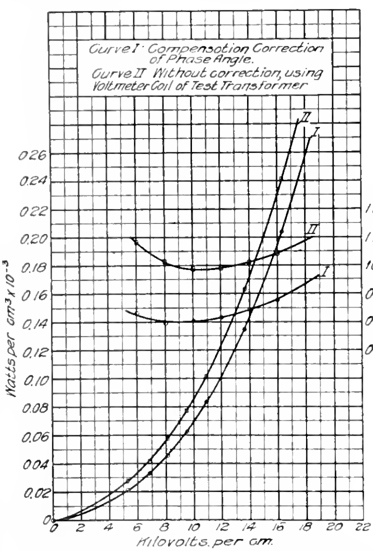


Fig. 18. Dielectric Energy Loss in Transil Oil at 60 Cycle Plates 40 cm. Diam. Distance Between Plates 2 cm. Temperature 25 deg. C.

Curve I: Compensation correction of phase angle.
Curve II: Without correction, using voltmeter coil of test transformer.

fact about these curves is that the error is not more than 25 per cent. Much larger errors were expected, notwithstanding the fact that the whole test was laid out in such a way that phase-angle errors would be reduced to a minimum.

Fig. 19 gives the measurements on an 8-foot sample of paper-insulated three-conductor cable with lead sheath. High voltage was applied to one conductor, the other two being connected to the lead sheath. Curve *I* was taken with compensated correction. Curves *II* and *III* were taken without this correction—curve *II*, using a potential transformer, and curve *III*, the voltmeter coil of test transformer. The phase angles, θ' and θ are in opposite directions. With the potential transformer, current I'_{vc} lags behind voltage E_P; while with the voltmeter coil, it leads E_P. Curve *II* shows an error of 16.5 per cent and curve *III* and error of 24 per cent.

When the compensated method is not available, it is much more desirable to use a

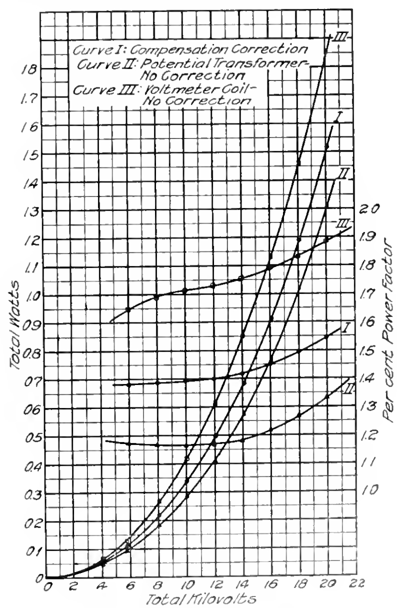


Fig. 19. Dielectric Energy Loss at 60 Cycles Three Conductor Paper Insulated Cable Length 8 ft. Temperature 25 Deg. C

Curve I: Compensation correction.
Curve II: Potential transformer—no correction.
Curve III: Voltmeter coil—no correction.

potential transformer rather than the voltmeter coil. The error is not only less with a well designed potential transformer but it is also independent of the value of current in the high-voltage circuit of the test transformer, depending only upon the relative values of the angles θ and $(\theta' - \theta)$.

Even when the compensated method is available, the potential transformer is the more desirable. With a voltmeter coil, the error increases with the capacity of the test sample and when correction is made the condenser must be adjusted to the same capacity as the test sample. The size of the sample is consequently limited by the capacity of the air condenser. With a potential transformer almost any size of sample can be used and the corrections are much easier and quicker to make.

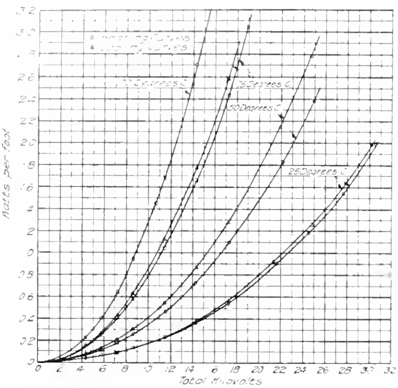


Fig. 20a. Dielectric Energy Loss Measurements at 60 Cycles Black Varnished Cambric Tape Wrapped on Rod ½ inch Diameter Total Thickness of Insulation 280 Mils

□—Heating curves.
△—Cooling curves.

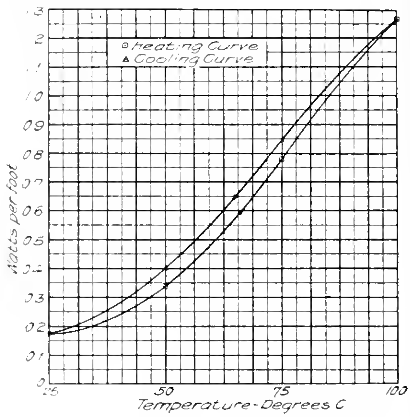


Fig. 20b. Watts Loss *vs.* Temperature at 10 Kilovolts

□—Heating curve.
△—Cooling curve.

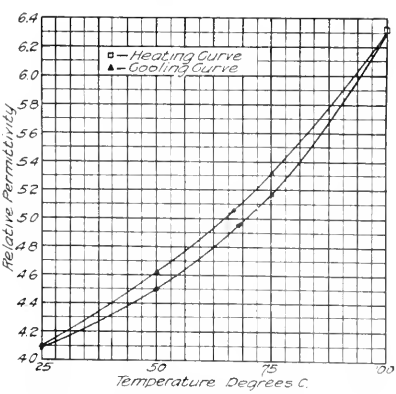


Fig. 20c. Per Cent Power-factor *vs.* Temperature at 10 Kilovolts

□—Heating curve.
△—Cooling curve.

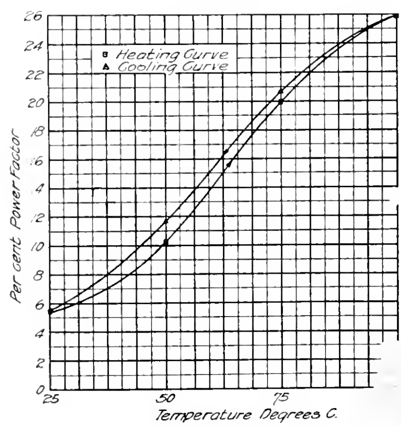


Fig. 20d. Calculated Permittivity *vs.* Temperature

□—Heating curve.
△—Cooling curve.

The characteristics of black varnished cambric are given in Fig. 20. Measurements were first taken at 25 deg. C. and the temperature raised by steps to 100 deg. C. The temperature was then lowered by the same steps to 25 deg. C., thus forming a complete heat cycle. The data at each temperature step were taken in about four minutes time.

A great deal of data have been taken on various liquid and solid insulations, as well as different types of cables and coils. Some of the characteristics noted are very interesting and will be described in a future article.

In concluding, thanks are due Mr. L. T. Robinson whose advice and support has made this development possible.

A NEW TIME LIMIT OVERLOAD RELAY

By H. G. French

Switchboard Engineering Department, General Electric Company

The time limit overload relays heretofore available, which come into action only at times of heavy overloads and short circuits, have been subject to the disturbing influences of abnormal fluxes in their magnetic circuits, more or less upsetting their accuracy. This article describes a new type of time limit overload relay in which these objectionable features have been entirely eliminated, and other improvements introduced, including an index plate of time delay values in actual figures, modifications in the temperature compensating device, method of arranging contact points, facilities for making adjustment, etc.—Editor.

Induction relays are constructed upon the principles of alternating current meters and instruments; but with the difference that the latter are required to operate only on currents within the limits of normal conditions of their circuits, whereas the former must remain inoperative while carrying normal loads, and act with precision under the extreme and severe effects of heavy overloads and short circuits. Relays of this type heretofore have not been free from the disturbing influences of heavy fluxes set up in their magnetic circuits during their periods of action, which greatly interfer with their accuracy and produce visible and audible evidences of distress.

A time limit relay of new design, shown in Fig. 1, is the first device of this kind that is so constructed as to be entirely free from such disturbances. Under the application of the heaviest currents that abnormal conditions of a circuit could cause, this relay performs its circuit-closing operation as quietly and with as much precision as an induction meter does with normal load. It is not only responsive to the conditions it is designed for, and capable of repeating its action under these conditions satisfactorily, but is substantially constructed and requires the minimum of attention.

It is made as a single pole, circuit-closing device, for frequencies of 25 or 60 cycles, with a continuous rated capacity of 5 amperes, and is suitable for operation from current transformers. Its characteristics are such that selective action of two or more relays is assured when settings are made with due regard to the time element inherent in the mechanism of the circuit breaker controlled. As seen from Fig. 2, the time current curves do not converge at the heaviest overloads. The time element is remarkably constant, and repeated operations exhibit little variation.

Referring to some time current curves of this relay, one of which is for lever setting 10, or full travel, and the other for lever setting 5, or half travel (see Fig. 2), it is seen that for a considerable range of overloads the characteristics are those of an inverse time limit relay; but at the heavier overloads the curves are of the definite time variety. The inverse portion of the curve is due to the automatic progressive limitation of the alternating magnetic flux acting on the relay disk in conjunction with the inherent characteristics of the induction device. This limitation of flux also serves the important purpose of securing quiet, steady operation under the severest conditions.

Another improvement embodied in this device is the index plate bearing time delay values in actual figures—80 values in all, covering the entire range of the relay from $1\frac{1}{2}$ times normal load upward. The provision of direct reading time delay values is consistent with the purpose of making a relay not only inherently accurate, but facilitating its setting by direct and simple methods which make its qualities easily available, without the use of auxiliary apparatus for determining time adjustments by trial, except where special precision is desired. Although given decimally as a matter of convenience, the time delays on the index plate should be recognized as mean values which are within reasonably close limits in actual operation.

Examination of the index plate shows that each vertical column of time delay values represents points in the characteristic time

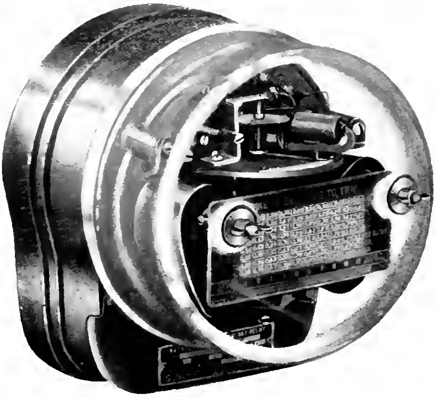


Fig. 1. Time Limit Overload Relay

current curve for a particular lever setting (see Fig. 3). The same time values apply for each of the current calibration points on which the relay may be set to act, these being 4, 5, 6, 8, or 10 amperes, according to the point at which the current plug is set. These are the minimum currents required to cause tripping. The currents corresponding to the time values in the vertical column are therefore expressed on the index plate as multiples of the current tap setting, each multiple referring to a horizontal row of time values. For instance, with No. 7 lever setting the relay will trip at the end of 1.44 seconds when the current plug is set at 6 amperes and a current of 10 times the current tap setting (i.e., 60 amperes) is applied. It will also trip after the same length of time when the current plug is set at 10 amperes and a current of 10 times 10 amperes (100 amperes) is applied. If for a particular current setting it is desired to set the relay to trip at some current the multiple of which is not listed on the plate, the required lever setting may be very closely found by interpolation of the "times current tap setting" value with the time delays corresponding to it, in the various columns.

The adjusting lever which limits the angular travel of the disk and thereby controls the time element, is just above the index plate, and has a scale with divisions from 1 to 10 inclusive for each of the corresponding numbered columns of time values.

Changes in surrounding temperature will cause an induction time limit relay to act with a large variation in its time delay, if uncompensated for such changes. This relay is provided with an efficient temperature compensating device, which is another point of excellence in its construction. This device keeps time delay variations within reasonable limits.

The vertical suspension jewel bearing of the moving element and the permanent magnet retardation represent the best known means of securing a time element of constancy, practically free from tendency to change. The friction of the bearing is very small and constant, and the relay disk, moving in the air gap of the permanent magnets, is subjected to a retardation which is free from friction or other mechanical influences.

Contacts of high heat resisting quality are used for the tripping circuit, both contact springs being mounted on a stationary support so that they are brought into contact by a moving arm actuated by the relay disk. This avoids carrying the tripping current through the return spring of the relay shaft, and allows the use of contact springs and contacts of ample size for carrying the current necessary for tripping directly even large oil circuit breakers without the use of any auxiliary relay. The contacts are held tightly together after the closing movement of the relay, by the pull exerted by an electromagnet connected in series with the contacts, so that the trip current holds them positively closed until its circuit is opened by the usual auxiliary switch actuated by the circuit breaker in its opening movements.

This construction makes it impossible for the trip current to be broken by the relay contacts, as they are automatically locked together until the circuit is properly opened elsewhere and in addition to this, a nonarcing contact is insured. The contact block with the springs and contacts is readily removable without disturbing any adjustments so that full provision is made for even the remote possibility of a needed renewal of contacts.

An instance of the attention given to convenience of adjustment is the spare current tap plug, located beneath the index plate.

When a change of current setting is to be made with the relay in service, this spare plug is first withdrawn and screwed into the current tap of the circuit on which a change is desired. The tap plug previously in use is removed from its setting in the current tap plate and placed in the receptacle for the spare. The change of current setting is thus accomplished without opening the secondary circuit of the current transformer, which would otherwise have to be short-circuited, involving more or less time and inconvenience.

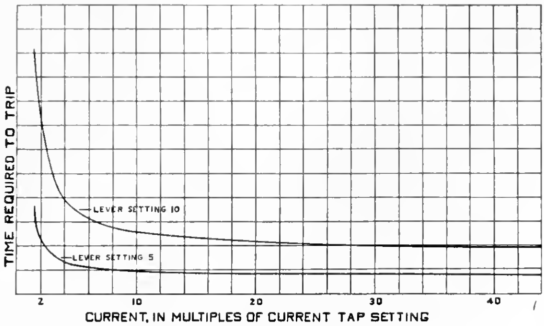


Fig. 2. Time-current Curves of Relay

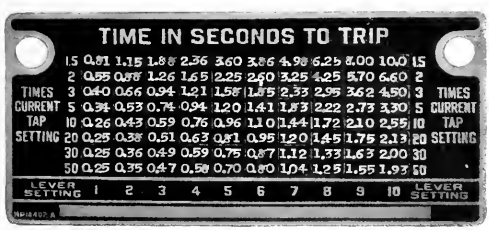


Fig. 3. Index Plate Giving Time Delay Figures

A particularly desirable feature of this relay is that its entire construction is such that it requires practically no attention to maintain it in service; there are no parts requiring lubrication, no adjustments that are subject to change by aging of the parts or influence of the weather. The case is dust-proof, and aside from making changes of time or current settings as may be necessary on account of operating conditions, nothing is required except to see that the glass cover, through which the moving parts are plainly visible, is secured to the relay against the felt gasket with which it is provided. The cover can be readily sealed if desired to insure the settings remaining unchanged except by authorized persons.

In general it may be said that this relay embodies the manufacturing and operating experience gained from various and widely divergent types of electrical devices, supplemented by exhaustive experimental work in new development, the result being a protective device combining in remarkable degree the qualities of accuracy, simplicity and reliability.

ELECTRICAL WATER HEATING IN THE HOUSEHOLD

By J. L. Shroyer

Heating Device Engineering Department, General Electric Company, Pittsfield, Mass.

This article records the results obtained in an extensive investigation of the various methods of heating water electrically for household use. A description is given of the three logical systems: the instantaneous, the intermittent storage, and the continuous storage. Valuable test data are given concerning both the operating cost and the water temperature and volume characteristics of each system. An analytical summary of the investigation together with recommendations conclude the article.—Editor.

A great many persons have become interested in the possibilities of heating water by electricity for household purposes. This interest is largely due to the introduction of electric ranges for cooking. In replacing a coal or gas range with an electric range, many prefer to eliminate coal and gas entirely from the household and therefore demand an electric water heater.

The experimental data in this article was first published in the "Report of the Electric Range Committee" and read before the National Electric Light Association at its thirty-ninth convention in Chicago, May 22, 1916.

Since more energy is required to raise the temperature of a given quantity of water one degree than to produce the same rise in an equal quantity of almost any other substance—for example, about ten times that required for the common metals—it is evident that the application must receive careful attention to become practical and successful. Various types of heaters for converting electrical energy into heat energy and transmitting it to water have been tried and found quite satisfactory. Efficiencies of 90 to 100 per cent are easily obtained.

Realizing, then, that a relatively enormous amount of energy is required to heat water, it is seldom practical to supply electrical energy at a rate fast enough to instantly heat the average quantities of water required. This condition makes the problem more difficult and the best solution seems to be the use of a storage tank, to which the following alternative methods are adaptable.

(1) To anticipate the requirement and turn on the heater for a sufficient time to heat the quantity of water desired (the operation being practically the same as for an ordinary gas heater).

(2) To maintain a storage tank of hot water (the heater being left on continuously or being controlled by a thermal or time switch).

Instantaneous Method

With this system the current is turned on at the time the faucet is opened and the water is heated from cold-water temperature to the desired temperature as fast as drawn. This method, considering service only, is ideal, but is very objectionable to central stations on account of the enormous power required at intermittent intervals. It would require a 40-kw. heater to heat 25 gallons of bath water from 10 to 40 degrees in five minutes, or a 20-kw. heater ten minutes. The cost of providing for the delivery of electric energy at such a rate for intermittent periods is prohibitive. At least a 6- to 10-kw. heater is required for satisfactory service for even small quantities of water. Even for 6 to 10 kw. very few central stations could offer a rate per kilowatt-hour which would be considered practical. For general household purposes, it is therefore evident that instantaneous water heaters need not be considered for the present.

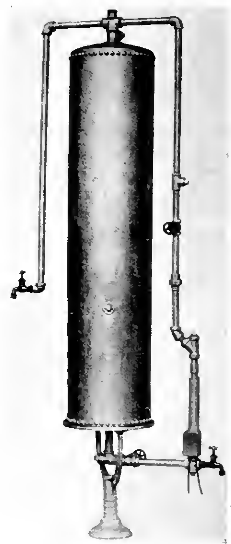


Fig. 1. Installation of an Electric Circulating Water Hater and Tank

Storage or Continuous Method

Various schemes of accumulating and storing hot water have been tried with results that have led to further improved methods. A study of the results obtained clearly indicates the importance of selecting the most suitable combination for the desired results. The merits of the principal methods will be treated as follows.

Immersed Unit System

This system consists of a storage tank containing a heating unit immersed directly in the water at the bottom of the tank. It is evident that this combination gives a maximum efficiency for the electric heater and, without further consideration, would appear to be satisfactory for all requirements. However, a more careful study discloses the fact that the whole tank heats up practically uniformly; therefore, this method would be exceedingly unsatisfactory for household purposes wherein the tank may nearly be drained of hot water for the laundry or the bath and then shortly thereafter a small quantity of hot water might be wanted for cooking, or for washing. Though not practical for general household purposes, this method is particularly suitable for heating large quantities of water to be drawn off at a given time or for maintaining a constant temperature where the water is not drawn off, as for some industrial requirements.

Circulation System

This system consists of a storage tank and a heater in an outside pipe circuit connecting the bottom and top of the tank. The hot water in the circulating pipe, being less dense than the water in the tank, rises and accumulates at the top. The temperature of the water delivered to the top of the tank depends on the capacity of the heater and upon the rate of flow. This method is quite generally used and is particularly suited for household requirements.

Regulation of Circulation System

As mentioned in the preceding paragraph, the maximum temperature to which the water in the top of the storage tank is raised, in a given time, depends upon the rate of flow through the heater. The curves in Fig. 2 clearly indicate the necessity of properly adjusting the rate of circulation for the capacity of the heater used. Since the rate of flow depends upon the water head and pipe resistance, the rate of circulation may be controlled by altering either. The first may be adjusted by varying the relative position of the heater and tank, the second by varying the size of the circulation pipe. Referring to the curves in Fig. 2, it should be noted that after two hours with a restricted pipe the water in the top of the tank is 23 deg. C. hotter than after the same time without restriction; also, that a reduced circulation is obtained by raising the position of the heater with respect to the tank. With this latter arrangement the same maximum temperature in the top of the tank was obtained after seven hours, as with restriction. While the circulation is reduced by raising the position of the heater, it is evident that the effective tank storage for hot water is also reduced; and an inspection of these curves indicates that the most desirable combination is obtained with the heater at the bottom of the tank and the rate of circulation limited by pipe resistance.

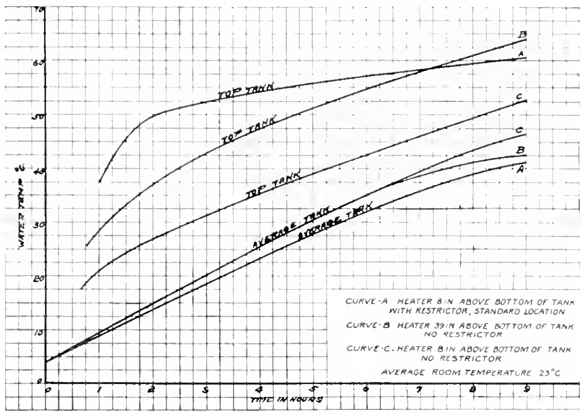


Fig. 2. Performance Curves of 1000-Watt Heater on Tank B (see Fig. 4)

Continuous Heater

Since a heater which operates continuously requires a minimum amount of attention, it is obvious that good service is obtained; and, if the central station is in a position to supply energy at a reasonably low rate, this method becomes practically ideal. In considering the service to be obtained, reference should be made to curves *E*, *A* and *C* in Fig. 3. These curves show the actual hot water obtained from 1000- and 600-watt continuous heaters as compared with a 3-kw. intermittent heater having a thermal control, that is, a thermostat placed in the circuit of a 3-kw. heater to open the electric circuit automatically when the water in the tank reaches the maximum desired temperature, and to close the circuit automatically when the tank water temperature falls below a certain temperature. From these curves it is evident that with a 750-watt continuous heater practically the same hot water would have been obtained as from a 3-kw. intermittent heater and that it would have been obtained at an efficiency of probably 76 per cent as compared with an efficiency of 72 per cent for the intermittent heater. It should also be noted that after the schedule of water for the day had been drawn off there was available, for bath or other purposes, 16 gallons of 40-deg. C. water with the 600-watt heater or 27 gallons of 40-deg. C. water with the 1000-watt heater, compared to 10.5 gallons of 40-deg. C. water with the 3-kw. intermittent heater. From an analysis of the curves, it is plain that a 600- to 1000-watt continuous heater and a well-lagged tank will provide excellent service for the average household; also, that a higher efficiency is obtained with a continuous heater. Furthermore, the intermittent type, without a thermostat, would require fully as much attention as an ordinary gas heater.

Continuous Water Heater Installed with Electric Range

Central stations have given considerable attention to the combined operation of the continuous electric water heater and the electric range, the object being to utilize the continuous load of the water heater to increase the load-factor of their circuits. To fully appreciate the importance of this combination to the central station, the effect on the range load-factor is brought out in the following example.

According to actual records of a circuit supplying 40 domestic ranges, the average total load for 24 hours was 4.68 kw. The maximum peak was 17 kilowatts. Assuming that the average load per range, in service at a given time, is 1000 watts, it is evident that the load-factor would be increased from 27.5 to 85 per cent or higher by using a 1000-watt water heater with a throw-over switch so that the heater is thrown off the circuit when the range is turned on, and vice versa.

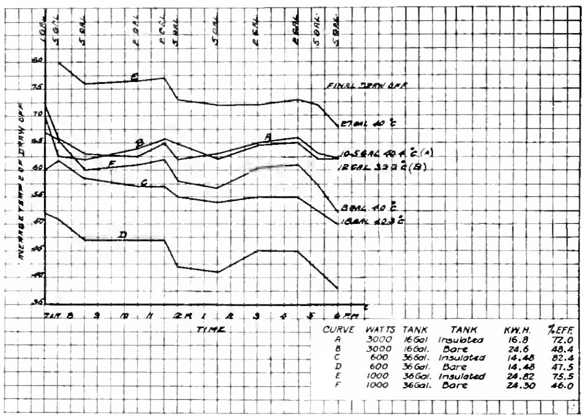


Fig. 3. Duty Curves for Average Daily Cycle. Average Room Temperature 22.5 Deg. C., Average Feed Water 3.5 Deg. C.

Effect of Waters Containing Large Amounts of Salts in Solution

It has been found that four months is sufficient to absolutely fill with scale a 1000-watt circulation type water heater, when heating some of the Western waters. The water circulation is then ended and the heater usually burns out. To meet this condition it has been found necessary to design a heater with sufficient outside radiating surface that, no matter if the interior is entirely filled with scale, the heater will not be injured. The scale can be chipped out or may be slowly dissolved with diluted hydrochloric acid.

Description of Apparatus Used in Tests

Figs. 1 and 4 show the apparatus used. Tank *A* is a 16-gallon galvanized tank which was used with the larger sizes of heaters. The purpose was to investigate the feasibility of using a small storage tank and high-wattage heater with a thermal control that automatically opened the heater circuit when the temperature in the top of the tank reached a desired maximum. This thermostat was placed in the circulation pipe between the heater and the top of the tank. The tank and piping was lagged with a one-inch layer of hairfelt, held in place by a canvas covering. Tank *B* is a 36-gallon iron tank such as is used in most domestic installations. The temperature of the water in this tank was observed by means of 10 horizontal thermometer wells spaced at equal distances along the length of the tank, each well extending into the center of the tank. Tank *B* heater and connections, as shown in Fig. 4, are considered to constitute the standard arrangement. The heater was placed low in relation to the tank and a restrictor was used in the circulating pipe. The restrictor was a short length pipe with a relatively small inside diameter, inserted to limit the rate of flow of the circulating water. Thus, a small quantity of hot water is quickly accumulated in the top of the tank, where it is immediately available. Where reference is made to tank *B* being lagged, a canvas jacket was used to hold a one-inch layer of hairfelt on the tank side and top; also, the pipe from the top of the tank to the heater was covered with a one-inch layer of 85 per cent magnesia insulation.

Tests

The water drawn off in the various runs was measured with a vessel of known capacity and the temperature of the water in the vessel was measured with a thermometer. The series of tests was made to determine the maximum quantity of water available after a given time, starting cold, from four standard sizes of heaters; viz., 600, 1000, 2000 and 3000 watts. These tests were made with tank *B* standard connections, with the heater and

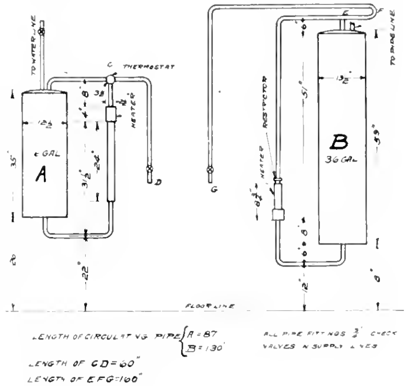


Fig. 4. Diagram of Piping for Circulating Water Heaters

piping lagged as described. The heater was run a certain length of time and then the water was drawn off until the average temperature of the draw-off was 40 deg. C. (104 deg. F.). The results of these tests are shown in Figs. 5, 6, 7 and 8. The curves show the number of gallons of water available at the temperature given, for any length of run. When the problem of water heating is merely to obtain a certain amount of hot water in a given time, this data is sufficient, but the average household requirements are an entirely different problem.

In general, the demand is for moderate quantities of hot water at varying intervals and not for a definite quantity at a given time. To determine the relative efficiency for various combinations, the amount of the average demand must first be decided upon. The following schedule was accepted as being representative of the average daily requirements.

Time	Gallons of Hot Water Drawn Off	Time	Gallons of Hot Water Drawn Off
7:00 a.m.	1.0	1:30 p.m.	5.0
7:15 a.m.	5.0	3:00 p.m.	2.0
8:30 a.m.	5.0	4:30 p.m.	2.0
10:30 a.m.	2.0	5:15 p.m.	5.0
11:30 a.m	2.0	6:00 p.m.	5.0
12:00 a.m.	5.0		

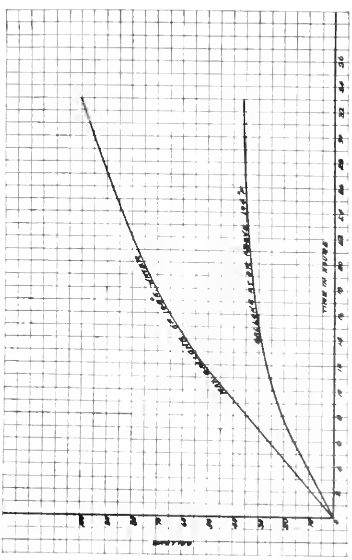


Fig. 5. Performance Test Curves of 600-watt Heater with 36-gal. Lagged Tank. Feed Water 59 Deg. F.

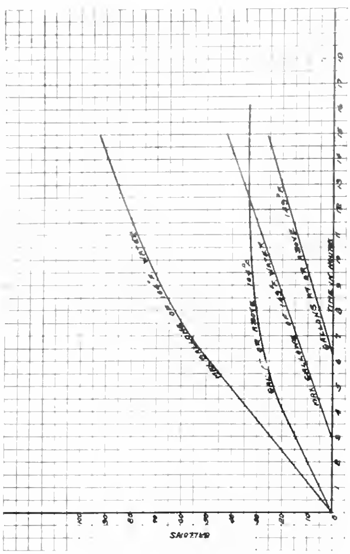


Fig. 6. Performance Test Curves of 1000-watt Heater with 36-gal Lagged Tank. Feed Water 59 Deg. F.

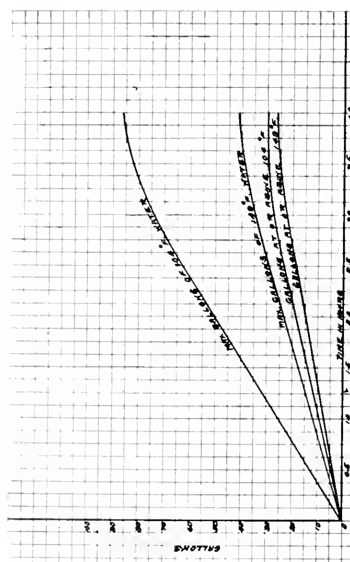


Fig. 7. Performance Test Curves of 3000-watt Heater with 36-gal. Lagged Tank. Feed Water 59 Deg. F.

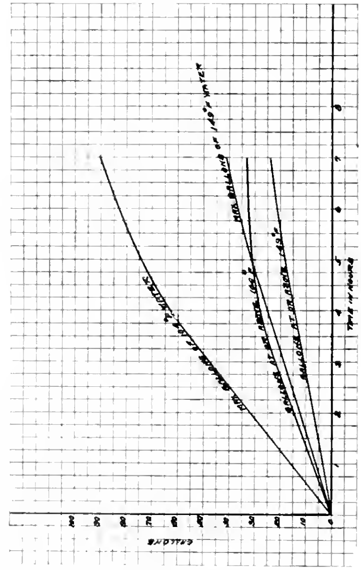


Fig. 8. Performance Test Curves of 2000-watt Heater with 36-gal. Lagged Tank. Feed Water 59 Deg. F.

This schedule was followed for two consecutive days, the power being left on continuously; and, after the scheduled gallons had been drawn off, an additional quantity was drawn off each evening until its average temperature dropped to 40 deg. C. (104 deg. F.). This last quantity represents the quantity of hot water available for bath, laundry, etc.

Explanation of Curves

Fig. 9, by the curves starting in the left-hand upper corner, shows the relation between time and energy to heat a given quantity of water from 15 deg. C. to 40 deg. C. (59 deg. F. to 104 deg. F.). The curves starting at the left-hand lower corner show the relation between total cost and rate per kilowatt-hour to heat a given quantity of water from 15 deg. C. to 40 deg. C. (59 deg. F. to 104 deg. F.). All the curves are based on 100 per cent efficiency.

Fig. 10 shows the relative rates for electricity and gas for the same total cost of operation and the same service. The upper curve is based on approximate actual efficiencies of electric and gas heaters. The lower curve is based on 100 per cent efficiency for both electricity and gas.

Fig. 11 shows test data for a standard gas heater.

Figs. 5, 6, 7 and 8 show the maximum gallons of 40-deg. C. (104-deg. F.) and 65-deg. C. (149-deg. F.) water that can be obtained after any given time: also the number of consecutive gallons drawn off having a temperature of 104 deg. F. or greater, and 149 deg. F. or greater, with 600-, 1000-, 2000- and 3000-watt electric heaters.

Fig. 12 shows the cooling curves for tank *B* bare and lagged.

Fig. 13 shows the ultimate tank temperature gradients with a 1000-watt heater, tank bare, and with a 600-watt heater, tank insulated with one inch of hairfelt.

Fig. 2 shows the relative heating characteristics with a 1000-watt heater connected, *A*, at the bottom of tank with restrictor, *B*, at the top of tank without restrictor, and, *C*, at the bottom of tank without restrictor.

Fig. 3 shows duty curves covering a 24-hour cycle, the water being drawn off in accordance with the given schedule. After the last five gallons were drawn off at 6 p.m., an additional quantity was drawn off until the average temperature of the water drawn off was 40 deg. C. (104 deg. F.). It should be noted that curves *A* and *B* represent the duty obtained with thermo-controls which limited the maximum temperature of the tank water. Practically the same quantity and temperature of hot water was obtained with an insulated and an uninsulated tank. Insulating the tank increased the efficiency from 48.4 to 72 per cent.

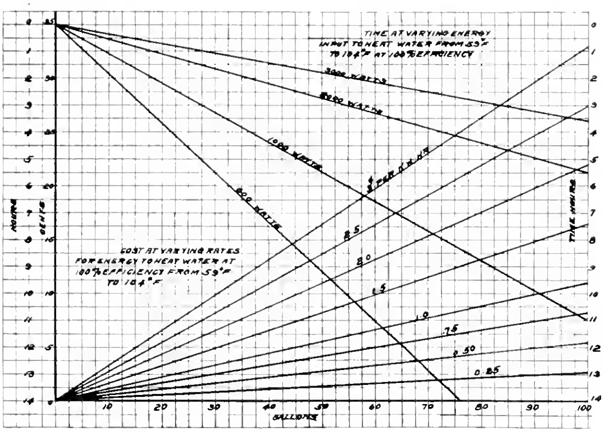


Fig. 9. Circulating Water Heater Time Curves (upper) Cost Curves (lower)

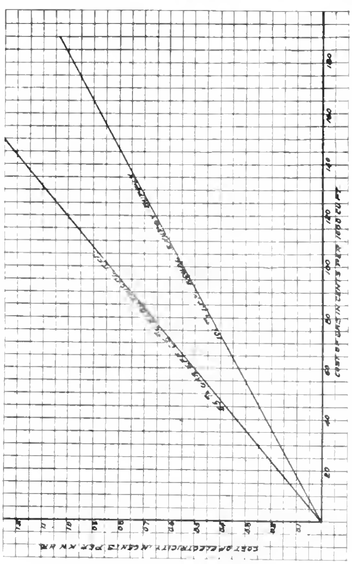


Fig. 10. Equivalent Rates for Equal Cost of Operating of Electric and Gas Water Heaters. (Based on Gas with 625 B.t.u. per cu. ft.)

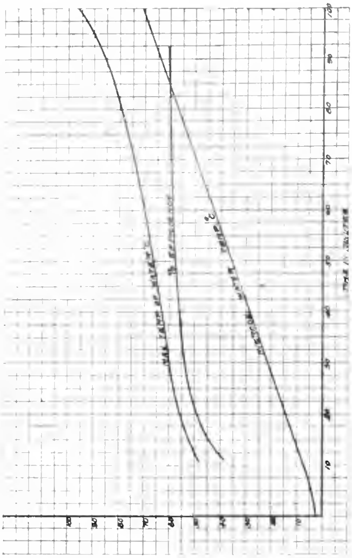


Fig. 11. Performance Test of Gas Water Heater with 36-gal. Bare Tank, One cu. ft. Gas per min. Average Room Temperature 20 Deg. C. (68 deg. F.)

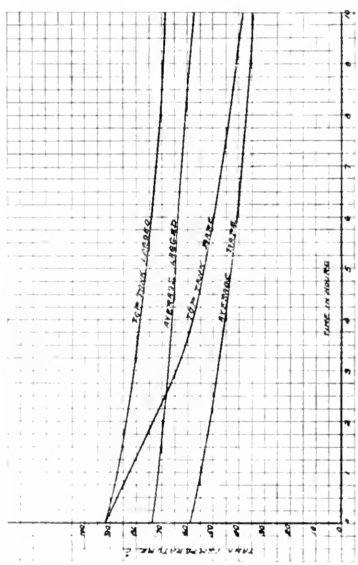


Fig. 12. Cooling Curve of Tank B with and without Insulation. Average Room Temperature: Lagged Run 23.2 Deg. C.; Bare Run 22 deg. C.

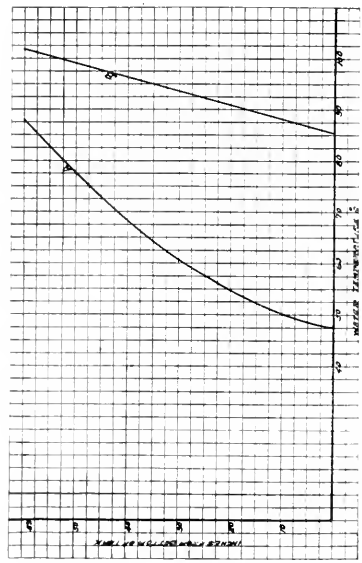


Fig. 13. Ultimate Temperatures of Tank B Curve A—1000 Watts Bare; Curve B—600 Watts Lagged. Average Room Temperature 22 Deg. C.

Intermittent Type Hand Control

The idea of using a heater of medium capacity, from 2 to 4 kilowatts, and operating it the same as a gas heater would be operated (that is, by turning on the heater after it is known that hot water will be required) is entirely impractical for household purposes. For details of such a service, reference should be made to the curves in Figs. 5, 6, 7 and 8. An inspection of these curves discloses the fact that more time is required to obtain even a small quantity of reasonably hot water than is practicable. Therefore, since improved service is necessary for the successful introduction of electric water heating, this method will not be considered. There are, however, peculiar requirements for which this method would be satisfactory.

Thermal Control

Considering the interest of both the consumer and the central station, a thermally controlled electric heater is most desirable. If the heaters are being operated at a flat rate, it saves energy for the central station and prevents the consumer's annoyance at drawing steam from the hot-water faucet when water has not been drawn off for a considerable time.

Time Clocks

Some central stations have used time clocks to turn on the water heaters during the off-peak period, as from 11 p.m. to 5 a.m. This scheme has proven more or less satisfactory. However, its value depends entirely upon the local central-station conditions and should therefore be considered separately for each locality.

Insulation of Storage Tanks

General experience, as well as special tests to determine the importance of properly insulating the storage tanks and circulation piping, clearly indicates the importance of insulation in decreasing the thermal losses and thereby increasing the efficiency and service. Fig. 12 shows the decrease in temperature for tank *B* lagged and bare, starting with the same temperature in the top of the tank. It should be noted that when lagged the top temperature drops only 23 deg. C. in 10 hours, while when bare the temperature drops 53 deg. C. in the same time; also, that the average temperature drops only 15 deg. C. when lagged, as compared with 25 deg. C. when bare. Furthermore, the *average* temperature when lagged was 15 deg. C. hotter at the start than when bare. This would tend to give a greater drop in average temperature for the lagged test. Fig. 13 shows ultimate temperature gradients in tank *B*, which shows that with the 600-watt heater and the tank lagged, the temperature in the bottom is 86 deg. C. or is 38 deg. C. hotter than with a 1000-watt heater with the tank bare. The

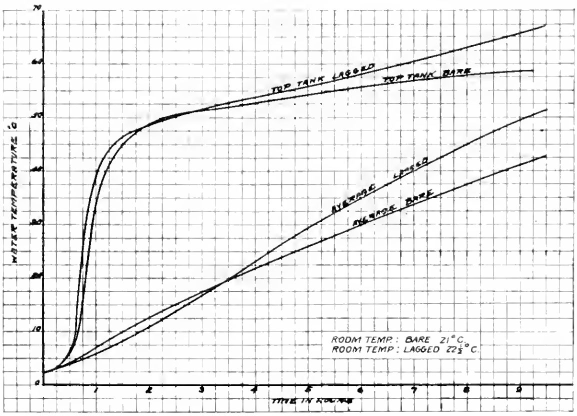


Fig. 14. Performance Curves of 1000-watt Heater on Tank B (see Fig. 4). Room Temperatures Bare 21 Deg. C.; Lagged 22½ deg. C.

data in Fig. 3 gives more conclusive evidence of the importance of insulation. Curves *C* and *D* show the relative service that can be obtained from lagged and bare tanks with a 600-watt heater. After the day's schedule of hot water had been drawn off, 18 additional gallons of 40-deg. C. water was obtained with a lagged tank and no 40-deg. C. water could be obtained without lagging. The average temperature of the water drawn off according to schedule was 11 deg. C. hotter with the lagged tank. An inspection of curves *E* and *F* show even a much greater difference in service obtained in favor of lagging, when a 1000-watt heater is used. In these runs, it should be noted that with insulation the average temperature of the water drawn off according to schedule was 15 deg. C. hotter than with the bare tank; and that after the schedule amounts were drawn off, 27 gallons of 40-deg. C. water was obtained from the lagged tank and only 8 gallons of 40-deg. C. water from the bare tank. Referring to curves *A* and *B*, covering the operation of lagged and bare thermally controlled tanks, there was practically no difference in the hot water obtained for the schedule used, but more energy was required to heat the water in the bare tank.

Efficiency

It is seen that lagging the tank greatly increases the amount of hot water that can be obtained from a given combination; therefore, the efficiency is also greatly increased. With a 1000-watt heater, the efficiency was increased from 45 to 75.5 per cent by lagging the tank and the circulation pipes with one inch of hairfelt and 85 per cent magnesia, respectively.

With a 600-watt heater, the efficiency was increased from 27.5 to 92.4 per cent. The importance of lagging the storage tank and circulation pipe is too obvious to require further consideration.

Tank Coverings

The requirements of a heat insulating tank covering for use on water heating tanks are:

1. It should have a high thermal resistivity.
2. It should be easy to apply and should have a neat appearance. Formed blocks are easier to apply than coverings that must be mixed and put on like plaster. Moulded parts that can be plastered together and covered with a canvas jacket make a very desirable combination. The filling of seams between the parts is important.
3. The material should be sanitary. Coverings that serve as lodging places for bacteria have no rightful place in a kitchen.
4. As nearly as possible the material should not be affected by moisture or by temperatures under 200 deg. C. The material should also be fireproof; that is, it should be non-combustible.

The following table gives some idea of the relative heat insulating qualities of the available materials.

Material	Thermal Resistivity in Deg. C. per Watt per in³.
High-Pressure Covering	550
85 per cent Magnesia	600
Air-Cell Asbestos	400
Mineral Wool	570
Hair Felt	790

CONCLUSIONS

The location of the heater, with respect to the tank, is important.

The circulation system gives the best results for average household requirements.

The circulation should be restricted to suit the size of the heater, the tank, and the service required.

The heater should be easily accessible for cleaning.

The tank and circulation pipe should be lagged.

The kind of insulation used is not of primary importance, (neglecting installation cost), as additional thickness may be used to effect the variations in resistivity of different materials.

The tank should be located as near the hot water draw-off as is convenient.

A 1000-watt continuous heater, properly connected to a well-lagged tank, will provide ample hot water for an average family of five persons.

A switching arrangement to cut out the water heater, when the range is in service, is desirable to the *central station*.

The three previous discussions point out three fundamentally different methods of heating water for household purposes: (1) the instantaneous; (2) the intermittent storage; and (3) the continuous storage.

Each of these methods may be particularly suited for certain requirements. Therefore, the selection is governed by the service required, the cost of operating and the initial installation cost.

Service

Considering the service only it is evident that the instantaneous method is preferable, the service being ideal when the heater is large enough to meet the maximum demands.

The continuous storage method would be the next choice, and with the proper size heater and tank is practically as serviceable as the intermittent method for ordinary requirements.

The intermittent method, with a two- to four-kw. heater, requires the most attention. The demands for hot water must be anticipated and the heater turned on for a sufficient time to heat the water. Figs. 7 and 8 show that the time required to heat water by this method is too long to compare favorably with gas heating or to be satisfactory for average household requirements. This method is most applicable where considerable quantities of hot water are required at definite but infrequent intervals.

Cost of Operation

As previously shown, at least a 20-kw. heater would be required for the instantaneous method. The load-factor of such a heater would probably be less than two per cent, and the central stations would be obliged to charge a kilowatt-hour rate many times greater than that for a lower capacity heater operating at approximately 100 per cent load-factor. The only advantage to off-set the additional rate is the increased efficiency. Referring to Fig. 3, at least 75 per cent efficiency can be obtained with the continuous storage method. This means that the relative rates per kilowatt-hour for the instantaneous method and the continuous storage method must be in the ratio of 100 to 75 for an equal cost of operation. Such rates cannot be obtained at present.

Flat rates as low as $3.00 per kilowatt-month are being obtained for continuous heaters. This immediately gives the continuous method first place, when considering cost of operation.

At the same rate, with the proper size of tank and heater, the continuous storage method is somewhat cheaper than the intermittent storage method, due to a slightly higher efficiency.

Initial Cost

The initial cost of a large heater for instantaneous service would make the installation more expensive than would the intermittent or the continuous storage system. The little difference in the cost between the intermittent and the continuous storage systems is in the favor of the continuous system.

Considering that the demand outlined in Fig. 3 represents the average household requirements, it is obvious that the continuous storage system is by all odds the most practical, considering service, cost of operation, and initial cost.

In fact, the advantages of this system to both the central station and the consumer would seem sufficient to confine all future endeavors to this line.

INDUSTRIAL MULTIPLE RECORDER

By R. H. Rogers

Power and Mining Engineering Department, General Electric Company

The device described in this article has been perfected to show a continuous record of the performances of various pieces of apparatus in industrial plants. Instead of bulky magnets and unreliable pens usually employed for apparatus of this kind, a short wire is made to scorch its record on a slowly moving strip of paper, the motion of which is regulated by a clock. As many as 375 records of as many different devices may be controlled by one clock.—Editor.

A device for accurately recording the operation of the various units in an industrial plant has recently been perfected; its novel features are the manner of recording and the simplicity of the apparatus. Briefly stated, the essentials are a clock, a sheet of paper moving one inch per hour and the recording "pens," which are of fine wire sufficiently heated to scorch lines on the paper when recording data.

The usual system is to make use of magnets which actuate pens using ink, the magnets occupying much room and the pens being unreliable. In this new recorder the tell-tale current makes its own record directly, thereby avoiding moving parts, allowing the use of many "pens" in a narrow space and reducing the cost.

Whenever a recording circuit is closed at some machine or device in the plant a ten mil calorite wire is heated to the scorching point by a current of 6 volts and 1 ampere, and a line instantly starts on the paper. When the circuit is broken the tiny wire, having so little thermal capacity, immediately cools and the line ends. Breaks of one minute duration, being one-sixtieth of an inch long, are easily read. The standard sheet is 18 in. wide by 26 in. long ruled into seventy-five spaces, numbered or named to correspond with the apparatus to be recorded and cross ruled for the hours and quarters. The sheet starts at 9 a.m. and runs 25 hours to allow a margin for changing sheets.

The clock is of a well-known make, weight and pendelum type, guaranteed within 30 seconds per month. The paper feed is simply an auxiliary clock weight which therefore does not retard or interfere in any way with the accuracy of the time piece.

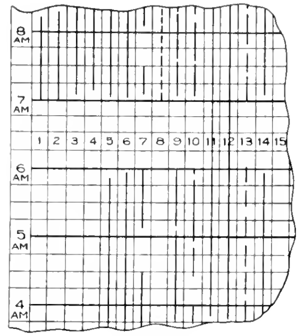
Additional banks of 75 pens each may be assembled on either side of the clock so that a total of 375 lines may be governed by the one pendelum.

An important feature from the standpoint of the purchaser is the fact that only one wire runs from the instrument to the machine in the factory, all having a common return No. 18 fixture wire is suitable for the individual leads and the energy may be supplied through a small transformer from a lighting circuit or through a motor-generator set from an exciter or other d-c. circuit. The energy applied may be a-c. or d-c. as desired.

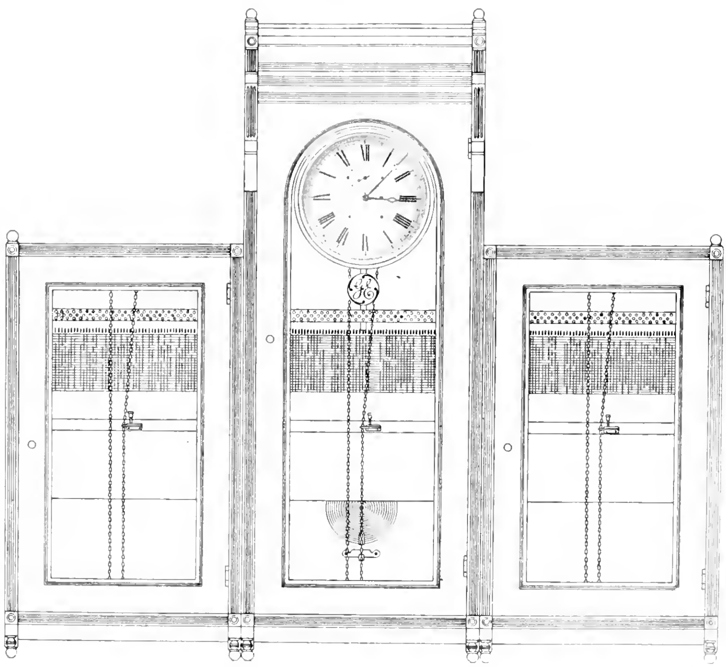
Industrial Multiple Recorder

A small resistance is inserted in each circuit for regulating the current and consequently the depth of marking, i.e., the total resistance of the circuits is adjusted until they are all alike whether ten or two thousand feet intervene between machine and clock.

There are a variety of contact-making devices available for closing the circuits at the machines or apparatus to be looked after. A simple push button answers for most machinery which is thrown into operation by some lever or similar device; the lever holding the button in contact as long as the machinery is running. For continuity of product, as from a paper machine, cloth printing and the like, a roller mounted on lever arms will complete or break the circuit. Pressure and vacuum systems record through gauges containing contact points; tanks, receptacles or hydraulic heads indicate by means of float actuated switches. Speed of line shaft or machine above or below normal is recorded by means of a centrifugal switch. Power or lights on and off indicate through a relay. Temperature limits are conveyed by means of thermostat contacts. Thus any item concerning which the management desires running information can be "hooked up" if there is sufficient change in conditions to make or break a circuit.



Section of Chart



Industrial Multiple Recorder with Two Additional Banks of Pens

In practical operation there are three periods of observation:

1st. The running inspection while the sheet is in process of making. The superintendent or manager can see at a glance just how things stand at any moment and can read the general status of the plant as far as the sheet has progressed.

2nd. Every morning the sheets for the previous 24 hours are on the desk, tabulated and noted by a clerk to indicate the ratio of possible machine hours to actual machine hours, causes of exceptional stops and such other data as may be of interest. The sheets are in a way a faithful history of the 24-hour period and the trained eye can read the ups and downs of every department and every machine without recourse to more or less inaccurate verbal or written reports.

3rd. The sheets acquire great value as comparative reference data after say six months have accumulated. Frequent shut downs in any spot become conspicuous, absence of trouble in others become equally conspicuous and the causes therefor may be traced to the ultimate good of the whole fabric.

The general appearance of the 75 unit equipment is shown by the photograph. The method of expanding and the details of the pen and arrangement of circuits are shown by the line drawings. A typical section of record sheet is also shown.

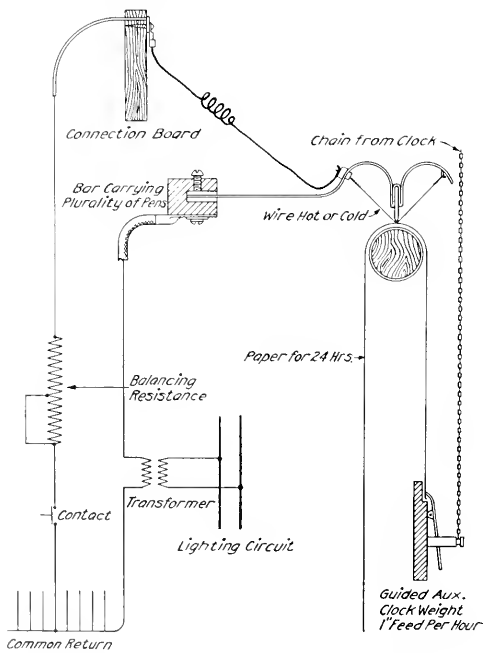


Diagram of Industrial Recorder, Showing Arrangement of Parts

ELECTRIC POWER TRANSMISSION ECONOMICS

By George P. Roux

Consulting Engineer, Philadelphia, Pa

According to Kelvin's law, maximum economy in electric transmission is obtained when the annual interest and depreciation charges equal the cost of the energy loss. This law, however, does not allow for additional capacity in lines to care for future growth in business, nor for voltage regulation; hence it does not hold good in practice to-day, where experience shows that both of these provisions are necessary for the highest economy ultimately. The transmission losses, permissible investment, and regulation are discussed in turn, and specific examples worked out to show their bearing on the economy of operation; and the impracticability of the Kelvin law to the average transmission system is also shown.—Editor.

Since the introduction of scientific management in the operating departments of light and power companies a great improvement has been made in both the quality and the economy of the electric service. Systematic cost keeping automatically exposes every weak spot in operation and institutes a study and analysis of its cause with the purpose of prescribing a remedy. These scientific methods, which are merely the application of common sense in the conduct of the business, were primarily directed toward improving the efficiency of the working force and were later extended to inanimate things, such as raw materials, tools, instruments, machinery and equipment; so that by keeping adequate records of their useful performances a selection based on merit could be made with a view to securing still better results.

The efficiency of a physical property is a broad subject, just as essential to the economical success of a business as is labor efficiency; it is a very fertile soil which, when properly tilled, yields a generous harvest of valuable information that is helpful in reducing the costs of operation and maintenance, and improving the reliability of the service.

In the transmission and distribution of electrical energy peculiar conditions are met which increase the ultimate cost of the product, due to two causes, viz., losses in transportation, and losses in conditioning for transportation and distribution. The ultimate cost of the product or commodity depends on the efficiency of the system of delivery. In the distribution of electrical energy it is a very important item, represented by the ratio of input to output of the electrical energy at each end of the system, or at the power house and the customer's premises where it is sold according to the units metered and delivered.

The transportation of electrical energy is widely different from other problems involving traffic; here the flow is continuous from end to end, while in railway transportation the traffic is intermittent and can suffer demurrage if necessary without great inconvenience. The means of transportation consisting of tracks and rolling stock can be increased to meet the demand imposed by the volume of the traffic; improvements, additions, and repair and maintenance work can be undertaken without seriously impairing the operation; while in a power transmission system provisions and work of this nature are almost impossible to be carried out except at great expense and with considerable annoyance and difficulties.

The losses occurring in the transportation of electrical energy are governed by the resistance of the conductor through which the energy flows and also by its degree of staunchness, that is, its insulation properties. The resistance of a circuit intended to transmit alternating current depends primarily on the material used for the conductors, and on their cross section, both factors affecting the investment, which in turn is subject to financial considerations that prescribe an expenditure for construction that will net the largest return on the capital invested. A reduction in the transmission losses cannot be secured except at the cost of an increased investment, and a point is reached where any additional reduction in these losses becomes an expensive saving represented by interest on the capital invested and depreciation charges.

The maximum transmission economy is attained when the sum of the annual interest and depreciation charges equals the annual cost of the energy loss. Other important factors must also be considered in the calculations affecting the initial investment, such as voltage regulation and the possible increase in the demand for electrical energy at the receiving end of the circuit at a later date, all of which involve the exercise of good judgement in the appreciation of the requirements to be fulfilled in the design and construction of the transmission and distribution lines.

No special or definite rule can be laid for the solution of electric transportation problems; each case must be considered separately and carefully studied, first on the basis of maximum transmission economy and then from the investment standpoint, estimating the additional capital expenditure that would be warranted by the immediate traffic to provide an increase in power carrying capacity from the start, and possibilities for further increases; bearing in mind that it is very seldom that a line has been designed in excess of the subsequent traffic requirements, but on the contrary it is generally found to be ultimately inadequate.

There is naturally a limit imposed on the power carrying capacity of electric lines by engineering considerations, such as strength of materials, stability and permanence of the supporting structures, and the important question of continuity and reliability of service, which may always be effectively improved by double tracking the circuit.

Transportation Losses

Neglecting certain constants only slightly affecting overhead transmission lines at voltages below 60,000 volts and at altitudes less than 3,000 feet, the total loss of energy in a transmission line is the sum of·

Ohmic resistance loss
Dielectric or leakage loss
Inductive reactance loss

The ohmic resistance loss depends entirely upon the conductivity, permeability and shape of the conductor and its temperature constant. This loss is generally a function of I^2R, in phase with the current. The true resistance (R) to the flow of alternating current, which is affected by the frequency of the current owing to skin effect, is slightly increased at ordinary operating frequencies, as shown in Table I.

The effective resistance of magnetic materials, such as iron wire, increases in a considerably greater proportion than that of non-magnetic material, due to the interference of eddy currents that are generated perpendicularly to the direction of the magnetic flux and that reduce the effective conductivity of the material to a very thin layer near its surface.

The dielectric loss in overhead transmission lines of voltages not exceeding 60,000 volts can be neglected when the conductors are properly insulated and are free from outside interference. It is appreciable, however, under certain weather conditions, inasmuch as there is no absolute dielectric material, but some of relatively high resistance that are used to insulate others of lower resistance. In insulated cables the leakage current through the insulating material, the lead sheath losses and the hysteresis losses in metallic conduit should all be considered, as well as the effect of capacity and low inductance. These losses are practically in phase with the current and can be added to the resistance loss.

Inductive reactance losses are those produced by a phenomenon of electromagnetic waves at right angles to a current changing in value or direction, as with alternating current. These losses are necessarily supplied by the current circulating in the conductor, from which originates the magnetic field, and they depend primarily on the frequency of the change in velocity or direction and on the intensity of the current

TABLE I

RESISTANCE OF HARD DRAWN COPPER AND ALUMINUM STRANDED CONDUCTORS.
CONDUCTIVITY: COPPER 97.3 PER CENT; ALUMINUM 61 PER CENT.
TEMPERATURE 20 DEG. CENT. OR 68 DEG. FAHRENHEIT

Gauge B.&S	EFFECTIVE RESISTANCE IN OHM PER MILE OF WIRE					
	Copper			Aluminum		
	D-C	25-Cycle	60-Cycle	D-C.	25-cycle	60-cycle
0000	0.2704	0.2706	0.2715	0.4330	0.4332	0.4337
000	0.3418	0.3420	0.3427	0.5438	0.5439	0.5444
00	0.4309	0.4310	0.4316	0.6893	0.6895	0.6898
0	0.5434	0.5435	0.5441	0.8670	0.8671	0.8674
1	0.6851	0.6852	0.6856	1.0932	1.0932	1.0935
2	0.8655	0.8656	0.8658	1.3786	1.3786	1.3788

itself. They are also affected by the spacing of the conductors (mutual inductance), and by their size, shape and permeability.

Like the ohmic resistance loss, the inductive reactance loss can be written as I^2Ri, where $Ri = 2\pi fL$, f being the frequency of the current and L the coefficient of mutual self induction of the conductor.

The resultant of the ohmic resistance and the inductive reactance represents the equivalent resistance or impedance of the circuit, and can be written:—

$$Z = \sqrt{Ro^2 + Ri^2} = \text{impedance}$$

The effect of capacity reactance in a transmission line is to compensate for the lagging current produced by the inductive reactance, not only that of the line but also that of the load connected thereto, to the extent that the leading wattless component of the current charges the condenser represented by the line.

The capacity, and hence the charging current, of a line increases with its cross section, and as the separation between the conductors decreases. It is of special importance in insulated cable installations and its effect on the regulation and losses should be taken into consideration in such cases, as well as when treating long transmission lines of high voltage carrying a relatively small current with respect to the power transmitted.

Thus in an alternating current circuit the ohmic resistance loss is substituted by an impedance loss, in phase with the current, which is the resultant of the ohmic resistance, hysteresis, and eddy current losses of the circuit, and denoted by Ro; and of an inductive reactance (Ri) having a negative sign, or of a condensive reactance (Rc) having a positive sign, both being at 90 deg. to the ohmic resistance Ro.

The impedance can then be expressed as follows:

$Z = Ro - jRi$, for an inductive reactance, and $Z = Ro + jRc$ for condensive reactance

Inasmuch as the vectorial sum of these two quantities is in either case the hypothenuse of a right-angled triangle, they can be more conveniently written thus:

$$Z = \sqrt{Ro^2 + Ri^2} \text{ and } Z = \sqrt{Ro^2 + Rc^2}$$

The impedance of a conductor carrying alternating current can, in most short lines, be treated as the ohmic resistance of direct current circuits for the determination of losses and voltage regulation.

When a current I is not in phase with the voltage, but is either lagging or leading, it consists of a power component Io, and of a wattless component Ix, at right angles to Io, and such a condition can be expressed by

$$I = \sqrt{Io^2 \pm x^2}$$

The line drop then becomes by Ohm's law:

$$e = \sqrt{(IoRo + IxRi)^2 + (IxRo - IoRi)^2}$$

for a lagging current and inductive reactance,

$$\sqrt{(IoRo - IxRi)^2 + (IxRo + IoRi)^2}$$

for a lagging current and condensive reactance

$$\sqrt{(IoRo + IxRi)^2 + (IxRo - IoRi)^2}$$

for a leading current and inductive reactance

$$\sqrt{(IoRo - IxRi)^2 + (IxRo + IoRi)^2}$$

for a leading current and condensive reactance where $e = IZ$

Along with the line constants must be considered the character of the load, as the complete circuit consists of the line with the

TABLE 1A

		Single-phase	Two-phase	Three-phase
True power	W	$EI\cos.\ \phi$	$2EI\cos.\ \phi$	$EI\sqrt{3}\cos.\ \phi$
True power losses	w	$eI\cos.\ \phi$	$2eI\cos.\ \phi$	$eI\sqrt{3}\cos.\ \phi$
or. ...	w	$I^2Z\cos.\ \phi$	$2I^2Z\cos.\ \phi$	$I^2Z\sqrt{3}\cos.\ \phi$
The current per wire.	I	W/E	$W/2E$	$W/E\sqrt{3}$
The true current per wire	Io	$I\cos.\ \phi$	$I\cos.\ \phi$	$I\cos.\ \phi$
The wattless current per wire	Ix	$I\sin.\ \phi$	$I\sin.\ \phi$	$I\sin.\ \phi$
The potential drop per circuit.	e	IZ	IZ	IZ
The impedance per circuit	Z	e/I	e/I	e/I
The impedance per wire	Z^1	$e/2I$	$e/2I$	$e/I\sqrt{3}$
The per cent potential drop	P	$100e/E$	$100e/E$	$100e/E$
The per cent efficiency..	F	$\frac{100W}{W-w}$	$\frac{100W}{W-w}$	$\frac{100W}{W-w}$

load at the receiver's end in series with each section. The treatment of such problems requires the analysis of each section separately.

Knowing the resistance, inductive reactance and condensive reactance of a conductor per unit of length, the impedance can be calculated and then the losses and line regulation can be determined for any line voltage, load and power-factor.

The constants of a transmission line carrying alternating current can be determined from Table IA.

To apply these formulæ to a practical case, we will assume for instance a three-phase, three-wire overhead transmission line 10 miles long, to transmit 1000 kw. at 60 cycle, 13,200 volts, at an average power-factor of customer's load 0.8, and with the necessary step up and step down transformers and substation equipment. The average annual load-factor is assumed to be 20 per cent, the revenue per kilowatt hour averaging 1.25 cents, and the ratio operating expenses to revenue 60 per cent.

Find:

The permissible investment
The gauge of the conductors
The regulation of the line
The transmission losses

Permissible Investment

From the information available the anticipated annual gross income is:

$1000 \times 0.2 \times 8760 = 1{,}752{,}00$ kw. h. at 0.0125 $= \$21{,}900$

With a ratio of operating to gross income of 60 per cent, the net annual revenue is:

$$21{,}900 \times 0.4 = \$8{,}760$$

The capital invested must earn a salary for the service it renders. Those who are responsible for its management are entitled to a compensation in the form of a profit; furthermore, the capital must be protected by a life insurance on the physical property it represents, to be taken care of by an allowance for depreciation, insurance, etc., and finally the investment is subject to fiscal taxes, all of which must be satisfied from the net earnings as follows:

6 per cent interest on investment
2 per cent profit
5 per cent depreciation
1.5 per cent taxes
0.5 per cent insurance

Total 15 per cent

The above net revenue therefore corresponds to a capital investment of:

$$\text{Permissible investment, } \frac{8{,}760}{0.15} = \$58{,}400$$

TABLE II

EFFICIENCIES OF AVERAGE STATION TRANSFORMER

% Load	5	10	20	25	30	40	50	60	70	75
% Core loss	20.00	10.00	5.00	4.00	3.33	2.5	2.0	1.66	1.43	1.33
% Copper loss	.05	.10	.20	.25	.30	.40	.50	.60	.70	.75
% Total loss	20.05	10.10	5.20	4.25	3.63	2.90	2.50	2.26	2.13	2.08
% Efficiency										
at 1.0 P.F.	82.39	90.82	95.05	95.92	96.49	97.18	97.56	97.88	97.91	97.96
at 0.8 P.F.	79.96	88.79	93.89	94.95	95.66	96.97	96.98	97.25	97.40	97.46
% Load		80	90	100	110	120	125	130	140	150
% Core loss		1.25	1.11	1.00	0.909	0.833	0.800	0.779	0.714	0.666
% Copper loss		.80	.90	1.00	1.100	1.200	1.250	1.300	1.400	1.500
% Total losses		2.05	2.01	2.00	2.009	2.033	2.050	2.079	2.114	2.166
% Efficiency										
at 1.0 P.F.		97.99	98.03	98.04	98.03	98.01	97.99	97.97	97.93	97.88
at 0.8 P.F.		97.50	97.54	97.56	97.55	97.52	97.50	97.45	97.42	97.36

This capital is to be invested in the contemplated improvement as follows, based on present market prices:

1000 kw. in step-up transformer installation, complete with switchgear and protective apparatus	$8,000.00
1000 kw. in step-down transformer installation, also complete with some housing provision for the secondary switchgear and metering devices	12,000.00
Balance applicable to line construction	38,400.00
Total investment	$58,400.00

Gauge of Conductors

The line and right of way, exclusive of conductors, may be estimated as costing to day, with a substantial type of construction using wooden poles, approximately (although varying according to localities) $2,500 per mile, or a total of $25,000.00, leaving for the conductors $13,400.00, which, with copper at 30 cents per pound, equals 44,666 lbs, or 1488 lbs. per miles of wire, corresponding to No. 1 B.&S. copper conductor.

Regulation

With a 24 in. spacing between wires, at 60 cycles, a No. 1 B.&S. stranded copper conductor at 20 deg. Cent. has an ohmic resistance of 0.6856 and an inductive reactance of 0.644 ohms per mile.

Impedance per mile of circuit:

$Z = \sqrt{0.6856^2 + 0.644^2} = 0.936 \times 1.732 = 1.61$ ohms and for 10 miles a total impedance of 16.1 ohms.

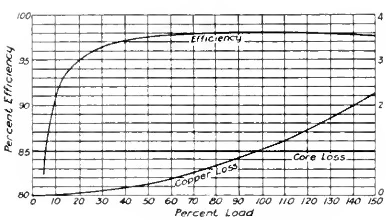


Fig. 1. Average Efficiencies and Losses of Large Substation Transformer

Line drop at full load,

$$e = \frac{43.7}{.8} \times 16.1 = 880 \text{ volts}$$

Per cent line drop $\frac{100 \times 880}{13200} = 6.66$ and also regulation at 0.8 power-factor, and at unity power-factor $6.66 \times 0.8 = 5.328$ per cent.

Transmission Losses

At full load the power loss in transmission is:

$880 \times 54.7 \times 1.732 = 83.432$ kv-a., or $83.432 \times 0.8 = 66.748$ kw.

or

$54.7^2 \times 1.732 \times 16.1 = 83.432$ kv-a., or $83.432 \times 0.8 = 66.748$ kw.

or 6.66 per cent of the full load output. The transmission efficiency of the line:

$$\frac{100 \times 1000}{1000 + 66.748} = 93.74 \text{ per cent}$$

The annual transmission losses at full load are:

$66.748 \times 8760 = 583,460$ kw-hr., or 6.66 per cent of the full load output.

The immediate load-factor is expected to be only 20 per cent of the output, and consequently the annual losses will be a fraction of the above full load losses, although not in the same proportion as the load-factor, as will be seen later.

Transformation Losses

The losses in voltage or phase transformation occuring in transformers depend not only on the efficiency of the apparatus but also on the load characteristics throughout the daily operation; that is to say, on the power-factor of the load and on the load-time curve.

When a transformer is connected to a circuit, the winding so connected is equivalent to a resistance across the line completing the circuit; the energy consumed in that part of the circuit is in proportion to its impedance and consists of exciting current. The energy loss in a transformer is made up of core or iron losses through the magnetic circuit and of copper loss in the electric circuit. The core losses for a given voltage and frequency are practically constant, so long as the properties of the magnetic material remain unchanged, while the copper loss varies with the resistance of the secondary circuit; that is, in proportion to the load or to the volt-amperes, slightly affected by variation of temperature and changes in the frequency of the current.

The energy losses and efficiencies of station transformers operating on 60 cycle circuits are tabulated in table II and shown graphically in Fig. 1.

Pole type transformers for use on distribution lines have special characteristics on account of their intermittent duties. The core loss is kept as low as is consistent with good operation in order to reduce to a minimum the expense of keeping them alive during periods of very light load or no load, specially in the day time. The losses and efficiencies of a typical pole type transformer of 10 kv-a. capacity are given in Table III and the curves of losses and efficiencies are shown in Fig. 2.

The effect of power-factor variation on the efficiency of the transformers is also indicated in both Tables II and III. It increases the losses and reduces the efficiencies proportionally to the angular displacement of the current with respect to the voltage. The regulation, or the per cent difference between the secondary voltage at no load and full load, is likewise affected by the power factor of the load. Station transformer regulation can generally be assumed to be from 1.5 per cent at 1.0 power-factor to 4.0 per cent at 0.8 power-factor, and the regulation of the distributing transformers varies from 1.5 to 3.0 per cent, although it is merely a question of design to meet the requirements of special cases, not only as regards regulation but also copper loss and core loss.

Lightly loaded induction apparatus, such as induction motors and transformers, draws from the line a current which lags behind the electromotive force in inverse proportion to the load supplied, the result being increased heating and a reduction in useful capacity.

Station and substation transformers for operation on transmission lines, (generally of high voltage) are designed with a higher reactance than pole type transformers, in order to increase the safety of operation in case of short circuit. This is obtained at the expense of regulation, but with an additional reliability well worth the sacrifice. Ultimately the increased reactance will help the regulation when the line drop is compensated with synchronous condensers.

Transmission Losses

The transmission losses consist of line and transformer losses, depending on the character of the load supplied, and an individual

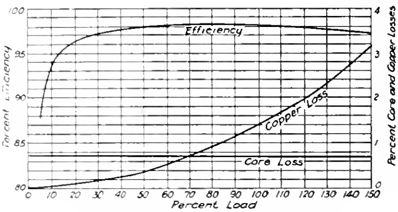


Fig. 2. Average Efficiencies and Losses of 10 Kv-a. Distribution Transformer

estimate must recognize the following factors in order to determine the total efficiency of the system.

Step-up transformer:—Load at receiver end, plus step-down transformer losses, plus transmission line losses.

TABLE III

EFFICIENCIES OF A 10-KV-A. POLE TYPE TRANSFORMER

% Load	5	10	20	25	30	40	50	60
Core loss	13.80	6.90	3.45	2.76	2.30	1.725	1.38	1.15
Copper loss	.07	.14	.278	.35	.417	.556	.695	.834
Total loss	13.87	7.04	3.728	3.110	2.717	2.281	2.075	1.984
% Efficiency								
at 1.0 P.F.	87.82	93.42	96.90	96.98	97.24	97.76	97.96	98.05
at 0.8 P.F.	85.03	91.91	95.55	96.26	96.72	97.23	97.46	97.58
% Load	70	75	80	90	100	110	120	125
Core loss	0.98	0.92	0.862	0.766	0.690	0.627	0.575	0.552
Copper loss	.973	1.043	1.112	1.251	1.390	1.520	1.668	1.737
Total losses	1.958	1.963	1.974	2.017	2.080	2.147	2.243	2.289
% Efficiency								
at 1.0 P.F.	98.08	98.07	98.06	98.02	97.96	97.89	97.80	97.76
at 0.8 P.F.	97.70	97.70	97.69	97.54	97.46	97.38	97.27	97.20

Transmission line:—Load at receiver end plus step-down transformer losses.

Step-down transformer:—Load at receiver end.

These losses are not only governed by the efficiency of the apparatus but also by the characteristics of the operation and cannot be estimated from the load-factor, unless a steady load is used continuously.

Where power is used continuously, with a load-factor practically constant, the losses, figured on the efficiencies of 60 cycle station transformers as given in Table II and for a line loss of 5 per cent at full load, are given in Table IV, all results being based on unity power-factor.

The efficiency of the transmission line decreases as the load increases, while that of the transformers increases from no load to full load. The maximum combined efficiency is reached when the load corresponds to the point where the curves cross each other, as shown in Fig. 3; and the maximum economy of operation of such a system would be between 40 to 60 per cent load. In Table IV it is assumed that the system does not contain step up transformers, but distributes at station voltage.

Where the load is not constant, for instance under the conditions set forth before for the transmission of 1000 kw. to a point 10 miles distant, and reducing the losses to a unity power-factor basis at 20 per cent load-factor, the transmission losses would vary between

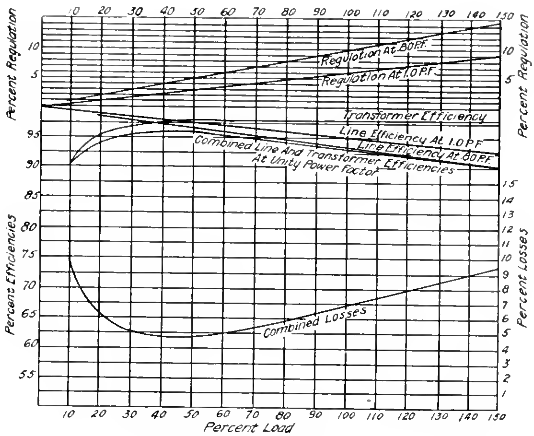


Fig. 3. Combined Efficiencies of Transmission Line and Step-down Transformer

TABLE IV.

COMPARATIVE LOSSES AND EFFICIENCIES OF 60 CYCLE SYSTEM

Load Factor %	LINE		STEP-DOWN TRANSFORMER		Combined Efficiency %	Combined Losses %
	Efficiency %	Losses %	Efficiency %	Losses %		
10	99.50	0.50	90.82	9.18	90.36	9.64
20	99.00	1.00	95.05	4.95	94.10	5.90
25	98.75	1.25	95.92	4.08	94.72	5.28
30	98.50	1.50	96.49	3.51	95.04	4.96
40	98.00	2.00	97.18	2.82	95.23	4.77
50	97.50	2.50	97.56	2.44	95.12	4.88
60	97.00	3.00	97.88	2.12	94.94	5.06
70	96.50	3.50	97.91	2.09	94.48	5.52
75	96.25	3.75	97.96	2.04	94.28	5.72
80	96.00	4.00	97.99	2.01	94.07	5.93
90	95.50	4.50	98.03	1.97	93.61	6.39
100	95.00	5.00	98.04	1.96	93.13	6.87
110	94.50	5.50	98.03	1.97	92.64	7.36
120	94.00	6.00	98.01	1.99	92.13	7.87
125	93.75	6.25	97.99	2.01	91.86	8.14
130	93.50	6.50	97.97	2.03	91.61	8.39
140	93.00	7.00	97.93	2.07	91.07	8.93
150	92.50	7.50	97.88	2.12	90.53	9.47

the two extreme cases A and B as shown in Table V.

In both cases the load-factor is the same, but the hourly power demand is widely different and represents in case A a kilowatt-hour loss equal to 18.04 per cent of the kilowatt-hours supplied at the customer service, while in case B this quantity is only 11.39 per cent. the power being used continuously.

In case B the character of the load would require transformers having a capacity of only one-fifth of those of case A, inasmuch as the load is below 200 kw.; and if such transformers were provided the losses would be reduced from 10.24 per cent to 5.03 per cent, or about 50 per cent less than in case A, the transmission losses remaining the same.

These two examples emphasize the economical importance of switching apparatus to at least disconnect large transformer installations from the line during idle hours when it is not possible to cut off the service at the station on account of power demands at other places on the line.

Inasmuch as the efficiency of transformers ordinarily decreases rapidly at fractional loads below 50 per cent. due mostly to the core loss, it is very important in the case just mentioned to select a transformer having a relatively high efficiency at fractional loads in order to obtain the most economical performance. This is accomplished by designing a transformer to have a small core loss and large copper loss at full load By thus properly proportioning the core and copper losses, the maximum efficiency of operation can be obtained at $\frac{3}{4}$ load or even less.

Transmission Economics

From Kelvin's law the investment theorically permissible in a transmission system should be such as to meet the following conditions on an annual basis:

Investment × % fixed charges = kilowatt-hour losses × cost per kilowatt-hour.

This economical law does not make allowance for business development and recognizes only certain immediate conditions which, if met, would preclude business expansion; and as experience shows that more business develops later, the above formula must be disregarded to a certain extent, compatible with the financial resources available at the time of the undertaking.

Returning to the concrete example taken before for the transmission of 1000 kw. to a point 10 miles distant, with an immediate load-factor of 20 per cent, we may assume a daily load curve average as shown on Fig. 4. Analyzing this curve gives the transmission efficiency shown in Table VI.

Transmission efficiency $\frac{100 \times 4800}{5574.06} = 86.11$ per cent.

The average daily losses are 774 kw-hr., and per year 282,510 kw-hr., which must be supplied by the generating station over and above the kilowatt-hours sold. To the cost of production of this power must be added the fixed charges on the power plant equipment, insurances, taxes, etc., all variable factors according to conditions and locations, but all of which average in a modern steam plant $\frac{1}{2}$ cent per kilowatt-hour generated.

We thus have Kelvin's formula as applied to this case modified as follows:

$$\underset{(13400 \times 0.15)}{\text{investment}} = \$2010 \text{ against } \underset{(282510 \times 0.005)}{\text{losses}} = \$1412.55$$

and we see the economical law upset. The investment in line conductor is too high by \$598, or 29.75 per cent. To comply theorically

TABLE V

		LOAD		TRANSFORMER		LINE			TRANSFORMER			Total Kw-hr. Losses
	Hours Operation	Per Cent Load	Kw-hr.	Per Cent Losses	Kw-hr.	Per Cent Load	Per Cent Losses	Kw-hr.	Per Cent Load	Per Cent Losses	Kw-hr.	
A	4.8	100	4800	2.00	96	102	5.72	280.05	107.72	2.01	104.04	480.09
	19.2	0	0	1.00	192	1	.06	.18	1.06	1.01	193.92	386.10
	24.0		4800	5.10	288		5.72	280.23		5.73	297.96	866.19
B	24	20	4800	5.2	249.6	21.04	1.12	56.55	22.16	4.72	241.01	547.16

Case A:—Output 4800 kw-hr., input 5666.19, efficiency 84.71, losses 15.29.
Case B:—Output 4800 kw-hr., input 5347.16, efficiency 89.76, losses 10.24.

with the Kelvin law the line losses could be increased 80 per cent, or from 6.66 to 11.98 per cent, corresponding to a copper conductor having a cross section between No. 4 and No. 5 B.&S.

The question of regulation must also be considered here, as it is an important factor from the point of view of quality of service. The increase in line drop for the range no load to 75 per cent load, as in the above example, is from 5.48 per cent, a regulation well permissible, to 9.86 per cent, and if full load is added later the line regulation would become still worse, or 11.98 per cent—a value inconsistent with good service and impeding any further load addition on peak. Furthermore, allowance must be made for certain contingencies, such as arise from low power-factor due to lightly loaded motors or transformers, this again impairing the regulation.

If we now assume the same transmission line and equipment as before, but additional business to increase the load-factor to 30 per cent, or a load curve as in Fig. 5, the efficiency and losses become as shown in Table VII

Transmission efficiency $\frac{100\times7200}{8079.67}=89.11$ per cent

The Kelvin formula compares as follows:

$$\frac{\text{investment}}{(13400\times0.15}=\$2010 \text{ against } \frac{\text{losses}}{(321029\times0.005)}=\$1505.15$$

That is, the losses are still below the original fixed charges, while the permissible investment in conductor could have been increased to $42600 and the annual losses to $6390, or more than four times the losses calculated above.

It is true that the original investment in line conductor once made can hardly be increased unless a second line is installed; but part of the additional permissible investment will be absorbed by the installation of feeder regulators or synchronous condensers to improve the voltage regulation at the receiver end. This will prove to be a better investment up to a certain transmission capacity, beyond which a second line becomes necessary. A deferred improvement fund should in time be available for this undertaking.

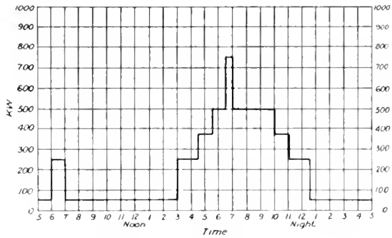


Fig. 4. Average Daily Load Curve 20 Per Cent Load-Factor

The Kelvin law is not applicable in most cases met in transmission problems and can at best be used only as a check on the calculations, the limiting factors being voltage regulation incident to good service, and allowance for future expansion in the scope of the business within the limits permitted by financial considerations, bearing in mind that all lines built into new territory are, in a sense, exploration lines opening the door to electric service, generally attracting business by the force of gravity through its economy and convenience.

The general use of electric service has been the result of its adaptibility, convenience and economy; its success depends on reliability and the demand for a limitation in voltage variation. Therefore the question of regulation becomes more important every day, and this fact must be borne in mind when figuring on transmission and distribution lines, except in special cases of trunk lines where line drop can be conveniently compensated at either

TABLE VI

1000 KW. TRANSMISSION, 20 PER CENT LOAD-FACTOR, 80 PER CENT POWER-FACTOR

	LOAD		TRANSFORMER			LINE		TRANSFORMER			
Hours Operation	Per Cent Load	Kw-hr.	Per Cent Losses	Kw-hr.	Per Cent Losses	Per Cent Load	Kw-hr.	Per Cent Load	Per Cent Losses	Kw-hr.	Total Input
.5	75	375	2.60	9.75	76.95	5.48	21.08	82.43	2.54	10.30	416.1[illegible]
4.0	50	2000	3.12	62.40	51.56	3.67	75.69	55.23	2.95	63.07	2201.16
2.0	37.5	750	3.80	28.50	38.92	2.77	21.56	41.69	3.52	28.16	828.22
4.0	25	1000	5.31	53.10	26.26	1.87	19.69	28.13	4.79	51.38	1124.17
13.5	5	675	25.06	169.15	6.35	0.45	3.79	6.80	18.45	156.44	1004.38
24.0		4800	6.72	322.90		2.76	141.81		5.87	309.35	5574.06

end. In computing the regulation of a line the regulation of the transforming apparatus must be considered and added to that of the line; the sum of both must be within allowable limits of efficient operation of the apparatus connected thereto, these limits being generally fixed by commissions, with provisions made for further load additions and power-factor variation.

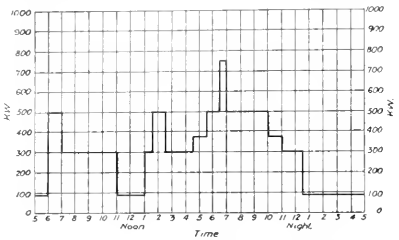


Fig. 5. Average Daily Load Curve 30 Per Cent Factor

A thorough investigation of future requirements should be made in all cases in order to prepare for the service. At the same time financial considerations must be carefully weighed, as they are in many occasions another limiting factor, and in such cases engineering provisions should be made as far as possible in anticipation of prospective emergencies, either in the style of construction for a duplicate line, loop, or for operation at a higher voltage.

The preliminary calculations can be made along the line described before to ascertain if the undertaking will bear the expenses from the start or within a reasonable time and yet allow for future growth. If the first check shows a narrow margin and there is evidence of future increase of business, a second calculation should be made on the basis of the ultimate probable requirements to determine if additional expenses can be carried until the new business is secured.

It is not necessary in all case to go into the tedious analyzis made in this paper, such a course is only indicated in case of doubt as to the successful development of a contemplated enterprise. The motto which must govern all electric transportation of power is "service," and all efforts must be bent toward maintaining this at its best.

TABLE VII

1000 KW. TRANSMISSION, 30 PER CENT LOAD-FACTOR, 80 PER CENT POWER-FACTOR

	LOAD		TRANSFORMER			LINE			TRANSFORMER		
Hours Operation	Per Cent Load	Kw-hr.	Per Cent Losses	Kw-hr.	Per Cent Losses	Per Cent Load	Kw-hr.	Per Cent Load	Per Cent Losses	Kw-hr.	Total Input
.5	75	375	2.60	9.75	76.95	5.48	21.08	82.43	2.54	10.30	416.13
6.0	50	3000	3.12	93.60	51.56	3.67	113.53	53.23	2.95	94.60	3301.73
2.0	37.5	750	3.80	28.50	38.92	2.77	21.56	41.69	3.52	28.16	828.22
8.0	50	2400	4.52	108.48	31.35	2.23	55.93	33.58	4.13	105.91	2670.32
7.5	9	675	13.61	91.86	10.02	.71	5.44	10.73	11.78	90.97	863.27
24.0		7200	4.61	332.19		2.88	217.54		4.25	329.94	8079.67

THE OPERATION OF LIGHT WEIGHT CARS

By J. C. Thirlwall

Railway and Traction Engineering Department, General Electric Company

This article constitutes an argument in favor of the light-weight one-man car, operating on a frequent service schedule, as a means of increasing the volume of traffic and reducing the operating expenses of street railway companies. The advent of the jitney made it obvious that some change in service was necessary to regain the business lost to the jitney or to reduce operating expenses to offset the loss in revenue. Careful study of the whole question disclosed the fact that what the public mostly wants is a greater frequency of service—a lessening of the time lost in waiting for cars. The light-weight one-man car, which can be operated for half the cost of the average heavy car and therefore in double numbers for the same expenditure, is the outcome of the efforts to satisfy this condition. The special features of the cars that have so far been developed are outlined.—Editor.

The past eighteen months has seen a wonderful activity on the part of designers of electric cars and electric car equipment to meet a situation which had been existent for a long time, but which was brought to a climax by the sudden advent of the jitney automobiles. For years, the tendency in the city transportation field had been toward the use of larger and larger cars of practically uniform design, and the endeavor to balance the increasing cost of platform wages and of maintenance by longer headways. In other words, a road which had been operating ten 30-passenger cars at three-minute intervals, purchased six 50-passenger cars and ran them on a five-minute headway. This scheme worked satisfactorily in the largest cities, where headways had become, with the small cars, extremely short, but for the smaller urban properties, where the initial headways were five, ten or fifteen minutes, any lengthening out meant a decided loss of patronage on the part of people who would rather walk than wait, or who would take some other form of conveyance which happened along, whether the private automobile of a friend or the jitney.

The larger road with traffic sufficient to fill 50-passenger cars at five-minute intervals could save enough on the reduced car hours or car miles run daily to justify the initial cost and high power consumption and maintenance of the large cars in spite of the fact that weights and prices were double or triple that of the small single-truck cars they displaced. The smaller road using such equipment as a measure of rush hour economy was seriously handicapped by the increased operating expense during the light hours, which are 80 per cent of the total, and the result was that the headway during these hours stretched out to such a degree that the riding habit was not promoted, and the available business was not developed.

These remarks apply to the most commonly used double-truck cars of the past six or seven years, cars which seated from 44 to 54 passengers and weighed from 34,000 to 56,000 lb., the average probably being in the neighborhood of 44,000 for four-motor equipments and 36,000 for two-motor equipments. The electrical equipment on these cars, the motors and controllers, weighed about 7000 lb. in the case of two-motors, and from 11,000 to 13,000 lb. for the four-motor layout.

The advent of swarms of jitneys in nearly every city in the fall of 1914 and the spring of 1915 was a tremendous blow to the transportation companies, coming as it did on top of a business depression that had cut deeply into the earnings of most roads. The serious competition by these jitneys lasted in most communities but a few months. The inherent cost of the service they pretended to render was in excess of their earnings in most instances; the realization of this fact, primarily, aided in many places by regulating ordinances, bonding, etc., and by an increasing demand for mechanics in other fields, led the majority of auto drivers to seek other means of livelihood.

But while they lasted, they demonstrated conclusively that there was a widespread public demand for a different kind of service from what the railway companies had been furnishing; this was shown by the fact that the earnings of the jitneys in strictly competetive service was very much greater than the decrease in trolley earnings that ensued. In other words, the jitneys secured a large number of patrons who would not have ridden the street cars in any event.

This was due in a measure to their higher schedule speeds, to the supposed comfort of open air riding, and to the novelty of the service; but was chiefly due, the writer believes, to the greater frequency of the service. The home-going crowds have repeatedly been observed in various cities when the jitney epidemic was at its height and the majority of people waiting on a corner would take the first conveyance, street car, auto bus, or jitney that stopped at their corner. It is of course obvious that many people living within moderate walking distance of their places of business will start walking if a car is not in sight, and if they cover a large part of the distance they have to go before a car overtakes them, they will walk the remaining way. Others, who stand on a corner waiting for a car, are seen by a friend in a private automobile who picks them up. Many of both classes were claimed by the jitneys.

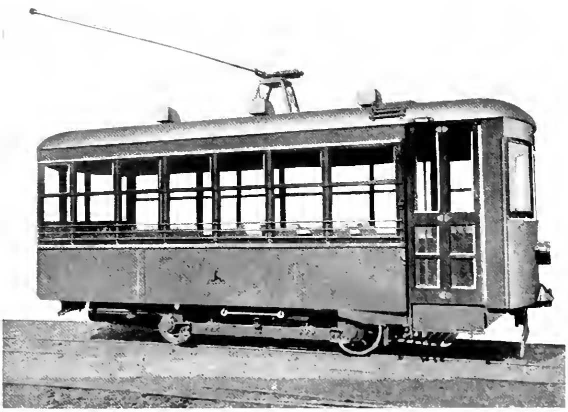


Fig. 1. A Representative Light Weight, One-Man Car, Seating 29 Passengers and Weighing 10000 Lb.

These facts led many railway executives to figure very seriously on what means they could adopt that would make it possible to supply a similar class of service. This meant, in most instances, more cars, faster schedules, or both. Faster schedules could be secured by eliminating a portion of the stops. The skip-stop or the nearside stop plans, where the public would accept them, were found to help very materially in this direction. Faster rates of acceleration and of braking, and cutting down the duration of stops were other means adopted by various roads to shorten up the running time on their lines; and with no other changes than this many companies found that a big part of their former partons who had gone over to the jitneys were brought back to the electric cars.

But the study devoted to this situation, particularly in the smaller cities, led to the inevitable conclusion that what the public most desired was a greater frequency of service, a shortening of headways. If more cars of the standard type were used, with two men per car, all expenses of operation climbed in direct proportion to the number added. In other words, if 50 per cent more cars were run to cut headways from 15 minutes to 10 minutes, the cost of operation per day went up 50 per cent. The increased receipts from such an increase of service did not advance 50 per cent, and in fact it has been found that an increase of 100 per cent in the number of cars will result in about 30 per cent to 40 per cent more business.

The answer to this, in the minds of a great number of railway managers and engineers was that the type of cars used must be changed and the biggest item of operating expense, that of the car crews, must be reduced by eliminating the conductor, whose duties in the last few years have become less and less exacting, and the need of his services less and less imperative. The almost universal introduction of the prepayment fare system, of trolley retrievers, and of signal push buttons, has left the conductor practically nothing to do while the car is in motion except to issue transfers—and but little of that ordinarily. The motorman, on the other hand, has nothing to do while passengers are boarding or alighting, and it is imposing no hardship on him to require him to watch the dropping of fares into the fare box, to make change, and to issue transfers, during this interval.

But to put this scheme into operation meant closing off the rear entrance and exit—in other words, the one-man car. Inasmuch as the introduction of such a car was based on the desire to give more frequent service they obviously did not have to be as large or to have as many seats as the cars they were to replace.

A number of designs for such cars have been worked out by the car building companies, assisted by the engineers of operating companies, but all are of approximately the same size, seating from 26 to 32 passengers, and weighing from 10,000 to 12,000 lb. completely equipped.

To assist in securing such extremely low weights the two leading manufacturers of electrical equipment designed and built motors and controllers of an exceptionally light and compact design; special air brake apparatus was also developed and applied.

A typical example of such a car is illustrated in Fig. 1. This was developed by the American Car Company working along ideas advanced by Mr. C. O. Birney of the Stone & Webster Engineering Corporation. This car seats 29 passengers and weighs complete only 10,000 lb. It has many interesting features to ensure safety of operation.

The controller handle (as shown in Fig. 2) has an air attachment which is connected to the circuit breaker. If the motorman, through accident, illness or any other reason, removes his hand from the handle while power is on the motor, the circuit breaker is opened, dropping off the power automatically, the brakes are applied, sand is thrown on the rails, the front door is opened, and the emergency door at the rear of the car is unlocked.

Fig. 3. Another Type of Light Weight, One-Man Car

Fig. 2. Control Apparatus of the Car Shown in Fig 1

Under ordinary operating conditions, the doors can only be opened when the brakes are fully applied, and the brakes cannot be released until the doors are closed, both operations being controlled by the same handle. These features will absolutely eliminate accidents caused by passengers attempting to board or alight from a moving car; they also prevent the chance of the car running away, should the motorman faint or fall dead. Such details are especially desirable in a car operated by but one man. Two small G-E motors are used on this car. Cars of this type have been purchased for Stone & Webster properties on the Pacific Coast and in Texas, and some will soon be put into operation in Sedalia, Missouri.

The St. Louis Car Co. has recently built cars of very similar design, though without air brakes, for Aberdeen, South Dakota.

Another type of car for similar service was designed by Mr. Haller of the Federal Light & Traction Co. This car (see Fig. 3) has the same seating capacity as the one just shown and weighs about 11,000 lb. The most novel feature of this car was the use of four small automobile types of G-E motors, each motor being connected directly to the wheels by concentric gears. No live axles are used, and the motors are mounted as shown in Fig. 4.

Automatic application of the brakes and shutting off of power if the motorman releases his operating handle are secured by means of springs and levers instead of air.

Several of these cars have been put into service in Tucson, Arizona, and their use has already resulted in a marked increase in receipts and a decrease in operating expenses.

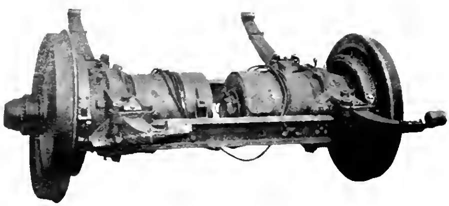


Fig. 4. Method of Mounting Motor on Car Shown in Fig. 3

The writer is informed by the designer, however, that in other cars he may have to build in the future several changes will be made—two motors of the size used on the Birney car will probably be substituted for the four $7\frac{1}{2}$-h.p. machines, and a differential drive will be employed similar to that on an automobile. The control will be of the standard platform type with circuit breakers mechanically interlocked, instead of being hung beneath the car floor as at present.

In both these cars, the dominating idea was to provide a car which was especially suited to one man operation, and which would avoid the suspicion that the safeguarding of passengers would be decreased by doing away with the conductor. In both types, the brakes are automatically set, and neither car could start up on a grade if the motorman left for any purpose, and both would stop automatically should he release his hold on the control handle while power was on.

These features are highly desirable, but not an absolute necessity, as has been shown by the operating data in two properties of the Federal Light & Traction Co. On these two roads, which have been operating standard type single-truck cars which were simply changed over for one-man operation by closing off the rear entrance and exit, the accident expense has been running at approximately one-third of what it was when two men per car were used.

Another car designed along standard lines by Mr. Burke of the American Railways, seats 28 and weighs 12,000 lb. For convenience in operation, it is double-ended (the rear doors being closed off during operation). This feature accounts for the increased weight over the single-end designs. A number of these cars are in service in Corpus Christi, Texas, and the results obtained are striking. A sufficient number were put into service to cut headways on all lines down from 15 minutes to $7\frac{1}{2}$ minutes, and on one line to 5 minutes. Within a month after this was done, receipts rose 40 per cent with only 6 per cent increase in operating costs—that is, it cost but little more to run ten of these cars than it had to operate five of the two-man cars they displaced. They have been very well taken to by the public, and it has been found that the schedule speeds could be and have been increased. Their operation has been remarkably successful in every respect.

Mr. J. M. Bosenbury of the Illinois Traction System has also devoted considerable time and study to the design of light weight cars as has Mr. R. D. Long of the Muskogee Electric Traction Co. of Oklahoma. Both of these gentlemen designed and placed in operation extremely light weight two-man cars which have a very low power and maintenance cost.

In regard to the economy of substituting such cars for those of standard types, some very interesting figures have been shown the writer by the Federal Light & Traction Co., who operate the traction properties in Grays Harbor, Washington; Hot Springs, Arkansas; Los Vegas, New Mexico; Springfield, Missouri; Trinidad, Colorado, and Tucson, Arizona. Hot Springs has had one-man operation for three years, and Los Vegas for four years, and a comparison of their costs with that of the other properties is interesting.

The average cost per car mile for the four properties using two-man cars was 18.1 cents in 1914. For the two cities with one-man cars it was 9.73 cents. In 1915, the figures were 16.2 cents and 9.79 cents respectively. These figures correspond closely with estimates made by various engineers that the reduction in operating costs in medium sized cities would be at least one-third and probably one-half.

On the roads in question, the various items going to make up these totals compare as follows, for the two years 1914 and 1915.

	One-man Cars Cents	Two-man Cars Cents
Way and structures	1.04	1.75
Equipment	0.98	1.8
Power	1.99	2.79
Traffic and operation	3.2	6.41
General	2.54	4.37
Total	9.75	17.12

Had the two properties using one-man cars been equipped with cars and equipment of modern design, the power account would probably not exceed 1 cent, and both the equipment account and the way and structure account would be appreciably reduced, and the total would probably be about 8 cents per car mile. In other words, by the use of such cars and this method of operation, costs can be cut squarely in two, or double the service can be provided for the same annual expenditure in dollars and cents.

Assume a city railway operating the ordinary two-man cars on 12- to 20-minute headways and with average receipts per car mile of 22 cents and operating costs of 16 cents per car mile, a fairly typical instance. Assume they operate 50 cars and average 1,500,000 car miles per year. Their total receipts are $330,000, and the operating expense is $240,000, leaving $90,000 net to meet fixed charges. To replace these 50 cars with the new one-man type would cost $150,000 approximately. With operating costs cut in two there would be $120,000 increase in the net annually, or a return of 80 per cent on the investment, and if for reasons of rush hour congestion it were necessary to still operate the old cars during the rush hours (even with two men per car), the increased receipts due to shorter headways would more than compensate for the increased cost during these periods.

In the small city there can be no question of the advantages and the positive necessity for the adoption of this method of operation. The advantages in larger cities are just as obvious, but certain difficulties will be encountered in putting them into operation. These are:

1st. City ordinances requiring two men per car.

2nd. Nearside stops are essential to the best operation.

3rd. Delays and reduced schedule speeds due to the time required to issue transfers and to longer stops in the congested portions. These will be largely offset, however, by the reduced number of stops where more cars are operated, and it is possible, as in Cleveland, to have the passengers pay as they leave the car on outbound trips.

4th. Flagmen might be required at railroad crossings. Cities already using these cars, however, have found no need of this latter precaution.

The service in the larger cities for which such cars are especially fitted are stub lines, lines where headways are especially long, and close-in lines where a large percentage of people walk to and from work. The latter class is where the use of such cars would probably show the greatest return to the operator.

The greatest obstacles to a wide extension of this plan of operation will undoubtedly be the attitude of the labor unions and of the city authorities. It will be necessary to do a large amount of educational and publicity work before these can be overcome, and it probably will be advisable to pay the operators of the one-man cars a somewhat higher rate. But provided there are no wholesale reductions of forces, that is, if by running more cars the former conductors can be continued in service as motormen, and at a higher wage, there should be no great trouble in convincing the employees that the move is to their own advantage as well as to the company's; and the public will offer no objection if by this means better service is afforded them.

In conclusion it is well to note that this scheme has been put into actual operation in at least twelve cities, ranging from 25,000 to 110,000 population, and almost without exception they report it as a success. It is therefore beyond the experimental stage. The types of cars and equipments mentioned here should and will aid materially in the extension of the benefits that both the public and the operators will derive from a wider application of the idea.

SAFETY FIRST SWITCHBOARD DEVICES

By B. Parks Rucker

Switchboard Engineering Department, General Electric Company

Much has been done of late by railway companies and industrial concerns, under the motto "Safety First," to reduce the ordinary hazards to life and limb; and in keeping with these efforts the electrical control devices described in this article have been developed. Wherever possible they have been made "fool proof" by interlocking, with the purpose of making it impossible for the operative to come into contact with live parts through thoughtlessness. The general use of electricity in the industries has made its control by uninformed persons necessary in many cases, and for such installations these devices are specially appropriate.—Editor.

"Safety" first as a slogan is of comparatively recent origin, but "safety first" as a principle may well be classed with self preservation as one of the first laws of nature. "Safety first" in one form or another, is encountered in every phase of modern life. In medicine, it is seen in the many forms of vaccine, antiseptics, and modern sanitation; in architecture, in the introduction of fire escapes, automatic sprinklers, safety devices on elevators, etc.; in railroading in the modern signalling systems and rigid operating and equipment regulations; in our roads and streets by speed and traffic regulations; and on the sea in the maritime laws and regulations as recognized by international law.

The introduction of these safeguards to life and property has been, in many instances, a slow and tedious process, but once installed they are universally accepted as necessities of modern life. Within recent years our city, state and federal governments have appointed public service and safety commissions to study conditions in mines, factories and other industrial plants and to make recommendations looking to the better protection of the safety, health and well-being of employees in such institutions. These investigations, supplemented by the help of leading manufacturers and independent organizations, have resulted in many improvements in factory conditions, and in a considerable decrease in the number of accidents that occur yearly in industrial plants.

The use of electricity for lighting and power has been one of the most important factors in making our factories comfortable and healthful places in which to work—in addition to increasing the quality and quantity of the output. For, besides lighting one's path, a good light is a foe to unsanitary conditions—and the individual motor drive eliminates many dangerous belts, pulleys, shafting and much other power transmitting machinery.

With the enormous increase in the use of electricity in industrial establishments and in our homes has come a demand for safer switching and control apparatus—apparatus that may be successfully and safely operated by the merest novice. This demand is accentuated by actual and proposed rules and regulations of such bodies as the Bureau of Standards, The National Board of Fire Underwriters, and by public service and safety commissions in the several states. The electrical manufacturers are now fully prepared to comply with any reasonable requirements in this line and are developing devices to fill and, if possible, to anticipate the rapidly growing demand for safer and more nearly "fool proof" types of electrical control apparatus.

SAFETY FIRST ENCLOSED LEVER SWITCH

One of the most common forms of electrical control devices is the knife, or lever switch. Many types of this switch are now on the market but the great majority of them do not fully meet the generally accepted requirements of 'safety first" apparatus. A lever switch, to be properly classed as "safety first" must comply with the following specifications

1. It must comply with the rules of the National Board of Fire Underwriters.
2. All current carrying parts must be completely enclosed and inaccessible while alive.
3. The fuses must be accessible only when they are "dead" and when the switch is in the "off" position.
4. Provision must be made for locking the switch in the "off" position.
5. Independent provision must be made for locking the fuse chamber to prevent access by unauthorized persons and without interfering with the operation of the switch.

The safety first enclosed lever switch shown in Figs. 1 and 2 meets all these requirements. The unit consists of a standard lever switch enclosed in a cast iron box. This box is rugged, compact and lends itself readily to single or group mounting and to open or conduit wiring. Eight "knockouts" for conduit are provided, and in wiring the cover and mechanism are removed thus converting the switch box into a very convenient pull-in box. Bus junction boxes are provided for group mounting as are also convenient ammeter or voltmeter units for attaching to the switch when desired.

The operating mechanism is exceedingly simple, consisting merely of a curved shaft operated by an external handle and engaging with a hook shaped malleable iron casting attached to the cross bar of the lever switch. The lid to the fuse chamber can be opened only while the switch is "off" and the switch cannot be closed while this lid is open.

These switches may be used to advantage wherever front connected knife switches are required. They are especially adapted to the control of motors on machine tools or in industrial plants for the control of motors or lighting. They are practically "fool proof" and some switches should be installed whereever lighting or motor switches are operated by inexperienced persons. By means of the hole in the handle and an ordinary padlock the machine operator may lock his switch in the "off" position and inspect or adjust his machine in safety. The key to the padlock on the fuse cover may be carried by the

Fig. 1. 250-volt, 60-ampere, Double and Triple-pole Single-throw Safety First Enclosed Lever Switches. Double-Pole Switch Locked "Off" and Fuse Cover Locked Closed; Triple-pole Switch in "Off" Position and Fuse Cover Open

plant electrician—thus preventing unauthorized persons from tampering with the fuses.

The ideal working conditions for a machine tool operator are, of course, those under which he can give his whole time, attention and nervous energy to the work in hand. Thus, on a motor operated lathe, with all gears, other finger amputating and motor control devices completely enclosed, he may give his undivided attention to his work—and one greatly desired result will probable be an increase in the quality and quantity of the

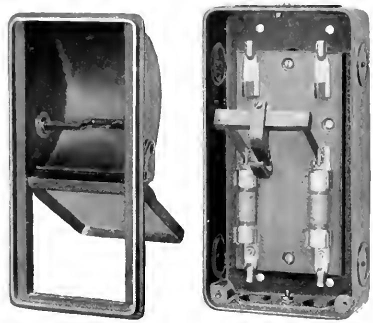


Fig. 2. Double-pole Switch Shown in Fig. 1 with Switch and Fuse Cover Open

tools' output, and certainly the accident insurance adjuster will make fewer visits.

LOW TENSION DEAD FRONT PANEL SWITCH

Another recently developed safety-first switch is shown in Figs. 3, 4, 5 and 6, and is known as the low tension dead front panel switch. The current carrying parts of this switch are made up largely of standard knife switch and fuse clip parts, mounted on a slate base supported by iron studs at the back of a sheet steel panel. These steel panels are $\frac{3}{16}$ in. thick, and their other dimensions are graded so they present a uniform appearance even when several sizes are mounted together.

The operating handle has the same general appearance as the standard oil circuit breaker handle and is so arranged that it stands in an upright position when the switch is "on" and at an angle of 60 degrees with the panel when the switch is "off." The operating link passes through the steel and the slate panel and transmits motion from the handle to a lever secured to the cross bar of the switch. In the two pole unit this link is of one piece of steel, but in the three pole it has an insulating section and is attached directly to the middle blade of the switch.

The steel, or front, panels of the switch units are each provided with a hinged sheet steel door, opening upward, and placed just behind the operating handle. As will be noted from the illustrations this door gives access to the fuses from the front of the panel; also that this door cannot be opened while the switch is "on" and that the switch cannot be closed while the door is open. This makes it possible to examine or replace fuses at any time, but also makes it practically impossible for the operator to come in contact with live current carrying parts. The switch can be locked in the "off" position by means of an ordinary padlock, the hasp of which is passed through holes in the operating handle and the hinge.

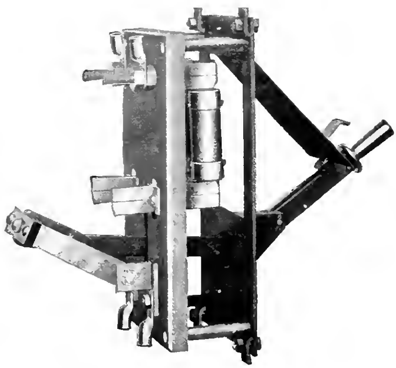


Fig. 3. Safety First Panel Switch Unit

Carbon break circuit breakers are mounted on these panels in the same manner, so a complete line of panels, using either lever switches or carbon break circuit breakers, or both, may be readily built up. The capacity of these switches, as is the case with the safety-first enclosed switches, is limited only by the sizes of the 250 and 600-volt enclosed fuses as approved by the National Board of Fire Underwriters.

The panel frame is built of angle iron, riveted, and the current carrying parts back of the panel are enclosed in expanded metal. The wires and cables to and from the switches may be brought out at the top or bottom of the panel. The steel bases of the switches are not drilled for mounting bolts, but are secured to the panel frame by bolts and a special clamp. By this means switch units and panel frames may be taken from stock and assembled without additional drilling or machine work.

These switch units and panels are primarily intended for use as distributing panels for light and power and for generator and feeder panels for the smaller lighting and power plants. They are especially applicable to use in factories where switchboards are operated by inexperienced or careless employees and where the ordinary switchboard is in constant danger of short circuits or grounds from outside sources.

PEDESTAL TYPE SWITCHING UNITS

The switches and panels just described are of necessity limited to use on circuits having a voltage of 600 and under. For the control of single circuits up to and including 300 amperes at 2500 volts, the pedestal type switching units have been developed. As

Fig. 4. Safety First Switch Panel Side View

will be seen in Fig. 7 this unit consists of a standard industrial type oil circuit breaker mounted on a pedestal built up of angle iron and steel plates. The space below the switch and enclosed by the steel plates serves as a compartment for the mounting of current and potential transformers. The housing above the switch encloses the disconnecting switch and also serves as a mounting for an ammeter or voltmeter, or both, when desired. Watthour meters or other instruments may be mounted on the sheet steel front panel.

The disconnecting switch is interlocked with the oil circuit breaker so the former cannot be opened when the latter is closed—nor can the oil circuit breaker be closed while the disconnecting switch is open. The disconnecting switch is operated by means of a key projecting through the front of the housing. This key may be removed when the disconnecting switch is open—thus locking the oil circuit breaker in the open position. By carrying this key with him the operator can feel assured that no one will close the switch while he is working on lines or apparatus on that circuit. Access to the interior of the switch compartment cannot be had when the switches are on, nor can the oil tank be removed while the switch parts are alive.

A very similar unit, as shown in Fig. 7-a., is made for wall or post mounting. This unit uses the same circuit breaker, disconnecting switch and cast iron housing, and differs only in that the sheet steel housing is omitted and the instrument transformers are mounted in a small cast iron compartment above the disconnecting switch. An ammeter or voltmeter, or both, may be mounted in the housing, but independent provision must be made for other instruments.

The pedestal type is particularly adapted to the control of circuits feeding banks of transformers, motors in pumping plants, steel mills, etc. It is self contained and may

Fig. 5. Safety First Switch Panel Front View

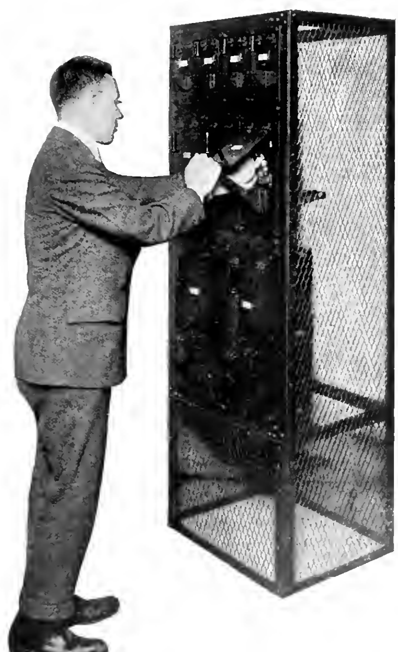


Fig. 6. Safety First Switch Panel Showing Method of Removing Fuses

be ranked as "safety first" in every particular. The wall or post type is especially well adapted to use in mills or other industrial plants where it is desired to mount the con-

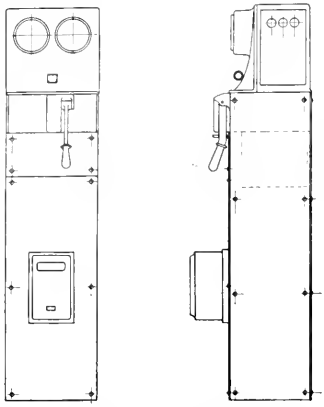


Fig. 7. Iron Clad Switching Pedestal, 300 Amperes, 2500 Volts, 3-phase

trol apparatus on the walls or pillars. It is designed for group mounting—and for this purpose a bus compartment of liberal dimensions is provided just above the disconnecting switch and within the cast iron housing. Conduit connection with these units may be made from above, below or either side.

STEEL SWITCHING CABINET

The demand for switching units for circuits of greater capacity than may be handled by the pedestal switching units has led to the development of the Steel Switching Cabinet. This consists, primarily, of switching units, instrument transformers and disconnecting switch, enclosed in a sheet steel compartment with operating levers, instruments, etc., mounted on its sheet steel front or panel. This unit is shown in Fig. 8, the usual dimensions of the panel being 1¼ in. thick, 24 in. wide and 76 in. high. The compartment is usually 36 in. deep, has sides and cover of $\frac{1}{16}$ in. steel and a hinged rear door of ⅛ in. steel. All current carrying parts are completely enclosed, and leads may be brought out at the top, bottom or sides of the unit.

The switching apparatus usually consists of a standard switchboard type oil circuit breaker operated in the ordinary manner. This oil circuit breaker is interlocked with the disconnecting switch so that this switch cannot be opened or closed while the oil circuit breaker is closed. The disconnecting switch is operated from the front of the panel by means of a special wrench, and is interlocked with the rear door so this door cannot be opened while the switch is on, nor can the switch be closed while the door is open. This makes it practically impossible to gain admittance to the compartment while the current carrying parts are alive.

This apparatus has been designed to serve as distribution and tying-in switches, as control switches for induction and synchronous motors, etc. It is usually mounted singly, but may be installed in groups if desired. It may be made with a drip roof and nearly water, dust and gas proof, and so is especially applicable for service in mines or wet and exposed places. It should also come into favor as a means for controlling large motors in pumping plants, steel and cement mills, etc.,

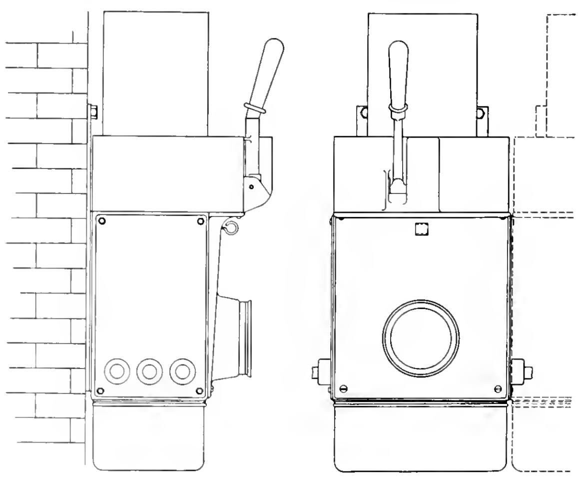


Fig. 7a. Iron Clad Switching Unit for Wall or Pillar Mounting

where the usual switching apparatus is often damaged or put out of service by dust, moisture, chains from traveling cranes or other external source. The apparatus can be shipped assembled and requires only to be bolted to the floor.

The front panel, 24 in. by 76 in., is large enough to permit the mounting of the usual instruments. The unit is made in capacities up to 500 amperes at 6600 volts and up to 800 amperes at 600 volts, and for single, two and three phase circuits, though the 6600-volt units have somewhat greater dimensions than those given above.

SAFETY FIRST TRUCK TYPE SWITCHBOARD PANELS

The safety first truck type switchboard panels as illustrated in Figs. 9, 10, 11, 12 and 13, represent the latest development in switchboard design and are especially adapted to use in small and medium size power plants and in distributing centers of larger capacity and moderately high voltages in industrial plants.

Each complete unit consists of two elements—the truck or movable element carrying the panel, oil circuit breaker and instrument transformers, and the stationary or housing element enclosing the truck (when it is in the operative position), the busses, and the terminals of the incoming and outgoing cables.

The truck is substantially made with a cast iron frame rigidly braced with latticed steel bars, and is carried on four flanged wheels. These wheels have two treads—one of which takes the weight of the unit when it is removed from the housing and a machined thread of smaller diameter to run on the steel track within the housing.

The steel panel, usually $\frac{1}{4}$ in. thick, $23\frac{1}{2}$ in. wide (24 in. c to c of panels) and 76 in. high, carries the operating mechanism for the oil circuit breaker and the usual switchboard instruments; also handles for use in replacing or removing the truck from its compartment, and an interlock so arranged that the truck may not be replaced or removed while the oil circuit breaker is closed. When in the operative position the panel serves as a door in completely enclosing all current carrying parts within the housing.

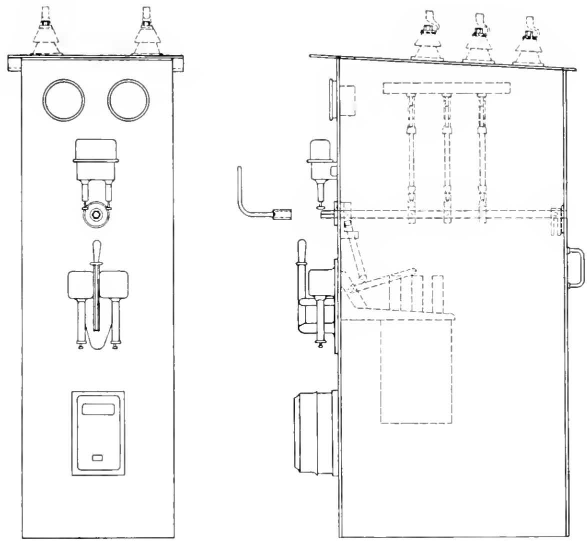


Fig. 8. Steel Switching Cabinet, 500 Amperes, 2500 Volts, 3-Phase

The housing is built up of sheet steel plates riveted to angle iron and is provided with two part doors at the back. The sides, cover and rear doors are of sheet steel, the first $\frac{3}{16}$ in. thick and the two latter $\frac{1}{8}$ in. thick. The housing is usually 4 ft. 6-in. deep, and the complete unit therefore occupies a floor space 24 by 54 in. in size.

Contact studs of a substantial disconnecting switch of novel design are carried on porcelain insulators attached to a cast iron frame that is built in as part of the truck. Leads from the oil circuit breaker terminate in these studs which, when the truck is in the housing, make connection with contact jaws on similar insulators mounted in a cast iron frame within the housing. This latter frame forms part of a partition completely isolating the bus compartment from the remainder of the housing. Electrical connection between the contact jaws within the housing and the busses is by means of copper studs through the porcelain insulating bushings. These studs also serve as supports for the busses, no other supports being necessary.

Provision is also made in the housing for the mounting of potential busses. These busses, when desired, may extend the entire length of the switchboard, and electrical connection with the wiring on the panels made by means of smaller contact studs.

Fig. 9. Safety First Truck Type Switchboard Unit

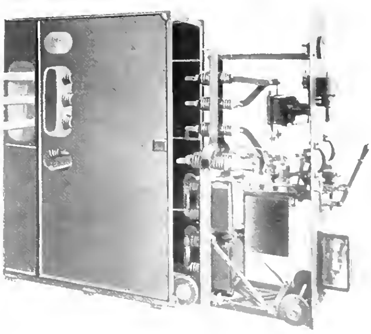


Fig. 10. Safety First Truck Type Just Entering Compartment

From the above it will be seen that removing the truck from the housing opens the disconnecting switches--thus completely isolating the apparatus on the truck from the busses and outgoing leads. Calibrating plugs may be provided so that the readings on the panel instruments can be checked or corrected without removing the truck from its housing.

These units, undoubtedly, make the most desirable switchboard for a distributing center that has ever been devised, especially when considered from the standpoint of safety to life, elimination of fire risk and continuity of service.

Fig. 11. Safety First Truck Type Switchboard, One Truck Removed to Show Rear of Compartment

All current carrying parts are completely enclosed when alive—and when withdrawn for inspection or repairs the wiring and apparatus on the truck is accessible from all sides and electrically dead. By the use of a padlock the circuit breaker may be locked in the "off" position, thus insuring the safety of men working on lines or apparatus controlled by that circuit.

Fire, caused by an explosion in the oil circuit breaker, or otherwise, would in all probability be confined to the compartment in which it originated. The busses, being in a separate compartment, are especially well protected. They are separated from the oil circuit breaker and all other conductors by heavy metal barriers—and the compartment in which they are placed contains no combustible of any character.

In case of accident to any switch or panel a spare panel may be substituted in an inappreciable time, as the units, within reasonable ranges, are interchangeable. One firm has recently installed 21 of these housing units and purchased 23 truck panel units—thus having two spare panels in reserve. The units are especially adapted to group mounting, and new units may be added to a group at any time. All that is necessary is to lengthen the busses and bolt the new housings to those already in place.

The truck units are shipped assembled and wired ready for service. The housings are shipped "knocked down" and need only to be bolted together, so these panels may be installed and put in operation within a remarkably short space of time.

The units as at present designed are limited to 800 amperes at 600 volts, or 500 amperes at 7500 volts, single, quarter or three-phase circuits. By a special design they may be used up to 300 amperes at 15,000 volts. In the standard apparatus the current on the main bus in the housing is limited to 2000 amperes at 60 cycles or 300 amperes at 25 cycles.

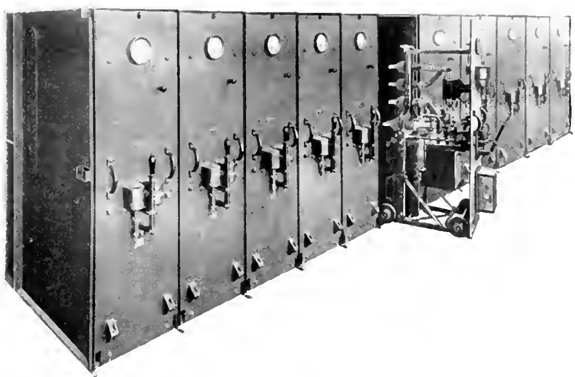


Fig. 13. Safety First Truck Type Switchboard, with One Truck Being Removed for Inspection

Fig. 12. Safety First Truck Type Switchboard, Back Covers of One Unit Removed

A LUMINESCENCE COMPARATOR

By W. S. Andrews

Consulting Engineering Department, General Electric Company

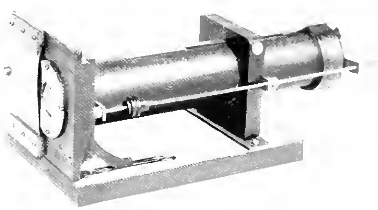
The device described in this article affords a ready means of determining the degree of increase or decrease in the luminosity of self-luminous compositions over a period of time. It consists essentially of a miniature incandescent lamp and transformer, colored glass screens, and the necessary adjusting screws and scales.—Editor

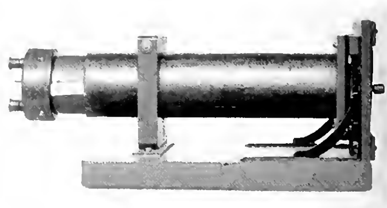
An instrument as illustrated in the accompanying prints has been designed to measure the increase or decrease of luminous intensity in various *self-luminous compositions*. This instrument is not a photometer, inasmuch as it does not measure candle-power or any other unit of light, but it permits a comparison to be made between a constant source of light and a source of light which may be gradually changing in brightness.

Fig. 1 is a perspective view of the comparator and Fig. 2 shows the other side to that seen in Fig. 1. Fig. 3 is the same view as Fig. 2, but with part of the outer tubes cut away to show the disposition of a moveable 2-volt 2-candle power incandescent lamp. The light of this lamp is screened down to the exact color tint of the self-luminous composition by colored glass, and it must be carefully seasoned by long burning before being used in the instrument in order to insure a constant illumination at a given voltage. Referring to Fig. 3, the numbers indicate as follows:

1. Miniature incandescent lamp.
2. Transformer which reduces the 120-volt a-c. from lighting circuit to 2-volts.
3. Porcelain receptacle.
4. Wooden block fastened in the end of the inner sliding tube.
5. Connecting wires running from receptacle to binding posts at the back.

The lamp is thus operated at its normal voltage of 2-volts by connecting the binding posts to a 118–120-volt a-c. lighting circuit. Its light, after being screened through colored glass at A is distributed in an evenly illuminated field 1½ in. in diameter by a plano-convex lens shown at the front of the instrument in Fig. 1. The intensity of light shown by this illuminated disk may be changed by varying the distance of the lamp, in relation to the back of the lens, the long adjusting screw shown at the side of instrument in Fig. 1. being used for this purpose. The distance of the lamp filament from the back of the lens is indicated by the sliding pointer on a millimeter scale seen on the top of the outer tube.





Figs. 1 and 2. Two Views of the Luminescence Comparator

The self-luminous compound may be used in the form of a dry powder enclosed between two glass plates, the containing chamber being made by cutting a circular hole 1½ in. in diameter in paper of suitable thickness, which in practice may vary from 0.25 to 0.5 mm. or thicker if necessary, or the compound may be mixed with a suitable varnish and painted on a plate of glass in a disk 1½ in. in diameter. The size of the glass plate used in the instrument here described is 3¼ by 4¼ in.

The instrument must naturally be operated in perfect darkness, and when connected up, two disks of greenish light will be seen side by side, one being the disk of luminescent material and the other the light of the incandescent lamp after it is screened through the colored glass and distributed in an evenly illuminated field by the plano-convex lens. The latter disk is then brought to the same degree of intensity as shown by the disk of self-luminous compound by moving the lamp backwards or forwards in the tube by the adjusting screw at the side, and the reading of the pointer on top will show the distance in millimeters between the lamp filament and the plane surface of the lens. This distance being noted, if in future observations the light of the luminous material has depreciated the lamp must be moved farther away from the lens to make a balance, or vice versa in case the light has increased, and a record of these readings from time to time may be plotted in accordance with the well-known photometric formula to show the curve of decay or increase.

The 1½ in. disks of self-luminous compound should be prepared on glass slides of uniform size, so that they will all fit alike

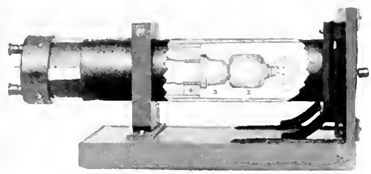


Fig. 3. Internal Construction of the Comparator

in the holder, and in this way any number of different preparations may be tested from time to time.

SHELTERS FOR AUTOMATIC WATER-STAGE RECORDERS

By Geo. J. Lyon, C. E.

Assistant Engineer, U. S. Geological Survey, Albany, N. Y.

The initial solution of even a very simple problem is almost certain to be inferior to subsequent solutions derived through the aid of experience with the former ones. For this reason, the tried and recommended instructions contained in this article should be of considerable value to anyone constructing an automatic water-gage recorder shelter and well.—Editor.

It is frequently necessary in stream gaging work to install an automatic gage in order to obtain a satisfactory record of the water stage. The relation of the automatic water-stage recorder, and the structure for its protection, to the other elements of a stream flow gaging station are shown in Fig. 1.

The type of shelter to be used at any station is determined by considering three elements: viz., utility, safety, and appearance. The weight given to each varies with the location of the station. In every case convenience in operating the gage should control the design. The shelter should be large enough to allow the engineer to pass conveniently around the gage table while inspecting or adjusting the gage and should be well lighted by means of windows properly located. It should also be well ventilated to be rid of excess moisture, while at the same time it must be closely built to exclude dust, insects, etc., which may interfere with the gage mechanism.

Such a structure has been developed by the engineers of the U. S. Geological Survey; its appearance is illustrated in Fig. 2. It is built in five sections, one roof section and four side sections, all of which are not too large to be carried from the shop or mill on a wagon. The side sections may be of tongued-and-grooved, car siding or of ship-lap lumber, with or without clapboards or shingles. If additional protection is required, the interior may be ceiled. The details of construction are shown in Fig. 3.

The floor of the shelter should be of 2-in. plank securely spiked to the sills. This floor carries the gage table, Fig. 1, the center of which is placed 30 inches from the back of the house and the same distance from each side wall. This table is best made of three layers of 1-in. material, the middle layer running across-grain of the top and bottom layers, which run in the same direction. The separate thicknesses are fastened together with screws so placed as to permit the location of the necessary openings through the table.

Adjustable legs for the table are made of pieces of 1½-in. galvanized iron pipe 24 to 30 inches long, threaded at both ends, the threads being cut long and to a tight hand fit. One end must have a left-hand and the other a right-hand thread. The threads fit into

1½ by 5-in. floor flanges, four of which are fastened to the floor and four to the under side of the gage table. Four of the flanges must have left-hand threads.

The shelter is placed over the well box, to which it should be fastened securely. The entrance to the well is through a trap-door, placed just in front of the gage table, see Fig. 4. In constructing this door ample allowance for swelling of the lumber should be made at the end and on each side. The bed piece of the hook gage should be fastened to the frame of the well and to a horizontal piece of 2 by 6-in. material placed behind it and across the top of the window frames. Lugs of Z-shape on the bed piece hold the hook-gage rod in place.

Where the change of water stage is considerable, it may be necessary to allow the hook-gage rod to pass through a small opening in the roof, which should be closed when not in use.

The well itself is essentially a stilling box for the float that actuates the automatic gage. The construction of the well is shown in Fig. 4. It should be placed far enough back from the river to be out of danger from floating ice or drift, and to prevent freezing of the water in the well. It should also be thoroughly ventilated so that excess moisture may not interfere with the operation of the gage. An intake pipe, which must always be

Fig. 2. View of a Standard Wooden Shelter

placed below the lowest water stage, connects the well with the river so that the height of water in the well fluctuates with the stage

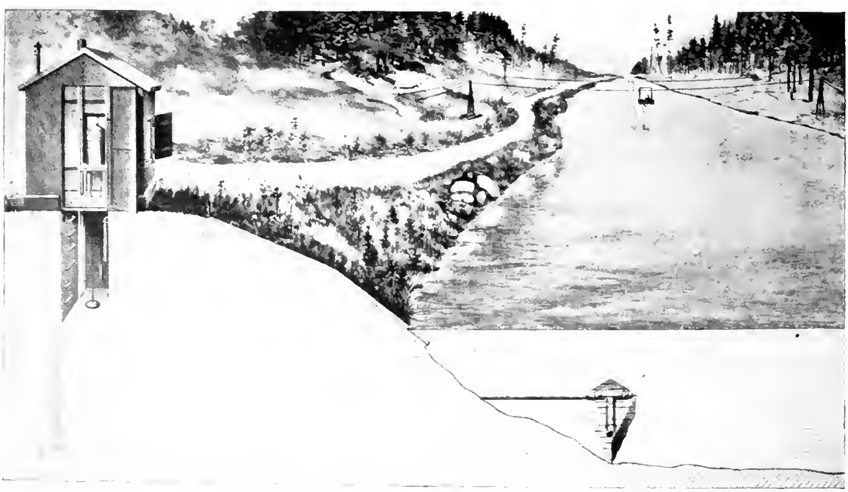


Fig. 1. Photograph and Drawing of a Typical Gaging Station Layout

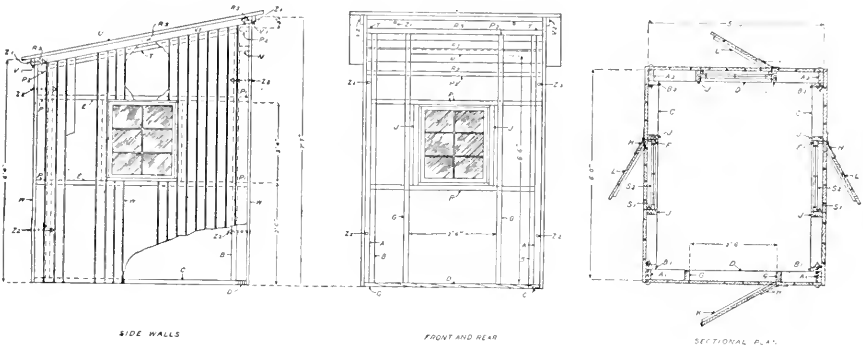


Fig. 3. Construction Drawings of the Wooden Shelter Shown in Fig. 2

of the river. The well box must be large enough to accommodate the float, the driving and counter weights, and the hook and staff gages, and to permit them to be inspected readily. Experience shows that a well 2½ by 6 feet in plan gives very satisfactory results in practice. When placed in fine earth the joints in the well box should be covered with battens. The lumber of which the box is made should be treated with a perservative and the shelter should be well painted, preferably a moderately dark gray.

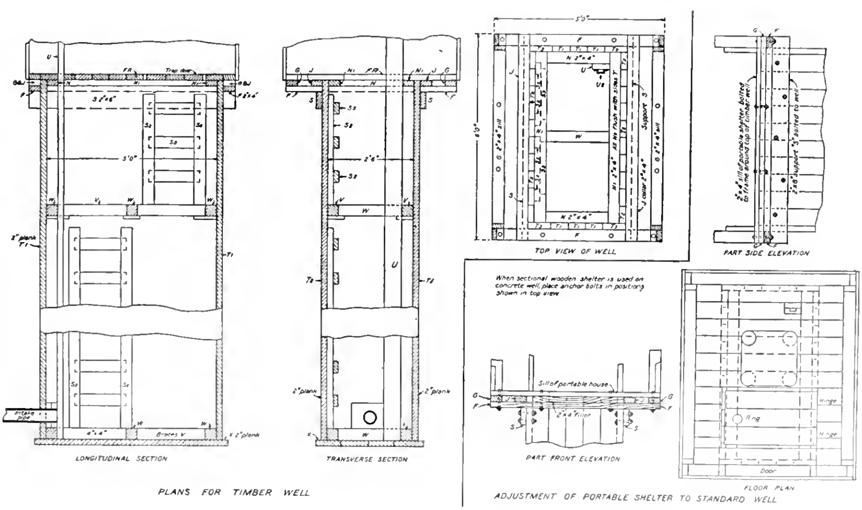


Fig. 4. Construction Drawings of the Standard Timber Well Box Used in Connection with the Shelter Shown in Fig. 2.

PROTECTION OF FEEDER LINES

By F. Dubsky

Transformer Engineering Department, General Electric Company

It has not been generally recognized that the installation of devices for the protection of feeders against trouble from excessive voltage, current and frequency is of increased importance for feeder lines controlled by regulators. An analysis of the operating conditions and of the protective devices for feeder lines controlled by regulators is given in the following article.—Editor.

Feeder lines may be subjected to high-potential stresses and to high-frequency disturbances due to causes that may be internal or external to the circuit. Short circuits, arcing grounds, operation of switches and circuit breakers, charging of electrolytic lightning arresters without charging resistances, phasing in of generators, and resonance may be classed as internal sources of disturbance and lightning as the external source.

Disturbances in underground or cable feeders are caused mainly by internal conditions; whereas those in overhead lines may be caused either by internal or external conditions. In feeders consisting of both underground and overhead lines the junction of the two is a particularly critical point, because of the possibility of the voltage building up at this point. Disturbances due to internal causes are generally of comparatively low frequencies—below 50,000 cycles per second—whereas those due to lightning may have a frequency of 1,000,000 cycles per second. Interruptions to underground feeder service depend somewhat upon the kilovolt-ampere capacity of the power station and those in overhead feeder service upon the extent and proximity of the discharge. However, lightning may, in turn, cause internal disturbances which condition is particularly liable to occur in feeders made up of overhead and underground lines.

It is a common practice to connect an aluminum-cell lightning arrester to the bus of a distributing station. The arrester will then be effective in taking care of disturbances arising in the station or in the various feeder lines, provided there is no obstruction between the arrester and the trouble to retard or prevent the action of the arrester. Such an obstruction may absorb or reflect the disturbance; and in the latter case it may not only defeat the object of the arrester but it may magnify the disturbance beyond the safety point and cause a breakdown in the circuit.

Current transformers, current-limiting devices, and feeder regulators may act as such obstructions because of their reactance; and the danger of breakdown in such apparatus itself must be given consideration. Because of their respective mechanical designs, current transformers and current-limiting reactances can be insulated more readily to withstand abnormal strains between turns and layers than can regulators. Properly designed regulators are insulated so that, regardless of the nature of the disturbance, the liability to breakdown internally is no greater than to ground; and the insulation to ground has an instantaneous safety-factor of approximately ten, when referred to line voltage. This equalization of internal and external insulation, however, generally requires a much higher safety-factor internally—may be of several hundred when compared to the normal induced voltage between turns and layers.

Regulator windings are of the same general design as those used in generators and motors and are similarly assembled in the slots of the core. A design to be satisfactory in operation and cost should have a fairly definite relation between the size of the core and the windings; this relationship also fixes the ratio of copper to insulation in the coil. It is furthermore impracticable and uneconomical to provide all windings with sufficient insulation to with-

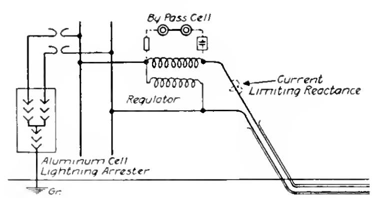


Fig. 1

stand maximum disturbances; first, because such disturbances are the exception rather than the rule, and second, because a better and safer protection can be provided external to the regulator and at a lesser cost. The following recommendations are made for the protection of feeder lines controlled by regulators.

An aluminum-cell lightning arrester should always be provided for the feeder bus.

In case line short-circuit troubles are experienced, it is advisable to install a current-limiting reactance for every feeder.

Regulators will generally withstand a short-circuit current of 25 times normal, but as their reactance—based on line voltage—does not exceed 1 per cent they are not self-protecting. The mechanical stresses produced in the regulator by excessive short circuits in the line may displace the coils, damage the insulation, or break the gearing. If the short circuit is sustained, the heat generated in the winding may damage the insulation. The amplitude of the distorted voltage wave induced in the shunt winding, due to full line voltage being impressed on the secondary, may puncture the insulation. In cases where line short circuits occur frequently, an auxiliary reactance of 3 per cent should be installed and connected between the regulator and the line. This reactance is generally more imperative for cable feeders than overhead lines, for the same length and size of the former has a reactance of only about 40 per cent of the latter which causes a corresponding increase in the short-circuit current under identical conditions.

Overhead lines should be provided with a multigap arrester on the line side of the regulator and, if no current-limiting reactance be installed, also a choke coil between the line and the regulator to delay any disturbance and reflect it back to the arrester. A combination of overhead and underground feeders should have a multigap arrester at their junction, although cases may arise where it will be necessary to install an aluminum-cell arrester at this point.

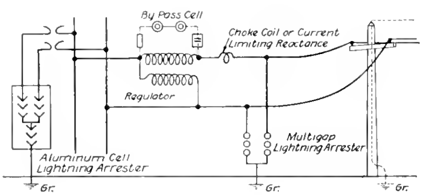


Fig. 2

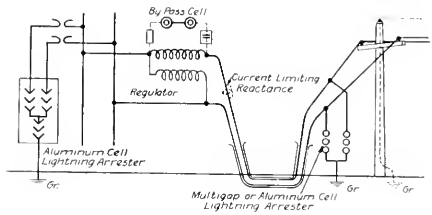
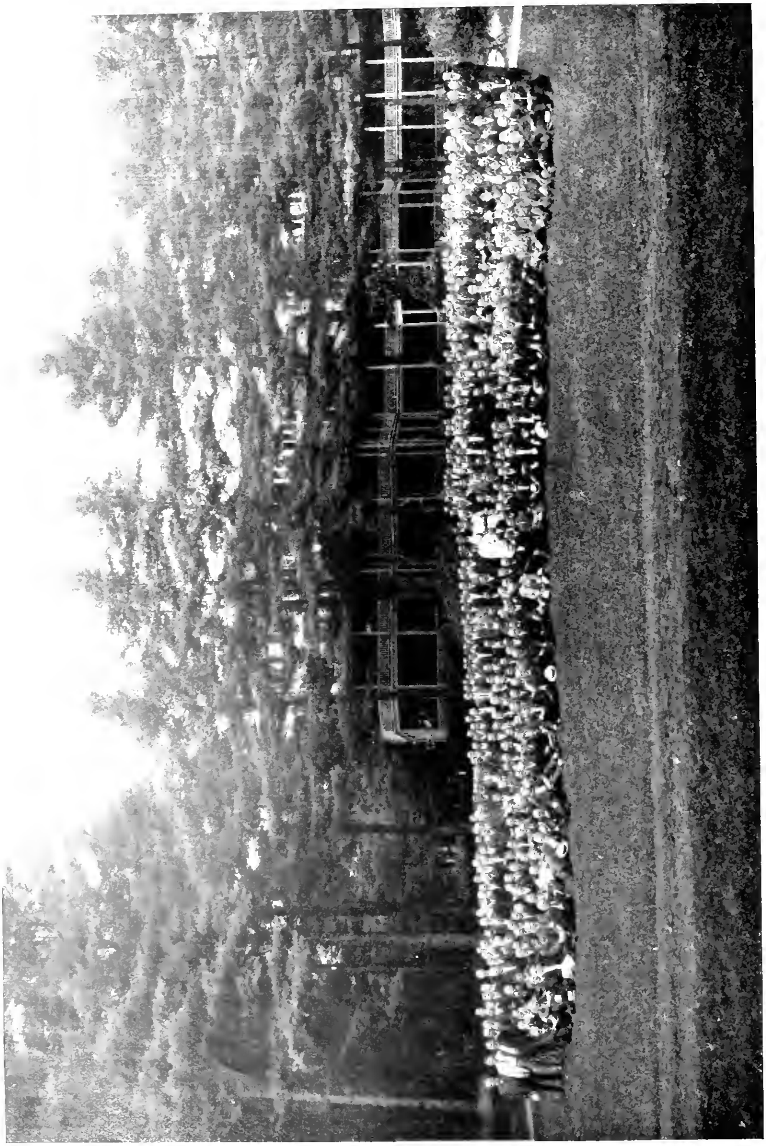


Fig. 3

In case an overhead, underground or combination line is subjected to frequent and severe disturbances, the series winding of the regulator should be shunted with a by-pass cell.

Figs. 1, 2 and 3 show the connections and arrangements of the apparatus, the full lines indicating the protection recommended for all installations and the dotted lines that for feeders subjected to unusual strains.



PHOTOGRAPH OF MEMBERS OF QUARTER CENTURY CLUB AT SECOND ANNUAL MEETING, SACANDAGA PARK, AUGUST 12, 1916

QUARTER CENTURY CLUB

By A. W. Clark

Welfare Department, General Electric Company

Some years ago, The Thomson Quarter Century Club was organized at the Lynn Works. The name, happily chosen, is significant and has a special value in that Prof. Elihu Thomson, honored member of the Quarter Century Club itself, chose as a young man to associate his genius with the Company bearing his name, which from very humble beginnings has grown to be the second largest separate organization in the group of organizations which now compose the General Electric Company. The Thomson Quarter Century Club was formed at a time when thirteen men only could qualify for membership which required a service period of twenty-five years. Among the original thirteen, Prof. Thomson had a place. From year to year annual meetings were held, the nature of these meetings being social rather than formal. They were "occasions of friendship" involving the renewal of long standing associations, the perpetuation of memories cherished alike by all, the observance of the spirit of "Auld Lang Syne." They were times of good fellowship where comrades of the shop and office met together as associates in business, away from work, enjoying a holiday together.

The annual outing of the Thomson Quarter Century Club held at Suntaug Inn on the fifth of August proved all that could have been desired. Led by Prof. Thomson and Walter C. Fish, the spirit of the day made the younger members of the Club wonder how the older men managed so well and permitted the last line of reserves, the eldest of all, to set a pace for the younger members to follow. Two hundred and seventy-one members are now enrolled in the Thomson Quarter Century Club.

The organization of the General Electric Quarter Century Club occurred at Schenectady early in 1914, A. L. Rohrer becoming its first president. A membership of one hundred and fifty furnished the nucleus for the club organization which now has four hundred and forty names on its roll. This membership still continues to grow. Two thirds of the Quarter Century Club members are to be found in the ranks of the Shop Organization, the remaining third having association with factory and office departments.

The membership token worn by the members of the Club is an attractive gold button of simple design which embodies the Quarter Century Club name and the monogram of the General Electric Company. This token is presented to all members of the Club by the Company. At an original meeting of two hundred members held at Schenectady, President E. W. Rice, Jr., made personal presentation of the first membership buttons issued. At that time in an informal address, Mr. Rice said, "It is a fine thing for any Company to have had men associated with its service for twenty-five years and a fine thing also for any man to have served a Company with a good record for such a period. I feel that it is a finer thing however for an industry to have had the benefit of an association like this where a Company and its men have worked together for a quarter of a century of mutual and useful endeavor."

The second annual meeting held at Sacandaga Park, Saturday, August twelfth, was a day long to be remembered by all who shared its pleasures. President E. W. Rice, Jr., in an informal address stated the happy memories of his first association with Prof. Thomson and the Lynn Works. He characterized the prevailing spirit of the General Electric Company as one of "comradeship in all ranks of service." "Today I am deeply impressed by the remarkable significance of this gathering," said Mr. Rice. "We are sharing together the pleasures of friendship, on a holiday, which only comrades whose mutual service has outlasted a Quarter of a Century know. Mr. Rohrer has told me that the total service which the men present today have given the General Electric Company represents a period of over ten thousand years. Further, the same service of the total membership in the Quarter Century Club, including members at Schenectady, Lynn, Pittsfield, Harrison, Erie, Fort Wayne and the various district offices of the Company represents a period of twenty-five thousand years. Yet it was but thirty years ago that a 'few venturesome shoe-makers,' who enlisted the confidence of few other working associates, set out as pioneers in a new industrial world. The world of electricity was little known at that time. The history of the growth, which has followed small beginnings, cannot be related here. Suffice it to say that as a group of men, we of our Company have contributed enormously to the wealth, comfort and service of the modern time by our achievements in the electrical industry. This contribution is not yet complete. While our responsibilities are great, our opportunities are even greater. Much remains to be done. Through all the changes passing years may bring, regarding our Company as an institution of permanent good, we must continue in our service of great human need. New demands will be made upon the inventive genius within our midst. New and heavy demands will rest upon us all in the practical execution of great ideas set before us. Those who administer the affairs of the Company and those who execute its work are bound together by ties of mutual obligation and service. Throughout whatever of success or failure may come, it should be remembered that all alike desire to do the right things. We need your suggestions and help to accomplish this end. Many things are being done which serve the common welfare of all. Our mutual interest commits us to mutual service."

Mr. Rice's address, wholly unprepared, was spoken from the heart. No less genuine were the remarks of George E. Emmons, who did not hesitate to say that the great development of the General Electric Company had resulted from the united loyalty of its men, who had put shoulder to shoulder in times of great need and gone forward to accomplish real work waiting to be done. "While there have been times of trouble, our Company's history has been marked by a spirit of good will. For the most part the best of relations have obtained between those whose duties are duties of administration and those whose other duties accomplish the great work of our production. Co-operation has been the rule. The tasks we are now doing require the best every man has to give. Work well done, is great accomplishment in itself. Loyalty to one's self and to others is the basis of our presence here today. We are as a great family circle having a common interest at heart."

The absence of C. A. Coffin was referred to by M. F. Westover, who paid high tribute to his work and character. "The splendid administrative and financial genius of Mr. Coffin parallels the inventive genius of great engineers in other fields. The spirit of comradeship which prevails widely in our midst contributes greatly to our success. This spirit finds expression in our leadership. Those who direct the business affairs of the Company are men of integrity and sympathy. These same characteristics exist among thousands of others upon whose work the Company depends and their presence in the Company's life is a source of great satisfaction to all."

The Quarter Century Club is little more than at the beginning of its existence. Indeed the year 1917, will see the twenty-fifth anniversary of the formation of the present General Electric Company. Among a membership of four hundred and forty at Schenectady it is highly significant that the average age is but fifty years and the average service period twenty-seven and one-half. Complete statistics are not available covering the total membership. Opinion holds that the above figures would be subject to but little change. In the Schenectady Works, the membership of the Quarter Century Club is widely distributed. No less than eighty-four departments are represented.

The various works and offices of the Company have representation as follows:

Schenectady Works	440
Lynn Works	271
Harrison Works	25
Pittsfield Works	8
Erie Works	1
Fort Wayne Works	35
Sprague Works	7
District Offices	81
Total	868

In both the Schenectady and Lynn meetings, special recognition was paid the members whose faces are forever missing. "Some of our friends and comrades," said Mr. Rohrer, "have gone the long journey westward from which there is no returning, leaving vacant places in the family circle and shop life. We miss all such today and hold them in affectionate memory."

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

A DEVICE FOR CALCULATING CURRENTS IN COMPLEX NETWORKS OF LINES

Owing to the great increase in the number and to the complexity of modern power transmission systems, resulting mainly from the consolidation and interconnection of small systems, an increasing number of occasions are arising in which it is desired to calculate the currents in a complicated network of lines under certain conditions of load and short circuit. There may be several generating stations of different capacities situated at various points in the network operating, perhaps, at different voltages and connected to the network through transformers of appreciable reactance. The simplest method of treating such a problem is to assume that all the impedances are pure reactances and reduce them all to a percentage basis. Mr. H. R. Wilson, in his article in the June 1916 number of the REVIEW entitled "An Approximate Method of Calculating Short-Circuit Current in an Alternating Current System," has shown how this may be done after a fixed kilowatt output has been assumed. Even after this has been carried out the algebraic solution of a network problem of any appreciable complexity is a very laborious matter and the chances for error are large.

To aid in the solution of problems of the type referred to above, an electrical device has been designed by which the results can be obtained directly and with sufficient accuracy for most practical purposes. It consists of a table under which are mounted a number of rheostats of the disk type having the operating handles projecting through the top of the table as shown in illustration, Fig. 1. To each handle is fastened a pointer which revolves over a graduated dial. The terminals of each of the rheostats are brought out to metal blocks fastened to the top of the table which contain holes in which may be inserted taper plugs. Fig. 2 shows in detail the arrangement of these blocks. The holes marked A-A-A and B-B-B are those for the taper plugs. The plug hole C is arranged for an ammeter jack plug; the two terminals of the rheostat being connected to blocks A and D, while C is filled with a brass plug when the ammeter is not in use. The taper plugs A and B are connected to flexible leads so that the rheostats can be interconnected in any desired manner.

Fig. 1. Table Showing Method of Mounting Rheostats, Ammeter and Terminal Blocks

Direct current at 125 volts is used for the table and the resistance of the rheostats is taken as representing reactance in an actual system. The dials on the top of the table are graduated in per cent reactance (actually resistance). Thus a rheostat may be set for any value of equivalent reactance and plugged into the network in any manner desired. Two sizes of rheostats are used, one to represent the generating stations and the other to represent the lines. The former is calculated to read from 10 to 160 per cent and the latter from zero to 80 per cent. There are six of the generating station type and fourteen for the lines. On the former only one terminal is brought out of the top of the table, the other being connected directly to the positive side of the 125-volt d-c. circuit. Fig. 3 shows the schemes of connections. A stop is arranged so that the rheostat cannot

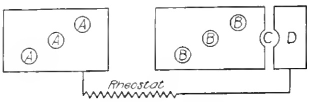


Fig. 2. Rheostat Terminal Blocks

be turned down below 10 per cent, which eliminates the possibility of obtaining a short circuit by a mistake in the connections and guards against an overload with the resulting risk of fire.

The negative side of the 125-volt supply circuit is connected to two isolated plug blocks called ground terminals. These are arranged in a similar way to the terminals of the rheostats. When it is desired to place a short circuit on any part of the system, that point is connected to one of the ground plug blocks, establishing thereby a circuit through the generating rheostats, the interconnected network of line rheostats and the ground block. The current in any part of the system can be read by plugging the ammeter leads into the corresponding rheostat terminal block. The resistance of each rheostat is such that when the dial is set at 100 per cent reactance and the normal line voltage is impressed upon it, 0.2 of an ampere will flow through it. This is called the normal full load current of the system and all the currents are recorded as fractions or multiples of the normal current; thus a current read as 1.4 amperes is recorded as seven times the normal current (0.2 amp.). To obtain the current in the actual system, it is necessary only to multiply the actual normal full load current of the system by the factor as obtained above. The normal full load current of the actual system is, of course,

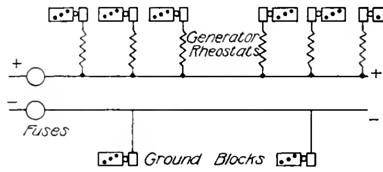


Fig. 3. Connections

that which is based on the number of kilowatts assumed when the percentage reactances were calculated.

Three-phase circuits are calculated by assuming them "Y" connected with a grounded neutral and solving them in the same way as for a single phase problem.

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.

GENERATOR: WAVE AND LAP-WOUND ARMATURES

(180) Why does a wave-wound armature deliver a higher voltage than a lap-wound armature having the same number of conductors?

Before entering into the explanation, mention should be made of the fact that the statement in the question is not true for two-pole generators. Two machines of this type, identical except that one has a wave-wound armature and the other a lap-wound armature, will deliver equal voltages under the same operating conditions.

The difference in voltage delivered by the two types of armature when in generators of more than two poles is the result of the scheme of grouping the conductors in one winding being different from that of the other. The conductors of a wave-wound armature are grouped in two parallel current paths between positive and negative lines with half the total armature conductors connected in series in each path. The conductors of a lap-wound armature are grouped in as many parallel current paths as there are field poles with a number of conductors connected in series in each path equal to the total divided by the number of poles.

For a more-than-two pole machine, it will be seen that a wave winding has more conductors per current path (positive to negative line) than has a lap winding, the consequence of which produces the difference in delivered voltage. For a two-pole machine it will be seen that the number of conductors per current path is the same for both types of winding, which results in the exception mentioned in the first paragraph.

E.C.S.

REGULATOR: THREE-PHASE ON TWO-PHASE

(181) Can a three-phase induction type regulator be employed on a two-phase three-wire circuit?

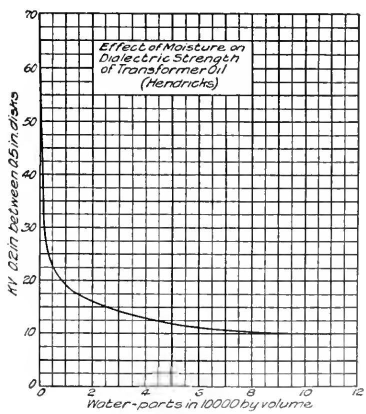
Satisfactory operation cannot be obtained from a three-phase induction type regulator on a two-phase three-wire feeder. Such a diversion from the intended application of the regulator is prevented by the following combination: *space* phase of the windings (120 deg. difference) and *time* phase of the currents in those windings (90 deg. difference). This discrepancy between space phase and time phase would cause a high reactive voltage drop and noisy operation of the regulator, due to the distorted revolving field. In some cases, the slot layout of such a regulator may be such as to permit of suitably reconnecting the coils of both the primary and secondary for operation on a two-phase three-wire feeder.

F.D.

TRANSIL OIL: WATER CONTENT AND DIELECTRIC STRENGTH

(182) What are the comparative dielectric strengths of dry transil oil and transil oil in a container in the bottom of which there is free water, provided in both cases there is no appreciable circulation?

It is impossible to predict what will be the dielectric strength of the oil that is in the container having free water at the bottom, because no satisfactory estimate can be made as to the amount of water that is held in *suspension* in the oil under those conditions. The amount of this water in suspension depends upon the thoroughness with which the water and oil mixed when the water entered and also upon the subsequent duration of standing. Consequently, reliable information on dielectric strength can only be obtained by a standard puncture test of samples of the oil.



(182) Fig. 1

For a case wherein the oil has a *uniform* content of water, Fig. 1 gives the relationship between puncture voltage and relative water content. Reference: "Law of Corona and Spark-Over in Oil," GENERAL ELECTRIC REVIEW, August, 1915, p. 821.

E.C.S.

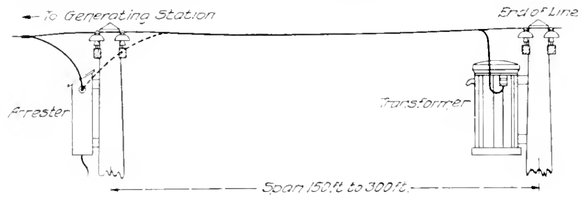
ARRESTER: LOCATION

(183) (a) When it is impossible, because of lack of room, to mount a multigap lightning arrester and a transformer on the same pole at the end of a distributing line, which would be the preferable arrangement Fig. 1 or Fig. 2?

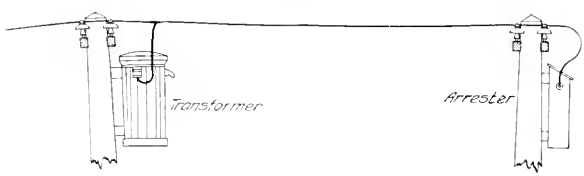
(b) Would the degree of protection by a given arrester be affected by sharp bends in the arrester wiring or by the direction in which the arrester lead curves from the line (full line and dotted line Fig. 1)?

(a) If choke coils are not used, the arrester would probably give better satisfaction if placed at the end of the line, Fig. 2.

A somewhat improved arrangement would be to employ the layout shown in Fig. 1 and install choke coils between the arrester and transformer.



(183) Fig. 1



(183) Fig. 2

It should be borne in mind, however, that these methods which involve the separation of the arrester and transformer are compromises and are inferior to one in which the two units are on the same pole with perhaps a choke coil between them.

(b) Sharp bends in the discharge circuit should be avoided because they give rise to a greater likelihood of corona formation. Small kinks, however, exert no appreciable influence. With regard to the direction from which the arrester lead curves from the line conductor, Fig. 1, laboratory tests made even at 5,000,000 cycles have been unable to detect differences resulting from the form of the connection wire to the arrester. E.E.F.C.

GENERATOR: DRYING OUT

(184) Please describe the best methods for drying out direct-current generators of 125, 250 and 500 volts when these have become damp.

A simple shunt machine should have its field opened and its armature short circuited by a cable which will carry two or three times the normal armature current and which is also of sufficiently low resistance to constitute a "dead short-circuit." When a generator of standard design is driven at normal speed under such conditions the residual magnetism will cause a circulating current to flow in the armature, its value being between normal full-load current and twice this amount, which is a good working value for drying out. Should it be found that the residual magnetism will not cause a sufficient current flow, the shunt field should be very weakly excited from some external source (the low field current necessary can be obtained either from a very low voltage source direct or from an ordinary voltage source by inserting a high resistance in the field circuit). If severe sparking takes place at the commutator when operating under these conditions it can be minimized by giving the brushes a forward shift.

Ordinarily enough heated air will be thrown off the rotating armature to dry out the field. In case this proves to be insufficient, or only the field is damp, heat can be localized in the field winding while the machine is at rest by connecting the spools to an external source of excitation. From one-quarter to normal voltage should be applied, depending on the dampness of the spools.

It has been suggested that a machine can be dried out by applying alternating current to the field winding while the armature is short circuited. This method is open to the serious objection that the alternating flux will cause excessive heating in those parts of the magnetic circuit which are not laminated.

A commutating-pole machine that has no series field winding should be dried out in the same manner as described for a simple shunt machine. Care should be taken that the brushes are not back of the neutral but are slightly forward of it. The commutating-pole winding is to be wired in exact accordance with the standard diagram of connections for operation; and the short-circuit placed on the machine is to include the commutating-pole winding as well as the armature.

A compound machine should be dried out as described in the foregoing except that the series-field winding should be cut out of circuit entirely. This latter is a precaution to prevent the possibility of the machine building up as a series generator in case no external excitation is applied to the shunt field. H.S.P.

CONTENTS Continued

BIRD'S-EYE VIEW OF THE GREAT FALLS DEVELOPMENT, MONTANA POWER COMPANY

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

In our special traction issue published two years ago we printed quite a number of contributions showing the results obtained on various electrifications widely distributed throughout the country. Among these articles was one giving detailed statistics concerning the Butte, Anaconda and Pacific 2400-volt direct-current installation and showing the truly remarkable economies effected. On that occasion we ventured to predict that the technical and financial success of this undertaking would have a far reaching effect on steam road electrification in general, and in particular would point to high potential direct-current apparatus as the logical equipment for heavy and exacting railroad service. It was in our editorial for this same issue that we were able to announce that plans were maturing for the electrification of some of the most important mountain divisions of the Chicago, Milwaukee and St. Paul Railway, and that direct-current high potential apparatus would most likely be selected for this important work, and that a trolley potential of 3000 volts was contemplated.

It is today a matter of common knowledge that this selection was made and that now 226 miles of main line track are actually under complete electrical operation, and that in a few months time a total of 440 miles will be operated entirely electrically.

It is too early yet to give detailed statistics showing the financial success achieved, but Mr. C. A. Goodnow's article in this issue shows in a most striking manner the success of the whole undertaking and the wonderful operating results accomplished. Mr. Goodnow's article will be especially appreciated by the operating man who is anxious to learn wherein the advantages of electrification lie.

The physical characteristics of the divisions electrified and the successful operating results achieved can be shown in rather an interesting manner by quoting part of the first and part of the last sentence in Mr. Goodnow's article: "The electrified portion of the road crosses the Belt Mountains, reaching an elevation of 5768 feet; the Rocky Mountains at a height of 6350 feet and the Bitter Root Mountains at 4200 feet." And "I think it quite within the fact to say that the Milwaukee road has forgotten that the Continental Divide exists." This is a most elegant tribute to the capabilities of the direct-current locomotive.

We have talked about steam road electrification for a number of years, and indeed there have been some very notable installations made, especially in the direction of terminal electrifications, but it has fallen to the lot of the youngest of our transcontinental railway systems to be the pioneer in main line electrification. It is worthy of special note that the railway divisions selected for electrification are not simple level tangent tracks, but are among the most difficult divisions in the country where the steam locomotives—huge Mallet compound engines—were taxed beyond their power in handling the freight and passenger traffic. The faith that the steam railroad men put in the electric locomotive is shown by the fact that the divisions electrified comprise the heaviest character of mountain grades and curves, etc., across the great Rocky Mountain divide.

It is because the Chicago, Milwaukee and St. Paul electrification is the most notable engineering achievement scored in the country during the last two years, that we are devoting a very considerable part of this issue to describing that undertaking and publishing articles showing, in considerable detail, the apparatus used.

We feel that no one factor will stimulate steam road electrification to the same extent as the development of our hydro-electric resources by independent companies, as such developments will relieve the steam road from the heavy financial burdens incident to the building of their own power houses. For this reason, Mr. J. D. Ryan's article will be of special interest to the steam road man, as it tells of the wonderful way in which the natural resources of Montana have been, and still are being, developed by the Montana Power Company. It was this particular development that enabled the Milwaukee road to electrify its main line tracks under such favorable circumstances. Further possibilities of relieving those steam roads, which are contemplating electrification, of the heavy initial investment required for power houses and rolling stock before the economies attending such electrification can be secured are considered in Mr. W. J. Clark's article.

The general extension of the use of high potential direct-current apparatus for railroad purposes is shown in a very marked manner by the large tabulation accompanying Mr. G. H. Hill's article. A great deal of interesting data are given and will be highly instructive to all those interested in following the modern trend of electric railroading.

SOME PRACTICAL RESULTS OBTAINED BY ELECTRIFICATION ON THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By C. A. Goodnow

Assistant to the President, C. M. & S. P. Ry.
In charge of Electrification

This is a most valuable contribution, being a real railway story by a real railway man. The success of the Milwaukee electrification is told by the man who was in charge of this most wonderful railway undertaking. The operating facts told are too many to abstract, but we can say with confidence that all steam road men contemplating electrification will learn much that is useful and instructive from Mr. Goodnow's article. —Editor.

The Chicago, Milwaukee & St. Paul Railway has now in electric operation 226 miles of main line track and will, within a few months, have a total of 440 miles electrically operated. The electrified portion of the road crosses the Belt Mountains, reaching an elevation of 5768 feet; the Rocky Mountains at a height of 6350 feet; and the Bitter Root Mountains at 4200 feet. The use of electric engines on this portion of the road has entirely displaced steam locomotives and has eliminated one division point, namely, that of Three Forks. The electric locomotives run through between Deer Lodge and Harlowton on both freight and passenger trains, with the crews on freight trains changing at Three Forks. On the 2 per cent grade over the Rocky Mountains the electric locomotives haul 10 or 11 steel cars at speeds varying from 20 to 30 miles per hour, and on this important grade, with one helping engine, 2500-ton freight trains are handled. It is expected to increase this tonnage to 3000 tons as soon as the entire apparatus in contemplation has been installed.

From the outset the operation of electric locomotives has been a success and it is not too much to say that they have practically eliminated the mountain grades. Where formerly it was necessary to employ a large number of helper engines to handle the passenger and freight trains over the mountain grades, one or two helpers only are required to handle the greatly increased freight traffic of the present year and no helpers are used on passenger trains.

The movement of trains is so uniform and there are so few failures with the electric locomotives that only one set of train dispatchers is now employed to handle the trains on the 226 miles under electrical operation while two sets of three dispatchers each are employed under steam operation. The tonnage on maximum grades has been increased from 1700 to 2500 tons per train, and will soon be further increased to 3000 tons, and this tonnage is handled at a speed of between 15 and 16 miles per hour on maximum grades while steam engines could only average 8 or 9 miles per hour.

Regenerative braking is a feature that has proved most successful and most economical. The heavy transcontinental passenger trains are moved down maximum grades at a uniform speed by this braking, and the maximum tonnage of freight trains are handled in the same manner without the use of the air brakes, unless the train is to be stopped. It is a fair statement to say that the use of electric locomotives, so far as easy and uniform operation is concerned, has practically eliminated the grades of the Continental Divide.

It is yet too early to speak of economies, but the elimination of water and coal stations, of cinder pits and of round house forces at intermediate division points, and the quick inspection and ready turning back into service of electric locomotives, can but mean economy. The saving in brake shoes and wheels, the delay to trains for the purpose of cooling brakes shoes and wheels is also an economy that has been found to be far reaching in the handling of both passenger and freight trains. Since the electric locomotives have practically doubled the speed of freight trains on maximum grades it was found that a large saving results from this alone.

The winter of 1914-1915 will be memorable in the annals of Montana. There were long periods in the Rocky Mountain district when the thermometer stood as low as 40 degrees below zero, and it was almost impossible to move trains by steam locomotives, but the electric locomotives were always ready for service and always were able to work to the maximum. In some instances, where steam locomotives had failed (it should be understood that during December and January 1915 there was only partial electric operation) and heavy freight trains were standing on the

Fig. 1. The Missouri River at its Source in Montana

Fig. 2. Electrified Line in Rocky Mountains East of Three Forks, Montana

Fig. 3 "The Columbian" on the Summit of the Rocky Mountains

Fig. 4. Jefferson River Canyon, Montana

main track the electric locomotives cleared the track without difficulty and pulled the delayed cars and engines into terminals, demonstrating in a practical manner that while the steam engine is at its lowest efficiency in cold weather the electric locomotive is at its highest point of efficiency.

There are many features in the handling of electric locomotives which will appeal to the operating man. For instance it is not necessary, unless there is work and inspection to be done, to house electric locomotives no matter what the weather may be. On arrival at terminals the engineer places the locomotive on a designated track, lowers his pantograph, and the locomotive instantly becomes dead. When it is again necessary to put the locomotive into operation all that is necessary is to raise the pantograph and the locomotive is ready for service. So great a contrast in the operation of steam and electric locomotives can only be appreciated perhaps by the man who has actually been in the field, and has had important trains to move and has had to wait while steam was raised in a steam locomotive. As an interesting illustration of the above: At a time when the thermometer was 40 degrees below zero two freight trains, having three steam locomotives and 75 cars, were standing on the main track east of Three Forks, Montana, with the engines dead on account of the bitter cold, and passenger trains were due in both directions. The Superintendent was naturally anxious to clear the main line but had no steam engines available. An electric freight locomotive was standing on a sidetrack at Three Forks. The line was not then in electric operation east of Three Forks, but, for a distance of about nine miles the trolley was energized. The Superintendent inquired of an engineer if it would be possible to take the electric locomotive and clear the main track. The engineer was confident that he could do it, and in company with the Superintendent, he boarded the electric locomotive, raised the pantograph, and instantly the electric locomotive was ready for service. In five minutes from the time the inquiry was first made the electric locomotive, manned by the Superintendent and engineer, was moving out on the main track toward the stalled trains. Without experiencing the slightest difficulty the two trains were coupled up and the 75 cars and three steam engines were pulled into the sidings at Three Forks, the main track was cleared and there was no delay to the passenger trains. The above is but one instance of many of a similar character during the severe weather of December and January 1915, but it has had the effect naturally of endearing the electric locomotive to the operating men of the Rocky Mountain division.

It was thought that but half an electric locomotive should be used in handling way freights. It seemed quite out of the question to accomplish the handling and switching of a way freight train by means of a great locomotive 112 feet long, but the importance of pulling tonnage was so great that it was finally decided to try the full locomotive on these trains. The success was phenomenal. The handling of the electric locomotive in switching service was so much easier than with steam service that the engineers came to regard the full electric locomotive as the only proper machine to handle way freights. The reasons for this were two. First, that the electric engines without pulling out drawbars would handle any tonnage attached to them; and second, that in the switching movements, instead of being obliged to look out of the window, and then, when he got a motion to move in the opposite direction to have to handle heavy reversing gear, with an electric locomotive he could hang out of the window all the time and without changing his position could handle the tiny reversing lever and control.

The electric locomotives while handling much greater freight tonnage, as has been stated, "get" fewer drawbars, because the pull is uniform and easily controlled and it is practically impossible to pull out drawbars except through an extreme degree of carelessness.

The handling of the regenerative braking descending 2 per cent grades presents perhaps a most interesting and instructive phase of mountain railroading. To one who is familiar with the movement of a train of heavy tonnage down a mountain grade under air brake control, the rolling of the cars under the application of the brakes is one of the noticeable and perhaps dangerous features, but with regenerative braking the whole train is bunched against the locomotive, and as there are no brakes applied, there is absolutely no rolling of the cars. They move as steadily and evenly as though they were on tangent prairie track. In the handling of passenger trains with regenerative braking perhaps the best idea of comfort and safety is obtained. In the use of the air brakes on 2 per cent mountain grades it is necessary to let the train accelerate to a speed where it must be

Fig. 5. In the Jefferson Canyon, Rocky Mountains

Fig. 6. Another View in the Jefferson Canyon

Fig. 7. East Side of the Continental Divide, Near Donald, Rocky Mountains, Montana

Fig. 8. The Rockies, between Butte and Janney, Montana.

Fig. 9. The Olympian at Eastern Portal of Eagle Nest Tunnel, Montana

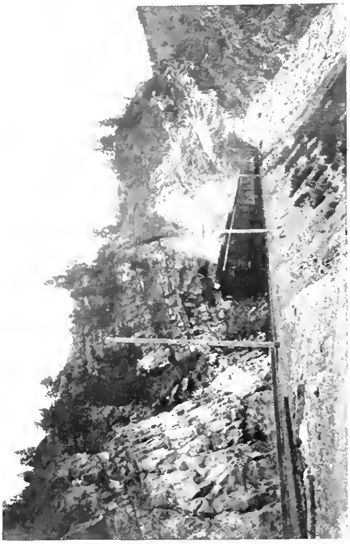


Fig. 10. The Olympian Emerging from the Western End of Eagle Nest Tunnel, Montana

Fig. 11. The Olympian in Montana Canyon, Montana

Fig. 12. The Olympian in Montana Canyon, Montana

checked and to apply the air brake to bring it down to the speed required. It is then again allowed to accelerate and then again checked; but with regenerative braking the speed is uniform and there is no grinding of brakes and no annoyance to passengers in consequence. In the practical operation of the transcontinental trains of the Milwaukee Company over the Rocky Mountain grades, eastbound, the train is brought to the summit at a speed of about 23 to 25 miles per hour and after pitching over the summit, as soon as the train reaches a speed of 30 miles per hour, regenerative braking is started and, without the slightest knowledge on the part of the passenger, the train is held uniformly at 30 miles per hour down the 22 miles of 2 per cent grade. There is no difficulty in obtaining a speed of 60 miles per hour on level grades with 10 all-steel cars, and woe to the competitor who attempts a speed trial with one of our transcontinental trains.

The Milwaukee railroad decided on two innovations for geared locomotives, first that the trolley potential should be 3000 volts and second that there should be a full guiding truck at both ends of the locomotive. A great deal of doubt was expressed by electrical engineers as to the feasibility of collecting current at so high a voltage, but, by the use of the sliding pantograph there has not been the slightest difficulty in this matter and absolutely no sparking, and eight months of continual use has demonstrated that there has been no appreciable wear on the trolley wire. The use of the guiding trucks aside from all questions of safety has resulted in a locomotive which at the highest speeds rides almost as smoothly as a Pullman car

Electrification has been such a tremendous success on the Milwaukee road that it is difficult to state the results without seeming exaggeration, but I think it quite within the fact to say that the Milwaukee road has forgotten that the Continental Divide exists.

THE MONTANA POWER COMPANY AND ITS PART IN THE ELECTRIFICATION OF RAILWAYS

By John D. Ryan

President Montana Power Company

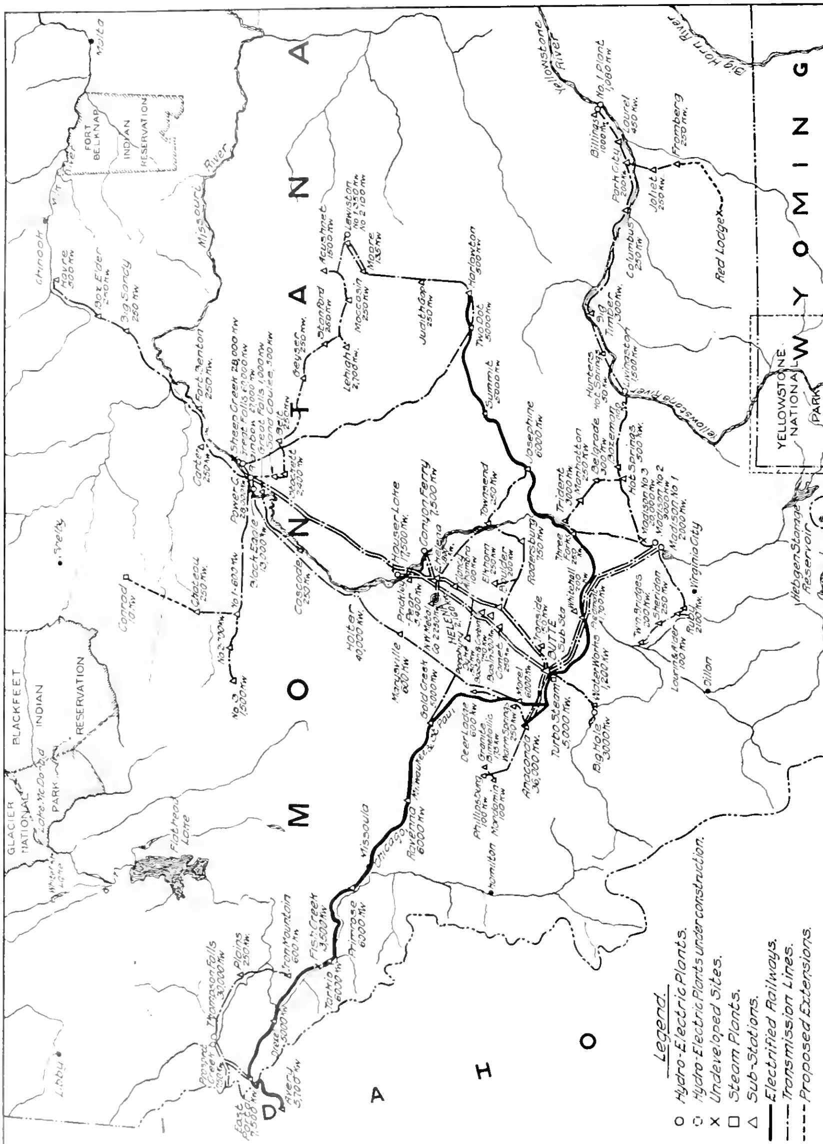
Mr. Ryan's article will be of special importance to engineers interested in the absolute continuity of service, the achievements of the Montana Power Company in this direction being wonderful. The general layout and tying together of the system is described and many of the interesting features noted. Both the B., A. & P., and the C., M. & St. P. Railways are supplied with electric energy from the Montana Power System, and in some of the opening paragraphs the author notes the successful results obtained.—Editor.

The development of water powers and the transmission of electrical energy had reached a point in Montana about the year 1912 where electricity began to force itself upon the attention of railway managers as a substitute for steam in railway operation.

More than a dozen hydro-electric plants had been connected with a great system of high tension wires to supply the fast growing needs of the State for power and light. The necessity for continuous service in the operation of mines forced the consolidation of plants into one system, out of which could be drawn the energy needed when the source of direct supply might for any reason fail temporarily.

The one vital need for railway operation is continuity of power, and the experience of the Butte mines and ore reduction plants at Anaconda and Great Falls had proved that, given the plant capacity, located at several points on different rivers, draining different water sheds and connected with ample transmission lines traversing different sections of the territory covered, as safe and certain a supply of power can be assured as by isolated steam plants, or any other possible means. The record of continuous operation with power from the Montana system, is, I believe, unparalled and unequaled.

The Butte, Anaconda & Pacific Railway Company took the first step by electrifying its main line and principal branches, about 70 miles in all. The work was completed in the autumn of 1913. The cost was within the original estimate; the operation has been an unqualified success and the economy at least 50 per cent in excess of the promises of the engineers at the time the work was undertaken. The tonnage handled over the lines has increased over 50 per cent in three years; no difficulty has been found in moving the increase, and in the opinion of the railway



Map showing Stations and Lines of the Montana Power Company, with special reference to the electrified section of the Chicago, Milwaukee & St. Paul Railway managers the main line and two of the principal branches had reached the capacity of single track when electrification came into use.

To any railroad management called upon to move heavy traffic with limited track facilities I would commend a study of what has been and is being done on the Butte, Anaconda & Pacific Railway.

The electrification of the Chicago, Milwaukee & St. Paul was a much greater stride; the courage was there, the money was found and the electrification of 440 miles of main line is practically a finished work. What the result has been I leave to others to tell in this magazine. I am proud of the part The Montana Power Company has in the accomplishment. It developed the water powers, built the transmission lines, contracted to do all overhead work on the railway line, and turned the work over, ready for substation and motive power equipment on time and in shipshape.

The following account of the Montana Power System will show many interesting features of the plans made to ensure a continuity of service, and other factors which go to make up a modern reliable system of energy distribution.

The growth of The Montana Power Company and its predecessors has been coincident with the development of the art of high voltage transmission and typical of the rapid progress which has been made in that field.

The beginning of the present system was marked by the construction of the Big Hole plant completed in 1898 and designed to deliver 3,000 kilowatts at 15,000 volts 22 miles to Butte, for public service use. Canyon Ferry plant was built independently at about the same time to develop and transmit 3,000 kilowatts to Helena and vicinity for public service, ore concentrating and smelting uses. In 1901 Canyon Ferry was enlarged to 7,500 kilowatts, and transmission 65 miles to Butte at 50,000 volts was immediately proven economical, the first large power loads consisting of air compressor and ore concentrating machinery. Madison No. 1 plant was completed the same year.

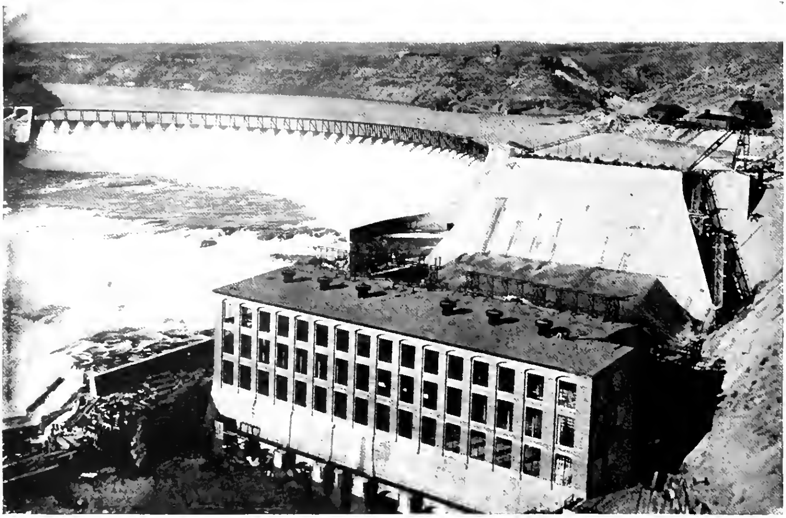
These small plants did much to establish confidence in the reliability of transmitted power. The natural caution of the mining companies, however, prevented the full adoption of electric power for urgent work such as ore hoisting and mine pumping until the construction of a 4,000 kilowatt steam reserve plant in Butte to provide for contingencies of line failures and possible shortage of power due to low water.

A steam plant was also kept in reserve for public service uses in the city of Butte. At that time steam power was costing upwards of $90.00 per horse power year, and electric power sold at about $50.00 per horse power year, delivered at Butte substations.

The economy and success attending the operation of these early hydro-electric plants created a rapidly growing demand for power, resulting in the development of larger sites, higher voltage current for transmission and longer transmission lines. Lower rates were also established. Transmission lines were extended to cities served by steam plants or small and unreliable water power plants and to many towns having no electric service at all, and low rates and good service secured even to towns of but 200 or 300 inhabitants.

In Butte the problem of mine hoisting was considered from all standpoints. There were then in operation more than a dozen steam hoisting engines rated above 2,500 horse power each of which was operating very inefficiently as to cost because of the intermittent character of the load. Direct connected motors of large capacity were not considered feasible because of their effect on the regulation of the transmission system and because of the serious inconvenience which would result from an interruption in delivery of power. This type of mine hoist, however, was adopted for sizes up to about 300 horse power. Ilgner flywheel sets were considered too expensive, not fully developed as to details of control and the energy stored in the flywheel insufficient to accomplish the necessary hoisting in case of failure of electric power. Storage battery reserves and direct current hoists were also considered and rejected as being unreliable or not ecomonical.

The Anaconda Copper Mining Company finally solved the problem for its own group of mines by converting its steam hoisting engines to air engines and providing a large storage of air in cylindrical steel tanks connected with a water pressure reservoir located on the adjacent hill at a height sufficient to maintain the working air pressure. This rendered the entire capacity of the air receivers available at practically full pressure and stored sufficient air to operate several hoists for thirty minutes in case the air compressors were not operating, and thus it was provided that the men could be taken out of the mines in case of failure of power.



Bird's-eye View of Dam and Power House at Great Falls

Hydro-Electric Power Station at Great Falls on the Missouri River
Montana Power Company

The compressors for this system of air hoisting now require eight motors of 1,200 horse power each.

Recent improvements in the control of fly-wheel hoisting sets have brought this system into favor for isolated mines, and such hoists are being used in Butte with capacities as high as 3,500 horse power.

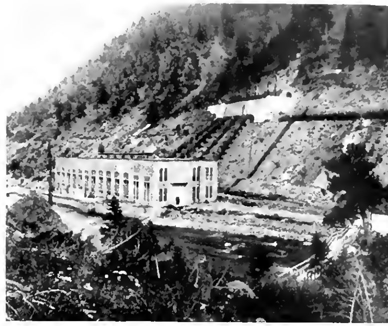
Electric power has been rapidly adopted for mine pumping and electric mine haulage. Coal mines suffering from bad boiler feed water adopted transmitted electric power as a way out of their troubles with such economy that it was adopted in other mines not so troubled. Several irrigation projects have been completed in which water is pumped to an elevation of 300 feet for orchards and a maximum of 150 feet for ordinary agricultural projects. The Power Company has been a pioneer in the introduction of electric cooking and has now nearly 1,000 stoves connected on its lines.

In 1910 the Rainbow power development at Great Falls was completed. 25,000 kilowatts were developed by the erection of a 30-foot dam and two-wheel conduits 15½ feet in diameter, which developed a total head of 110 feet by shunting the water around the Rainbow and Crooked Falls of the Missouri River. Power was transmitted to adjacent towns within a radius of 110 miles at 50,000 volts, and over duplicate steel tower lines to Butte 130 miles and Anaconda 160 miles at 100,000 volts.

The Hauser Lake plant was completed in 1911 and transmitted power to Butte and nearby irrigation loads at 66,000 volts. At this plant a solid concrete dam secured a working head of 60 feet and created a storage reservoir about 18 miles in length

In 1912 these various plants which had previously been operated independently of one another were physically interconnected and consolidated in The Montana Power Company. The interconnection was made between the low tension busses of the two principal substations in Butte and provision made for an interchange of about 10,000 kilowatts in either direction. The economies resulting permitted a further reduction in rates, reserve steam plants were shut down and have been operated since only temporarily, when the growth of load has outstripped the construction of new plants.

In 1913 active construction was started on the 60,000-kilowatt development at the "Great Falls of the Missouri" and a 30,000-kilowatt development at Thompson Falls on Clark's Fork of the Columbia. These plants were intended to supply the necessary power for the operation of the Chicago, Milwaukee & St. Paul Railway through the Rocky



Madison No. 2 Power House and Regulating Reservoir
110 ft. Head, 10,000-kw. Capacity

Madison River Dam, 34 ft. High and Stave Penstocks
12 ft. Diameter

Mountains, and to take care of the general growth of business. At the Great Falls Development at 70-foot concrete dam, close to the brink of the Great Falls, and steel penstocks about 300 feet in length developed 150-foot head. At Thompson Falls a 30-foot dam above the falls and a short canal developed 50-foot head. Both of these plants have sufficient local storage to enable them to operate at 65 per cent daily load-factor utilizing the entire low water flow of the river.

On account of the rapidly increasing demand for power these plants will be fully loaded sooner than expected, so that work on a 40,000-kilowatt development at Holter on

The Great Falls of the Missouri River
Dam of the Montana Power Company in Background

TABLE I

COMPLETED HYDRO-ELECTRIC PLANTS

Rainbow Falls on Missouri River, completed 1910	25,000 kw.
Additions under way 1916	10,000 kw.
Black Eagle Falls on Missouri River, partly reconstructed 1913	3,000 kw.
Hauser Lake on Missouri River, completed 1911, enlarged 1914	18,000 kw.
Canyon Ferry on Missouri River, completed 1898, enlarged 1901	7,500 kw.
Madison No. 1 on Madison River, completed 1901, remodeled 1907	2,000 kw.
Madison No. 2 on Madison River, completed 1906	10,000 kw.
Big Hole on Big Hole River, completed 1898	3,000 kw.
Livingston on Yellowstone River, completed 1906, enlarged 1908	1,500 kw.
Billings No. 1 on Yellowstone River, completed 1907	1,080 kw.
Lewistown on Spring Creek, completed 1906, remodeled 1913	450 kw.
Thompson Falls on Clarks Fork of the Columbia, completed 1916	20,000 kw.
To be added 1917	10,000 kw.
Great Falls of the Missouri River, completed 1916	60,000 kw.
Total	171,530 kw.

HYDRO-ELECTRIC PLANTS UNDER CONSTRUCTION

Holter on Missouri River	40,000 kw.

STEAM PLANTS

Butte, completed 1905	5,000 kw.
Phoenix (Butte), completed 1895	250 kw.
Billings, completed 1906	560 kw.
Conrad, completed 1910	110 kw.
Total	5,920 kw.

UNDEVELOPED SITES

Madison No. 3 on Madison River	18,500 kw.
Black Eagle on Missouri River, reconstruction, (additional)	10,000 kw.
Great Falls Site "C" on Missouri River	28,500 kw.
Below the Great Falls on Missouri River	28,500 kw.
Fish Creek on Missoula River	13,500 kw.
Snake River on Snake River, Idaho	22,500 kw.
Total	121,500 kw.

the Missouri River is being pushed for completion in 1917.

A new process of electrolytic zinc refining has been developed by the Anaconda Company and a plant has just been completed at Great Falls which will consume about 25,000 kilowatts.

The transmission line system consists of:

Steel tower lines	340.5 miles
Pin type pole lines	635.4 miles
Suspension insulator pole lines	513.0 miles
Two pole bridge type lines	375.0 miles
	1,863.9 miles

Present standard types of construction are the two-pole towers spaced twelve to the mile for 100,000-volt construction, and a single pole, double armed structure for 45,000 to 65,000 volts. The former type has two 3/8-inch Siemens Martin steel ground wires strung above the power circuit. The latter type has one ground wire strand composed

Hauser Lake Development, 60 ft. Head, 18,000-kw. Capacity

Thompson Falls Station, 30,000 kw. in Six Units

of three No. 10 iron wires at one end of the top cross arm, all copper conductors. Telephone wires are commonly run about eight feet below the power wires on the power line poles.

Table I shows the present plant capacities and proposed capacities of undeveloped sites. Map, page 916, shows the location of plants and substations and routing of distributing transmission lines.

For many years Mr. Max Hebgen, who until his death in 1915 was Manager of The Montana Power Company, had in mind the construction of an immense storage reservoir on the head waters of the Missouri River. The consolidation of the ownership of plants along this river made this project feasible, and the Hebgen Reservoir was created, rendering available 325,000 acre feet of stored flood water which can now be used successively through six plants aggregating 500 feet working head. The completion of the Holter plant in 1917 will increase this aggregated head to 600 feet, and the completion of the listed undeveloped sites along this river will enable this stored water to be used through a total head of 880 feet. In addition to this storage the aggregate available local storage at the developments on the Missouri River is 180,000 acre feet usable through each of the plants located further down the river. The result is to increase by 87 per cent the minimum capacity of the system above the capacity determined by normal low water, and provides storage sufficient to develop at the site affected 100,000 kilowatts for 100 days in each year, in addition to the normal low water power. The reservoir ensures an adequate supply of water during periods of extreme cold weather and eliminates the need of reserve steam plants.

The presence of this large power system already operated in the mountain territory crossed by the Chicago, Milwaukee & St. Paul Railway, in addition to the success attained in the electrification of the Butte, Anaconda & Pacific Railway, undoubtedly was a prime consideration when the progressive management of that railway decided to electrify their mountain divisions. It was obvious that no isolated plant or plants could furnish power for the operation of such a system of railway as economically or efficiently as it could be obtained from plants serving a general commercial load and having as large a capacity.

The great number of power sources and the duplication of transmission line feeders in The Montana Power Company's system ensures a continuous supply of power, while the well-known advantages of diversity of load enables the power company to carry the railway company's load of relatively low load-factor and still maintain at the generating stations 85 to 90 per cent. load-factor.

The number of plants on the same river permits the economical use of stored water, which in turn reduces the plant cost per unit of capacity.

The relatively large commerical load combined with the railway load has permitted the development of the larger power sites, usually at a lower cost per unit of capacity than smaller isolated plants would have cost.

The dispatching of load under one central management has reduced the station capacity necessary to be held in reserve, and has resulted in minimum economy in the use of water.

These factors illustrate the very considerable economies attained by the symmetrical development of the system of The Montana Power Company by which both the consumer and the power company are mutually benefitted.

The growth of the system has developed no serious operating difficulties; in fact there is a steady improvement in the matter of continuity of service and of the successful operation of relays and circuit breakers arranged to isolate damaged lines and apparatus without affecting the customers supply of power.

It requires no great stretch of the imagination to visualize the day when a continuous network of transmission lines will parallel the main railroads from the eastern Rockies to the Pacific coast, conserving water power by using it and benefitting the general public by lower rates, increased comfort in traveling, and an almost universal distribution of energy at less cost from "white coal."

THE MILWAUKEE ELECTRIFICATION

By W. B. Potter

Chief Engineer Railway and Traction Engineering Department, General Electric Company

This contribution briefly points out the success of the Milwaukee installation and shows the reason for the adoption of the 3000-volt as the trolley potential.—Editor.

The electrification of heavy railway service has been undertaken in many instances for a somewhat limited purpose, and under conditions that were fairly uniform as to the requirements, with either grades or substantially level track being the particular characteristic of each installation. The Butte, Anaconda & Pacific, and more particularly the Chicago, Milwaukee & St. Paul, are illustrations of heavy service over long heavy grades, as well as on extended stretches which are practically level. The requirements as to speeds and the handling of trains are, naturally, more varied over a profile of this character than where the gradient is more nearly uniform.

The Chicago, Milwaukee & St. Paul is, presumably, the best illustration extant of electric operation with widely varied service over many changes of grade. To eliminate the Rocky Mountains, and also keep faith with the prairie, is no small accomplishment. The impressions from traveling on the Milwaukee are in keeping with the country it traverses, and a more intimate acquaintance than is possible from a description is essential to a full appreciation. There is merit not only in the operating success, but also in the initial investment, as figures published by the Railway Company show something less than $30,000 per mile of route.

The distinctly novel feature is regenerative control,—utilizing the locomotives as gravity driven power houses for the purpose of regulating the speed on down grades, the flexibility of regeneration as applied to direct current equipment being such that the air brakes are not used during the run, but are applied only for the purpose of stopping the train. The variable characteristic of the direct current motor permits a variation in speed in proportion to the grade, conforming closely to the established rules under former operation with the air brakes. The smoothness of grade running with regeneration, and the absence of hot brake shoes and wheels are details needing but mention to be appreciated. Incidentally, under some circumstances, the return of energy available for the hauling of other trains may be an item of considerable moment.

The decision in favor of 3,000 volts d.c. for the Milwaukee followed a careful study of the relative cost and other features of split phase alternating current and other direct current voltages, commonly considered as being indicative of the type of locomotive and equipment. This review showed figures and operating characteristics favorable to direct current, with but little difference in the investment between 3,000 and 5,000 volts d.c.; intermediate voltages and those lower and higher being rather less favorable. There was this difference, however, between 3,000 volts and 5,000 volts: the investment for copper in the former was transferred to investment for locomotives in the latter, and obviously feeder copper is subject to less depreciation and maintenance than in the case of rolling stock. Further, as the investment for substations and copper was sufficient for a material increase in traffic, such locomotives as might be subsequently purchased, if built for 5,000 volts, would continually add the burden of a higher cost.

The vital problem of collecting the current at 3,000 volts required by the heavy freight and high speed passenger service has been successfully solved, and with ample margin. The locomotives are provided with two pantographs in the expectation that both would be used, but in practice it has been found that one is sufficient, leaving the other as a reserve.

The results on the Butte, Anaconda & Pacific have shown conclusively the success of electrification in heavy service with a substantial reduction in the cost of operation as compared to steam locomotives. The success of the Milwaukee is unquestionable as to the service performance, and the economic results will be awaited with much interest. There can be no question as to the demonstrated ability of the electric locomotive to outhaul and outdistance its steam associate.

THE ELECTRIFICATION OF THE MOUNTAIN DISTRICT OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By W. D. Bearce

Railway and Traction Engineering Department, General Electric Company

The author gives a brief description of the physical characteristics of the Chicago, Milwaukee & St Paul Railway electrification and comments briefly on the principal features involved. Detailed description of the locomotives, substation layout, motor generator sets, switchboards, etc. is contained in other articles in this issue.—Editor.

The Chicago, Milwaukee & St. Paul Railway is the most recent transcontinental line to cross the western states to the Pacific Coast, its lines being extended about seven years ago from Mobridge, South Dakota to Seattle and Tacoma in the state of Washington. This step was accomplished by building 1420 miles of road across the Rockies, the Bitter Root and the Cascade Mountain ranges. Unlike the earlier transcontinental railroads, this project received no grants of public land or other governmental aid. The engineers and financial backers, however, did not fail to profit by the mistakes of earlier roads and the route chosen is the shortest line from Chicago to the Pacific North Coast and the roadbed is of the most permanent character. The Milwaukee system now includes over 10,000 miles of track and is one of the most extensive systems in the United States. This progressive railway company owns and operates all train equipment including parlor, sleeping and dining cars and runs over its own rails the entire distance from Chicago to the Pacific Coast.

The Electrified Divisions

The tracks of the mountain district of the Chicago, Milwaukee & St. Paul Railway, in surmounting the obstacles imposed by the Rocky Mountain and coastwise ranges, represent the solution of one of the most difficult problems ever mastered by railway engineers. Out of this section of rugged mountain railway, including many long grades and short radius curves, four steam engine divisions were selected for electrification aggregating 440 miles in length. Steam engines were first abandoned on the Three Forks—Deer Lodge Division, 115 miles long and crossing the main Continental Divide, thus giving the electrical equipment its initial tryout under the severest service conditions of the entire system. The first electric locomotives were placed in regular service on December 9, 1915, and during the month of April 1916, service was extended to Harlowton, making a total of 226 miles of electrically operated road. By the beginning of 1917, it is expected that steam engines will be superseded over the entire distance from Harlowton, Montana, to Avery, Idaho.

This project is the most extensive steam railway electrification in the world, the length of haul being nearly six times as great as any trunk line now operating with electric locomotives. The length of track to be electrified is approximately equal to that from New York to Buffalo or from Boston to Washington.

In crossing the three mountain ranges included in the electric zone, there are several grades of one per cent or more, the most difficult being the 21 mile two per cent between Piedmont and Donald, and the longest the 49 mile one per cent grade on the west slope of the Belt Mountains.

The curvature is necessarily heavy, the maximum being ten degrees. There are also numerous tunnels in the electric zone, 36 in all, the longest being the St. Paul Pass Tunnel, over a mile and a half in length piercing the ridge of the Bitter Root Mountains.

Passenger and Freight Traffic

The passenger service consists of two all-steel finely equipped transcontinental trains in each direction, the "Olympian" and "Columbian" and a local passenger train in each direction daily between Deer Lodge and Harlowton.

Freight traffic through the electric zone comprises from four to six trains daily in each direction. Westbound, the tonnage is made up of manufactured products and merchandise for Pacific Coast points and foreign shipment. Eastbound tonnage includes grain, lumber, products of the mines and live stock.

The larger part of the traffic is through freight. Trains are made up of an assortment of foreign cars, including box and flat cars, coal and ore hoppers, stock cars, refrigerators, etc., varying in weight from 11 to 25 tons empty and as high as 70 tons loaded. These cars being owned by many different railway systems are equipped with air brakes adjusted for different conditions of operation, and in accordance with different standards as to braking power and type of equipment, thus making the problem of holding the long trains on the heavy down grades by air brakes, a most difficult undertaking.

Electrical Operation

Electrification promises a material reduction in running time. It has been found, for example, that on the 21 mile two per cent. grade from Piedmont to Donald, the electric locomotive can reduce the running time of passenger trains from an hour and five minutes to approximately 40 minutes. On the run from Deer Lodge to Butte which, under the steam locomotive schedule, required one hour and 20 minutes, a saving of approximately 30 minutes can be made.

In the freight service, it has been found that on the first division where the steam locomotives have required 10 to 12 hours to make 115 miles, electric locomotives can meet a schedule of from 7 to 8 hours for the same distance. The heavy grades and frequent curves at certain points offer serious obstacles to steam locomotive operation even in the summer time, but with winter temperatures as low as 40 deg. F. below zero and heavy snowfalls in the Bitter Root Mountains, serious delays have occurred owing to engine failures or to inability to make steam. The capabilities of the electric locomotive are in no way impaired by cold weather or by inability to obtain fuel or water in case of snow blockades. During a series of record-breaking temperatures in December 1915, Mallet engines were frozen up at different points on the system and the new electric equipment was rapidly pressed into service to replace them. On several occasions electric locomotives hauled in disabled steam engines and trains which would otherwise have tied up the line.

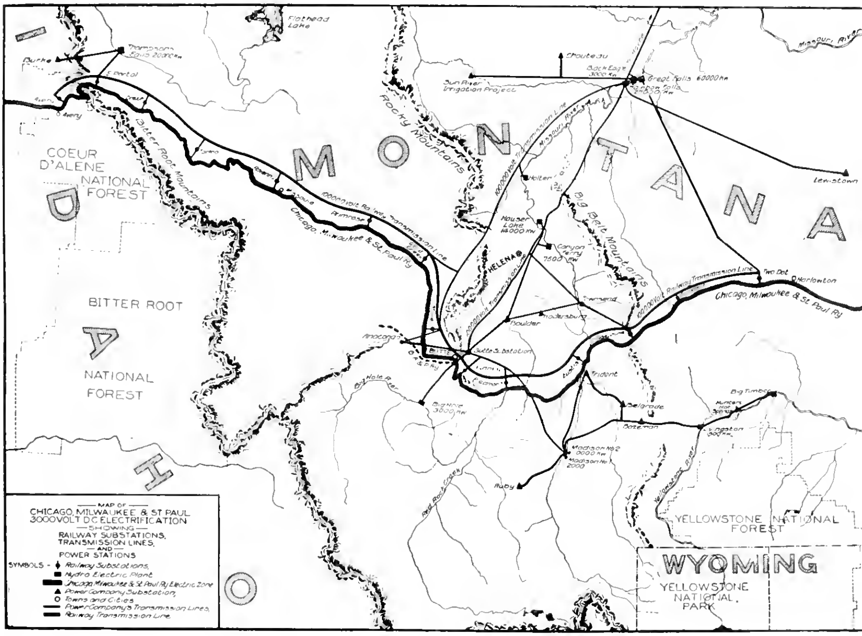


Fig. 1. Map of the Chicago, Milwaukee & St. Paul Electric Zone

During initial operation on the Rocky Mountain Division, the capacity of the new locomotives has been thoroughly tested. Trains of 3000 tons trailing have been hauled east and 2800 tons west, using a helper on the heavy grades. From the operating data obtained on the first division, it is evident that much heavier trains can be hauled with the electric locomotives than with steam engines and all passing tracks are being lengthened to one mile to take advantage of longer trains. On some of the runs where the grades are less than one per cent trains of as many as 130 cars and as heavy as 4000 and 5000 tons are hauled with a single locomotive.

Fig. 2. All-steel Passenger Train "Olympian" in Silver Bow Canyon

Fig. 3. Electric Locomotive and Freight Train on 2 Per Cent Grade at Grace

The four through passenger trains "Olympian" and "Columbian" are taken across the two mountain ranges by a single passenger locomotive. These trains at present consist of nine full vestibuled steel coaches weighing approximately 650 tons. Instead of changing locomotives at Three Forks as has been the practice under steam operation, the same locomotive is run through the 226 miles from Deer Lodge to Harlowton, changing crews midway. Passenger trains will travel over the entire electrified division in approximately 15 hours including all stops and the tourist thus will have an opportunity of traversing by daylight some of the most beautiful scenic regions in the United States and without suffering the annoyance of cinders and smoke incident to the use of steam locomitives. The local passenger trains operating in the electric zone between Deer Lodge and Harlowton are handled by half units weighing about 150 tons with equipment similar to the main line locomotives.

Regeneration

Regeneration or the recovery of energy on descending grades by reversing the function of the motors reduces the cost of operation and furnishes a ready solution of the difficult braking problem. On the long sustained grades encountered in crossing the three mountian ranges, great skill is required to handle either the heavy and varied freight or the high speed passenger trains with the usual air brakes.

The stored energy due to gravity which must be dissipated by the friction of the brake shoes on the wheels approximates 3500 kw. or 4700 h.p. for a 2500-ton train running at 17 miles per hour on a 2 per cent grade. This explains why it frequently happens that brake shoes become red-hot and other serious damage is done since all of the potential energy stored in the train at the summit of the grade must be dissipated during the descent.

With regenerative braking, the motors become generators which absorb the energy of the descending train and convert it into electricity, thus restricting the train to a safe speed down the grade and at the same time returning electric power to the trolley for use by other trains. The strain on drawbars and couplings is reduced to a minimum since the entire train is bunched behind the locomotive and held to a uniform speed. The electric-braking mechanism automatically controls the speed by regulating the amount of energy fed back to the line. This smooth and easy descent is in marked contrast to the periodical slowing down and speeding up of a train controlled by air brakes.

In case there are no other trains between the substations to absorb the power generated by a descending train, this power passes through the substation machinery, is converted from direct to alternating current and fed into the distribution system connecting all substations. The Power Company's lines are so extensive and the load of such a diversified character that any surplus power returned by regenerating locomotives can readily be absorbed by the system, credit being given for all energy returned.

Fig. 5. Typical Overhead Work at the Entrance of Three Forks Yards

Fig. 4. Overhead Construction at Siding near Butte Yards

Electrical Equipment

The scheme of electrification includes the generation of electricity from the several water power plants of the Montana Power Company; transmission at 100,000 volts, three-phase, 60 cycles; conversion in substations to 3000 volts direct current and distribution over catenary overhead construction to electric locomotives.

Electric Locomotives

The development of the electric locomotive is primarily the achievement which has made electrification of trunk lines feasible. There are 42 of these main line locomotives (30 freight and 12 passenger) and two switching locomotives. The locomotives are the first to be used for railroad service with direct current motors operating at a potential as high as 3000 volts* and the first to use direct current regeneration.

Control

The control equipment is the well-known Sprague General Electric Type "M" arranged

Fig. 6. Janney Substation showing Bungalows for Housing Substation Operators

for multiple unit operation. The main control switches are mounted in steel compartments inside the locomotive cab with convenient aisles for inspection and repairs. A motor-generator set in each half of the locomotive furnishes low voltage current for the control circuits, headlights, cab lighting and for charging the storage batteries on the passenger coaches. Under steam operation, the charging current for these batteries is furnished by a steam turbo-generator set located in the baggage car. The blower for ventilating the traction motors is also direct connected to one end of the motor-generator set.

The pantograph collectors, one of which is mounted on each half of the locomotive, are of the double pan type with a working range of from 17 ft. to 25 ft. above the rail. The contact elements are of the same metal as the trolley wire, so that current passes from copper to copper.

The air brake equipment is practically the same as that used on steam locomotives except that motor-driven air compressors are used to furnish compressed air. Aside from the air brakes, compressed air is also used for signals, whistles, bell-ringers, sanders, flange oilers, pantograph trolleys, part of the control equipment, and on the passenger locomotives for the oil fired steam boilers.

* It is of interest to note that this is the first direct current installation to use a potential as high as 3000 volts and this equipment was adopted after a careful investigation of all systems available for electrification. The Butte, Anaconda & Pacific Railway in the immediate vicinity of the Chicago, Milwaukee & St. Paul electrification has been in operation with 2400-volt direct current locomotives since May, 1913, and has furnished an excellent demonstration of the entire practicability of high voltage direct current operation.

Switching Locomotives

The switching locomotives are of the swivel truck type weighing 70 tons each and equipped with four geared motors. A single pantograph of construction similar to that used on the main line locomotives is mounted on the cab and in other ways the locomotive represents the standard construction commonly used with the steeple cab type of switcher. The motors (known as Type GE-255) are of box frame, commutating pole, single geared type designed for 1500 volts with an insulation of 3000 volts to the ground. Many of the switching locomotive parts are interchangeable with those used on the main line locomotives; for example, the air compressors, small switches, headlights and cab heaters.

Source of Power

Utmost precautions were taken by the Railway Company in making plans for this electrification to insure a reliable source of power. The Montana Power Company, with whom the contract was closed for electric power, operates a network of transmission lines covering a large part of Montana which are fed from a main plant at Great Falls and a number of other widely separated water power plants of adequate capacity at all seasons of the year. A notable feature of this pioneer electrification is, therefore, the conservation of fuel consequent upon the utilization of water powers.

The Transmission Lines

The Montana Power Company's transmission lines, which are carried in some cases on steel towers and in others on wooden poles, tap into the railway system at seven different points where the power is most needed. The Railway Company's transmission line extends the entire length of the system on wood poles. In most cases this line is built on the Company's right-of-way, although at several points there are cutoffs which make a considerable saving in the length of line.

With this completely interconnected transmission system, each substation may be fed from either direction and also at the tie-in points from a third source of power.

Substations

Fourteen substations are equipped for converting the 100,000-volt alternating-current to 3000 volts direct-current. They are distributed along the route at an average distance apart of 32 miles. Each station contains step-down transformers, motor-generator sets, switchboard and the necessary controlling and switching equipment. The transformers receive the line current at 100,000 volts and supply the synchronous motors at 2300 volts. Each synchronous motor drives two 1500-volt direct-current generators connected permanently in series, thus supplying 3000-volt current for the locomotives.

Overhead Construction

The overhead construction employs the principle of the flexible twin catenary originated by the General Electric Company. The details of construction and installation were entirely under the supervision of the Railway Company's engineers. With this quite novel but remarkably successful construction, the current is collected in both high speed passenger service and heavy freight service without any sparking.

Cost

Electric locomotion has been undertaken with the expectation of effecting a sufficient reduction in the cost of operation to return an attractive percentage on the investment required, as well as to benefit by all the operating advantages of electric locomotives. According to statements made by the Railroad officials, about $12,000,000.00 will be expended, and with the work more than half completed there is every reason to believe that the cost of construction will come inside the estimates.

THE MECHANICAL FEATURES OF THE LOCOMOTIVES OF THE CHICAGO, MILWAUKEE & ST. PAUL MAIN LINE SERVICE

By A. F. Batchelder

Engineer Locomotive Departmrnt, General Electric Company

The author gives a concise statement of the most important mechanical features of the St. Paul locomotives. He describes the make-up of the frames and superstructure and gives the arrangement of apparatus. The article is profusely illustrated, many of which show considerable detail.—Editor.

Much has already been said about the operation of the electrified portion of the Chicago, Milwaukee & St. Paul Railway in the Rocky Mountains, it having been in operation now approximately a year, including an extremely severe winter, when many steam operated roads were unable to keep their trains moving regularly enough to prevent congestion at points even where the natural conditions are not considered severe. This electric division, through a most difficult section of the Rockies, with long grades both up and down and with severe cold weather and bad storms operated with its new equipment without any apparent difficulty, not only keeping the road clear of congestion, but almost universally making up time that had been lost on the adjoining steam operated portions of the road. It, therefore, seems fitting at this time to give a more detailed description of the mechanical part of the electric locomotives that were making such a remarkable record in the hauling and braking of the enormous trains that were handled up and down these mountain grades so effectively. The principal dimensions and features of these locomotives are as follows:

GENERAL DATA

Gage	4 ft. 8½ in.
Service	Freight
Voltage	3000 volts d-c.
Wheel arrangement	4-4-4-4-4-4
Maximum tractive effort	132,500 lb.
Continuous tractive effort	71,000 lb.
Length over all	112 ft. 0 in.
Total wheel base	102 ft. 8 in.
Width over all	10 ft. 0 in.
Height, trolley locked down	16 ft. 8 in.
Rigid driving wheel base	10 ft. 6 in.
Rigid guiding wheel base	6 ft. 0 in.
Diameter driving wheels	52 in.
Diameter guiding truck wheels	36 in.
Size main driving journals	8 by 14 in.
Size guiding truck journals	6½ by 12 in.
Total weight	576,000 lb.
Weight on drivers	450,000 lb.
Weight per driving axle	56,250 lb.
Spring borne weight per driving axle	40,000 lb.
Dead weight per driving axle	16,250 lb.
Weight on guiding truck wheels	126,000 lb.
Weight per guiding axle	31,500 lb.
Spring borne weight per guiding axle	27,274 lb.
Dead weight per guiding axle	4,226 lb.
Maximum tractive effort in per cent of weight on drivers	30 per cent
Continuous tractive effort in per cent of weight on drivers	16 per cent
Normal braking power in per cent of weight on drivers	89 per cent
Normal braking power in per cent of total weight	69 per cent

On account of the enormous tonnage to be handled and the great power of these locomotives, a total of eight traction motors are used, requiring an overall length of locomotive of 112 ft. For the purpose of negotiating curves easily with minimum flange wear, and in order to secure a simple and effective weight equalization and foundation brake system, the running gear is made in sections or individual trucks, articulated in such a manner as to give positive guiding from one to another, and also to take up the bumping and hauling stresses directly through the running gear frames. This arrangement also gives a most convenient opportunity for supporting the motors and is advantageous for receiving forced ventilation. In order to eliminate any possibility of undue lateral strains on the track and for operating in either direction, a four-wheel bogey guiding truck, see Fig. 1, has been connected to the outer driving truck at each end of the running gear.

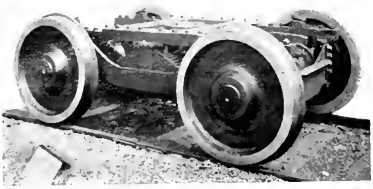


Fig. 1. Guiding Truck

The complete locomotive consists of two duplicate sections, each having a cab mounted on two driving trucks, one truck being symmetrical and the other unsymmetrical with an extended frame carrying the draft rigging and center pin for the guiding truck, see Fig. 2. The guiding trucks are of the well-known equalized type common to steam locomotives, having inside journal bearings, $6\frac{1}{2}$-in. by 12-in., and are arranged to carry the load on the center bearing through a bolster which provides a lateral movement 4 inches each way from the center against a constant pressure. This lateral movement of the bolster is only required in cases where the locomotive negotiates curves greater than 14 degrees, or where entering sharp curves at high speeds tending to produce lateral lurches of the locomotive.

As stated above, the extended frame of the unsymmetrical driving truck carries the bumper beam, buffer and draft gear of the Miner Class 18A friction type, see Fig. 3. Also one end of the superstructure is carried on longitudinal center sills through cast steel center bearings. The center bearing for the cab superstructure, see Fig. 4, is so located as to distribute the weight properly between the guiding truck and the driving axles. The side frames, transoms and other parts taking the bumping and hauling stresses are designed to stand 500,000 lb. static pressure with liberal factors of safety. The side frames are of cast steel, $4\frac{1}{2}$ inches thick, placed on 80-inch centers and are bolted to the machined surfaces of the cross transoms with taper bolts. At the inner end of this truck is bolted a cast steel end frame, see Fig. 8, to which is fastened the hinge joint which is also designed to stand 500,000 lb. static pressure. The middle transom, see Fig. 9, is of steel, cast hollow, with supporting lugs for the nose of the traction motor and with provision for taking air from the blower duct in the superstructure through a telescoping duct directly into the motors. This gives a very simple and effective method of conducting the air from the blower to the motors. The symmetrical driving truck has a transom at each end identical to the inner end transom of the unsymmetrical truck, with hinge joint bolted to each of them. This truck has a middle transom, also identical, which carries the motor supports in the same manner as on the other truck and also serves as a support for the superstructure, the air duct being through the center bearing. This center bearing, see Fig. 10, is made to provide for any change in distance between bearings, due to the curving of the trucks, allowing longitudinal motion besides swiveling, but preventing all transverse movement of the superstructure.

The weight of the locomotive is distributed to the wheels by an equalizing system consisting of main elliptic springs, side equalizers, and double coil springs. The unsymmetrical trucks are so equalized as to effect a three point bearing which is accomplished by side equalizers between the driving wheels on each side, making an effective transverse axis one-half way between the driving axles, the third point being the center bearing of the guiding truck. This unsymmetrical truck being supported in equilibrium, serves through its hinged joint as the steadying agent for the symmetrical truck, which is also provided with side equalizers having its transverse axis one-half way between the axles. With this

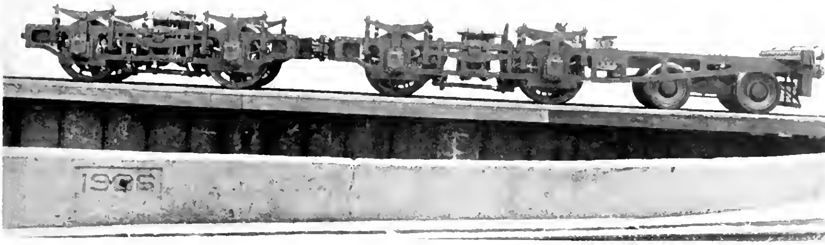


Fig. 2. Running Gear of One-half Unit

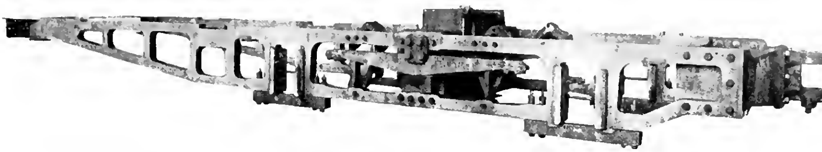


Fig. 3. Unsymmetrical Truck Partly Assembled

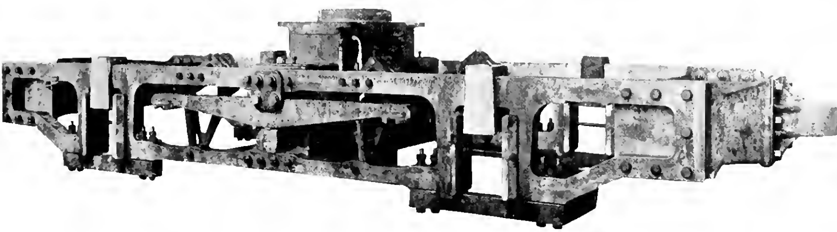


Fig. 4. Symmetrical Truck Partly Assembled

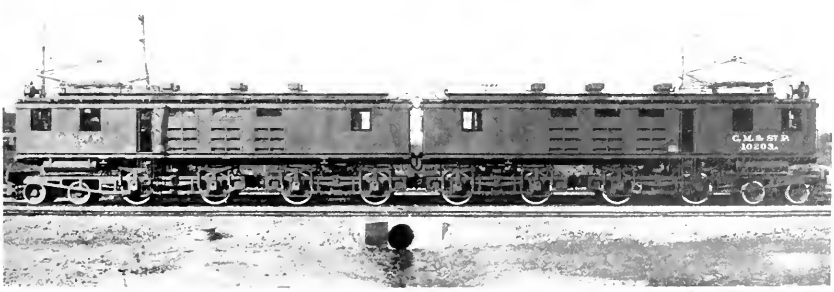


Fig. 5. Freight Locomotive for Chicago, Milwaukee & St. Paul

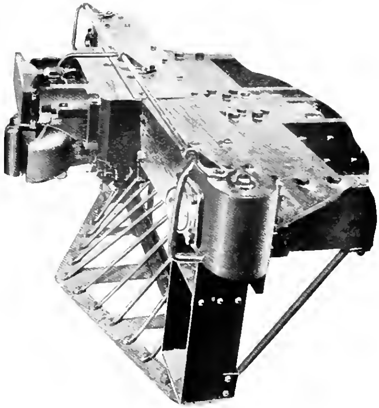


Fig. 6. End Frame and Draft Gear

Fig. 7. Forward Cab Center Plate

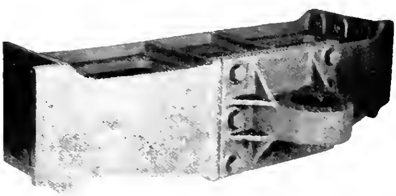


Fig. 8. Truck Inner End Frame

Fig. 9. Main Transom of Driving Truck

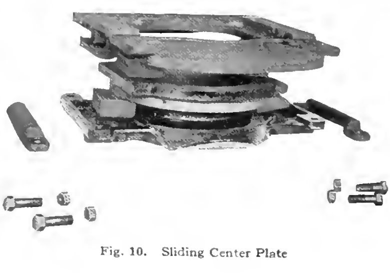


Fig. 10. Sliding Center Plate

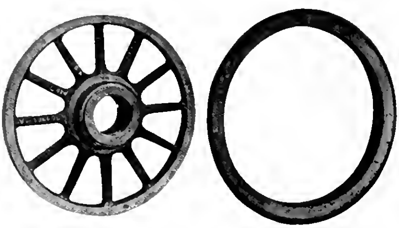


Fig. 11. Wheel and Tire

arrangement the end of the symmetrical truck which is attached to the unsymmetrical truck follows the same vertical movement as the latter, the hinge allowing no vertical play. This necessitates allowing vertical play in the hinged joint between the two symmetrical trucks.

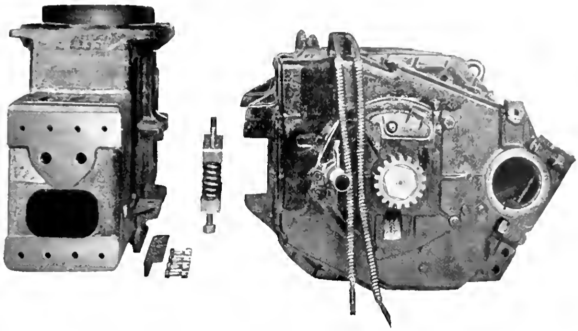


Fig. 12. Motor Nose Suspension

Each of the driving trucks is equipped with inside hung brakes of the simple push rod

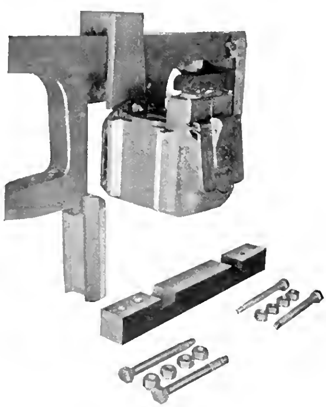


Fig. 13. Journal Box Assembly

type supported by specially designed brackets, each side being operated by its own individual 12-in. by 10-in. cylinder. There are no brakes furnished for the guiding trucks.

The wheel centers are of steel castings with twelve spokes and provided with hub extensions to receive the motor gear. The tires with MM tread and flange are $5\frac{1}{2}$ inches wide and 3 inches thick and are held on by shrinkage.

The journal boxes are steel castings machined to receive the bearing brasses and the frame pedestal shoes. The pedestal shoes and journal box flanges are so designed that when the shoes are dropped the journal box can be removed from its place without lifting the frame, making it convenient to renew the thrust plates which are provided at the back of the boxes.

The motors are supported in the usual way directly on the axle on one side, and by a

Fig. 14. Spring Gear

nose bracket through double acting springs to the bolster on the other side. The motors drive through yielding gears mounted directly on the axle, one at each end of the motor.

The superstructure of each section is made up with two 12-in. longitudinal center sills

Fig. 15. Top View of Cab Platform

Fig. 16. Underside of Cab Platform

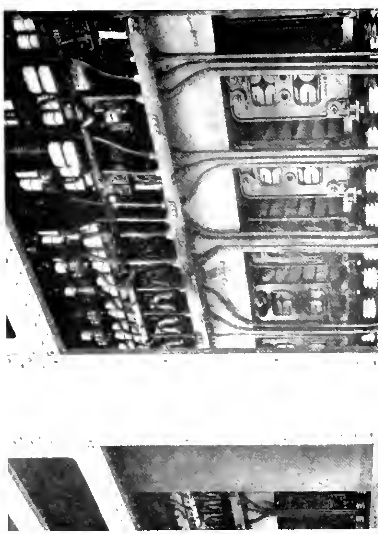


Fig. 17. Contactor and Rheostat Compartments

Fig. 18. Locomotives Under Construction, Showing Hatches and Openings

spaced 31 inches apart, with a plate bolted to the bottom and a $\frac{3}{8}$-in. floor, extending over the entire structure, bolted to the top, forming a box girder and providing the air duct to conduct the ventilating air from the blower to the motors. These sills also serve as struts for the bolster girders. A second floor carried by the first floor through 6-in. channels forming ducts for the wiring conduit is provided as the floor for the apparatus cab.

The cab is made of steel and structural shapes built up in the usual way with ventilating louvres in the sides. Doors are located at each end and one on each side. The windows are conveniently located to provide

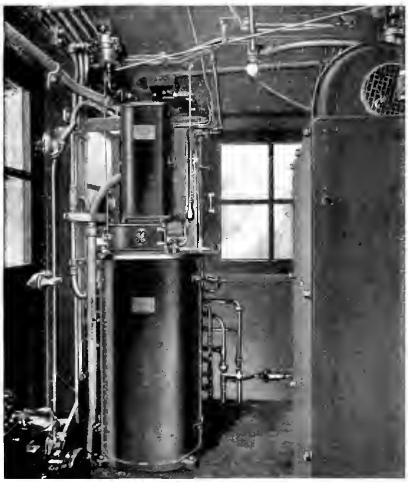


Fig. 19. Motorman's Cab

light for the inspection of all apparatus. Each cab is divided into two compartments consisting of the main apparatus cab 47 ft. long by 10 ft. wide, and the motorman's cab, 5 ft. long by 10 ft. wide. The motorman's cab is arranged in the usual way with a front door, and two doors leading into the apparatus cab. The apparatus cab is arranged with an aisle 23 inches wide and extending the entire length on each side with the control and other apparatus compartments arranged in the middle, and with hatches in the roof for the placing of all apparatus. The motor-generator set for regenerative braking, the blower, and air compressor, are carried

Fig. 20. Side Aisle of Apparatus Cab

directly through their supports, on the main box girder forming the air duct.

Fig. 21. Center Aisle of Contactor Compartment, Looking Toward Blower, showing Contactor Arc Chutes and Method of Fastening Hatches

The compartment for the rheostats, switches, etc., is arranged with the rheostats supported near the floor, and above them, a floor between, are mounted the contactors, switches, etc. Ventilating flues leading from the rheostat compartment through the roof provide excellent natural ventilation. Ventilation by this method is obtained by air being taken through openings in the floor, passing over the rheostats and up the flues to the top. Doors are arranged to be easily removed to get at the connections of the rheostats and the back of the contactors. The front of the contactors and switches are accessible from a center aisle.

The arc chutes of all contactors face into this aisle which provides liberal arcing space. The arrangement of these rheostat and contactor compartments has been found particularly desirable on account of the ease of inspection and removing of parts for replacement. Also by this means all the high tension apparatus which might be a source of danger is safely enclosed.

Freight Train on Two Per Cent Grade

THE MOTOR USED ON THE 300-TON LOCOMOTIVES OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By E. D. Priest

Engineer Railway Motor Department, General Electric Company

This article gives a good description of the mechanical features of the traction motors used on the Chicago, Milwaukee & St. Paul Railway. It is well illustrated with views and diagrams, which themselves give much important data. Operating results have proved the design of these motors to be highly satisfactory.—Editor.

The motors used on the 300-ton electric locomotives in service on the Mountain Divisions of the Chicago, Milwaukee & St. Paul Railway are known as the GE-253 and are the largest geared motors, mounted on an axle, which have been used in the electrification of steam railways. This article briefly describes the design and construction of these motors.

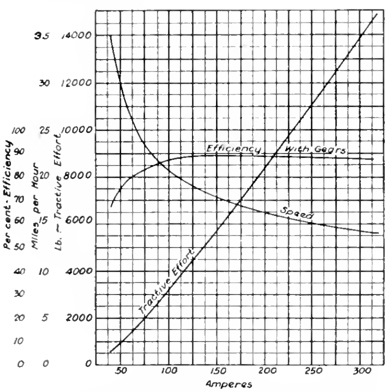


Fig. 1. Characteristic Curves. GE-253-1500/3000-volt Railway Motor. Volts per Motor, 1500; Gear, 82 teeth; Reduction, 4.56; Pinion, 18 teeth; Wheel Diameter, 52 in.

Based on the A.I.E.E. standard method of rating, the one hour rating of the GE-253 motor is 452 h.p.; the continuous rating, based on 100 deg. C. rise by resistance of the armature and 120 deg. C. rise by resistance of fields, is 396 h.p. These ratings are for a potential of 1500 volts, two motors being coupled in series for operation on 3000 volts. The motor is designed for operation with an external blower, and the volume of air used at the continuous rating is approximately 2500 cubic feet per minute. The air is blown into the motor through a large opening on the front of the magnet frame at the commutator end. It passes in parallel streams through the armature and over the field coils and is exhausted through openings in the magnet frame and bearing head at the opposite end of the motor from the commutator.

The motor complete, including spring gears, pinions, gear case and axle lining weighs 14,860 pounds. It has four main poles and four commutating poles. It is designed for shunted field control, the fields being shunted fifty per cent in motoring at full speed.

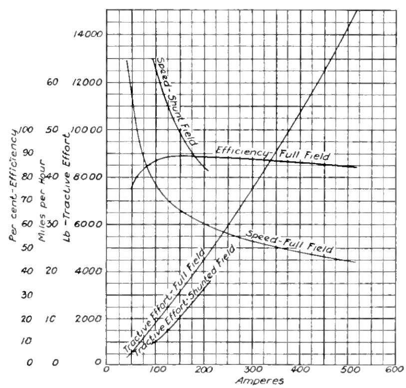


Fig. 2. Characteristic Curves. GE-253-1500/3000-volt Railway Motor. Volts per Motor, 1500; Gear, 71 teeth; Reduction, 2.45; Pinion, 29 teeth; Wheel Diameter, 52 in.

The armature has forty-nine slots, with seven coils per slot, and the commutator three hundred and forty-three segments. The armature coil has a single turn winding. The diameter of the armature core is $29\frac{1}{2}$ in. The coils are insulated with mica and asbestos. At the one hour rating the speed of the armature is 446 revolutions.

There are four brush-holders per motor, each brush-holder having two brushes $\frac{11}{16}$ by $1\frac{3}{4}$ inches.

The main field coils are wound with strip copper in two sections with asbestos between turns. They are insulated with mica and asbestos, and have a final wrapping of strong cotton tape. They are, therefore, capable of withstanding high temperatures without injury. The commutating coils are made of edgewise wound strip copper and are insulated in a similar manner to the main field coils. All the field coils are thoroughly impregnated by the vacuum process. The main exciting field coils are not subjected to full voltage, since the armatures of two motors are connected in series with the fields of both motors on the ground side.

The commutating characteristics of the motor are most excellent, and it is possible to raise the voltage on a stand test fifty per cent above normal without injurious sparking. During operating periods of regeneration at voltages materially higher than 3000 the fields can be shunted to a surprising extent without appreciable sparking.

Fig. 1 shows the speed, torque and efficiency curves of the motor with gearing for freight service; Fig. 2 shows similar curves for passenger service.

In mechanical design the motor, in general, follows well-known and thoroughly tried out lines of construction. Figs. 3 and 4 show

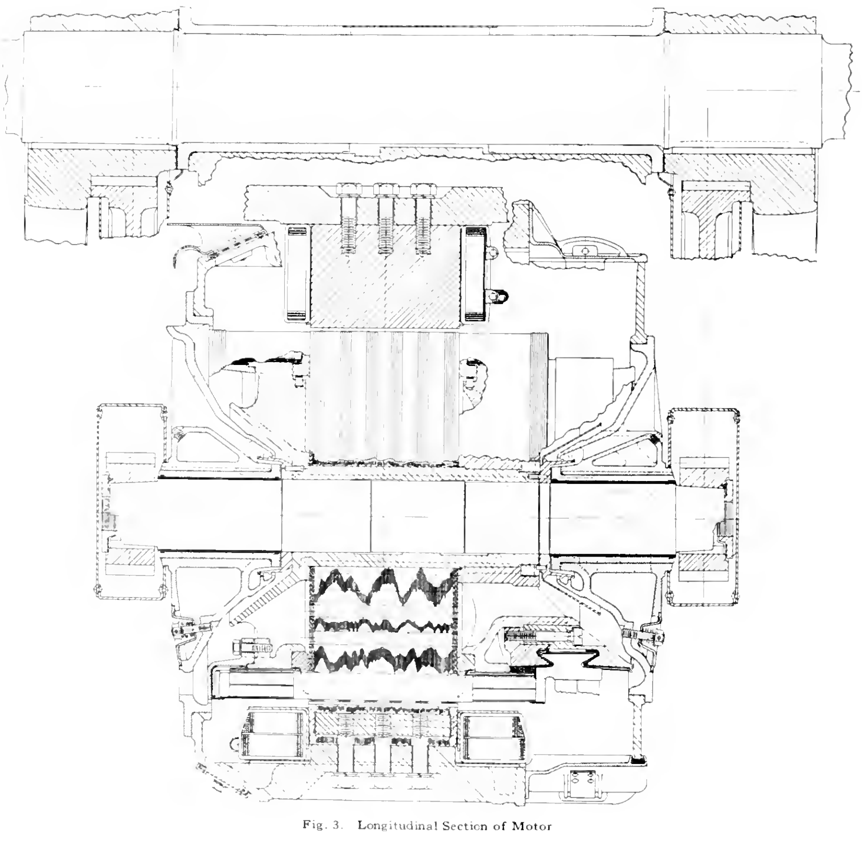


Fig. 3. Longitudinal Section of Motor

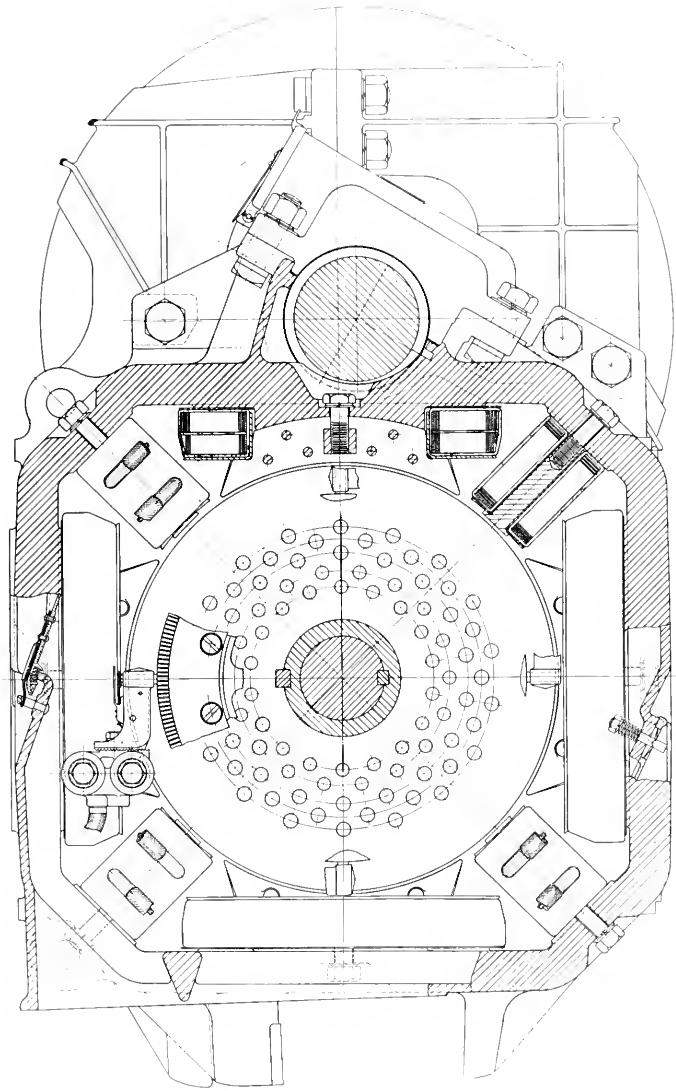


Fig. 4. Transverse Section of Motor

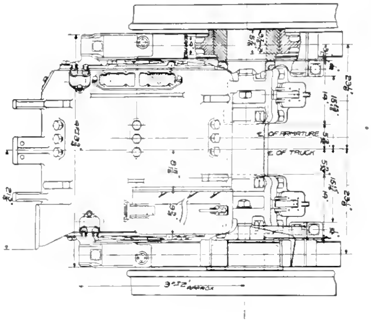


Fig. 5. Plan View with Dimensions

Fig. 7. Back Perspective View

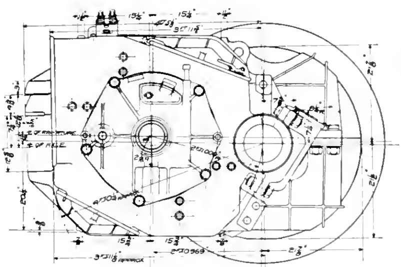


Fig. 6. End View with Dimensions

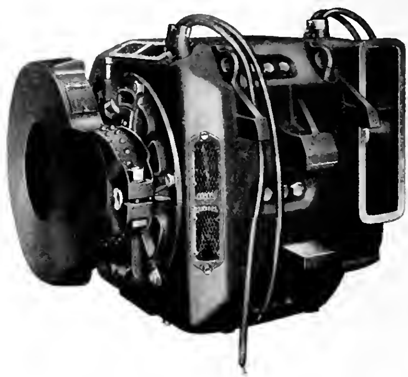


Fig. 8. Front Perspective View

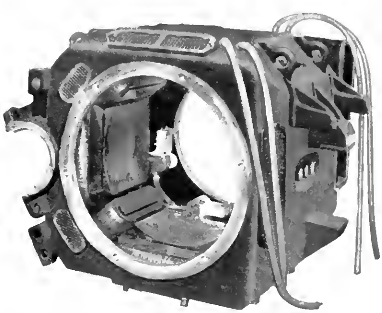


Fig. 9. Frame with Field Coils in Place

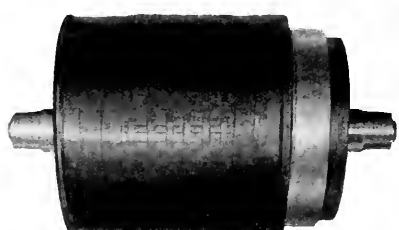


Fig. 10 Armature

longitudinal and transverse sections of the motor; Figs. 5 and 6 show outline diagrams with dimensions; Figs. 7 and 8 are perspective views of an assembled motor; Fig. 9, a perspective view of a partly assembled motor with field coils in place; Fig. 10, a view of a completed armature; Figs. 11 and 12 give an assembled and detail view of the spring gear used with the motors, and Fig. 13 a plan view of two motors mounted on a locomotive truck.

Fig. 11. Spring Gear

It will be noted that the armature core and commutator end core head are mounted on a central hub or spider into which is pressed the armature shaft. The commutator is mounted on the core head. Large openings are provided through the commutator, core head, armature core and spider head to secure effective internal ventilation of these parts. At the back end of the armature the end windings are protected by a removable flange. By making the flange removable the armature can be more easily wound or repaired.

The clips connecting the top and bottom bars at the back end of the armature are electrically brazed to the bars, thus insuring a reliable connection at any abnormally high temperature which might occur at excessive overloads.

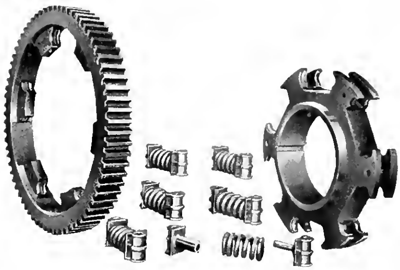


Fig. 12. Spring Gear Details

The armature bearings at each end are liberal in dimensions, being $5\frac{3}{4}$ inches in diameter and 10 inches long. They are lubricated with oil and waste, this method of lubrication having been found most reliable through long years of service on standard railway motors.

The motor has twin gears with a 4 inch face and 2-pitch. For the freight locomotives there are eighteen teeth in the pinion and

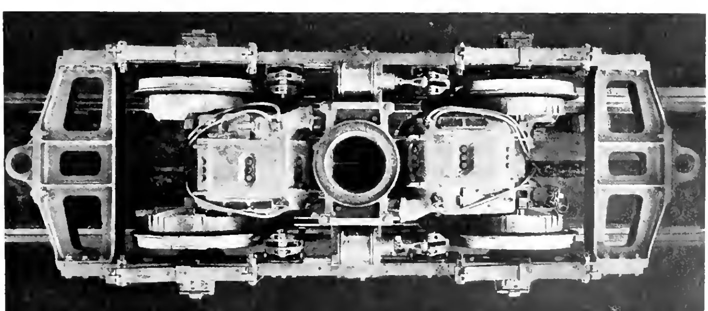


Fig. 13. Plan View of Two Motors on a Truck

eighty-two teeth in the gear, and for the passenger locomotives there are twenty-nine teeth in the pinion and seventy-one teeth in the gear. Both gears and pinions are made of high-carbon oil-treated stock, having an elastic limit of 85,000 pounds per square inch.

The gear cases are made of sheet steel with rim and sides securely riveted together. The supporting brackets extend over the rim of the case and are securely riveted to the rim and sides. The magnet frame is made of cast steel and, except in size, differs but little in general appearance from standard box frame railway motors.

The front of the motor is carried on the truck through an improved spring suspension. The design is such that both the downward and upward thrust is taken through springs. This form of suspension largely reduces the shock on the motor in passing over switches, crossings or other rough places in the track. The spring gears, and to a less extent the motor suspension, relieves the teeth of the gears of "hammer blows," and equalizes the load on the pinion and gear teeth at each end of the motor.

The brush-holder design is of standard construction. The holders are supported and protected from the ground through mica insulated studs.

In service the motors have operated with most excellent results. The commutators take on a bright, smooth polish, with no indications of etching at the edges of the segments. The effect of the spring gears and spring suspension is to make the motors run with unusual quietness. There is no noticeable gear noise while the locomotives are in motion. The absence of vibration is also noticeable. This is quite a marked contrast to heavy twin geared motors when operating without spring gears and spring nose suspension. The motors run at a comparatively low temperature in service, the capacity of the motors being sufficient to handle heavier trains than originally contemplated.

THE CONTROL EQUIPMENT, WITH REGENERATIVE ELECTRIC BRAKING FEATURE, ON THE LOCOMOTIVES OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By R. Stearns

Railway Equipment Department, General Electric Company

The author describes the control features of the St. Paul locomotives in great detail. The article is profusely illustrated which greatly helps an understanding of the text. Special attention is paid to the regenerative control.—Editor.

The engineer of a single 282-ton St. Paul electric locomotive has an enormous concentration of power at his command. The ease, efficiency, reliability and safety with which this power is made to serve the purpose of the engineer, while he maintains his train schedule involving wide variations in locomotive speeds, up and down grade, over the rugged profile of the Rocky Mountains, depends in a large measure upon the motor control equipment.

Owing to the great power needed in this exacting transcontinental service, the control design, both mechanically and electrically, includes many interesting departures. Particularly owing to the economic and safety requirements of definite speed regulation by electrical means down grades, the novel feature of regenerative electric braking has been provided in addition to the air brakes.

COLLECTION OF CURRENT

The system of current collection, which must be capable of handling unusually heavy currents at high speeds, has the distinctive feature of using two parallel adjacent copper conductors supported alternately and independently, by loop hangers from the same messenger wire. A continuously flexible contact surface, for the most part of double area, is thus obtained. In addition, each pantograph is equipped with two sliding contacts. Ordinarily, therefore, there are four points of contact between the collector and the trolley wires. With this very flexible combination a single pantograph, (and there are two on all locomotives for emergencies) can easily collect the heavy currents obtaining in the St. Paul service. Sparking is entirely eliminated. The current required for a single locomotive at the continuous rating of the motors is 840 amperes. In the passenger service, speeds up to 60 m.p.h. and over are attained.

Figs. 8 and 9 are characteristic curves based on 3000 volts line showing the amperes per motor obtained, at different locomotive speeds, in the freight and passenger service respectively. The current input through the collector as required by the eight traction motors is four times the ampere per motor reading as indicated.

The engineer controls the operation of his pantographs by means of an air valve. To raise the pantograph, air from the main reservoir is admitted to a pair of cylinders. The pistons of these cylinders energize powerful springs which in turn raise the collector and at the same time regulate the pressure against the trolley wire. The raising springs are energized at all times while the collector is in use, by maintaining air pressure in the cylinders. To lower the pantograph, air is exhausted from the cylinders, thus de-energizing the springs. The pantograph will then drop to its minimum collapsed height. The range of action of the trolley is between 17 feet and 25 feet above the rail.

As air is necessary to raise the pantographs, an auxiliary trolley pole with swivel base is supplied to collect current for the air compressor whenever the locomotive is first put into service. Fifty pounds is the minimum operating air pressure.

Fig. 1 shows one of the St. Paul locomotives equipped with two pantograph trolleys and also the auxiliary pole trolley used for starting purposes. It may be noted that the locomotive has two cabs. The pantographs installed on these cabs are connected by a bus line, so the duplex electrical equipments can be supplied from either trolley.

3000-VOLT PROTECTIVE APPARATUS

When 3000 volts was chosen as the desirable line potential for transmitting the great energy required by the locomotives of this extensive railway system, a further innovation was introduced into the design of the control equipment. It was appreciated from experience that, provided the protective devices in the main trolley circuit are reliable, short circuits clear themselves more quickly with high than with low voltages, and there is less attendant damage. The design of the main emergency switches and fuses was considered of great importance and these devices were accordingly mounted in a single high tension compartment of ample dimensions. Figs. 2 and 3 show this compartment.

The trolley lead starting from the pantograph trolley first enters the high tension compartment and is divided into two circuits, —main and auxiliary. A combination switch and fuse shown at the left in Fig. 3 is in the main circuit. An identical combination switch and fuse (except that a lower capacity fuse is used) is shown at the right of the picture. From the main switch and fuse, the main power lead goes directly to the controlling apparatus of the traction motors.

Fig. 1. St. Paul Locomotive Showing Twin Shoe Sliding Pantograph Trolley and Auxiliary Pole Trolley

The auxiliary lead passes to the four disconnecting switches shown at the top of the compartment and from there separate supply leads run to the motor generator set, air compressor and cab heater.

The compartment is made of sheet steel strongly reinforced with angle and channel irons and is thoroughly lined with insulation. A great saving in space has been effected by using for each combination switch and fuse a single arc chute containing two stationary contacts to which the incoming and outgoing leads are attached. The feature which combines the functions of switch and fuse consists in a cradle pivoted at one end carrying, on high voltage insulators, the supports for a copper ribbon fuse. These supports also carry spring contacts which complete the function of a switch. When the cradle is raised or lowered by a handle external to the compartment, the pair of spring contacts engages with the two stationary contacts and in this way closes or opens the switch. When the switch is closed the fuse is in circuit and automatically protects the circuit against overload.

The high tension compartment is equipped with three doors; one each for the main and auxiliary switches and one for the separate disconnecting switches. These doors are interlocked with the external operating handles so that no conducting parts can be approached without first opening its circuit by dropping the switch cradle. When either switch cradle is dropped it will be noted its fuse is entirely disconnected from the circuit.

Fig. 2. 3000-volt Switch and Fuse Compartment

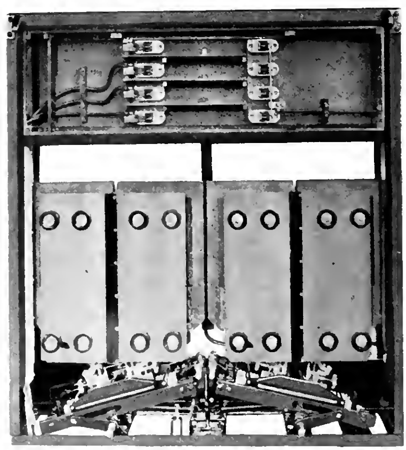


Fig. 3. 3000-volt Switch and Fuse Compartment with Sheet Steel Front Removed Showing Arc Chutes and Contact Mechanism

In addition to the protective apparatus in the high tension compartment, a 3000-volt aluminum cell lightning arrester is tapped into the main lead near the collectors. The lightning arrester, installed in a grounded sheet iron box, is mounted on the back of the high tension compartment.

3000-VOLT CONTACTOR COMPARTMENT

Aside from the apparatus already mentioned, the 3000-volt equipment of a locomotive consists of eight traction motors; two air compressor motors; two cab heaters; two driving motors for the motor generator sets; and the control equipment for all these devices. Since all this 3000-volt equipment is in duplicate, the following description will cover only that portion located in one of the two cabs which is entirely independent in operation. This controlling apparatus is grouped in a sheet iron compartment located near the center of the cab. Allowing for aisles on either side, the space occupied by this compartment, extends from the floor to the roof of the cab.

The complete set of rheostats used in regulating the current in the four traction motors is assembled at the bottom of the compartment along the floor of the cab. Each rheostat is mounted upon 3000-volt insulators as shown in Fig. 4. The rheostat is of the cast grid type shaped to effectively meet the space limitations of locomotive service. The remaining controlling apparatus is located in four groups directly above the rheostats. The rheostats are separated from the equipment groups above by a partition. The bottom of the rheostat compartment is open, and complete ventilation of the rheostats is obtained through six chimneys leading up to ventilators at the top of the cab. The control groups are installed between the chimneys. An idea of the space occupied by all this part of the equipment may be obtained by reference to Fig. 1 which shows clearly the location of each chimney.

Fig. 5 shows the groups of control equipment as they are located with respect to each other in the cab. Upon the supports of Group 1 are mounted the high voltage disconnecting switches and starting sets of the motor generator set and compressor, also the heater disconnecting switch, a portion of the rheostat and tap field contactors and the translating relays between motor running and regenerative braking connections.

Group 2 shows the rheostat contactors.

Group 3 contains the overload relay and a set of line contactors, governed by it. This apparatus protects automatically against careless operation on the part of the engineer while the fuse in the high tension compartment is final protection against short circuit.

The function of the contactors in Group 4, which are assembled along and actuated by a compressed air driven cam shaft, is to series parallel the traction motors in order to obtain two efficient continuous running speeds. The two handles which may be seen at the end of this switch in the foreground of Fig. 5 also provide for cutting out a pair of motors when one of them is damaged. With one pair of motors cut out the other pair of motors can be controlled either in single or multiple unit locomotive operation.

By removing the side covers of the control compartment, the switch groups can be made very accessible from the main aisles of the locomotive. The aisle down the center of the compartment between the groups provides for easy inspection in front. Fig. 6 is an end view of the contactor groups looking along this center aisle.

The circuit connections of the main power system supplying the traction motors are shown in Fig. 7. The relative location of

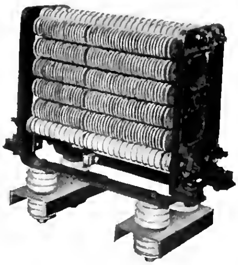


Fig. 4. Resistor Mounted on 3000-volt Insulators

the overload relay tripping coils, line contactors, rheostats, rheostat contactors, series parallel contactors, field shunts with their contactors and reverser, are indicated. This wiring diagram shows the complete progression, in schematic form, of the different circuits necessary to motor operation only. It may be noted that the motors of each half unit are connected in two series pairs. The master controller provides for operating these pairs in series through sixteen rheostat

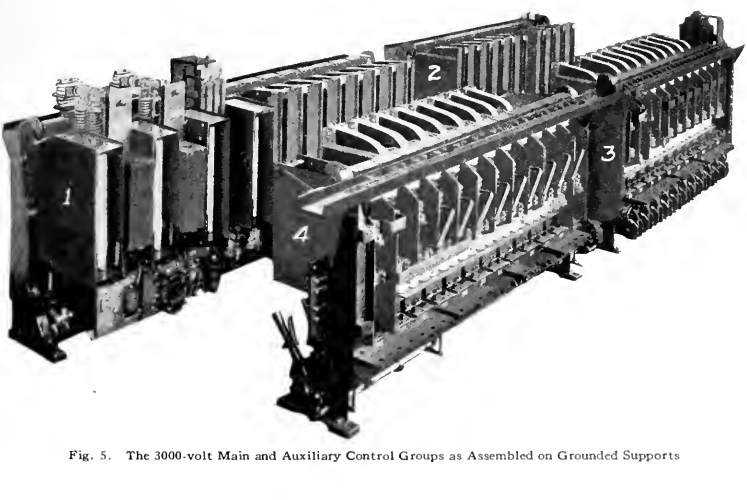


Fig. 5. The 3000-volt Main and Auxiliary Control Groups as Assembled on Grounded Supports

points, and a seventeenth full series running point; then through eleven rheostat points in parallel and a twelfth full parallel point. An additional parallel point with the fields of the traction motors shunted is provided on both the freight and passenger locomotives for efficient higher speed running.

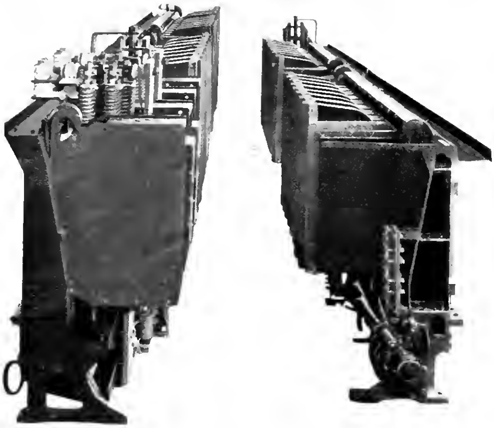


Fig. 6. End View of 3000-volt Equipment and Supports

Due to the large number of rheostatic steps provided to vary the voltage at the traction motor terminals during acceleration, and due to the extremely flexible drive between motors and drivers, the acceleration of a St. Paul locomotive is very smooth. Dynamometer car tests indicate that practically constant and continuous drawbar pull can be obtained. Experience in starting unusually heavy trains in the abnormally severe service of the past winter indicates that a very smooth acceleration is obtained at all times, permitting the locomotive to work close to the slipping point of the wheels, fulfilling completely the requirements of this severe Rocky Mountain service. Characteristic curves showing all the rheostat points of the freight and passenger locomotives, based on a constant potential of 3000 volts, are shown in Figs. 8 and 9 respectively. The curves made in dash lines show the transfer steps made while the series parallel switch passes from one position to another. This transfer can be effected without appreciable decrease in torque and any jerking of the train is absolutely eliminated by the method of transfer employed.

LOW VOLTAGE EQUIPMENT

Practically all the equipment not as yet described is more closely related with the master control circuits leading to the engineer's position and is therefore designed for low voltage—125 volts or less.

While the reverser switches the fields of the 3000-volt traction motors, it is necessary to insulate for low voltage only, since the fields are maintained on the grounded side of the armatures at all times. A view of the reverser is shown in Fig. 10. The same type air motor which drives the series parallel switch is used to operate the reverser. By means of a cam shaft and a set of powerful spring contacts driven from the former, through rocker arms as shown, a very positive wiping contact is obtained. The reverser is completely enclosed in a sheet iron box and is located outside, and adjacent to the high tension compartment of the high voltage control apparatus.

The shunts and similar apparatus associated with the motor fields are designed for low voltage.

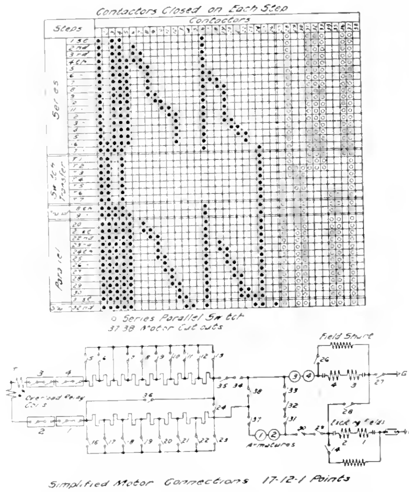


Fig. 7. Simplified Connections of Control with C-116 Controller, Motor Operation Only

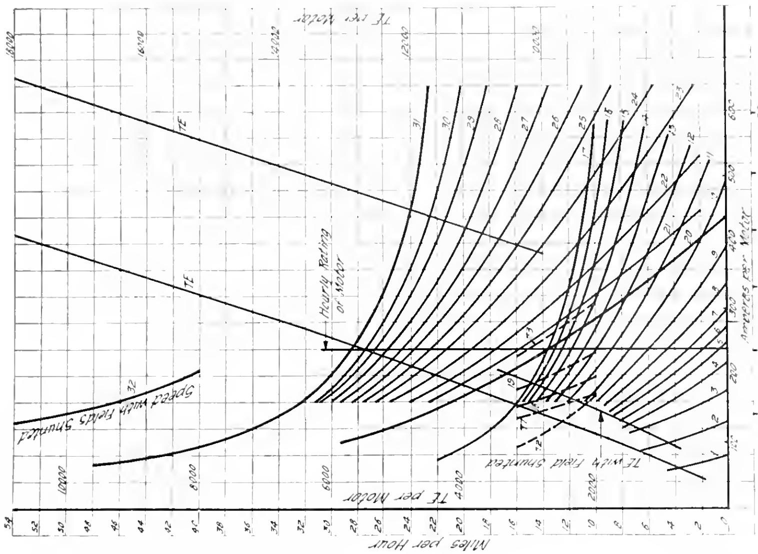


Fig. 9. Motor Operation in Passenger Service

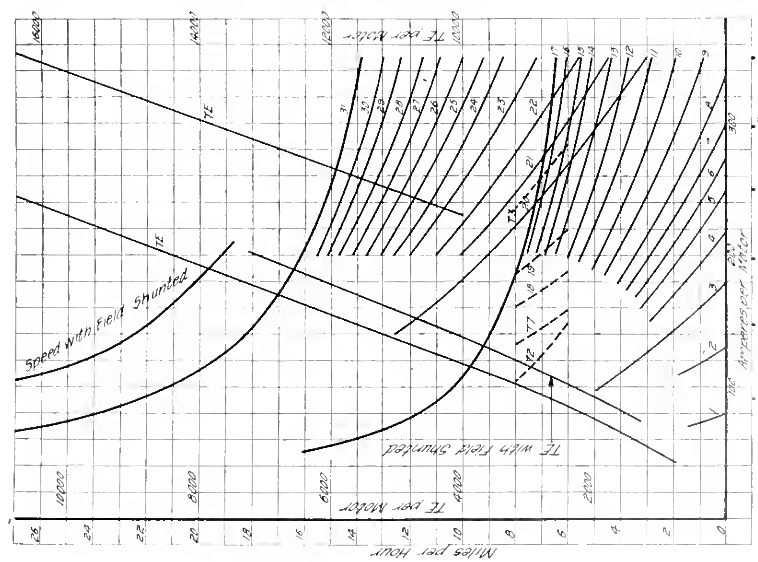


Fig. 8. Motor Operation in Freight Service

Typical Speed Tractive-Effort Curves at 3000 Volts Line for Each Point with C-116 Controller and 8 GE-253, 1500/3000-volt Motors

MOTOR GENERATOR SET

A motor generator set driven by a motor directly connected to the 3000-volt trolley supply is used for auxiliary purposes. Referring to Fig. 11, this set consists of a direct connected fan, the driving motor, an exciter

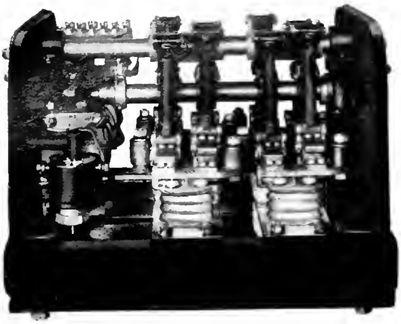


Fig. 10. Reverser

and a small 125-volt generator. The fan is used for ventilating the traction motors, thereby materially increasing their continuous capacity. The 3000-volt switching apparatus of the driving motor is located in the control compartment as already described. The exciter is used during electric braking, to super-excite the traction motor fields, and, while not thus employed in passenger service, to recharge the storage batteries required to light the trailing passenger coaches. The generator supplies power for the master control circuits, cablights, headlight and other low voltage auxiliaries.

REGENERATIVE ELECTRIC BRAKING

Regenerative electric braking is a feature of the control equipment on the St. Paul locomotives. This feature adds very materially to the safety of operation by supplying a second braking system in addition to the air brakes. It provides increased economy of operation by reducing wheel, track and brake shoe wear. It permits faster speeds down grades, due to the better ability of definitely controlling the locomotive which is difficult at best with the air brakes. It also adds materially to the comfort of the passengers, due to smoother operation down grades. All this is attained by very simple and reliable additions to the equipment required for motor running.

As the head-waters of the Missouri, falling down hill, turn waterwheels direct-connected to electric generators, thereby supplying electric power for hauling any St. Paul locomotive with its train up a grade, so do those locomotives which descend grades, by rolling down hill, revolve their motors in turn as generators and similarly deliver power to any other ascending locomotive. In this way a conservation of energy is effected in that a portion of the power required for raising the locomotives to the top of the divide is later returned in the descent.

With the simple direct current motor adopted for these locomotives, operation as motors or generators depends upon whether the voltage of the trolley system at the locomotive is above or below the voltage at the motor terminals. When the locomotive is motoring the voltage at the motor terminals is lower than the trolley potential and power flows into the locomotive. When the locomotive descends a grade, and is braking, the engineer, through his controlling means, effects an increase in the voltage across the motor terminals so that power flows from the locomotive into the transmission system. The generation of this returned energy reacts on the locomotive so as to cause retardation

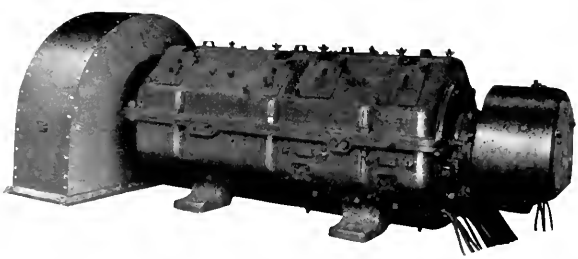


Fig. 11. Auxiliary Motor-generator Set

or braking besides effecting an economy by returning power to the line. The means for raising the voltage level of the motors, thereby returning power to the line in electric braking, rests in the use of the exciter before mentioned, so connected as to super-excite the traction motor fields when braking. Fig. 12 is a simplified diagram of these connections.

The series direct current motor has been found to be particularly well suited to traction service because of its inherent characteristic which automatically adjusts torque for change in grade. That is, to any particular speed and voltage there always corresponds one definite value of torque and current. With a decrease in speed there is an automatic increase in tractive effort, and with an increase in speed there is an attendant decrease in tractive effort.

With the connections as shown in Fig. 12, by properly proportioning the design of the

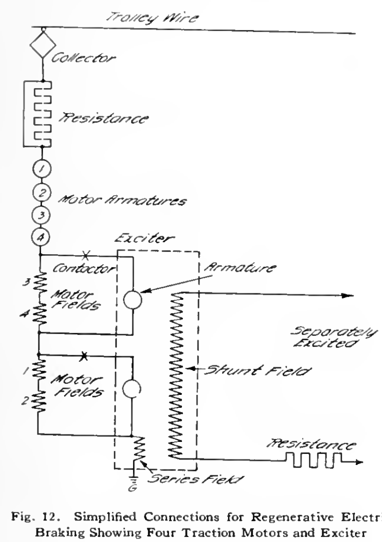


Fig. 12. Simplified Connections for Regenerative Electric Braking Showing Four Traction Motors and Exciter

exciter for its service in super-exciting the traction motor fields, the stable characteristic is inherent in the braking connection as in the motor connection. As the generator function is a reversal of the motor function, the traction motors in this case, provide in regeneration, that, with an increase in speed, there is an increase in braking effort and with a decrease in speed, there is a decrease in braking effort. The fact that a stable characteristic is closely maintained during regenerative braking, is one of the greatest contributing elements to the success of electric brak-

Fig. 13. Master Controllers Showing Operating Handles

ing in this service. This stable characteristic permits operation down grades at constant speeds with little regulating effort on the part of the engineer, except as changes in grade or curves occur, which require large variations in the intensity of the braking.

So far as the engineer is concerned there is nothing mysterious about the electric braking. In motor running he varies his tractive effort by changing the resistance in series with his traction motors thereby limiting the amount of power to be expended in his motors. In braking, he merely changes the resistance in the shunt field of his exciter thereby regulating the increment of voltage above the line and the power returned which reacts as his braking effort.

Fig. 13 shows the combined master controllers which the engineer uses for controlling his locomotive or locomotives if two or more are connected together. The large lower controller is necessary for motor operation. The small controller inverted upon the motor controller is used solely for the added regenerative braking feature. A combination of 3 handles, A, B and C is required. "A" is used to regulate the torque and speed, during motor running, through the rheostat points and the full running points with no external resistance in circuit and provides for changing the motor groupings between series and parallel; "B" is the braking handle which the engineer uses for varying the intensity of the retarding torque which may be accomplished with the motors running either in full series or full parallel; "C" is the handle for regulating the forward or backward movement of the locomotive and is called the reverse lever.

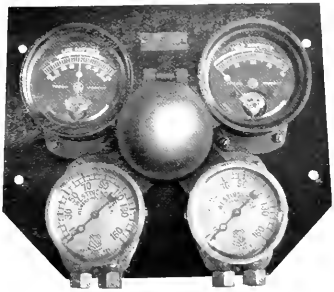


Fig. 14. Illuminated Gauge and Ammeter Panel which is Located in Front of the Engineer

Fig. 14 shows the illuminated ammeter and gauge panel which is located directly in front of the engineer to assist in operating both his electric and air brake systems. The pointer of the line ammeter, during motor operation, moves to the right as

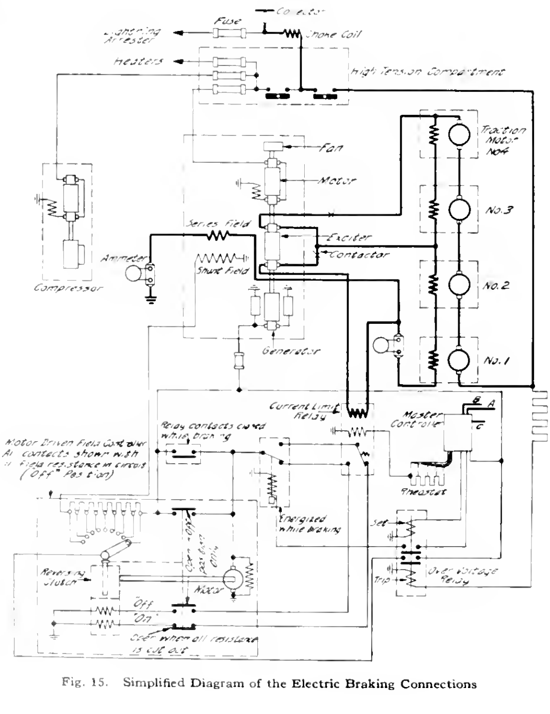


Fig. 15. Simplified Diagram of the Electric Braking Connections

indicated when showing the amount of current taken from the line. The engineer accelerates his locomotive by watching this ammeter. When the pointer of the ammeter moves to the left, the amount of current returned while braking is indicated. While braking, the engineer also watches his field ammeter which measures the current in the traction motor fields, at that time being super-excited. Red marks are located on the ammeter scales to show when the continuous capacity of the motor is being exceeded. Use of these meters provides, both in motor running and braking, for the most efficient operation of the locomotive.

Fig. 15 is a simplified diagram of the electric braking connections showing master controller, relays, field rheostat, exciter and the traction motors.

Fig. 16 shows the exciter field resistor with its controller. This device is regulated from the "B" or braking handle of the master controller. To assist in multiple unit operation, so the different sets of motors will properly divide their load, a current limit relay is used in the system of connections between the master controller and the exciter field controller to fix the setting of the latter.

In conclusion it may be said that, after ten months operation, including the severest winter season in a number of years, the electrical equipment on the St. Paul locomotives has satisfactorily fulfilled the requirements. Ease of operation is emphasized by the fact that the steam engineers could be given electric locomotives with but a few days instruction and that, from the first, electric locomotives were pooled with the steam so an engineer would not know, until called, whether he was to take out a steam or an electric locomotive. Reliability is evidenced by the fact that even, during the inauguration of this electrification, which took place in winter, heavy freight movements were maintained on the electrified zone of the St. Paul, while elsewhere in this mountainous region steam locomotives were tied up.

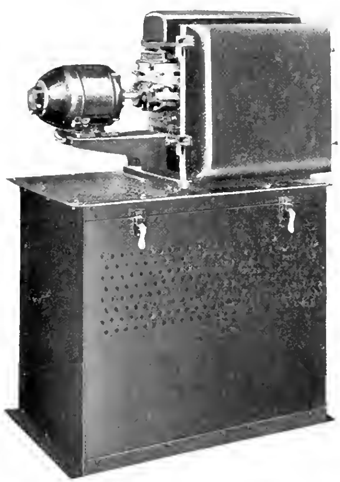


Fig. 16. Exciter Field Rheostat with Controller

THE AUXILIARY EQUIPMENT OF THE CHICAGO, MILWAUKEE AND ST. PAUL LOCOMOTIVES

By L. W. Webb

Railway Equipment Department, General Electric Company

The auxiliary equipment of locomotives of the nature of the Milwaukee units is considerable, and is of great importance. The present contribution describes the lightning arresters, the voltmeters, the watthour meters, the air compressor circuits, the motor-generator circuits, cab heaters, head lights and the train lighting apparatus.—Editor.

In addition to designing an electric locomotive so that it will exert drawbar pull, there are many other features which have to be taken into consideration; although these features are called auxiliaries many of them are really essential to the commercial operation of the locomotive.

By referring to Fig. 1, an idea may be obtained of the connections of the electrical apparatus which is auxiliary to the main circuits of the locomotive. As both halves of the locomotive are alike the diagram only shows the auxiliary equipment for one-half a locomotive. At times only half a locomotive is used on some of the local passenger trains.

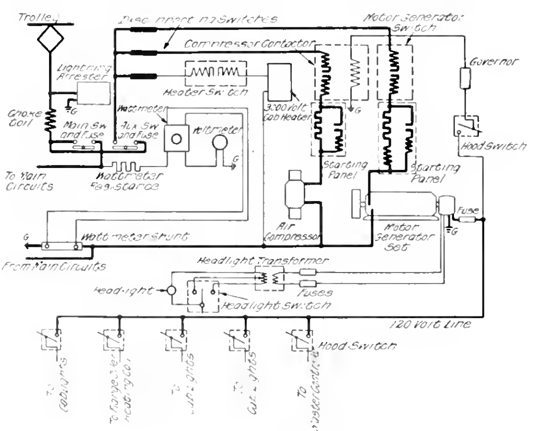


Fig. 1. Connections of Auxiliary Apparatus Chicago, Milwaukee & St. Paul Railway

Lightning Arrester

As an electric locomotive is connected to many miles of trolley wire and transmission line, lightning protection is a necessity. In order to give this protection, an aluminum cell lightning arrester is connected directly to the trolley. This arrester, shown in Fig. 2, consists of a sheet metal box containing twelve electrolytic aluminum cells, each with a balancing resistance across it. When the door is closed a 3000-volt expulsion fuse, held in clips on insulators on this door, makes contact with clips in the small fuse compartment. This fuse thus performs the double purpose of fuse and disconnecting switch.

Voltmeter and Watthour Meter

In order to keep a record of the power used by the different locomotives a railway mercury watthour meter is used. The special feature about this circuit is the extra high resistance which has to be used in series with the potential coil of the meter on account of the high voltage. This resistance, shown in Fig. 3, is similar to the ordinary meter resistance except that it contains more resistance tubes and is made in such a shape that it can be assembled on one of the regular equipment supports. In the low side of this potential circuit is connected a voltmeter with a five kilovolt scale for giving indications of trolley potential.

Air Compressor Circuits

The compressed air required for the pneumatically operated control apparatus and air brakes is supplied by a 3000-volt motor-operated compressor capable of delivering 150 cubic feet per minute at 135 lb. pressure. A 3000-volt double blowout contactor, shown in Fig. 4, is used for opening and closing the compressor circuit. As this contactor is only designed to handle 30 amperes a large number of turns can be used on the blowout coils. This insures a strong blowout which makes it possible to use only one break to open the circuit. The operating coil is supplied with current at 120 volts through a small hood switch and an ordinary governor. The governor then automatically starts and stops the compressor between certain given ranges of pressure.

There is required, of course, a starting set in order to keep down the current while the compressor is starting from rest. This set consists of a resistance and an automatic contactor which short circuits the resistance when the current has dropped to a predetermined value. The resistance is made up of spirally wound coils mounted on mica and porcelain insulation. These units are attached to one side of a narrow panel on the front of which is located, in a covered box, the automatic or series contactor. The contactor is so designed that a heavy current through its coil will hold it open and it will then only close when the current has fallen to a much lower value as the motor speeds up. The starting set, Fig. 5, is all supported by porcelain insulators and can be assembled on the regular equipment supports.

Motor-generator Circuits

The motor-generator set consists of a 3000-volt motor, a double commutator exciter for use during regenerative braking and for charging batteries on the cars for train lighting, and a 120-volt d-c. generator to furnish low voltage for the control. The blower for cooling the main motors is also connected to the shaft of this set. The motor-generator set is started and stopped by a 3000-volt manually operated contactor or switch. This switch, shown in Fig. 6, is the same as the 3000-volt compressor contactor in Fig. 4, except the operating mechanism. Instead of the electromagnetic coil there is supplied a handle and toggle joint for holding the switch closed. The handle extends through the sheet iron compartment and this eliminates all danger from live parts or flashes from arcs while operating. The same type of starting set is used for the motor-generator as for the compressor.

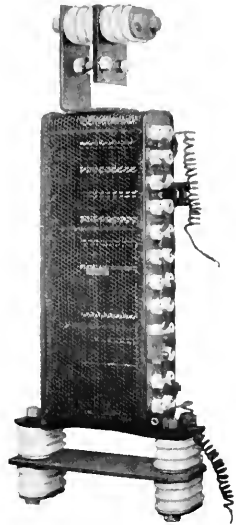


Fig. 3. Special Resistance for Use with Mercury Watthour Meter on 3000 Volts

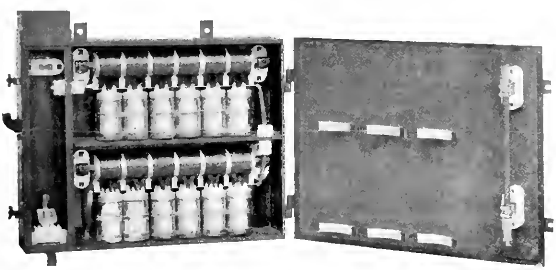


Fig. 2. 3000-volt Direct Current Aluminum Lightning Arrester for Locomotive Service with Series Expulsion Fuse Operating as Disconnecting Switch

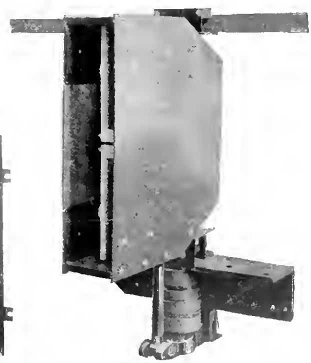


Fig. 4. 3000-volt Compressor Contactor

A feature which helped to simplify the installation of apparatus was the fact that this auxiliary apparatus, namely, the wattmeter

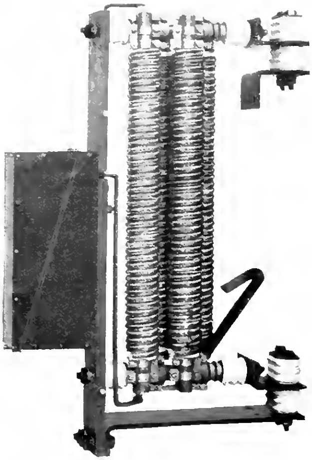


Fig. 5. Starting Set for 3000-volt Compressor and Motor Generator Set

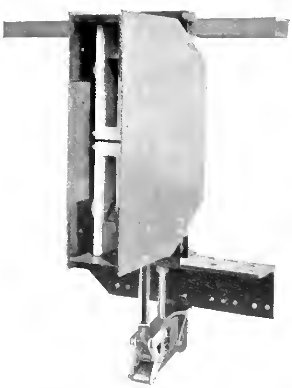


Fig. 6. 3000-volt Motor Generator Switch

resistance, compressor contactor, motor-generator switch and starting sets wer designed to go in the regular six inch spacing of the main contactors on the equipment supports.

Cab Heater

In the winter time the comfort of the engine-men has to be considered, especially in a region like the Rocky Mountains. In each operating cab there is installed a 3000-volt cab heater, Fig. 7. It is made up of ten resistance coils or units, nine of which are in series and the tenth is in parallel with the ninth and has the blower motor in series with it. The motor is connected in this manner so that if the motor circuit should become open circuited at any time there would not be 3000

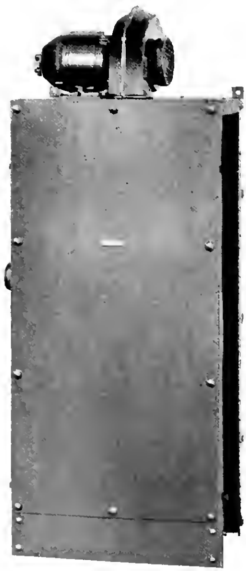


Fig. 7. 3000-volt Electric Cab Heater

volts on the motor. This scheme also allows the use of a low voltage motor in a high voltage circuit. The blower is located on the top of the heater and blows air from the cab down over the units and out at the bottom of the heater case where it is conveyed through ducts to points near the enginemen's feet. The units are designed to withstand the current even should the blower accidentally stop.

Headlight

In order to comply with the Montana law a headlight having 1500 unreflected candle-power had to be supplied. To produce this high candle-power a 750-watt, 34-volt concentrated filament lamp is used. The power for this lamp is taken from slip rings provided on the control generator for the purpose. The voltage at the slip rings is approximately 96 volts alternating current at anything from 40 to 70 cycles due to the variation in speed of the motor-generator set. From here the current goes through fuses to a small transformer, shown in Fig. 9, where it is stepped down to 34 volts. Fig. 8 shows how the number plates are put on the headlights at an angle so that the numbers can readily be read at the side or from a point directly ahead.

Train Lighting Apparatus

The train lighting system used on the Chicago, Milwaukee and St. Paul Railway is the head-end system with three train lines. One line carries the outgoing current from a generator and is called the generator line. The batteries along the train are connected between the generator line and a second line known as the battery line, while the lamps are connected between the generator line and a third line which is known as the lamp line. An adjustable resistance is provided in the locomotive so that the voltage between the generator line and lamp line may be held constant while the voltage between the generator line and battery line is being varied in order to maintain the desired amount of charging on the batteries.

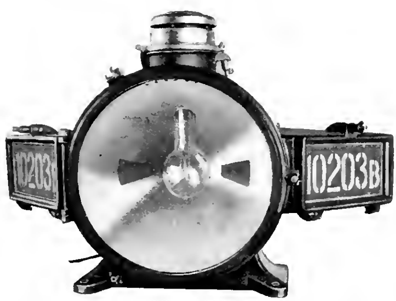


Fig. 8. Incandescent Headlight for Locomotive Service

When the trains are being operated by steam locomotives the power for lighting is furnished by a steam turbine driven generator installed in a baggage car at the front of the train and the voltage is controlled there. When in the electric zone, the train lines are coupled up to the locomotive and power for lighting is furnished from the two exciters ordinarily used for regenerative braking, but now connected in series to give the proper voltage.

Fig. 9. Small Transformer for Locomotive Headlight

An electro-pneumatic commutating switch is used to change over the connections from braking to train lighting. This switch is very similar to the main reverser but with different sequence of contacts. The connections are so arranged that the engineer always has control of this switch and is enabled to throw it from lighting connections to braking connections at any time unless he has opened the small snap switch which controls the commutating switch on the rear half. This commutating switch can never be thrown over to the lighting connections if it is being used by the engineer for braking. The snap switch is provided so that the rear half of the locomotive may be left with train lighting connections while the front half is braking. This is usually the procedure at night except while going through Butte on the 2400-volt section and also on the heavy grade. In the day time, however, the batteries are not on charge unless they are pretty low or there is a lamp load of 20 to 25 amperes.

The control of the battery charging in the locomotive is taken care of at a large panel, shown in Fig. 10. The two lines from the generator armatures, after passing through fuses, lead to this panel. Here the positive lead goes through an ammeter shunt to a knife blade switch and then to the generator line. The negative lead goes through an overload and reverse current circuit to a knife blade switch and thence to the battery line. The circuit breaker also has a shunt coil which will trip the breaker when relay "A," Fig. 11, is de-energized. This relay is energized only when the batteries are to be charged and when it drops out it short circuits a resistance and allows sufficient current through the shunt coil to trip it. In changing back from lighting connections to braking this takes place before the commutating switch throws and thus opens the generator circuit. Between the circuit breaker and battery switch a lead goes through an adjustable resistance, ammeter shunt and knife blade switch to the lamp line. As the voltage of the generator has to be held constant between 75 and 78 volts while charging, this resistance is used to reduce the voltage on the lamps to 62 to 66 volts.

Fig. 10. Battery Charging Panel

In making the change from steam to electric operation the lamps of the train are thrown directly on the batteries by closing the lamp switch at the panel in the baggage car. This insures having the train lighted during the change of engines.

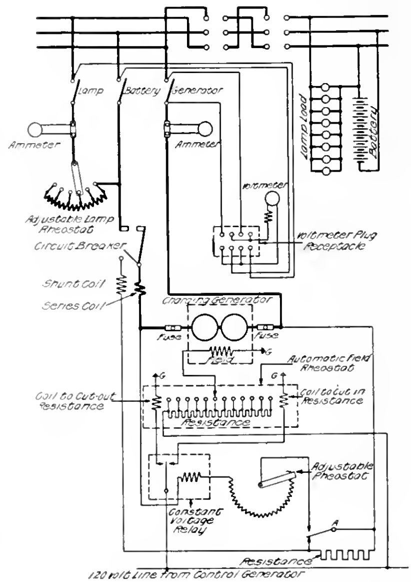


Fig. 11. Connections of Train Lighting Apparatus Chicago, Milwaukee & St. Paul Railway

The voltage is kept at any desired point by means of a constant voltage relay which energizes either the "cut in" or "cut out" coil of an automatic field rheostat in the generator field. The setting of this relay may be varied by means of an adjustable resistance in series with the coil.

This lighting apparatus is only used on the passenger locomotives and a few freight locomotives which are expected to be used at times in place of regular passenger locomotives.

THE OPERATION OF LOCOMOTIVES IN SERVICE ON THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By W. S. H. Hamilton

Railway Equipment Department, General Electric Company

The author writes an interesting account of the manner of operating the electric locomotives on the C., M. & St. P. Ry., going into considerable detail concerning the actual handling of the trains. The article is written in such a manner that it will be especially interesting to the operating man. The results of regeneration are stated briefly; and in a subsequent issue we hope to deal at greater length with this phase of the installation.—Editor.

Electrical operation between Deer Lodge and Three Forks on the Chicago, Milwaukee & St. Paul Railway was commenced early in December 1915 and the last steam engine was removed from regular service in July 1916. In the 9 months ending Sept. 1, 1916 there has been a gradual change from steam to electric power and a period of about a month and a half of complete electric operation of the entire Rocky Mountain Division.

The Rocky Mountain Division extends from Deer Lodge, Mont., to Harlowton, Mont., a distance of 226 miles. It is divided into two subdivisions, familiarily known as the West End and the East End. The West End extends from Deer Lodge to Three Forks and the East End from Three Forks to Harlowton. The shops are located at Deer Lodge and the division headquarters at Three Forks. From the latter point the dispatching of the trains is handled. Engine crews on both freight and passenger trains change there and train crews on freight trains only.

The profile and location of substations is shown in Fig. 1. The line is single track throughout, passing tracks being located at each station, the distance between them varying from 1.3 to 9.7 miles, the average being 5 miles. In addition to the heavy grades there are many sharp curves, particularily in the mountains, 10 degrees being the maximum. Automatic block signals are in use through the mountain sections now and are being installed over the entire division. There are several tunnels, of which Pipestone Pass Tunnel, 2580 ft, is the longest one. This is near Donald, the summit of the Rocky Mountains and the Continental Divide. As will be noted from the profile there are all kinds of grades both as to length and magnitude, so that the locomotives have been tried out under almost all conditions of service to be met with anywhere on main trunk lines.

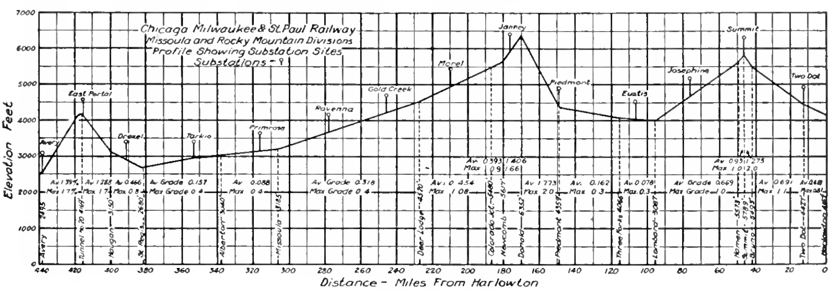


Fig. 1. Profile of Electric Zone

The climatic conditions that have been met are also severe. Last winter there were several weeks of weather when the thermometer was 20 deg. F. to 30 deg. F. below zero continuously, the coldest on the section then operating electrically being about 45 deg. F. below. There was also considerable wind but only about 2 feet of snow at any time, which however was of the extremely fine dry variety. This summer the weather has been very hot and dusty so that really

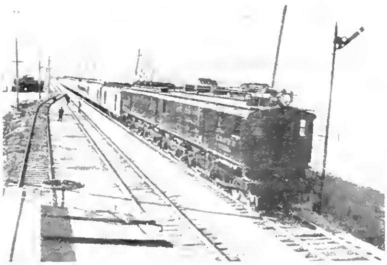


Fig. 2. Passenger Locomotive and Standard Through Passenger Train

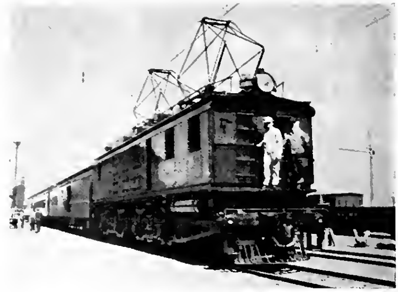


Fig. 3. Passenger Locomotive and Local Passenger Train

the only condition these locomotives have not faced has been a heavy fall of wet snow. From their performance in other respects there is every reason to expect that they will prove entirely successful in heavy snow.

The pictures, Figs. 2 to 7 inclusive, show some of the types of locomotives used on this division, both steam and electric. The steam locomotives used were practically all coal burning, coal being obtainable at several places near the division. The type of locomotive used for passenger service is shown in Figs. 5 and 6. Fig. 5 is an oil burner, these being occasionally used on passenger runs and identical in all other respects with the coal burners. The locomotives used for freight service were mostly heavy engines of the Mikado Type of Mallets (Fig. 7).

It is the intention of the writer to describe in detail how the electric locomotives are used to handle the trains and point out from this their superiority over the steam locomotives they have superseded, and, also, in a general way some of the results that have been attained in traffic handling. Inasmuch as freight traffic forms the greater percentage of the business and as in many respects more care is required in handling heavy freight than passenger trains this subject will be taken up first.

Freight Service

The freight traffic on this division consists mostly of loaded cars eastbound and about equal numbers of loads and empties west bound. The cars employed are of all kinds from different roads, of different capacities and with different air brake equipments so that the problem of handling the trains smoothly and quickly is exceedingly difficult, much greater care being required than on roads handling ore and coal trains of greater

Fig. 4. Freight Locomotive and Westbound Train at Donald

Fig. 5. Type of Passenger Locomotive Used During Steam Operation

total weight, but with cars almost entirely all steel and of nearly uniform size. The fundamental requirement which applies first, last and all the time is to properly control the slack action. Everybody is probably aware that the couplers in a freight car are not rigidly fastened to it but are connected through a friction or spring arrangement or both, which means that there is considerable stretch in them when transmitting a large drawbar pull. For practical purposes this may be taken as about 1 foot per car so that with a train of 80 cars, the locomotive would move about 80 feet before the caboose started. Little imagination is required to picture the shock to the rear cars if the locomotive is started suddenly, or especially if stopped suddenly after having the drawbar springs compressed (drawbars fully extended) while exerting the tractive effort necessary to pull the train. This condition requires that torque be developed by the locomotive very gradually while the train is first starting, which requires a large number of steps on the controller. These locomotives are excellent in that respect, the first step giving only about 17500 lb. tractive effort (61 lb. per ton of locomotive weight) and successive ones about the same increment.

Fig. 6. Double Heading Passenger Train out of Three Forks During 20 deg. F. Weather

Inasmuch as the air brakes play an important part in the handling of the trains, a very brief description of the locomotive equipment may be of value in helping to make clear what follows. This equipment is the Westinghouse No. 14 EL, being similar to the No. 6 ET equipments used extensively on steam locomotives. It has two interconnected operating valves, one controlling the brakes both on the train and the locomotive and the other controlling the locomotive brakes only. This latter is known as the independent brake valve and permits applying or releasing the locomotive brakes regardless of the train brakes.

The operation of these locomotives can best be appreciated by following in detail the movement of a freight train from Deer Lodge to Harlowton.

Trains of about 3000 to 3500 tons trailing are taken out of Deer Lodge eastbound by one locomotive. The trains are made up in the yard, and brakes, etc., inspected before the locomotive is coupled on. As soon as the locomotive has been coupled on, the brake pipe is charged from the locomotive and then the brakes are applied and released once, an inspection being made by the train crew to see that they apply and release properly on all cars. As soon as this has been done the locomotive is started. As shown above the starting must be very gradual at first and the controller is usually brought on and off the first notch two or three times until the slack has been taken out of the forward end of the train. It is then brought on notch by notch gradually so that the locomotive is kept moving very slowly until the distance covered equals the amount of slack in the train, after which the rate of acceleration may be increased as desired consistent with the wheel slipping point of the locomotive. The above should not be interpreted to mean that the first notch gives too much tractive effort, for it gives only enough to just start the locomotive itself; but if the controller should be left on the first notch from the beginning the

Fig. 7. Type of Mallet Locomotive Used for Freight Service

locomotive would accelerate enough so that the cars a short distance back in the train would be started with a bad shock. This may seem to be a fairly simple operation and so it is in ordinary weather, but the first starting of a train in −10 deg. F. weather and colder is not accomplished easily and usually requires two or three attempts and a thorough sanding of the tract, particularly if the train has been standing some time. The train friction under these conditions is exceedingly high due to the congealed oil on the journals and the locomotive must sometimes be moved back and forth in order to start the train. When finally started it requires a long time to accelerate to the series position of the controller, which demands ample rheostat capacity as well as carefully distributed steps, both of which these locomotives possess to a remarkable degree. During very cold weather the train is usually allowed to run two or three miles in series to let the journals on the cars warm up before accelerating to parallel position of controller. Of course it is necessary to reduce the tonnage of the trains handled in this extremely cold weather (−10 deg. F. and below) and the reduction varies from 10 to 25 per cent or even more under the most severe conditions. The friction drops off to a fairly reasonable value when the train has run a few miles, but if it is allowed to stand any length of time, the journals freeze up again and starting becomes just as difficult as at first. This difficulty is also increased due to the rail being frosty or covered with snow, thus making the locomotive slip its wheels easily.

After the locomotive has been accelerated to full parallel position it is allowed to run there until the current drops to about 150 amperes per motor when the controller can be brought to the last notch, which shunts the motor fields about 50 per cent and gives about 5 m.p.h. increase in speed. This can be done with train weights as high as 2800 tons by taking advantage of one or two nearly level stretches of track.

The first place which might be called a regular stop for freight trains is the Butte Freight Yard. This place is not shown on the profile but is between Colorado Junction and Newcomb and is near the beginning of the mountain grade. There are usually enough cars to be set out here so that the train is reduced to about 3000 tons or less. A second or helper locomotive is cut into the train at this point. The general practise under steam operation was to put the helper engine at the rear of the train and electric operation was started the same way, but after considerable experimenting it was found that the best place to locate the helper locomotive was at about the middle of the train so that each locomotive would handle approximately its own trailing tonnage. It was originally the intention to put the helper at the head end of the train when descending grades and operate both locomotives in multiple unit but it was found to be entirely practical to leave the helper in the middle of the train and regenerate with both locomotives.

After the helper has been cut in, the air brakes are applied and released once, each car being inspected to see that they are operating properly. When this has been done the train is ready to start. The start out of Butte Yard is easy because the grade is not heavy and there are two locomotives in the train, but as the method employed in starting with two locomotives is interesting it will be described as used when starting on the heavy grades between Newcomb and Piedmont.

When ready to start, the train brakes have been released, the train being held by the independent brakes on the two locomotives. The engineer on the leading locomotive "Whistles off" (two long whistles) and the engineer on the helper locomotive answers with the same if he is ready. As soon as the engineer on the leading locomotive hears the signal from the helper locomotive, the controller is brought on to the 1st or 2nd notch and the independent brakes on the locomotive released. This amount of power applied keeps the locomotive from starting back against the train. As soon as the brakes release the controller is brought on slowly until the train starts or as near the wheel slipping point as advisable to go. This stretches all the slack in the train as far back as the helper locomotive. The engineer on the helper locomotive usually watches the drawbar of the car forward of his locomotive closely and as soon as this stretches out, brings the controller to the 1st or 2nd notch and releases the independent brakes. As soon as they have released he brings the controller out slowly and carefully until either the train starts or he has reached as close to the wheel slipping point as desirable to go. When the train starts both engineers watch their ammeters and accelerate as close to the wheel slipping point as desirable until they have reached the full parallel position.

If however, the train does not start in what the engineer on the leading locomotive considers a reasonable time, he notches back the controller very slowly and allows the train to move back very gradually against the helper locomotive. This is a signal to the helper locomotive to be ready to start and as soon as the jolt of the train bunching up is felt, the leading engineer again attempts to start as before. In cases where several attempts are made to start, this "rolling back" operation is usually repeated with increasing severity so that there may be no doubt on the part of the helper locomotive engineer as to what is required. If the latter sees the train dropping back against him as shown by the drawbar of the car ahead he holds himself in readiness to assist in starting by pulling the controller on to the 1st or 2nd notch and as the slack is pulled out of the car ahead, brings it out further.

As noted before, trains are very hard to start in severe winter weather and this difficulty is greatly increased on a heavy grade. The locomotives if overloaded, frequently slip their wheels when starting and this necessitates beginning over again. It is under these conditions that carefully laid out rheostat steps and ample rheostat capacity are of the greatest advantage. With these locomotives it is possible to accelerate at the ordinary wheel slipping current and consume as much as 20 minutes in going from off to full series position without heating the rheostats to a dangerous temperature and no trouble has been experienced from this cause.

If the engineer on the leading locomotive desires to stop he notches his controller off very slowly, the train slowing down meantime. This is shown on the helper locomotive by the needles of the ammeters going higher on their scales. The helper locomotive engineer observes this and shuts off the controller slowly keeping the current at a slightly lower value than that obtained while running. This operation he continues until the train comes to rest when he sets the independent brakes and shuts off the controller. The engineer on the leading locomotive does likewise and sometimes sets the train brakes to assist in stopping. This process of stopping a train requires just as much or more care than starting and the control on the locomotives must be arranged so that the same rheostat steps are obtained in turning off the controller as in turning on.

All freight trains are required to stop at or near the summit of the Rockies (Donald on the profile) and make another test of the air brakes. This is made by making a light reduction in the brake pipe pressure at the locomotive and this shows on a gauge in the caboose. When noted, a further reduction is made by means of the conductors valve in the caboose which shows on the engineers gauge. This insures that the brake pipe is continuous throughout the train. At the same time a stationary test of the regeneration on the locomotives is also made.

At this time retainers are also put into service or as commonly expressed "turned up" on some of the cars. Inasmuch as there has been considerable misunderstanding relative to the use of retainers on these trains together with regenerative braking, a description of their purpose will be given to make this matter clear. All cars are equipped with these retainers but their use is confined to descending mountain grades. The retainer is simply a valve connected in the exhaust pipe from the brake cylinder of the car. A cutout cock also forms part of the retainer which with its handle down, "turned down," allows the air from the brake cylinder to exhaust freely to atmosphere whenever the brakes are released. With the valve handle turned upward 90 deg. or, "turned up," the air from the brake cylinder, when the brake pipe is recharged, passes through the retaining valve proper which allows it to exhaust to atmosphere until the pressure in the brake cylinder has dropped to 15 lb. The valve then closes and keeps this remaining pressure in the brake cylinder. This pressure of course decreases due to leaks in the cylinder and piping so that under ordinary condition of the equipment the air will have leaked off entirely in from 7 to 15 minutes after the retaining valve has closed. It will be seen from the above that this arrangement keeps the brakes applied to a certain extent for some time after the engineer has started to recharge the brake pipe. This prevents the train speeding up too much during the time required to recharge the brake pipe between successive applications of the brakes.

During steam operation when the descent was made entirely with the air brakes, retainers were "turned up" on every car in the train so that the brakes were continuously applied during the descent. When used in connection with the electric locomotives retainers are "turned up" on 50 per cent of the cars at the head end of the train if consisting of loaded cars and on 40 per cent if empties. They do not in any manner assist the regeneration in holding the train except for the first few minutes after an air brake application has been made. The only reason for using them is to assist in controlling the slack action of the train in case a stop has to be made during the descent. After a stop has been made and the brakes released the rear portion of the train runs down against the head portion and tends to force this down against the locomotive. These retainers, however, hold back this action and allow the train to roll down against the locomotive slowly as they gradually leak off. In one case that the writer is personally familiar with where retainers were not used the train ran down against the locomotive with sufficient force to move it ahead nearly 10 feet with its brakes applied. This was while descending the grade between Donald and Piedmont. On the lesser grade between Donald and Newcomb, this action is considerably less. On the grades either way from Summit, (now called Loweth), retainers are not used.

If the train was stopped before it reached the summit of the grade for the above tests, it is started up and as the leading locomotive passes over the summit and begins to descend, the controller which regulates the regenerative braking is brought on gradually, leaving the main controller in the full parallel position, and the locomotive begins to regenerate. This bunches the train slack gradually as car after car starts down the grade and when the engineer on the helper locomotive sees the slack crowd back against his locomotive he too brings on the braking controller. The helper locomotive is supposed to hold back only enough so that the leading locomotive can readily control the speed of the train during the descent. The speed down from Donald to Piedmont varies from 18 to 25 m.p.h. depending on the weight of train. There are several places where it is necessary to run at the lower speed and the trains are slowed down by means of the regenerative braking. The variable speed feature of these locomotives, while regenerating, is one of their greatest advantages and will be discussed more fully later.

Should it be necessary to stop while descending the grade the engineer on the leading locomotive applies the air brakes on the train, keeping the independent brakes released and gradually shuts off the braking controller as the speed decreases. When regeneration has ceased he shuts off the main controller (to prevent motoring) and applies the train brakes further for the desired stop. The locomotive brakes are allowed to come on after regeneration has ceased. About the same procedure is followed on the helper locomotive. After being stopped the train is held by the independent brakes on the leading locomotive only, the train brakes being released.

When starting out again from such a stop the engineer on the leading locomotive releases the independent brakes and starts the train moving gradually, sometimes using power to do this. Considerable care is required in doing this not to allow the locomotive to start too fast or there will be enough shock near the middle of the train to pull out a drawbar. This is another example of the action of the train slack. The train is allowed to speed up to about 19 m.p.h. when a light application of the train brakes is made, the main controller is notched out quickly to full parallel position and regeneration commenced by means of the braking controller. As soon as regeneration begins to take effect the train brakes are released. Brakes are kept off the locomotive during this procedure. This application of the train brakes is a signal to the engineer on the helper locomotive who also commences to regenerate.

The helper locomotive is usually taken with the train from Butte Yard to Piedmont. Occasionally it becomes necessary to cut off the helper at Donald (the summit of the grade) and the leading locomotive takes the train down alone. One locomotive can control about 2400 tons on this grade by regenerative braking and with heavier trains the train brakes are applied occasionally to assist in controlling the speed.

The helper locomotive is cut out at Piedmont and the train proceeds on with one locomotive, the run being down grade to Lombard. Usually one half the locomotive is shut down entirely on this stretch.

Crews are changed at Three Forks, this requiring from ten to thirty minutes, although sometimes the trains are held here longer depending on other train movements. Under steam operation a roundhouse was maintained here for the engines and a force was also kept to inspect the brake equipment on all cars passing through, this inspection requiring about 2 or 3 hours. This has been entirely discontinued with electric operation, the regenerative braking feature having eliminated the necessity for repairs to the brake equipment The force has been replaced by one electrician who examines and changes pantograph shoes when necessary and furnishes such supplies as the engineers may require.

No more significant fact could be cited of the results of electrification, particularly when coupled with regeneration, than is supplied by the sight of this empty and deserted roundhouse and a yard once busy enough to require the continuous services of a switch engine, now unused except for few cars handled by the way freight trains.

The trains taken east out of Three Forks are usually not over 2500 tons and are entirely handled by one locomotive. The grade from Lombard to Loweth is the longest one on the division but there are enough places where it lets up so that the locomotives can make use of the field shunting position of the controller and make good time. This field shunting feature adds greatly to the speed control of the locomotive without increasing the heating of the motors objectionably and saves a great deal of time on the lesser grades.

The descent from Loweth to Harlowton is made at considerably higher speed than that from Donald to Piedmont as soon as a very short grade just east of Loweth has been passed. The trains are run between 25 and 30 m.p.h. (this being the running speed limit of the freight locomotives). Usually one half the locomotive is shut down entirely, the other being sufficient to hold the trains by regeneration. In commencing regeneration it is not necessary to apply the train brakes first, as the slack action on these lesser grades does not require it. Also no retainers are used.

It is on these lesser grades that there is secured the greatest advantage of the variable speed form of regeneration used on these direct current motor locomotives. The speed may be controlled over nearly a two to one ratio (17 to 30 m.p.h.) efficiently and without interruption of the braking effort. Very material improvements in running time are thus made by adjusting the speed to the maximum permissible by grade curvature and train weight. This variable speed characteristic is inherent in direct-current motors without any additions to the equipment over that required for the minimum or full load speed.

The conditions and results so far described with regeneration have assumed the parallel connections of the traction motors, but it is also possible to regenerate with series connections over a range from about 9 to 17 m.p.h. This is occasionally used when one train is following another in the same block and it is desired to run slowly to let the first one get farther ahead or when track repairs are being made.

At Harlowton the trains are inspected before being taken on east. The locomotives are also looked over but nothing is done to them unless trouble has been experienced on the road.

The west bound trains from Harlowton are 2500 tons or less and are taken over the short heavy grade between Bruno and Loweth in two sections so that no helper is required. A helper locomotive is taken at Piedmont and very often shut down entirely while descending from Donald to Butte as one locomotive can easily handle 2500 to 2800 tons on this 1.66 per cent grade, particularly when the train friction is high due to many empty cars. Regeneration is usually used on one half of the locomotive only between Butte Yard and Deer Lodge this 0.6 per cent grade requiring but very little braking effort to control the train speed. Freight trains make 25 to 30 m.p.h. through this section, slowing down where necessary for curves, mostly by means of regeneration.

Passenger Service

The passenger train service on this division consists of two through and one local train each way each day. The cars used are all steel and are considerably heavier than the majority of steel passenger equipment. The standard through trains consist of nine cars weighing approximately 650 tons (see Fig. 2). One locomotive handles as many as 12 cars or approximately 875 tons eastbound over the entire division. Westbound, 10 cars or 725 tons are handled and with heavier trains a helper is used from Piedmont to Donald only. This has made a material reduction in the number of engine crews required, as during steam operation eastbound trains were double headed out of Deer Lodge over the entire division when consisting of 10 cars or over. This necessitated considerable double heading when westbound in order to return the locomotives to the proper terminals. All through steam trains had a helper from Butte to Donald eastbound and from Piedmont to Donald westbound. With this helper the speed up the 1.66 per cent grade between Newcomb and Donald was about 21 m.p.h. for a train of 8 cars and on the 2 per cent grade between Piedmont and Donald about 18 m.p.h. The electric locomotives make considerably faster time, the speeds being about 28 and 25 m.p.h. for the above sections and approximately the same speeds are made with heavier trains. The schedule running time between Deer Lodge and Harlowton is approximately 8 hrs. and has not been changed since the electric locomotives were put in service, but has been redistributed slightly to take advantage of the higher speeds now made up the grades and thus allow the trains to be handled at a more uniform speed. The electric locomotives are able to make up approximately 1½ hours over the scheduled time between Deer Lodge and Harlowton. This is of great advantage in maintaining good service as delays due to the physical conditions of the country passed through are common and unavoidable. This ability to make up time is due not only to faster speeds on grades but also to the elimination of stops for water and to take on and cut off helpers. Helper service over the short stretch of heavy grade near Loweth has also been eliminated as the electric locomotives are able to stand the overload occasioned by this short pull, lasting only 6 or 7 minutes.

In handling the trains considerable care is taken in starting to take the slack very gradually so that there will be no jolting of the train and in this respect the electric locomotives are much superior to steam. It is a noteworthy fact that there has never been a drawbar pulled by the electric passenger locomotives despite their much greater power, whereas this occasionally happened with steam engines especially when double heading. In commencing regeneration with the passenger locomotive it is not necessary to set the air brakes as in freight service, the train slack not being enough to require it. In descending either way from Donald it is customary to regenerate in series at about 20 to 25 m.p.h. most of the way on account of the curves. In all other places regeneration in parallel is used and the variable speed feature of these locomotives is especially noticeable and useful in passenger service. The speed range during parallel regeneration is from about 30 m.p.h. to 55 m.p.h. and this wide range has made it possible to use the electric brake for slowing on nearly all curves over the division in preference to using air brakes and has resulted not only in considerable power saving but in easier riding of the train.

The local passenger trains usually consist of 3 cars weighing approximately 210 tons. The locomotives used for these trains consist of one half of a standard passenger locomotive. See Fig. 3. These trains make a large number of flag stops in addition to 19 regular stops over the entire division. The running time is fast and this run was a hard one with steam engines, no helpers being used. The half locomotives used give good results and are able to make up considerable time due to their faster speeds on grades, the elimination of stops for water and their faster acceleration.

The passenger locomotives have proven very successful in operation particularly as regards riding characteristics. At speeds up to 65 m.p.h. the locomotives ride as smoothly as a coach, the rear end but slightly less so than the head end and there is absolutely no nosing on tangent track. The spring gears used on both freight and passenger locomotives practically eliminate the vibration usually noticeable with geared motors of large capacities.

The through passenger trains are all electric lighted, the head end system being used. On steam divisions this requires the running of a steam turbine and generator in the baggage car. On electric divisions the necessary power is supplied from the locomotive motor-generator set used for regenerative braking. The train batteries are charged while running on level track and on up grades, the lamps being fed from the batteries on such down grades as require both halves of the locomotive for regeneration. The system is a combined hand and automatic one and is taken care of by the fireman who also takes care of the oil fired boilers which are used to furnish steam for heating the train.

Mention has been made previously of the helper service which is used on the heavy grades between Newcomb and Piedmont and this is one place where the use of electric locomotives has had very noticeable results. Under steam operation, helpers from trains of all classes were run from Butte Yard to Donald and from Piedmont to Donald up the grades, sometimes descending the other side with the trains requiring four crews at Butte Yard and five crews at Piedmont. There was also a force at each place and sheds etc. to take care of the engines which were mostly of the Mallet or heavy Mikado types. The electric locomotives have eliminated the helper service for passenger trains except on very rare occasions out of Piedmont. Due to the fact that the electric locomotives do not require water, or fires cleaned, etc., it is possible to keep them in service more continuously and this has also permitted the elimination of the forces at both places for caring for locomotives. The locomotives are now taken care of by the enginemen in so far as oiling, etc., is concerned and after being in service as helpers for a week or ten days are exchanged with a road locomotive and sent into Deer Lodge for inspection. The number of helper crews has been reduced to 3, all being located in Piedmont, and only two electric locomotives are used in this service.

Helper service over this grade was eliminated entirely at one time by having the through trains reduce at Butte or Piedmont to the full tonnage for one locomotive, and increasing the train to full tonnage on the other side. A shuttle service was then operated between these points in order to handle the excess tonnage set out at these places. There were a number of advantages in this, such as the elimination of delays due to waiting for helpers, easier operation over the heavy grades due to less train weight and a lower peak load demand for power and higher load-factor. Only one locomotive was required for this service and two engine crews. However, the expense of the train crews and the objection to splitting up certain through freight trains led to its abandonment.

Instructions in operating the electric locomotives were given both by men riding on the locomotives and by a series of lectures and practical talks at one of the subdivision points by two traveling engineers of the division and three or four men from the General Electric Company factories. One of these latter was later taken off the road to give instruction at subdivision points as noted above. Two of the engineers were also on the road as instructors for about a month, at a time when the largest number of engineers and fireman were under instruction. All regular road instruction was discontinued about Sept. 1st, the steam engineers and firemen having picked up the operation of the electric locomotives very rapidly.

The power consumption of these locomotives including auxiliary apparatus is measured by a watthour meter in each half and is read by the fireman on leaving and arriving at each subdivision terminal and when regeneration is commenced and ended on descending grades. These readings are entered on a report which covers the performance of a locomotive for the day and is turned in daily. The meters are arranged to read backward while the locomotive is regenerating so that the meter always gives the net power consumed. While it is entirely beyond the scope of this article to go into a discussion of the power consumption, the following table may be of interest.

These percentages of power are made up from a number of different runs of through passenger trains with different engineers and different locomotives. It will be noted that the average for both directions is 14 per cent of the power used and does not include power saved in making slow downs etc.

There are a few points on other parts of the equipment not previously mentioned which the writer would like to bring out. The one probably of most interest is the pantograph. This is of the double pan sliding type, the pans being provided with copper strips to collect the current and to take the wear. Only one pantograph is used per locomotive, in ordinary weather this being able to collect the 800 to 1000 amperes required for one locomotive with absolutely no sparking and without overheating the frame. In cold frosty weather both pantographs are used in order to allow the head one to clear the frost, etc., off the wire. The pans are greased approximately every 100 miles at present, although in winter this distance has to be

TABLE SHOWING APPROXIMATE POWER SAVING ON THROUGH PASSENGER TRAINS DUE TO REGENERATION

Run	Direction	Power Used Between Stations in Per Cent	Power Regenerated on Heavy Grades in Per Cent of Power Used
Deer Lodge to Three Forks	East	100	25
Three Forks to Deer Lodge	West	100	7
Three Forks to Harlowton	East	100	11
Harlowton to Three Forks	West	100	9
Total	East	100	19
Total	West	100	8
Total	Both	100	14

decreased. A mixture of graphite and grease is used for this purpose. The wear on the strips became steadily less as fewer steam engines were used on the division and at present with no steam engines in regular service, they take as fine a polish as any commutator. Pantographs on freight locomotives are usually inspected at Three Forks, but the passenger locomotives are usually run through without inspection, changing from one pantograph to the other at Three Forks.

Next to the motive power equipment the air brake equipment is most important. Without going into this in detail the writer would like to point out one feature and that is that while the equipment of two 150 ft. compressors or a total of 300 ft. may seem excessive it is not too much for severe winter service on heavy grades. Under these conditions the hoses between cars freeze stiff and it is impossible to keep them tight or even approximately so. This not only makes work for the compressors but also renders the proper use of the air brakes very difficult. The compressors have direct connected 3000-volt motors and have proven very successful in operation.

In closing a few general statements or rather comparisons between electric operation and steam operation may be of interest.

The running time required over each section of the electric division has been reduced from 12–16 hours for steam operation to 7–10 hours for electric. With the elimination of inspection at Three Forks this means that the time over the entire electric division of 226 miles has been reduced to one half the total elapsed time of steam operation. Hence a very considerable increase in the capacity of the division to handle freight has been made.

A quite considerable amount of trouble and delay due to brake rigging failures, wheels and brake shoes overheating, etc., incidental to operation on heavy grades have been entirely eliminated since the introduction of the electric locomotives.

Drawbar troubles have not been entirely eliminated and it could hardly be expected that they would, as the drawbar pull of these locomotives when working at their wheel slipping point with sand will run as high as 120,000 lb. and this value is beyond the elastic limit and sometimes the ultimate strength of many of the older freight cars in service. The troubles however are now less than they would have been with steam locomotives handling the same total tonnage movements. As noted before there has never been any trouble with drawbars on electrically hauled passenger trains.

The view obtained of the track ahead is far better on the electric locomotives than on the steam engines and this should result in increased safety of operation. A fair view is obtained from the steam passenger locomotives used, but the view from the cab of a Mallet, especially in winter time, is poor to say the least and in tunnels is usually nil.

No other electric locomotives have ever been run under the variety of operating and climatic conditions as found on the Rocky Mountain Division and the success of ten months service leaves no room for doubt as to the superiority of electricity over steam.

REGENERATIVE ELECTRIC BRAKING

By J. J. Linebaugh

Railway and Traction Engineering Department, General Electric Company

After first noting some of the previous uses of regenerative control in railway work, the author passes on to show the difficulties which have been encountered in designing regenerative control apparatus for the standard direct-current series railway motor. The advent of the commutating pole motor has removed many of these difficulties. The operation of regenerative control on the 3000-volt direct-current locomotives of the Chicago, Milwaukee & St. Paul Railway is then dealt with. A table showing the amount of energy returned to the line for various train weights, grades and speeds is given and the article is concluded by a summary of the advantages derived by the use of regenerative control.—Editor.

The successful regeneration of power by electric locomotives when descending grades has been the dream of inventors and engineers ever since the initial trip of the first electric car at Richmond, Va. in 1887.

A great many different combinations of fields, armatures, motors and control have been proposed to accomplish this purpose, and several schemes have been tried out with such indifferent success that, until recently, very little has been heard of this method of operation. It has been the common opinion that a commercial system of regeneration of electric power could not be produced with the well-known standard direct-current series motor, owing to the series characteristics of these machines and the operating difficulties caused by the great and rapid fluctuations in trolley voltage.

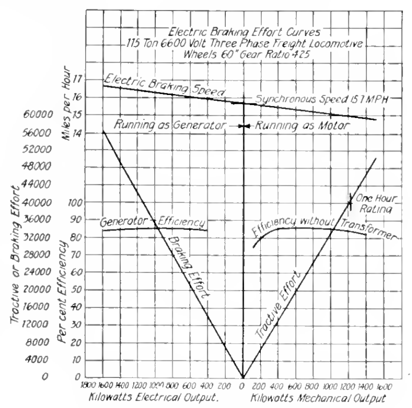


Fig. 1. Curves Showing Braking Effort and Speeds of Three-phase Locomotive

There have been several very successful installations of regenerative electric braking in connection with the three-phase or split-phase electrifications using induction motors on the locomotives, such as the Great Northern Railroad's three-phase installation at the Cascade Tunnel, the Italian State Railways in Italy, and more recently, the split-phase electrification of the Norfolk & Western Railroad at Bluefield, West Virginia.

The three-phase induction motor characteristics are such that it lends itself very readily to this method of control as it is only necessary to operate the motor slightly above the synchronous speed to cause it to work as a generator; but it has the serious inherent disadvantage that electric braking cannot be obtained at any other speed.

The Great Northern Railroad has used regenerative electric braking in connection with its 115-ton, three-phase locomotives through the Cascade Tunnel on a 1.7 per cent grade ever since this electrification was completed in 1909, with very gratifying results from an operating stand-point, as regards brake shoe wear, wheel troubles and ease of control, etc. Passenger and freight trains up to 2500 tons are taken through the tunnel safely and easily without the use of the air brakes and the railroad officials have been so greatly impressed with the desirability of this method of braking that they would not consider any other method of operation. *Fig. 1 shows the general characteristics of these locomotives when motoring and regenerating.

The Norfolk & Western Railroad also reports very satisfactory results with electric braking with their split-phase system; full descriptions of this electrification have been given in the technical press.

Very few attempts have been made to develop electric braking control for the commutator a-c. railway motor, such as is used on some of the first single-phase electrifications, so that electric braking is only used commercially at the present time with the direct-current and three-phase or split-phase systems.

* For a complete description of this electrification see paper before the A I E.E. by Dr. Cary T. Hutchinson, Vol. 28, 1909.

General interest was greatly revived in regenerative electric braking by the announcement that the officials of the Chicago, Milwaukee & St. Paul Railroad had adopted the 3000-volt direct-current system with the regenerative braking feature for their extensive electrification across the Rocky Mountains through Montana and Idaho, a distance of 440 miles. This decision was made after a careful study of the merits of the different systems, one of the requirements being that electric braking must be provided as part of the locomotive equipment. This interest increased as the electrification approached completion and the tests on the locomotive indicated that the equipment more than met the expectations of the designers. Operation in actual service for a period of ten months over the very irregular profile shown on page 957, on 226 miles of line has proved that the complete system is an unqualified success, electric braking with passenger and freight trains at all speeds being successful in every way.

This is the first time that electric braking has been used on large locomotives equipped with standard direct-current series motors operating over heavy mountain grades, and without doubt marks one of the greatest advances in steam railroad electrification work in the last few years.

At first glance it would not seem very difficult to devise a system of control, motor connections, etc., such that series wound direct-current motors could be made to act as generators; but until recently the additional cost and complication of motors and control were so great and operation so difficult and unreliable that regeneration had never come into commercial use, although a great many systems have been proposed. Most of the schemes suggested involved special motor with special combinations of shunt and series field windings and a complicated control equipment.

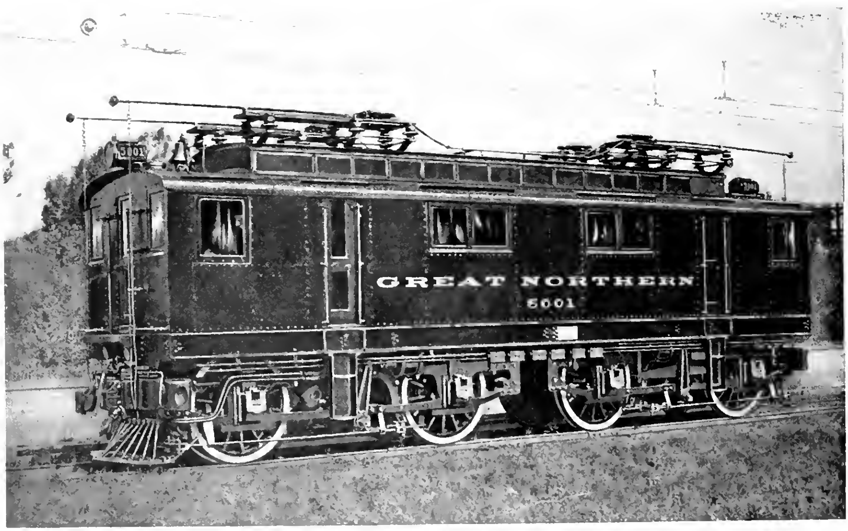


Fig. 2. Three-phase Locomotive Used for Electric Braking

One of the fundemental causes of failure was due to neglect to take into account the great and rapid changes in trolley voltage encountered in regular railroad work, with the result that the motors could not take care of the extreme overloads caused by a sudden decrease in trolley voltage. It is evident that if the motors acting as generators are generating a certain voltage and held at constant speed by the train, which cannot quickly change its speed, a rapid decrease in the trolley voltage, due to line drop caused by the acceleration of another train in the immediate vicinity, would cause a very bad overload and probably lead to the flashing over of the motors, if some means were not provided to take care of such a condition. The few early trials of electric braking were made before the advent of the commutating pole railway motor with its rugged construction and great overload commutating capacity. The commutating pole motor automatically becomes a very excellent generator and its use has contributed greatly to the very successful results obtained.

A scheme of regenerative electric braking control was developed a short time before the Chicago, Milwaukee & St. Paul Railway decided to go ahead with their electrification, such that a standard series direct-current commutating pole railway motor could be simply and easily caused to act as a generator when driven by the weight of the locomotive and train on down grades, without adding to the weight of the motor or changing its fields or connections.

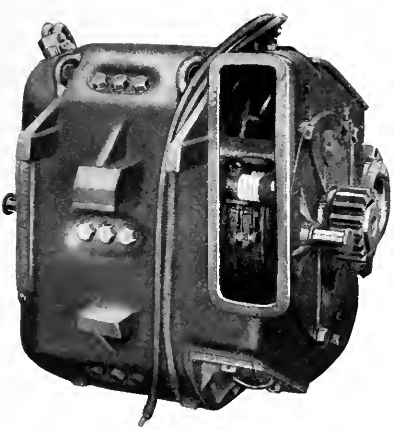


Fig. 4. 1500/3000-volt Series Direct-Current Railway Motor Which will Function as Motor, or as Generator for Electric Braking

The additional equipment for regeneration is very slight, consisting simply of a small generator, electric braking controller and a small amount of control apparatus to make the few connections required. The small generator is used to excite the motor fields and forms part of the motor-generator control set which furnishes power for operation of the control, headlights and blower. (Fig. 5). The control and manipulation of the locomotive is accomplished by a small braking controller similar to and placed immediately above, the main master controller used to control the locomotive. (Fig. 6). These controllers are suitably interlocked so that the possibility of the engineer making mistakes is entirely eliminated. The control is so designed that the motors can be connected in series or parallel, giving two high efficient running points, and the same flexibility is obtained when operating as generators for electric braking as when running as motors. The controllers are interlocked so that electric braking can only be applied when the motors are connected in series or parallel. This scheme of control with the great variation in voltage obtainable as generators gives a very wide range in possible operating speed.

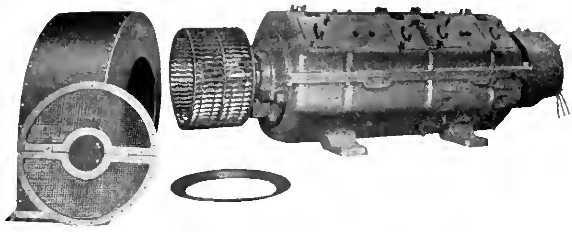


Fig. 5. Motor-generator Set Used to Supply Excitation for the Railway Motor Fields when Regenerating and Power for Control, Headlights, Blower, etc.

The sequence of operations of the controllers is so self evident in combination with the ammeters in the main locomotive and motor circuits, that the regular steam locomotive engineers have no difficulty in operating the locomotive without special training under all the severe conditions encountered in moving heavy trains over mountain grades.

The regular operation of the locomotive as a straight locomotive is not interferred with in any way, but electric braking is immediately available at any time either to slow down the train at curves or stops, or to hold the train on the heavy grades. If the speed of the train on any grade reaches a higher point than desired before braking is applied, electric braking can be applied very slightly and gradually brought up to the point required to slow down the train and hold it at the desired speed. This is a distinct advantage and is only possible with direct-current electric braking.

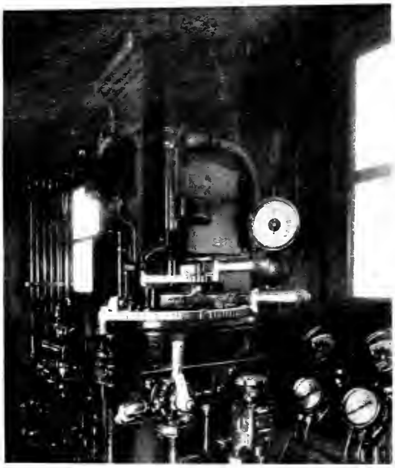


Fig. 6, Electric Braking Controller and Main Master Controller on Locomotive

The regeneration control is entirely automatic and the braking effort is held constant for any definite setting of the braking controller, being entirely independent of the change in trolley voltage, distance from substations or nearest locomotive, change in grades, etc. The wide latitude in braking speeds is shown in Fig. 7 and 8 which indicate very clearly the great flexibility of this type of braking. Trains can be taken down the grades at practically any speed desired by using the proper series or parallel connection of the motors.

It is evident that the motors acting as generators must generate a gradually increasing or decreasing voltage as the locomotive leaves or approaches a substation if the braking effort is held constant and the train is held at constant speed. The control takes care of this automatically, without attention, while giving practically constant speed braking. A locomotive or locomotives descending a grade with a train act exactly the same as a portable substation on wheels moving between the substations. but electrically and physically connected to the substation buses. The substation generators fix the voltage and the locomotive must generate this voltage plus the voltage drop due to current returning to the station busbars. If power is fed into another locomotive the generated voltage is dependent upon the drop in voltage due to load taken from the substations by the locomotives not regenerating. It is possible for one train descending the grade to take a lighter train up the other side of the mountain with all the power passing through the substation busbars, but without power being supplied from the substation. In this case the generating apparatus simply floats on the line and determines the trolley voltage.

A locomotive equipped with electric braking can take a heavier train down a grade than it can pull up the same grade, due to the fact that the friction of the train has to be overcome when ascending the grade but assists the locomotive in holding the train on the down grade. It has always been necessary to figure on a larger motor for braking than would ordinarily be used, due to the fact that it would be used continuously, but the internal ventilated type of motor used on high voltage d-c. locomotives has such a high continuous capacity that it can be operated continuously at the normal locomotive rating without over heating.

The advantages of electric braking are so many that it is difficult to pick out the most important; but as the saving in power is self evident it is usually the one given the first consideration, although there are other benefits, which in the end may prove of greater value.

The saving in power is undoubtedly one of the most important benefits obtained from electric braking and reaches a very appreciable figure, if the profile consists of many grades above one per cent. The amount of power returned depends upon the length and the steepness of the grade, and the weight of the train. If the grade is steep and short a large amount of energy would be returned for but a short time, so that the actual value of the returned power would not be very great. If the grade is a long one, power is returned for a much longer period, and may be an appreciable percentage of the total power required to operate the road.

Calculations and actual demonstration indicate that there will be a saving of at least

15 per cent of the total power demand with a profile as usually encountered in mountain divisions, if the power conditions are such that all the returned power can be utilized.

A train descending a two per cent grade will return nearly 60 per cent of the power required to haul it up the same grade besides the attendant advantages as regards operation, safety and decreased wear on wheels, brake shoes and track. The fact that a 2500-ton trailing train descending a two per cent grade at seventeen miles per hour will return 3000 kw. or 4000 h.p. to the trolley gives a good idea of the amount of power made available for the operation of other trains on the system which was absolutely thrown away in heating the brakeshoes and wheels with the old method of braking. If this grade is seventeen miles in length, 3000 kw-hr. would be available at the locomotive with a value of $21.60 at 0.8 cent per kilowatt hour, assuming 10 per cent loss in transmission to the nearest trains or substations.

It is interesting to note the amount of power which would be returned to the overhead conductor by freight and passenger

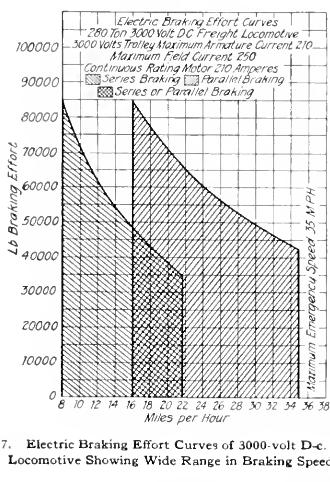


Fig. 7. Electric Braking Effort Curves of 3000-volt D-c. Freight Locomotive Showing Wide Range in Braking Speeds

trains usually moved over mountain divisions when descending different grades. The number of kilowatts and kilowatt-hours returned to trolley under certain conditions will be found in the following table The kilowatts regenerated on any grade are directly proportional to the speed and weight of train and the energy returned for any speed and train weight can be calculated from data in the table.

Weight Train Including Locomotive Tons	Grade Per Cent	Speed m.p.h.	Kilowatts Returned to Trolley	Power in Kilowatt hours if Grade is 20 miles long
1100	.7	40	600	300
1100	1.	35	930	530
1100	1.5	30	1360	900
1100	2.	30	1920	1280
3000	.7	25	1030	820
3000	1.	20	1450	1450
3000	1.5	20	2500	2500
3000	2.	17	3000	3500

Fig. 8 Electric Braking Effort Curves of 3000-volt D-c Passenger Locomotive Showing Wide Range in Braking Speeds

Electric braking has many advantages in addition to the saving of power, one of the most important being the great increase in ease and safety of operation in taking a long heavy freight or passenger train down a mountain grade. With regular air brake braking it is necessary to repeatedly recharge the auxiliaries; and all the braking is dependent upon the air pumps upon the locomotive. With electric braking but very little air is required, as it is only necessary to keep the train line charged while the locomotive does the braking. Under these conditions the air brakes on the cars are always in condition and the brake shoes and wheels are cool and not red hot or worn out, due to excessive use on a long grade, with the result that in case of emergency the air brakes are instantly available at maximum efficiency, giving a duplicate braking system.

Fig. 9. Freight Train Using Electric Braking Descending 2 per cent Grade on East Slope of Rocky Mountains. Chicago, Milwaukee & St. Paul Railway Electrification

With electric braking the entire train is bunched against the locomotives and the braking effort is absolutely uniform and constant as there is not the surging back and forth in speed encountered with air braking, which results in decreased wear and tear on brake equipment and greatly increases the comfort of passengers. There is also an entire absence of noise due to grinding of brake shoes and wheels, which is especially disagreeable on heavy passenger trains.

The operation of heavy trains on long steep grades has long been the dread of all railroad operators on account of trouble with brake rigging, hot and worn out brake shoes, broken wheels, trouble with air compressors, etc., which are entirely eliminated by electric braking. The saving in maintenance due to the elimination of these troubles can only be obtained by actual demonstration over a period of time, but it should amount to an appreciable item in addition to the increased safety to passengers and train crews.

It is a well established fact that track rails wear very fast on steep grades with standard air braking if the traffic is very heavy, and it has been proved that this wear is greatly reduced and is practically the same as on the up-grades if regenerative electric braking is used. The experience of the Italian State Railways in this respect indicates that this saving may be one of the most important advantages of this type of braking; but operation in this country has not yet been extensive enough to show the actual saving.

It is evident that if regeneration is used, all of the apparatus on the locomotives and in the substations, etc., must be capable of operating inverted. Not only must the motors on the locomotives act as generators, but the generating equipment in the sub-stations must invert, and if motor-generator sets are used, the direct-current generators must operate as motors and the synchronous motors as generators. They must be capable of doing this instantly and as often as required without affecting reliability or successful operation in any way.

All of the apparatus in the locomotives and substations for the Milwaukee electrification have been designed to meet these severe conditions and successful operation for over almost a year has demonstrated that they have more than met the requirements of actual service and the railroad company.

SUMMARY

The advantages of regenerative electric braking may be stated as follows:

Saving of approximately 15 per cent of total power required.

Elimination of brake shoe and wheel wear and brake rigging troubles with material reduction in maintenance charges.

Removal of difficulties encountered in operation of long heavy freight and passenger trains on long grades due to inherent operating characteristics of air brakes.

Reduction in wear of track on grades and severe curves.

Increased safety to passenger and train crews due to duplicate braking systems.

Increased comfort to passengers and reduced wear on equipment due to constant speed on grades and uniform braking when slowing down for curves and stops.

Elimination of grinding and noise of brake shoes and wheels on heavy grades.

SUBSTATIONS OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY ELECTRIFICATION

By A. Smith

Construction Engineering Department, General Electric Company

This contribution comprises a brief description of the St. Paul substations, dealing with the general arrangements of the building and apparatus and the principal features of construction. Special attention was paid to facilitating the handling of apparatus and the ease of operation in designing the layout.—Editor.

General Arrangements

The fourteen substations, distributed along the 440 miles of electrification, differ only in the number and capacity of units and high tension transmission lines. Substations serving heavy grades contain three 1500-kw. motor-generator sets with their corresponding three-phase stepdown transformers. The remaining stations contain two 2000-kw. units with transformers. One unit in each station is held as a spare, thus, the stations are really of 3000- and 2000-kw. capacity respectively.

Each substation building, as w ll be noted from representative views, Figs. 1, 2 and 3, consists of a short and comparatively low building, housing the motor-generators and low tension switching equipment, and a longer and higher building contiguous thereto for the high tension transformers and switching equipment. All of the a-c. and d-c. switchboard panels, the power limiting apparatus, signal and lighting transformers, the negative quick acting circuit breaker and the low tension running and starting switches for the synchronous motors are located in the main generator room. The 100,000-volt oil switches and the lightning arrester tanks, together with all high tension wiring, are located in the transformer room. The lightning arrester horn gaps are mounted on the roof of the high tension room, except in three stations, where, due to the heavy snow loads, the roofs were constructed in gable form, whence the arrester horn gaps were mounted inside the building.

Power is supplied from the Montana Power Company through four 100,000-volt transmission lines. Such substations as are provided with an incoming transmission line are equipped with two oil switches on the railway company's high tension tie line, which parallels the track and connects all of the substations together. Stations being served exclusively from this tie line are connected through horn gap air break switches located on the roof of the building. By referring to Fig. 4, which shows the general system of connections, it will be noted that the high tension bus practically forms a part of the high tension tie line and that but one lightning arrester is employed in each station. The motor-generator transformers are fed from these busses through oil switches of the

Fig. 1. Substation No. 4 at Eustis

K-21 type, while the 2300-volt secondaries on these transformers, together with the starting taps, are controlled from "running" and "starting" oil switches mounted in cells built into the dividing wall between the two rooms. The direct current conductors from the motor-generator sets are carried to the 3000-volt d-c. switchboard located at one end of the building from which point it is distributed through the feeders running east and west.

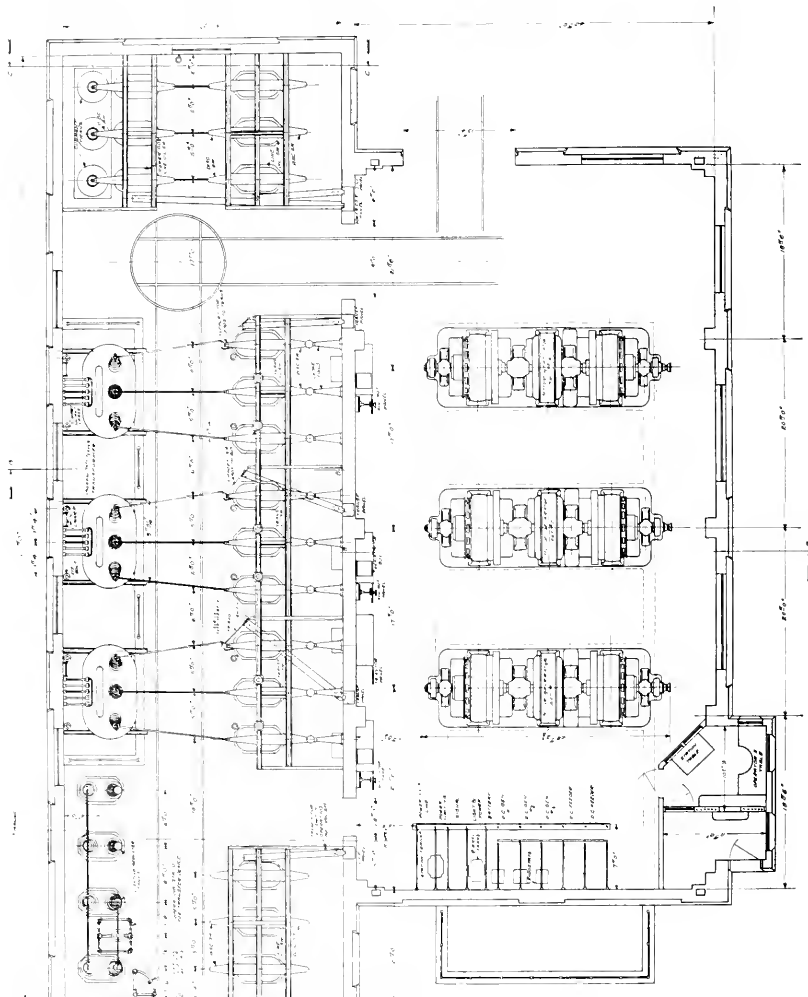


Fig. 2. Arrangement Plan of Piedmont and Janney Substations, 100,000-volt Alternating Current, 3000-volt Direct Current, 31,500-kw. Sets

A selector oil switch provides means for connecting the signal and lighting supply to the secondary of either of the two main transformers.

Building Construction

The buildings are constructed of a very good grade of brick resting on concrete bench wall. The flat roof construction with parapet wall was adopted as standard and employed in all cases except for stations in localities subject to extremely heavy snow-

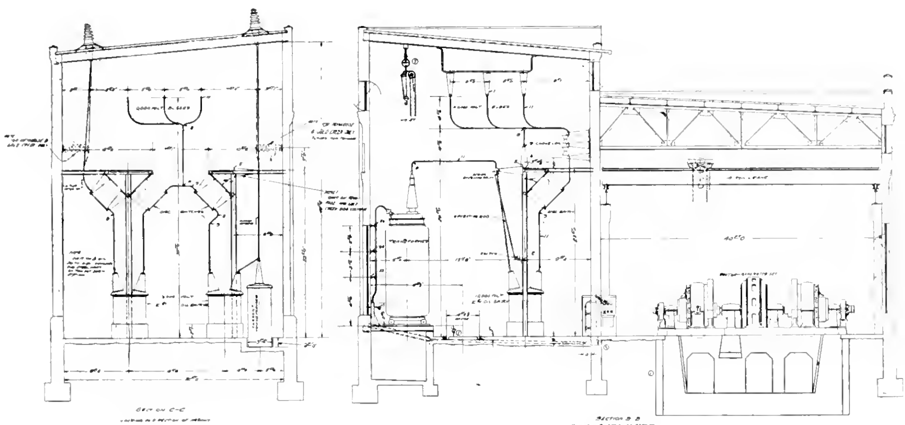


Fig. 3. Cross Sections. Two-dot Josephine, Piedmont and Morel Substation 100,000-volt Alternating Current, 3000-volt Direct Current

falls. For the latter it was considered advisable to resort to the gable roof construction. The roof of the transformer room is of plain "I" beam construction, but for the motor-generator room, which is considerably wider, the roof is supported on light steel trusses.

All windows are of steel sash construction and are of liberal dimensions and carefully placed to insure good general illumination. A number of pivotted sashes are placed in all of the windows at points near the floor and near the roof with a view to permitting unrestricted ventilation in all kinds of weather.

Ordinarily the air for cooling the motor-generator sets is taken from the outside of the building and discharged in an upward direction from the sets towards the upper ventilating windows. In the winter time it is necessary to retain this heat in the building, and the air supply is then taken from the interior of the motor-generator room so that with the upper ventilating windows closed this air may be recirculated. Inasmuch as some of these stations will be subjected to rather severe winds and low temperatures in winter, it is proposed to maintain only the ticket office or operator's room at a comfortable temperature.

The buildings are constructed without basements with the exception of a common pit under the motor-generator sets extending to the switchboard and a small pit under the main transformers. The pit under the sets acts as an air duct for the supply of air to the machines or for the location of separate blowers. It is also used to carry the direct current cables from the machines to the switchboard. The pit under the main transformers accommodates the necessary oil tanks for draining off the oil from any transformers in case of emergency, or for storing the oil while making repairs or for the storage of oil during the process of drying.

Convenience of Handling Apparatus

A spur track from the main line enters the motor-generator room of each substation. From this track apparatus can be unloaded from cars directly with a ten-ton hand-operated travelling crane. Another track, permanently built in the floor, together with

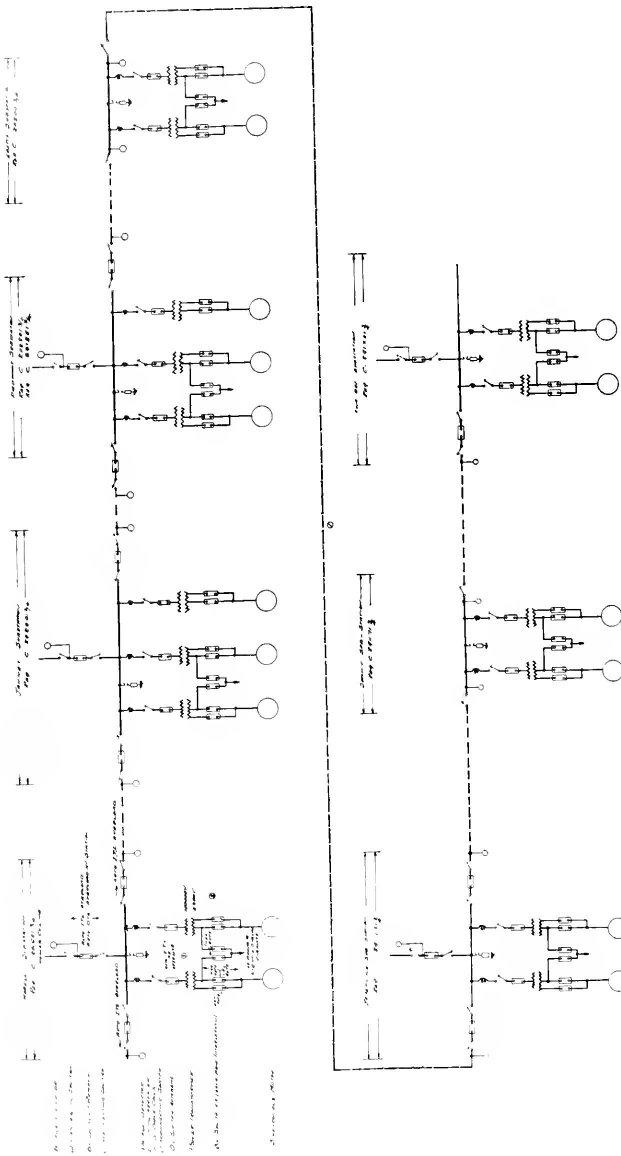


Fig. 4. System of Connections of Substations

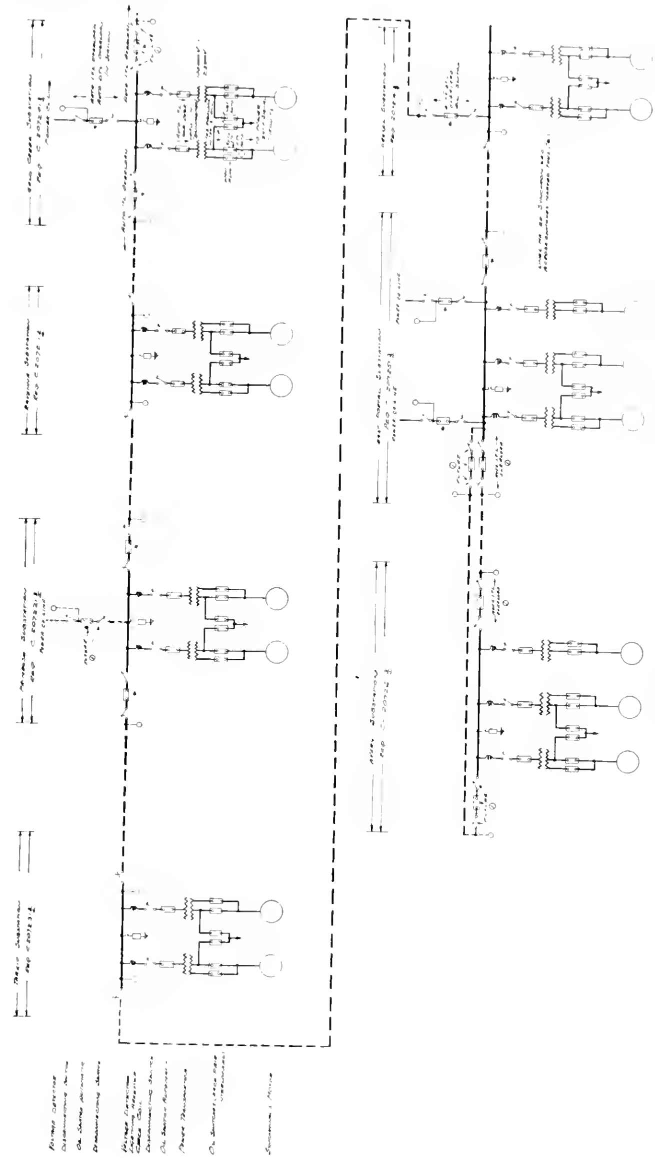


Fig. 4-a. System of Connections of Substations

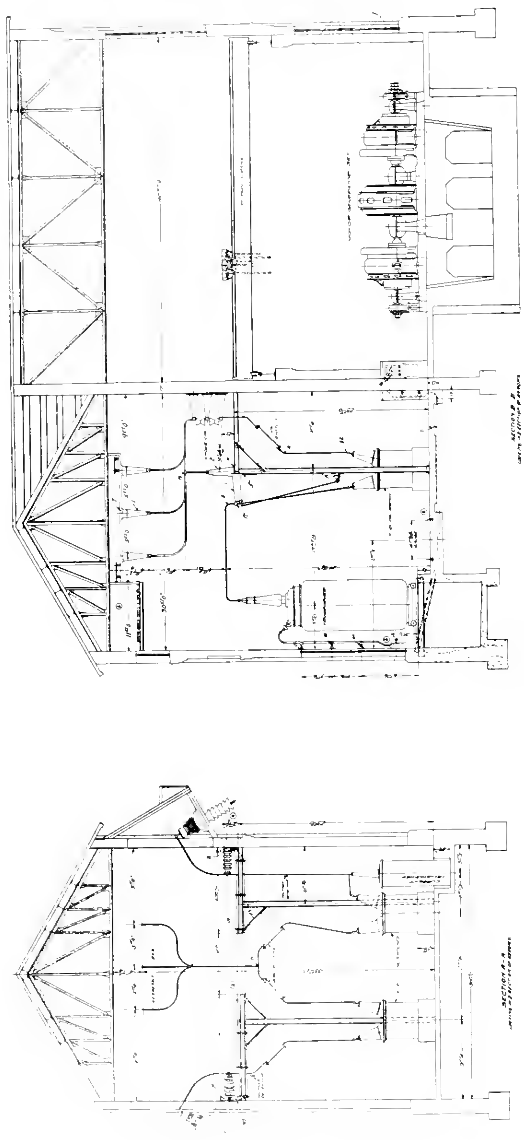


Fig. 5. East Portal Substation

a turn-table provides means of handling the transformers with a specially constructed four wheel truck.

A 5-ton chain hoist carried on an eye beam supported to the roof immediately above the transformers provides for the lifting out of any transformer core for inspection or repairs without transporting the case or removing the oil.

Wiring

Compound filled bushings are used exclusively for carrying the high tension conductors into the building. Stations constructed with flat roofs have the bushing built in the roof, but for stations employing gable roofs the same type of bushings were set in the side wall at an angle of 30 degrees from the vertical as shown in Fig. 5.

The 100,000-volt conductors inside the station consist of $\frac{3}{4}$ in. copper tubing with flush joints rigidly supported on post insulators. High tension wiring on the roof consists of solid copper wire supported on sectional rigid post insulators of the same kind as employed for the outside disconnecting switches.

As previously stated there is but one 100,000-volt lightning arrester per substation; but not withstanding the fact that the high tension bus and arrester tanks are inside the station while the horn-gaps are mounted on the roof the interconnecting wiring is extremely simple and free from sharp bends and inductive loops which would reduce the effectiveness of the protection they afford. The horn gaps are operated from the floor of the transformer room by means of a vertical mechanism extending down through the roof.

In Drexel, East Portal and Avery substations, which have gable roof construction, the horn-gaps have been mounted inside the building.

The 2300-volt conductors from the transformers to the motor-generator sets are non-leaded cable run in fiber conduit laid in the floor. The conduits are drained toward the pits so that water will not accumulate in them. The auxiliary 2300-volt circuits are controlled from oil switches mounted on the panels at one end of the d-c. switchboard.

The 3000-volt direct-current positive and negative cables are carried on insulators on the wall of the pit. The positive cables run directly to the generator panels while the negative cables, which are of equal lengths to insure more perfect equalization of load, are connected to a common point on the negative quick acting circuit breaker located near the ticket office.

A copper ground bus for the grounding of lightning arresters and the frames and cases of all apparatus (the motor-generators and switchboard frames are grounded for high voltage d-c. service) is carried around all sides of the transformer room and back of the main switchboard. This ground bus is connected to ten foot lengths of $1\frac{1}{4}$ in. iron pipe driven in the ground on 20 ft. centers along three sides of the station several feet outside of the building foundation.

The division of the grounds into a large number of small units facilitates the distribution of current from the ground conductor to the earth in case of a heavy lightning discharge and avoids placing absolute dependence on a single ground plate or conductor which may become disconnected by mechanical injury or corrosion. A direct path for a lightning discharge to ground is provided without passing it through apparatus ground connect'on or busses.

The signal feeders and 3000-volt positive feeders are carried on the wall at the back of the switchboard to one side of the building where they pass through the wall above the ticket office, Fig. 6. Aluminum cell lightning arresters enclosed in metal cases are provided for each positive generator conductor and feeder.

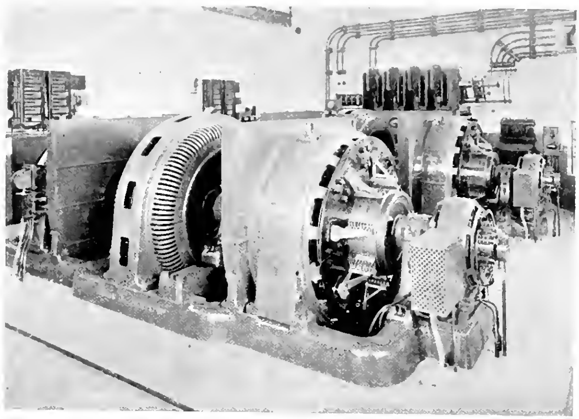


Fig. 6. Two 2000-kw., 3000-volt D-c., 2300-volt A-c. Synchronous Motor-generator Sets in Morel Substation

Operation

The small ticket office, which also serves as a waiting room, is located in the corner of the motor-generator room at the switchboard end. This room has an extended bay overlooking the track so that the operator not only has the switchboard and motor-generator sets under his direct observation but can likewise keep in touch with the train movements and perform other duties besides those pertinent only to substation operation.

The main operating aisle extends from the door of the ticket office past the main switchboard and thence between the motor-generators and the dividing wall. Along this dividing wall are located the low tension motor-generator control panels and the hand operating levers for the high tension oil switches in the transformer room.

The substations being situated in sparsely settled districts bungalows have been constructed near each station for the housing of the operators. These buildings are shown in Fig. 1.

DESCRIPTION OF THE 1500- AND 2000-KW., 3000-VOLT D-C. MOTOR-GENERATOR SETS OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

By F. C. Helms

Alternating Current Engineering Department, General Electric Company

By C. M. Fulk

Direct Current Engineering Department, General Electric Company

The motor-generator sets described in this article have many interesting features. Considerable space is devoted to the operating characteristics, and the ventilating scheme for the d-c. units is fully described. Regenerative braking on the locomotives has called for features in these units which are unique.—Editor.

The electric locomotives which haul the trains over the mountain divisions of the Chicago, Milwaukee & St. Paul Railway are designed to operate from direct current at 3000 volts. The transmission system of The Montana Power Co., from which power is purchased, and the transmission lines of the railway company are operated at 100,000 volts a-c. In the railway substations transformers and motor-generator sets are employed to change from 100,000 volts a-c. to 3000 volts d-c. power. The transformers reduce the voltage from 100,000 to 2300 volts. The synchronous motor-generator sets which transform the 2300-volt, three-phase, 60-cycle alternating-current power to 3000-volt direct-current power have several features of operation and design which distinguish them from any sets previously used. The distinguishing features are as follows:

1. Heavy overloads for direct operation and for reversed operation during regenerative braking.
2. Compounding of the motor exciters so as to furnish the most advantageous excitation required by the wide variations in the load.
3. 3000-volt d-c. operation.
4. Ventilation of the d-c. generators.

There are two sizes of sets used: nine 1500-kw. 600-r.p.m. and twenty-three 2000-kw. 514-r.p.m., or a total of 59,500 kw. distributed in fourteen substations along the 440 miles of main line through the picturesque mountainous section, extending from Harlowton, Montana, on the east to Avery, Idaho, on the west. The substations are distributed along the route at average intervals of about 32 miles, and the motor-generator sets are distributed as follows: ten substations each containing two 2000-kw. sets; three substations three 1500-kw. sets; and one substation three 2000-kw. sets. One set is a reserve in each station. Fig. 1 shows a 2000-kw. set with direct connected fans on the generators, while Fig. 2 shows the same set equipped with a separate blower for ventilating the generators. The 1500-kw. sets are practically the same except for size and speed. They may be described as three unit, four

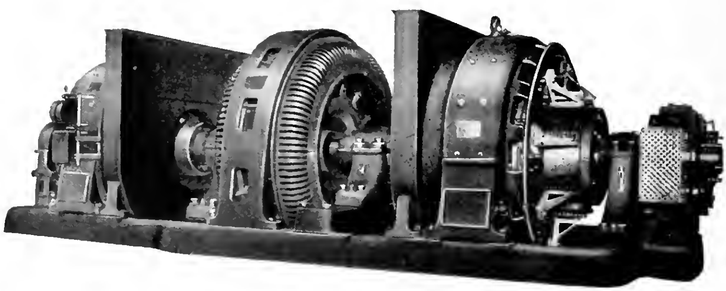


Fig. 1. 2000-kw. Motor-generator Set, with Direct Connected Fans

bearing sets with two direct connected exciters, one of which furnishes excitation for the two generators, and the other for the motor. The rotor shaft of the motor is directly supported by two bearings. This shaft extends through these bearings and carries a half coupling at each end for coupling to the shafts of two duplicate d-c. generators. Each generator shaft is supported by an outboard bearing, and is provided with an extension beyond the bearing which carries an exciter armature. Great care was taken in designing the couplings, shafts, etc., to successfully stand the mechanical strains imposed by heavy overloads and short circuits on the machines.

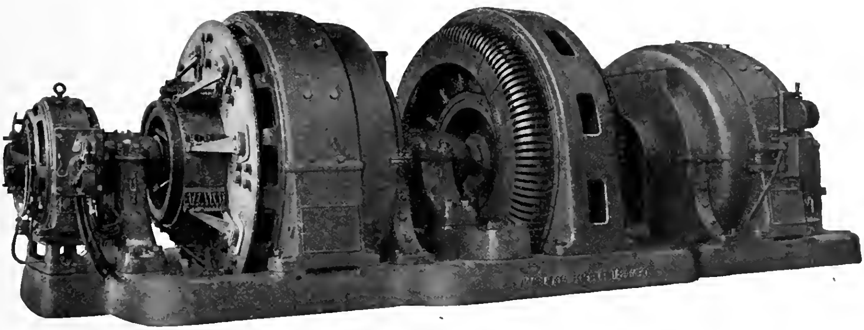


Fig. 2. 2000-kw. Motor-generator Set Ventilating Air is Provided by a Separate Blower

Capacity

The sets are designed for either direct or reversed operation, the capacity being expressed in terms of direct-current output for direct operation, and direct-current input for reversed operation. They are capable of carrying their rated load continuously with a maximum temperature rise in any part not to exceed 35 deg. C.; 150 per cent load for 2 hours with a temperature rise not to exceed 60 deg. C.; and 300 per cent load (with 85 per cent normal voltage at the motor terminals for direct operation) for five minutes without injury. The following data will be of interest, and will aid in comparing the capacity of these sets as expressed in kilowatts, with the capacity expressed in terms of train service.

The 1500-kw. set weighs about 50 tons and occupies a floor space of approximately 200 sq. ft. Consider a 2500-ton freight train consisting of, say, 50 loaded cars. It takes a drawbar pull of approximately 15,000 pounds to haul such a train on level track free from curves. The locomotive will develop this tractive effort and move the train at a speed of 24 miles per hour taking about 1000 kw. electrical energy from the trolley and the generator of the motor-generator set. If now a 2 per cent grade (a rise of 2 feet per 100 feet of track) is encountered, the drawbar pull will be increased to 115,000 lb., which at a speed of 14 m.p.h. would require 4100 kw. from the motor-generator set or 274 per cent load. When the top of the hill is reached the train will coast down on the other side. If the grade has a 2 per cent slope, the train will exert a push or tractive effort of approximately 85,000 pounds on the locomotive. If now the fields of the series motors on the locomotive are energized by current from the small "control motor-generator set" in obedience to the regenerative control, the motors will act as generators returning 2600 kw. electrical energy to the trolley. The train will run at approximately 16 m.p.h. under these conditions. If there are no other trains in the section, this energy will be delivered through the motor-generator set back into the alternating-current system to be used elsewhere.

Heavy Overloads and Compounding of Motor Exciters

To perform their duty in a manner similar to that described above the motor-generator sets are required to operate at loads, under certain conditions, varying from 300 per cent load for direct operation down to zero and up to 300 per cent load in the opposite direction during regenerative braking. Other sets have been built in which the load varied from zero up to 300 per cent for direct operation only, the *excitation* of the synchronous motors being controlled dif-

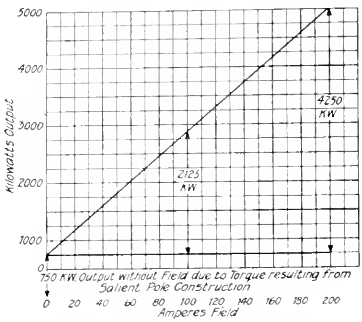


Fig. 3. Breakdown Tests. Synchronous Motor ATI-12-1900-600-2300 Volts. Line Voltage Held Constant at 2300 Volts. Amperes Field Varied from 0 to 200

ferently in various installations. In some cases it has been set at a fixed value, which naturally must be great enough to take care of the maximum overload. This results in a wide range of power-factor for the different loads and low efficiency at the light loads. In others it has been varied by a regulator designed for voltage or power-factor control. In still other cases, as in the present one, it has been varied by a compound wound exciter the series fields of which were excited by the line current of the generator of the set. The importance of compounding the exciter, so as to obtain excitation for the synchronous motor, which increases or decreases with the load, is apparent when it is noted that the torque, and hence the maximum capacity, of a synchronous motor, for different values of line voltage and field excitation, can be considered to vary (within the limits of commercial accuracy) directly as the voltage and excitation, or as the product of the two.

Fig. 3 shows the relation of the maximum capacity to the field excitation, when the line voltage is held constant. This curve was taken for one of the 1500-kw. sets. It should be noted that the motor carries nearly 50 per cent load without field, when running at synchronous speed, due to the salient pole construction. From the illustration it is noted that the maximum output, after deducting the output without field, varies directly as the field current.

In Fig. 4 there are presented three curves *A*, *B* and *C* showing the variation of maximum output with changes in line voltage. Curve *A* gives the results of a test without field.

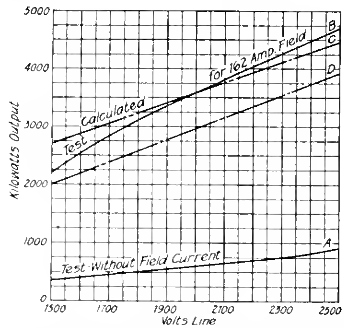


Fig. 4. Breakdown Tests. Synchronous Motor ATI-12-1900-600-2300 Volts. Field Current Held Constant at 0 and 162 Amps. Line Voltage Varied from 1500 to 2500

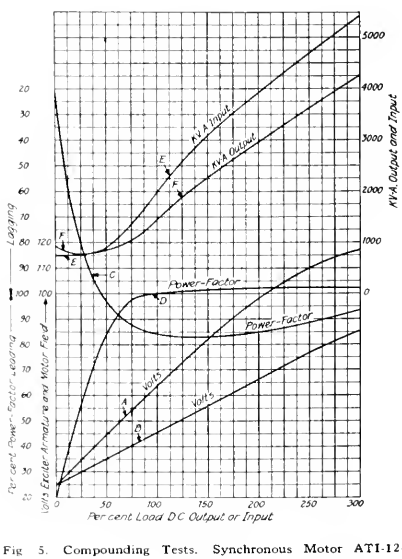


Fig. 5. Compounding Tests. Synchronous Motor ATI-12-1900-600-2300 Volts. Exciter-EC8-6-18-600-25 125 Volts

A few calculations will show that the maximum output varies as the square of the voltage. Curve *B* gives the results of a test with 162 amperes field, while Curve *C* shows the calculated values of maximum output for the same field current. These calculations are based on the assumption that the maximum capacity varies directly as the voltage. Curve *D* is obtained by subtracting the values of curve *A* from Curve *B*, and is approximately a straight line parallel to Curve *C*.

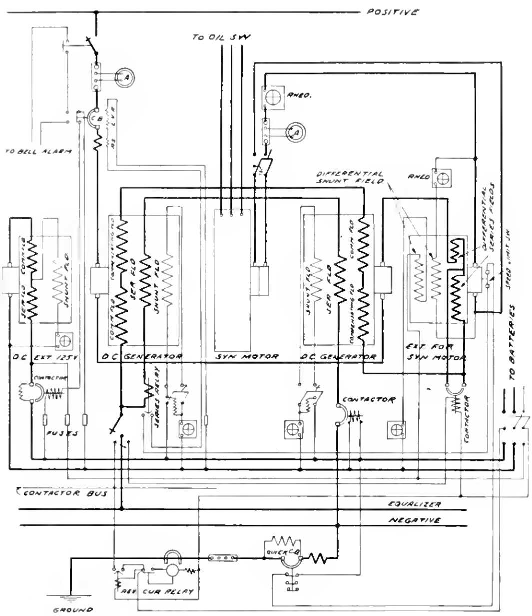


Fig. 6. Diagram of Connections of Motor-generator Sets

In the present installation it was desired to get the highest possible all day efficiency for the variable railway load and also to maintain as near constant voltage on the power company's transmission system as practicable which made it desirable to obtain 1.0 power-factor at about 50 per cent load direct operation. For loads from 50 to 300 per cent it was desired to obtain leading current input. It was also desired to have the motor capable of carrying 300 per cent load with a 15 per cent drop in line voltage. For reversed operation during regenerative braking, it was desired to have the synchronous motor act as a generator returning power to the alternating-current system at approximately 1.0 power-factor. To accomplish these results, it was necessary that the motor exciter of the 1500-kw. set should give 41 volts at 50 per cent load for both direct and reversed operation, 120 volts for 300 per cent load direct operation, and 80 volts for 300 per cent load reversed operation. Fig. 5 gives results of compounding tests at the factory. *A*, *C* and *E* show the voltage, power-factor, and kv-a. input, respectively, for direct operation, and Curves *B*, *D* and *F* for reversed operation.

The exciter is equipped with two shunt and two series fields (see Fig. 6) that give great flexibility in adjustments, which are necessary to meet the requirements of the service. The main shunt field is separately excited from the generator exciter. The second shunt field is self-excited and connected differentially with respect to the main shunt field. The main series field is excited by the line current from the generators and is accumulative (for direct operation) with respect to the main shunt field. This field is short circuited by a contactor operated by a reverse current relay during reversed operation. The auxiliary series field is excited by current from the generators and is differential with respect to the main shunt field for direct operation and accumulative for reversed operation. Both of the series fields are provided with adjustable shunts and are connected in series.

3000-volt D-c. Operation

The direct current voltage of 3000 employed in this installation is the highest ever applied to any extensive railway electrification and is obtained from two duplicate 1500-volt generators operated permanently in series and driven by one motor.

The use of two 1500-volt generators permits practically double the speed of a single 3000-volt generator, resulting in a smaller motor, lower cost, less floor space and smaller weight.

The armatures of all machines of a given size are exact duplicates and interchangeable.

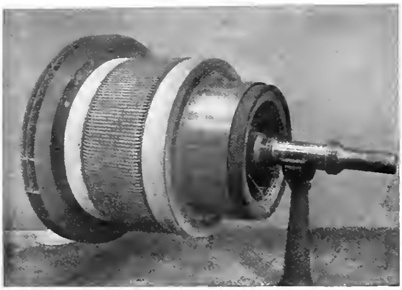


Fig. 7. Generator Armature of Set Shown in Fig. 1 Showing Double Section of Fan

The advantages obtained from interchangeability and standardized manufacture more than offset the slight economy gained by building one machine insulated for 1500 volts and the other for 3000 volts.

The generators are of the multipolar type, separately excited from a small direct connected exciter, and are equipped with compensating, commutating and compound windings operating in series with the armatures.

From the diagram of connections, Fig. 6, it will be noted that all the series fields of both machines are connected on the ground side of the set. This reduces the operating potential strain and in addition permits the easiest possible equalizing between sets.

The armature windings are insulated with mica and asbestos tape. The compensating windings are insulated with mica and fiber. The commutating and compound windings are made up of bare copper so supported on metal spools as to allow free radiation of heat from all surfaces and yet afford ample insulation.

With the heat-enduring character of the insulation and the commutating characteristics obtained by the use of compensating windings in addition to the commutating set, these generators are capable of handling even greater loads than indicated by the guarantees without injury to the insulation or flashing at the commutator.

As a further protection against flashing caused by trolley short circuits or other excessive loads, the front end of the machine is protected by asbestos guards covering the brush-holder yoke and the commutator risers. Barriers are also placed between brush-holder brackets, which prevent arcs from being carried from bracket to bracket under all but the most severe short circuits.

On account of the heavy overloads required in railway work, ventilation of unusual design for this type of machine, but similar to that used on railway motors, was adopted. With this arrangement axial holes through the core replace the usual radial ducts, and air is forced through these holes and over the surface of the armature by means of fans, insuring the positive ventilation of all parts.

The machines for the first seven substations (see Fig. 1.) have a double section fan mounted on the back flange of the armature (see Fig. 7).

Fig. 8. Air Distributing Chamber Showing Nozzles for Forcing Streams of Air Over Surface of Armature

The outer section draws air in under the commutator and through the axial holes in the core, which in passing cools the under surfaces of front and back end windings as well as the core laminations and windings before passing out through the fan into the discharge case. The inner section of the fan takes air in through the brush-holder yoke openings, drawing it over the surfaces of the fields and armature, and then delivers it into the discharge case. The heated air has sufficient velocity upon leaving the opening at the top of the discharge case to carry it well up above and away from the machines.

The machines for the second seven substations (see Fig. 2) have a modification of the above method so as to use a separate motor-driven blower. With the separate blower the air is forced into a casing at the rear of the armature where it divides between an interior and exterior path. The air for the interior path is blown under the armature core and, on reaching the front end, which is closed, is forced to return through the axial ducts and into the discharge case, where it is dissipated as before.

The air for the exterior path is delivered from the receiving chamber encircling the armature (see Fig. 8) through special nozzles which distribute it over the external surface of the winding. It then passes over the remainder of the armature surface and field surfaces and out through the brush-holder yoke openings.

The separate blower can be designed with greater efficiency than the direct connected fan and in addition permits the use of a temperature control, which governs the starting and stopping of the blower within selected

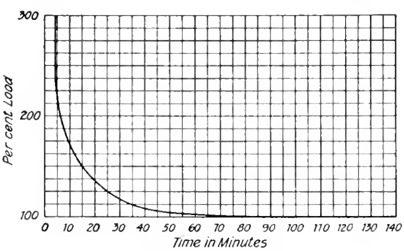


Fig. 9. Time to Increase Temperature of M.C.F. 8-1000-514 1500 Volts 60 Degrees C. without Blower

temperature limits of the generator. The curve in Fig. 9 gives the time that the generators can carry given loads for a final temperature of 80 to 85 deg. C. with a room temperature of 20 to 25 deg. C. The temperature control follows this curve very closely and does not start the blower until the machines have reached the above temperature, which is entirely safe for this class of insulation. The saving effected by this combination amounts to approximately 500 kw-hr. daily for each 2000-kw. set and a proportionate amount for the 1500-kw. set.

Efficiency

The curves given in Fig. 10 show the efficiency of a 2000-kw. set, first fitted with

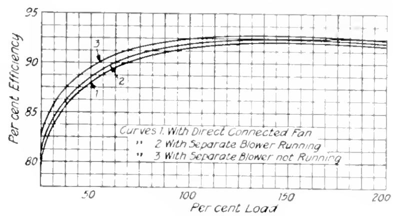


Fig. 10. Curves Showing Efficiencies of Motor-generator Set Under the Conditions Named

direct connected double fan; second, with separate blower, blower running; third, with separate blower, blower not running.

It should be noted that the efficiencies take into account all the determinate losses from the motor terminals to the generator terminals, including those of the exciters.

Reversed and Parallel Operation of D-c. Generators

An interesting feature in connection with the operation of these sets is that the regenerative operation of the locomotives requires the d-c. generators to motor. This motoring is performed with no change in the field windings. A d-c. machine connected as an accumulative compound generator, when reversed in operation, becomes a differential compound motor which, if operated from a source of constant potential, has a rising speed characteristic with increasing load. The speed being fixed by the synchronous motors acting as generators there is a slight tendency for the load to build up, but the excitation of the motors on the locomotive may be controlled to hold any load desired. In actual service there has been no tendency to unequal division of load between machines in parallel or unstability between the substations and locomotives under any condition of generator or motor action of the direct-current generators.

HIGH TENSION SWITCHING EQUIPMENT

By J. W. Upp

Manager Switchboard Department, General Electric Company

The dividing line between the relative terms "low-tension" and "high-tension" can well be established at the voltage where a decided change occurs in the character and design of the connected apparatus. In the introduction of this article the author names the distinguishing voltage values for alternating current and direct current. The first half of the article he then devotes to a general discussion of the adverse conditions that have been met in producing successful indoor and outdoor switching equipments and of the design features that have rendered their operation reliable. In the remaining half of the article he describes the switching and control equipment employed by a typical large power company that distributes its output in large blocks.—Editor.

As a distinction between high and low tension equipment, we will draw an arbitrary line at 22,000 volts a-c. and 750 volts d-c., because it is at these points that there is a marked change in the character and type of the apparatus which is recommended for station and switchboard installations.

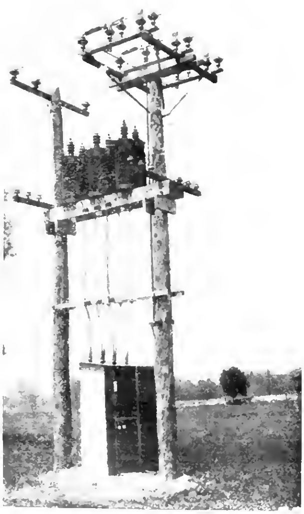


Fig. 1. Belleville Outdoor Substation, Eastern Michigan Edison Company for Supplying 75 kv-a. at 2300 Volts Three-phase from a 23,000-volt Transmission Line

The upper limit for high tension installations has probably not as yet been reached, and without attempting to make any predictions for the future, it can be stated that at present the limits of practical operating voltage are 155,000 volts a-c. and 3600 volts d-c. Higher voltages have been discussed and considered and experimental apparatus has been built and tested, but at this writing there is no immediate prospect of higher voltages being used.

High tension d-c. apparatus is invariably installed indoors because circuit breakers and other necessary control devices cannot be properly protected out of doors.

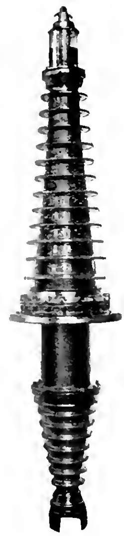


Fig. 2. 135,000-volt High Altitude Inter-departmental Standard Bushing with Fittings, for Oil Circuit Breaker

For a-c. operation up to and including 22,000 volts, it is usual, although not invariable, to place the switching equipment indoors, whether at generating or large distributing stations, space factors being influenced more by the size of the generating units than by the size of the switching equipment. Above 22,000 volts, however, it has

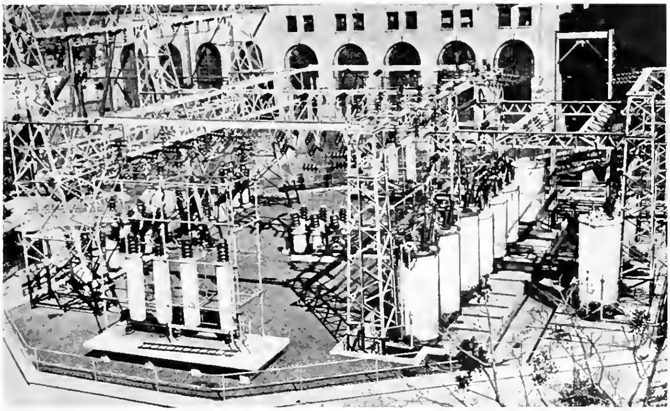


Fig. 3. Outdoor Substation 60,000/2400-volt, Ft. Worth Power & Light Company, Fort Worth Texas

been found advisable to install many high tension equipments out of doors, as the space factors involved in the higher voltages, 45,000, 70,000, 110,000 and 150,000 volts, are of such magnitude that the indoor installation of apparatus seriously affects station expense.

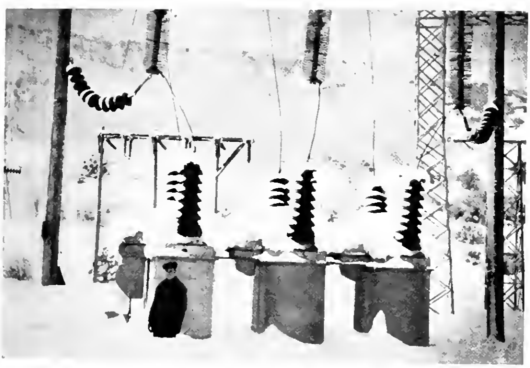


Fig. 4. Oneida Development Switch Yard. Snow on 130,000-Volt Oil Switch in Service, February 15, 1916

Roof and wall entrance bushings for these high tension installations are also very expensive and introduce complications in station design that are avoided when the apparatus is located out of doors.

Practically all high tension equipment is operated from a control board which can be located at any convenient distance from the apparatus itself. It is therefore usual in high tension equipments to find the control switchboards and the low tension equipment under cover, and the high tension equipment including transformers, disconnecting switches, oil circuit breakers and lightning arresters, out of doors. These outdoor installations vary from a substation of small capacity, as illustrated in Fig. 1, to the very elaborate distributing station, such as illustrated in Fig. 3.

The same attention is given to the design of these outdoor distributing stations as is given to those stations where the apparatus is all installed indoors. The steel framework must be substantial for it must carry the line strains, wind pressures and sleet weights which become of serious moment in many localities. It is also necessary to so design the steel structure that the incoming and outgoing lines can be arranged for simple operation and ready inspection. Transfers from one line to another must be easily and quickly made and increased space factors must be used to allow for weather conditions which are not provided for in the indoor installations.

It is interesting to note that outdoor switching apparatus, contrary to the expectation of many designing and operating engineers, has given less trouble in actual operation than the same voltage apparatus which has been installed indoors. This can be partially explained because moisture is the principal cause of difficulties with electrical apparatus and moisture is more quickly dissipated outdoors than indoors and in apparatus where oil is the principal insulating medium it is only necessary to keep the moisture from the oil to insure successful operation.

Fig. 4 serves to illustrate the severe weather conditions which are frequently present in those localities where outdoor apparatus is used. It was because of these known conditions that the designing and operating engineers were cautious in the use of outdoor apparatus and it is all the more to their credit that they have been able to design apparatus which properly performs its functions, even under such adverse conditions.

For installations of 110,000 volts and above at altitudes over 2500 ft., it is common practice to furnish specially designed switching equipment, and the special bushing for this purpose is illustrated in Fig. 2. These longer bushings are used to give arc over values which the higher altitudes make necessary. To obtain the best results from high tension control equipment it is now considered good engineering practice to specify that the bushings shall have an arc over value less than the puncture value, and installations where this specification has been applied have been remarkably free from interruption difficulties.

High tension switching equipment is not always placed out of doors. The most marked instance of an installation of indoor equipment, modern in type, is that at Keokuk and partially shown in Fig. 5. All busbars and connections are open to inspection, in some cases barriers separating the phases and isolating the circuits. The disconnecting switches are of simpler design than those of outdoor equipments because here weather protection is not required. It will be noted that the oil circuit breakers do not vary materially in appearance from those

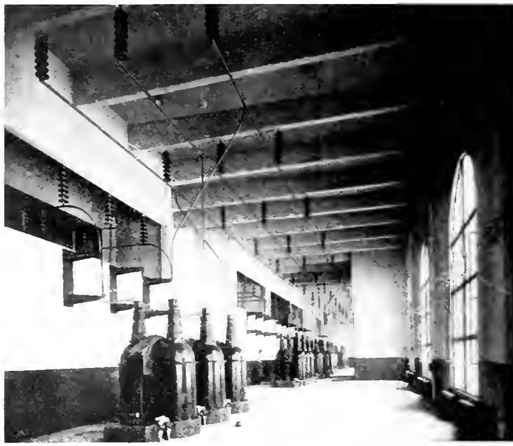


Fig. 5. Section of a High Tension Room, Mississippi River Power Company

Fig. 6. Main Switchboard in Ingham Mills, New York Power Station, East Creek Electric Light & Power Company

Fig. 8. Alternating-current Closed Type Benchboard

which are installed out of doors except in the design of the bushings.

The control boards for high tension apparatus, which are always located indoors, vary in many particulars. Typical illustrations are given in Figs. 6, 7, 8 and 9.

There are two distinct types of high tension transmission; one where it is necessary to distribute the output in small units, such as the systems of the western operating companies where irrigation and small community loads are the principal items, and others like the Montana Power Company which delivers large amounts of power to given points for distribution in large units. A description of the switching equipment of the last named company follows:

Fig. 10 shows in general the system of connections of the Power Company. Some of the smaller substations are not shown, nor the power station of the allied system of the Thompson Falls Power Company. This station will eventually feed into the system of the Montana Power Company.

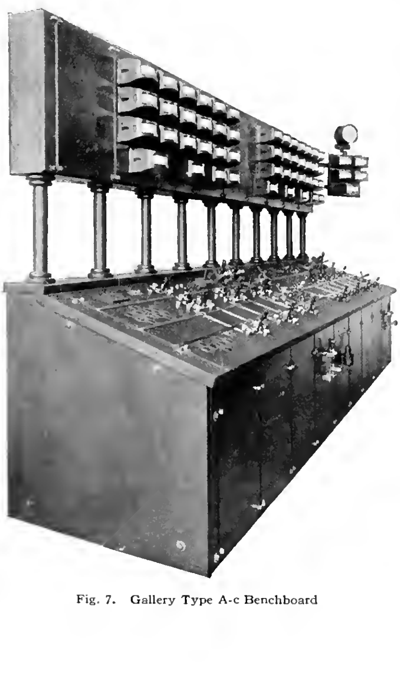


Fig. 7. Gallery Type A-c Benchboard

Fig. 9. Control Switchboard, Mississippi River Power Company, Keokuk, Iowa

In addition to approximately eight hundred miles of transmission of the Power Company, there is shown nearly two hundred miles of transmission of the Chicago, Milwaukee & St. Paul Railway Company, which receives power from the Montana Power Company. The railway company's lines are now being extended some two hundred miles more.

The main power plants are at Great Falls, Montana, and are known as the Rainbow and Volta plants, which have generating capacity respectively of 21,000 and 40,000

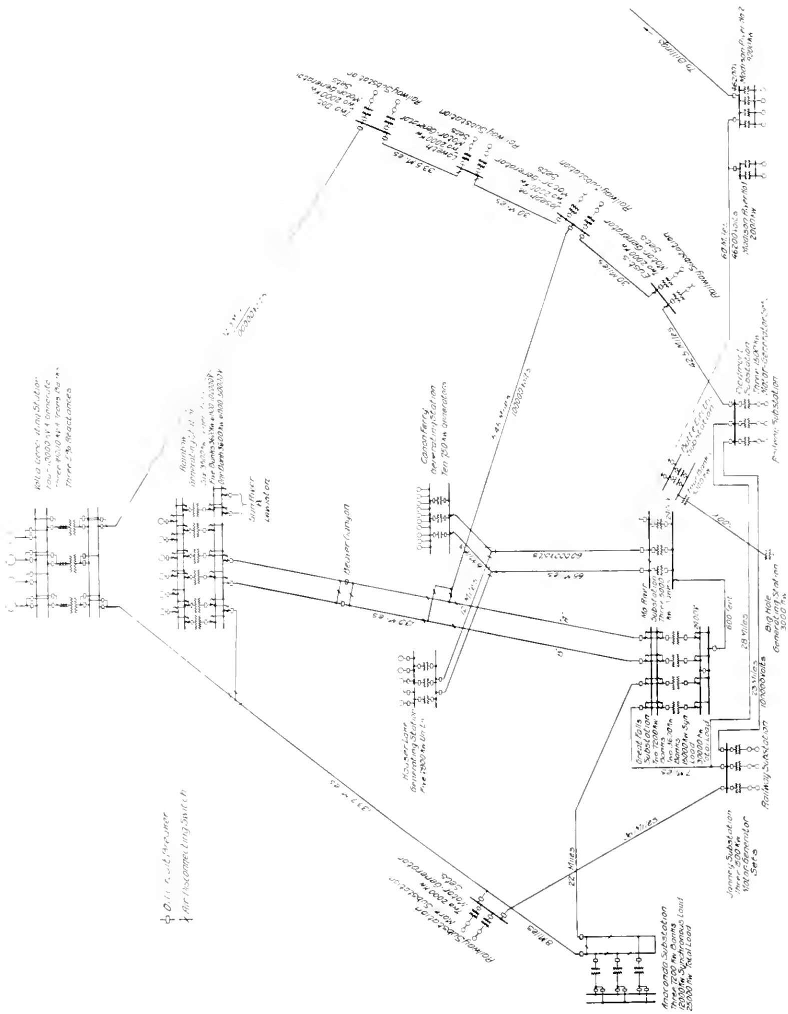


Fig. 10. Distribution System of the Montana Power Company

kw. In both of these stations, the power is stepped up to 100,000 volts and transmitted to the main distributing station at Butte and to the railway company's substations.

The Power Company also generates power at several smaller stations, namely, at Hauser Lake, Cañon Ferry, at two stations known as Madison River No. 1, and No. 2, and at the Big Hole Station. The first two stations transmit power at 60,000 volts, the Madison River Stations at 46,200 volts, and the Big Hole at 15,000 volts. All the power stations are tied together either by direct connection, or through the various substations at Butte, where a large amount of energy is used in the mines.

Besides the substations at Butte, there is a large substation at Anaconda, used to supply power to the smelters and for the 2400-volt d-c. railroad between Butte and Anaconda, known as the Butte, Anaconda, & Pacific Railway, and the substations of the Chicago, Milwaukee & St. Paul, of which there are seven in operation, and seven more nearing completion.

The Volta plant is a modern plant in every way, and the switching equipment is representative of successful up-to-date practice. Figs. 11, 12 and 13 show some views of the switchboard and equipment. Fig. 14 shows a view of the Rainbow Plant. Figs. 15, 16 and 17 show some views of the main distributing substation at Butte.

One of the features of the Volta plant is the special design of disconnecting switches. The use of the ordinary knifeblade disconnecting switch operated by a hook on the end of a long rod was practically prohibitive on account of the narrowness of the space where the operator would have to stand, in relation to the height of the disconnecting switch. The special switch designed to meet the condition is shown in Fig. 18. This switch is operated from directly below, whereas, with the ordinary switch, the operator must have his rod at a considerable angle to open or close the switch.

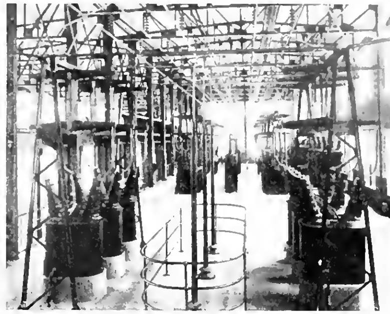


Fig. 12. 100,000-volt Switches, Volta Plant, Montana Power Company, Great Falls, Montana

Fig. 13. 6600-volt Switches and Busses, Volta Plant, Montana Power Company, Great Falls, Montana

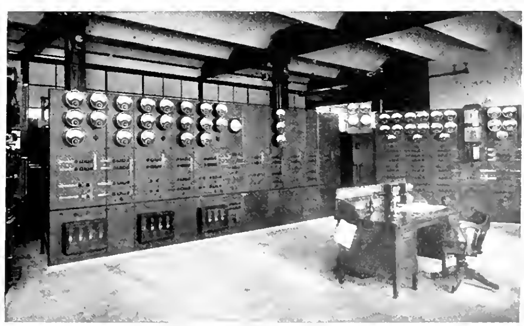


Fig. 11. Main Switchboard, Volta Plant, Montana Power Co. Great Falls, Montana

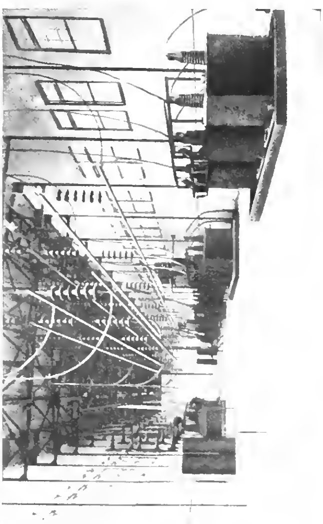


Fig. 14. Rainbow Plant, High Tension Room Containing Oil Switches, Lightning Arresters and Busbars, Great Falls Power Company

Fig. 15. Butte Substation Showing 100,000-volt Line Switches

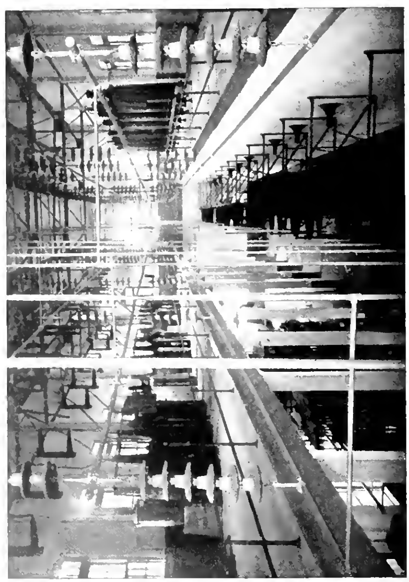


Fig. 16. Butte Substation, Showing 100,000-volt Bus Construction, Great Falls Power Company

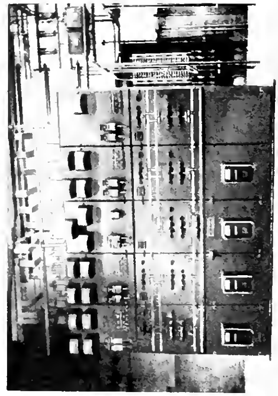


Fig. 17. High Tension Control Board in Substation, Great Falls Water Power & Townsite Co., Butte, Montana

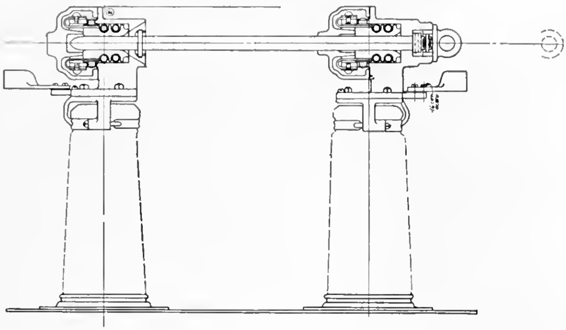


Fig. 18. Special Disconnecting Switch for Restricted Quarters

The substations of the railway company have the usual high tension a-c. equipment including lightning arresters, roof entrance bushings, instruments, transformers, and oil circuit breakers. The circuit breakers are hand-operated from a handle in the main switchboard room, which is separated from the high tension room, see Fig. 19.

When these substations were installed, there arose the difficult problem of arranging the automatic overload protective devices, so that trouble on the railway system would not shut down the power company's lines, and vice versa. This was accomplished after weeks of study, by a system of interconnecting relays, so that the relays, which are of the two-coil dynamometer type, will operate only with a certain relative direction of power flowing in the power company's and the railway company's lines.

The d-c. end of these stations is extremely interesting, being of the highest voltage

Fig. 19. Chicago, Milwaukee & St. Paul 3000-volt D-c. Electrification Two 2500-kv-a. Three-phase 100,000/2300-volt Transformers and Oil Switches in Morel Substation

Fig. 20. 1500-amp., 3600-volt D-c. Automatic Circuit Breaker and Lever Switch

regularly used for railway operation, viz., 3,000 volts. The most important feature of the switching installation is the circuit breaker design. The breaking of an arc at 3000 volts d-c. presented a serious problem, but after considerable experimenting a magnetic blowout circuit breaker, as illustrated in Fig. 20, was developed. The blowout chute had to be very large, and of a shape which was determined by many tests. The circuit breakers have now been in successful operation for some time.

The general arrangement of the d-c. switchboard is shown in Fig. 21. The circuit breakers are out of ordinary reach, and the ammeters have protecting covers, making the switchboard safe for the attendant. Other special features of the d-c. board are the d-c. reverse current relays for changing the series field connection of the d-c. generators when regeneration takes place (that is, when trains feed power back to the line on going down grade), and the voltage killing device for lowering the d-c. voltage at time of short circuit, by automatically connecting a resistance in series with the generator field.

In all high tension equipment design it has been the aim of the engineer to so arrange the apparatus that it would be free from accidental contact, easy to inspect, easily replaced when it was necessary to overhaul or renew worn parts, and as far as possible, so designed that a single operator could inspect any device with safety and without assistance from others. Where "safety-first" is a desirable aim in apparatus of low voltage, it becomes an absolute necessity for voltages of the higher values.

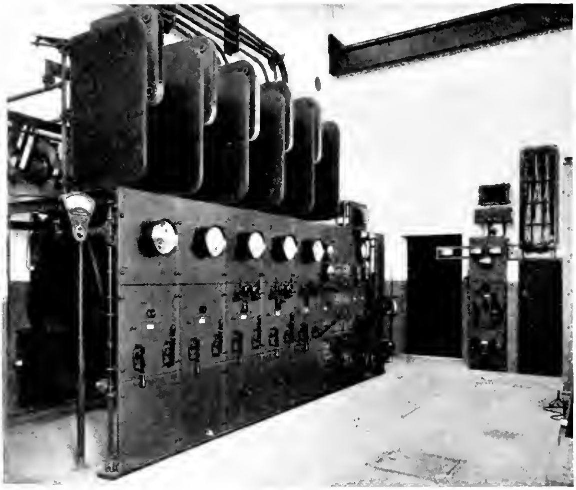


Fig. 21. Chicago, Milwaukee & St. Paul 3000-volt D-c. Electrification. Switchboard Controlling Three 1500-kw., 3000-volt D-c. Motor-generator Sets and Outgoing Feeders, Piedmont Substations

BETHLEHEM CHILE IRON MINES ELECTRIFICATION

By W. S. Bourlier

Bethlehem Steel Company, Bethlehem, Pa.

This is an interesting description of the lines, crusher plant, substation, 2400-volt railway (with fourteen lines of three per cent grade), power house, docks and storage facilities of a unique property in Chili. The climatic conditions, which are most unusual, have dictated many of the novel features.—Editor.

Some three hundred miles north of Valpariso, Chile, lies a village and port known as Cruz Grande. Four miles east, inland from this place is Tofo, a mining village. At Tofo, which lies 2200 ft. above seal level, is located the iron mines of the Bethlehem Chile Iron Mines Company, Cruz Grande is the shipping port for ore.

The electrification, broadly speaking, covers the apparatus and equipment for mining, crushing and transporting the ore to the coast for shipment. The project may be clearly segregated in to the following groups for description; but, inasmuch as the electrification concerns chiefly the railroad and the power house, only these subjects will be elaborated on.

The Mines

The Crusher Plant—For crushing the ore to facilitate handling and transportation.

The Substation—For supplying electric power and compressed air for mining and crushing operation.

The Electric Railroad—For transporation of ore to the coast.

The Storage Facilities—For storing and classifying the ore at the dock before shipment.

The Basin Dock—For the loading of ships.

The Power House—For the supply of all power.

Mine

The mine consists of two hills separated by a slight depression. These hills and the depression consist of iron ore. The ore is a mixture of hematite and magnetite. It is very hard, dense and abrasive. The mining will be done by blasting and loading into cars by electric shovels. The operation of mining will somewhat resemble trap rock quarrying. There is practically no stripping as the ore is exposed.

Substation

The substation at Tofo is supplied from two 22,000-volt transmission lines from the power house. Transformers will step down the potential to 2300 volts for supplying the crusher motors, pumps, lighting, etc. From this 2300-volt system will also be operated the large air compressors in the substation and 600-volt d-c. motor-generators for supplying electric shovels at the mine. These motor generators will later also supply 600 volts d-c. to 65-ton locomotives for use between the crusher and the electric shovels.

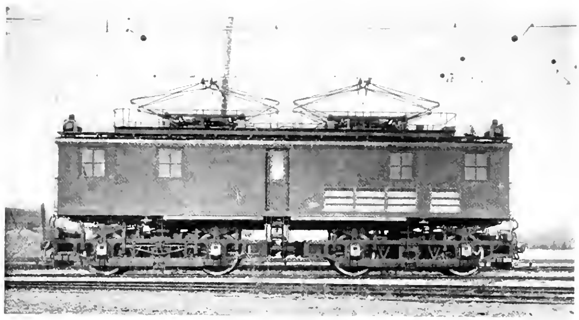


Fig 1 0440-E-240-4GE253A-2400-volt Locomotive Bethlehem Chile Iron Mines Company

Crusher Plant

The crusher plant is built on a hillside and the ore is discharged as mined from side dump cars into the top of the crushers. The ore runs entirely by gravity from the entrance of the crusher to the stock pile, first passing through a jaw crusher and thence through two gyratory crushers which reduce it to a 4 inch size. Should the ore come to the plant fine enough it may be passed directly to the gyratory crushers.

The crusher plant together with the entire project is planned for a production of 5000 ton of ore a day initially, with an ultimate production of 10,000 ton a day.

Railroad

The railroad proper is standard gauge, and 15 miles long, having a uniform grade of 3 per cent for 14 miles and about one mile at

Tofo with 1 per cent grade. There are four sidings each 1100 ft. long which are built on the level.

The ballast is entirely of stone which has been removed from the cuts. About 75 per cent of the material removed was solid rock.

There is about 1½ miles of track at the mine, most of which will be shifted from time to time as the mining progresses. This section of road is now being operated with steam locomotives but will eventually be changed to 600-volt electric operation. The ore is carried over the road to the crushing plant from which it discharges to a stock pile over a tunnel. The trains which will consist of an electric locomotive and from twelve to twenty 50-ton hopper bottom ore cars will be loaded in this tunnel for transportation to the coast. On account of the elevation of the mine all of the loaded cars come down grade.

The 2400-volt trolley is of catenary construction supported largely from bracket arms on reinforced concrete poles. Because of the mountainous nature of the country the railroad is laid out in four lateral loops. The transmission lines and 2400-volt d-c. feeder are carried on the trolley poles except where they leave the road bed to cut off these loops whence a separate pole line of similar construction is employed. The total length of the transmission line is only five miles.

Locomotives

The motive power furnished for operating the foregoing railraod consists of three 120-ton, 2400-volt electric locomotives. The mechanical design of these locomotives is of the same simple type as has been found so successful on such roads as the Butte, Anaconda & Pacifc, the Michigan Central, and the Baltimore & Ohio Railroad, namely, a platform and cab housing the electrical apparatus and air brake equipment mounted on two articulated driving trucks carrying four large twin geared railway motors.

The cabs on these locomotives are of the box type 44 ft. long by 10 ft. wide. At each end is a motorman's compartment containing the master controllers, brake valves, and various gauges, etc. The remainder of the cab between the two end compartments is taken up with the main electrical apparatus. In designing this central portion of the cab, use has been made of certain of the features found so desirable in the case of the Chicago, Milwaukee & St. Paul locomotives; namely, locating the rheostats in a special compartment provided with abundant ventilation and placing the contactors and main line switches in a second compartment above the rheostats, and so arranged that the contactors will be accessible from all sides and at the same time provided with ample arcing space.

These locomotives are provided with the usual type of control equipment to provide for operation of the motors in series or series parallel connection. They are also provided with regenerative braking control through the use of a small generator for exciting the traction motor fields so as to operate these traction motors as generator and pump back current to the line. By this field excitation control, regenerative braking of various amounts can be secured over a wide range of speed and the transition from motoring to braking can be made very smooth. Besides the rheostats and contactors, the principal other electrical apparatus located in the main cab consists of the special high tension compartment containing fuses and main disconnecting switch, and a motor-generator blower set to provide secondary current for the operation of the control, and to provide forced ventilation for the motors.

The air brake equipment on these locomotives is of special interest as it contains several new features which were added to meet the difficult requirements of operation on 14 miles of continuous 3 per cent grade. This air brake equipment provides for straight air operation on either the train alone or the locomotive alone, or both together, as well as automatic operation of the brakes on either train or locomotive, or both together. In addition to this the cars are all provided with an empty and loaded brake to secure maximum braking power of each car whether empty or loaded. In addition to these special air brake features, the locomotives, as stated above, are provided with regenerative braking control. These points will be gone into further in connection with the service described below.

The train of hopper bottom ore cars will be dumped at the docks by air from the locomotives. An air control valve is provided at each end of the locomotive for this operation. The change of the brakes on the train, from load to empty operation, is automatically accomplished when the car doors are being closed by air. The change of the brakes from empty to load positions is also controlled from the locomotives by increasing the air pressure in the straight air train line.

The motors provided on these locomotives are the largest high voltage direct current geared type railway motors ever built. Each motor has a continuous rating of 300 h.p. on 1200 volts, two motors being designed to operate in series on 2400 volts. At this continuous rating the locomotive will develop a tractive effort of 35,600 pounds. The locomotive will develop a tractive effort of 62,600 pounds for a period of five minutes when starting trains. The motors include the latest features of design such as the twin spring-geared drive and the spring nose suspension. The trucks are built up of cast steel outside side frames, transoms and end frames carrying the draft rigging at one end and the articulating joint at the other end. The cab and spring borne parts of the trucks are carried on a complete side equalized and cross equalized system of elliptic and coil springs, providing a three point suspension.

As noted above the crusher plant will have a capacity of from 5000 to 10,000 tons of ore a day. One locomotive will be expected to handle from 12 to 18 empty cars, weighing a maximum of 405 tons trailing, from tidewater up to the cursher in 95 minutes actual running time, and after loading will take down a total of 1500 tons trailing in about 81 minutes actual running time. In coming down with this load, the weight of the locomotive will not be sufficient to hold back the entire train by means of the regenerative braking, and it will therefore be necessary to use the air brakes to some extent also.

The train brakes are applied automatically at the top of the grade and the control of the pressure in the brake cylinders is by straight air from the locomotive. The automatic part of the system being held in reserve. Retaining valves are not required in service on the cars due to the straight air control which allows prompt release of brakes at the railroad sidings which are level. While the locomotives are regenerating the brakes are applied only on the train. The running speed down grade will be 12 miles per hour, at which speed, with the above train, the locomotive will be capable of returning energy to the line at a rate of approximately 1000 kilowatts, depending upon the voltage adjustment at the substations. The schedules will be so arranged that an empty train going up will be on the line at the same time as a loaded train going down, so that the power returned to the line will not have to be absorbed in other ways.

The current collection for the locomotives will be by pantograph trolley from the 2400-volt overhead wire on the main line. In the case of the ore docks, however, current collection will be from the 1200-volt third rail which will provide for half speed operation of the locomotives on the docks.

Basin Dock

At Cruz Grande a basin 900 ft. long by 240 ft. wide by 40 ft. deep is being excavated out of rock for the admission of 17,000-ton ore boats. Alongside of this basin is constructed a steel dock 123 ft. above low tide surmounted with three tracks and equipped with two steel bins each holding 15,000 ton of ore. The ore is discharged by gravity from these bins through 17 shutes, set on 20 ft. centers, directly into the boat.

An approach tressle 800 ft. long, carrying double tracks leads the trains out over the intervening low ground on to the dock where the ore is dumped into the bins.

On account of the travelling gantry crane which it is proposed to erect along side the dock for the storage to, or reclamation from the immense storage immediately adjacent thereto; it was found impractical to carry the catenary trolley construction on the dock. Twelve hundred-volt third rail construction was therefore substituted and is fed from the low voltage generator of either of the two railway motor-generator sets in the power house.

POWER HOUSE

The power house equipment selected to provide for the mining and transportation of 5000 tons of ore a day with necessary provision for additional machines to ultimately handle 10,000 tons of ore a day is as follows:

	Present	Future Additions
440 h.p. oil fired boilers..	4	2
3500 kw. turbines............	2	1
300 kw. turbines............	1	1
1000kw. railway motor-generator sets........................	2	1
2000 kw. bank step-up transformers............	2	1
Evaporator equipment	1	0

The steam pressure adopted was 200 lb. 100 deg. superheat at rating. The boilers are good for 100 per cent over-rating continuously. The main generating voltage is 2300, three-phase, 60-cycle. The railway motor-generator sets, which are 2400-volt, direct-current units are fed directly from the main 2300-volt busses. Power to the mine is supplied through step-up transformers at

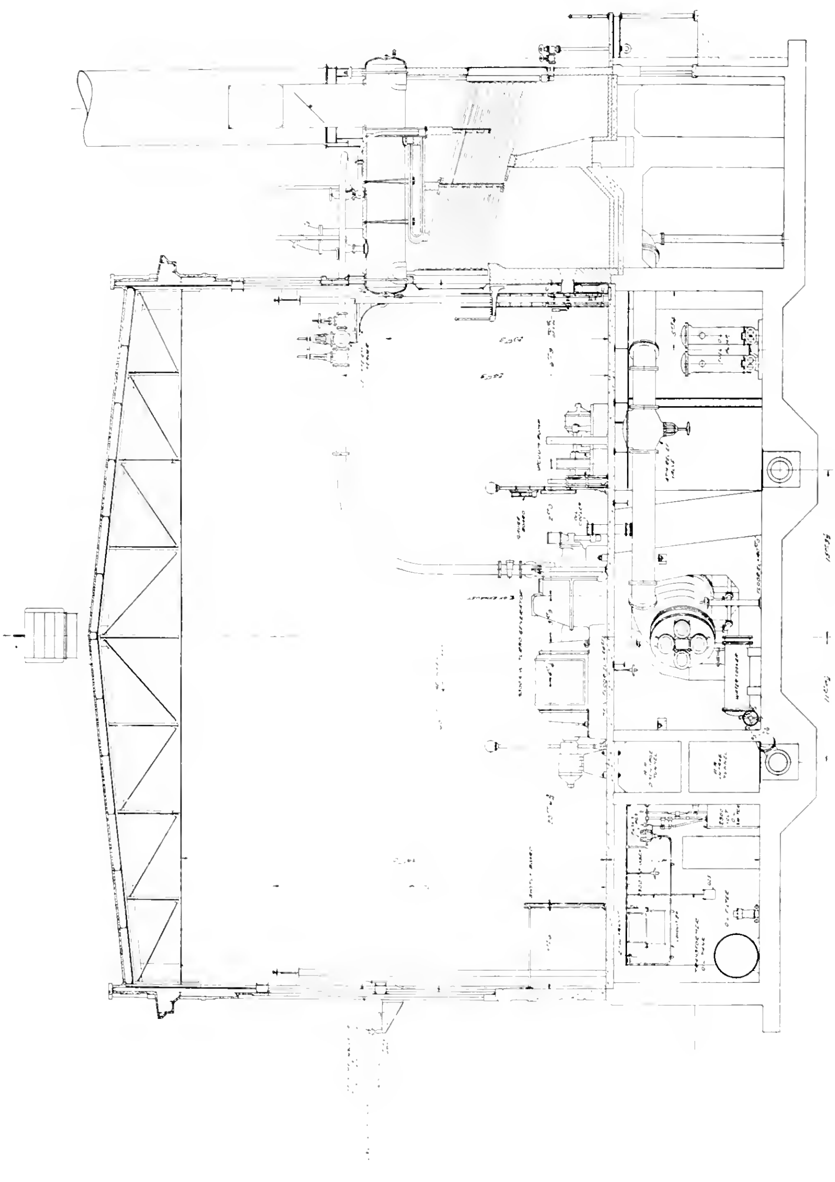


Fig. 2. Cross Section Through Boiler and Turbine Room, Power House, Bethlehem Chile Iron Mines Company

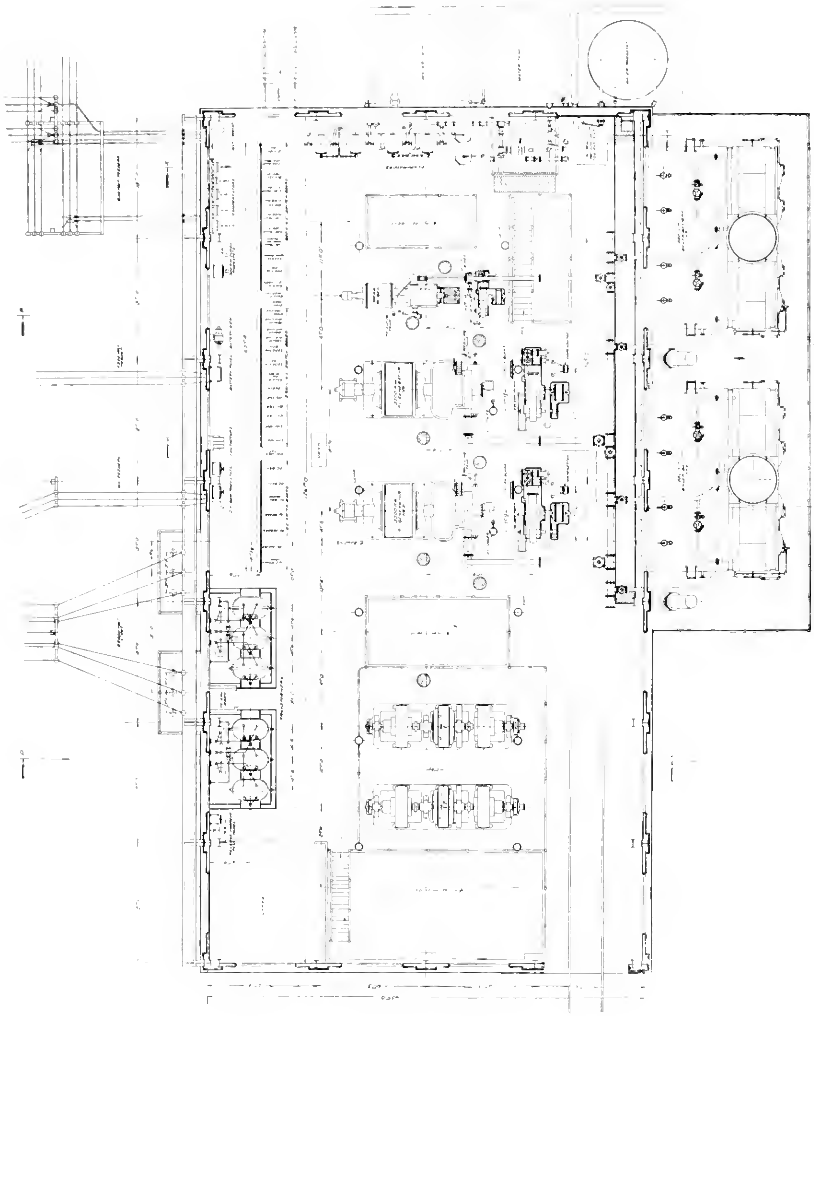


Fig. 3. Main Floor Plant of Power House for Bethlehem Chile Iron Mines Company

22,000 volts, over duplicate transmission lines. The auxiliary power for the station and surrounding locality is generated at 600 volts, 60-cycle, three-phase.

Local Conditions

The prevailing local conditions had a considerable bearing on the apparatus supplied and the arrangement and installation of the same. The climatic conditions are rather interesting. There is no rain except during July and August when there may be two or three showers. The total rain fall in a year has, from available records, never exceeded 2 in. The temperature is very mild and quite constant throughout the year. The winds are moderate, seldom exceeding eight miles an hour and the prevailing direction is from the south-west. Electrical storms are comparatively few and gentle. The ocean water temperature, due to the controlling influences of the Humboldt Current varies from 60 to 64 deg. during the year. The only fresh water available is that pumped from an abandoned copper mine, about 6 miles from Tobo. The water is very hard and therefore very poor for boilers. A lime-soda ash water softening plant is now being installed to improve the water for boilers and domestic use. Earthquakes are numerous, several occuring each month, but the shocks are usually not severe. On account of the earthquakes all building structures are made of reinforced concrete and steel.

Location

The controlling factors entering into the selection of the power house site; were: to locate it as close as possible to the ocean to obtain circulating water for the condensers at reasonable cost without endangering it during abnormal sea disturbances, and to establish an elevation of the power house which would keep the pumping head within reasonable limits and still make it safe against extreme high tide and sea.

The location selected was about 300 feet from the most protected part of Cruz Grande Cove with the main turbine room floor level 54 feet above low tide.

To avoid the high cost of constructing underground circulating water tunnels or submerged pipe lines, the circulating water pumps have been installed in a separate building on the shore line 700 ft. from the power house and the elevation of the floor is several feet below mean low tide. This site, although considerable farther from the power house than the nearest shore line, was selected because the water at this point is free from sand due to the rock bottom and because it is protected by a small natural breakwater.

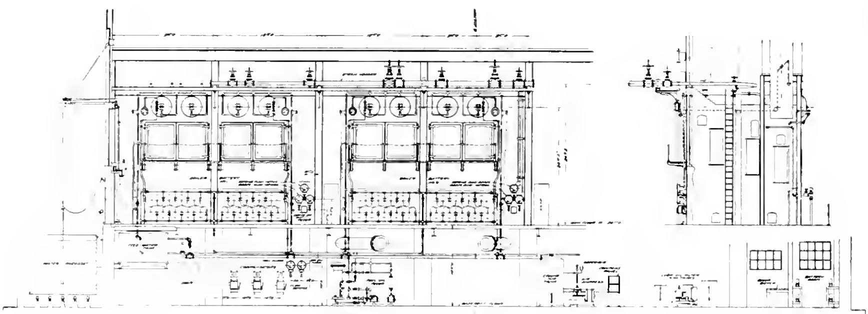


Fig. 4. Elevation of Boiler Room Wall Bethlehem Chile Iron Mines Company

Boilers

Because of the ideal climate and comparatively high cost of building structures it was decided to erect the boilers out of doors. The fact that the boilers were oil-fired made this arragnement quite practical as will be seen from Figs. 2 and 3. The boiler fronts are built in the turbine room wall; thus the entire boiler control is handled from the turbine room. Reference to Fig. 4, which illustrates a view looking towards the boilers from the turbine room, will show the location of the control equipment. Water gauges,

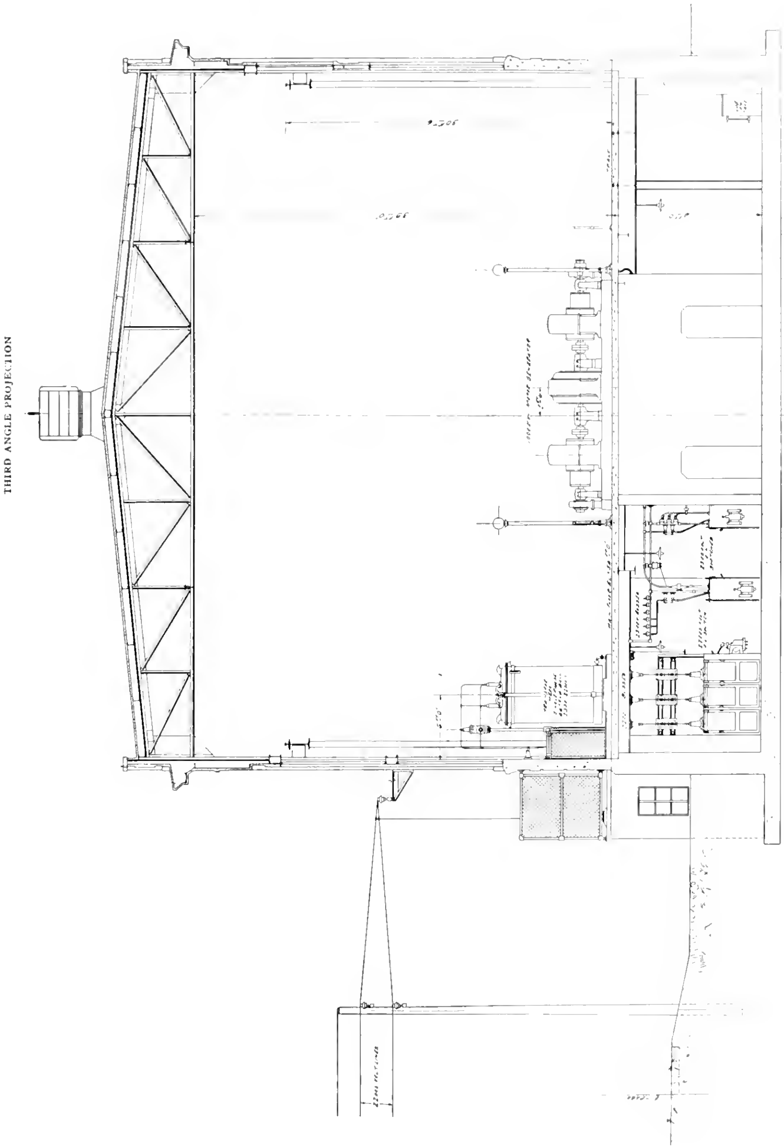


Fig. 5. Section at Motor-generator Set, Bethlehem Chile Iron Mine Company's Power House

steam pressure gauges, boiler and turbine steam flow meters and generator curve drawing wattmeters are under the operator's constant observation. The stack damper regulator mechanism, oil supply valves to individual burners and group valves and boiler feed regulating valves are all within convenient reach. The selection of oil as fuel was made because it was cheaper, when comparing it with coal on a calorific value basis, and because it greatly facilitates the regulation of the steam pressure which otherwise would fluctuate widely due to the variable electrical load demand. Nowever, should the price of coal be reduced to such an extent that the use of coal would be economical it is proposed to fire the boilers with coal from the rear, either entirely or in connection with the fuel oil firing.

Stacks

Guyed steel stacks are used; one for each battery of boilers. This particular type of stack was settled on because of the earthquake condition. In spite of the fact that these stacks are located comparatively near the ocean, the exceptionally dry prevailing climate should be conducive to a long life of the material. The stacks are seven feet in diameter and 125 feet above the top of the boilers.

Oil Firing

Because of the absence of suitable boiler feed water and the possible difficulty in obtaining expert operators, it was decided to simplify as much as possible the firing of the boilers. The pressure oil atomizing system was, therefore, adopted in preference to the steam atomizing system. It was found after experimental tests had been made that practically the same overall boiler efficiency could be obtained with the pressure system as with the steam atomizing system. The oil is heated in surface heaters sufficiently to obtain the right viscosity for atomization and pumped to the burners at a pressure which will range from 100 to 150 lb. Exhaust steam, or live steam, or both may be used for heating the oil to the required temperature. If the exhaust steam is insufficient or the oil too viscous live steam may be added. The amount of live steam used is controlled by a thermostat so as to maintain a constant predetermined oil temperature. There are two main oil storage tanks some 85 feet in diameter and 32 feet high located on the hillside a safe distance from the power house. These tanks will hold about a year's supply of oil. Near the power house is located a 550 cu. feet. tank, with arrangement for a similar reserve tank, at an elevation just below that of the power house basement floor. This auxiliary tank will hold about a day's supply of oil for the initial load. The fuel oil pumps get their suction directly from this tank through duplicate suction lines.

Circulating Water Supply

As previously stated the circulating water pumps are located in a separate building 700 feet away. These pumps, as well as practically all of the station auxiliaries, are motor driven and are controlled from the main power house switchboard. The pumps are located below low water level and therefore need no priming. The water from any or all of the pumps is fed to a common 20 inch bell and spigot pipe line leading to the power house. Thus, any condenser can be operated from any pump or one pump may serve two condesners.

The discharge line from the condensers leads to a concrete sealing well 25 feet below the top of the condensers thus, a full syphon action of from 20 to 25 feet is expected to partly counteract the high pumping head. This syphon action under certain load conditions extends back through the condensers and out into the feed line from the pump house. For this reason expecial care has been taken to employ a pipe line of suitable construction to remain free from air leaks. This pipe line is constructed of selected sections of pipe with double grooved bells and machined end spigots and packed with oakum and lead wool.

The sealing well into which the discharge pipe ends is made to serve as a measuring wier. That is the discharge end of the sealing well is made in the form of a wier opening and provided with the necessary baffles to dampen out any turbulence of the water. The height of the water over the crest of the wier will, of course, show immediately any deficiency in supply due to pump troubles, air infiltrations in pipe lines, etc.

The overflow chamber of the sealing well also serves as a baffle for the boiler blowdown. The blow-down pipe line extends down close to the surface of the water and a curved baffle at the bottom is provided to deflect and dampen the resulting agitation.

Arrangement of Condensers

The condensers, which are of the surface type, are set directly below the turbine exhaust outlet. As it will be observed by

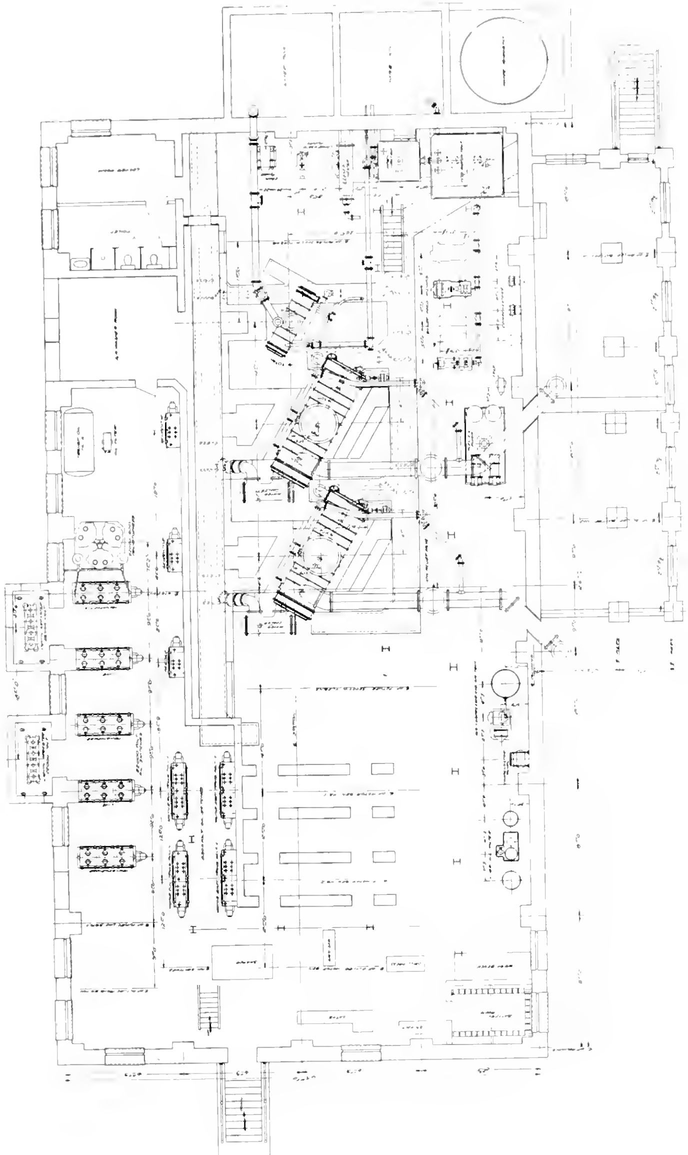


Fig. 6. Power House Basement Plan, Bethlehem Chile Iron Mines Company

referring to Fig. 1, the condensers are at an angle of 60 deg. from the turbine shaft. This arrangement permits the removal of tubes or shell and still retains a close spacing between turbines.

Condensate is used for cooling the turbine bearings. The water is recirculated and is cooled by means of surface coolers connected in series with the circulating water line to each condenser. The ntroduction of these coolers requires an additional pumping head of less than 5 feet and a reduction in the temperature of the circulating water of about one-tenth of one degree.

Feed Water Heater

All the station auxiliaries except one steam driven plunger feed pump for night service and the two reciprocating fuel oil pumps are motor driven and are supplied from the 300-kw. 600-volt turbine. Until the future auxiliary turbine is installed, which will be held as a reserve unit, the supply for the auxiliaries can be obtained in case of an emergency from the main 2300-volt buses through step-down transformers.

The major portion, if not all, of the exhaust from the above steam driven auxiliaries is utilized in heating the fuel oil. Therefore, the heating of the feed water is accomplished by extracting steam from the first stage of the 300-kw. turbine. The heater is of the usual

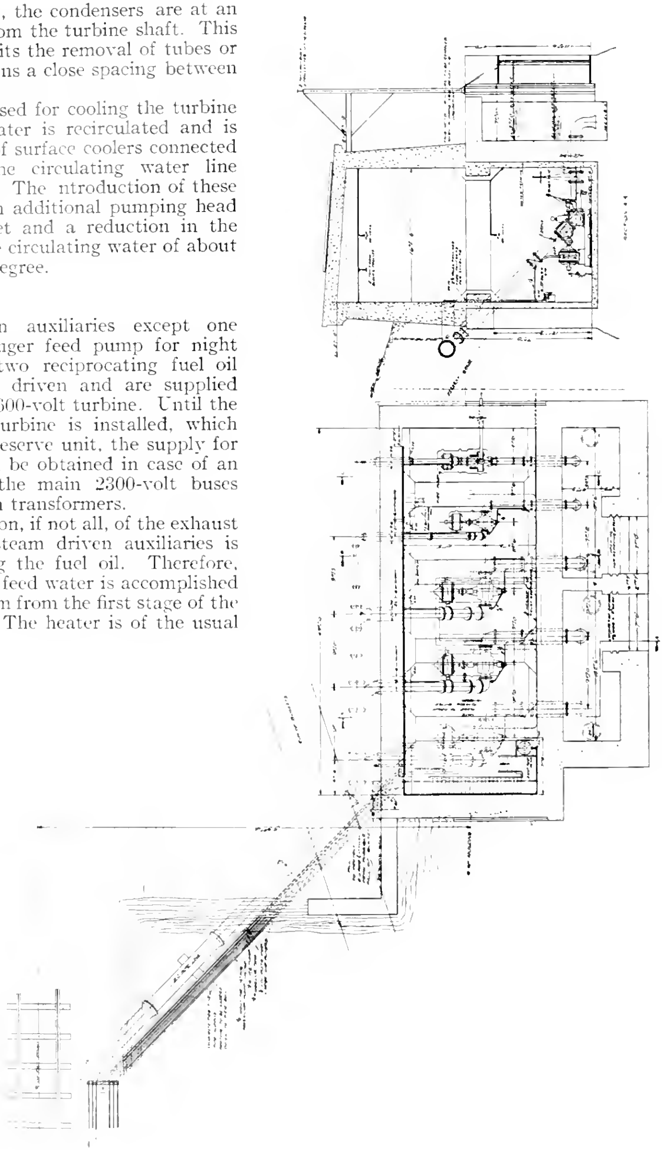


Fig. 7. Pump House Bethlehem Chile Iron Mines Company

type of open heater construction but to prevent a waste of fresh hot water, so common in stations carrying a variable load, the heater capacity has been augmented by a 2500-gal. cast iron tank so that considerable leeway is provided for the spasmodic feeding of the boilers or for the variable electrical load. By providing for a large storage capacity the rate of boiler feeding may greatly exceed the return condensate from the condensers or vice versa without the periodic overflow of hot water and the frequent draft on the cold water make-up supply.

Evaporators

It was considered advisable to install the necessary equipment to produce suitable boiler feed water from the ocean water or from the mine water supply in preference to attempting to use the poor grade of mine water directly.

Ordinarily the cost of producing fresh water is quite expensive, but, where the amount of fresh water required represents but a small part of the total water being used, distillation may be accomplished in a very inexpensive manner. The evaporating system consists of two effects, each effect consisting of two shells in multiple. This part of the system is not unlike any other multiple effect system. The vapor produced by the second effect instead of being condensed in the ordinary distiller is condensed in a closed feed water heater: the circulating water being the feed water to the boilers. Thus, in this system the usual excessive waste of heat in the distiller is conserved in heating the feed water.

Other accessories are provided in the nature of heat exchangers for extracting a large part of the heat from the blow-down or waste and consequently the only heat loss is in radiation and the remaining heat in the blow-down. The resulting efficiency is therefore extremely high and will probably run from 25 to 50 lb. of distilled water per net pound of high pressure steam.

Power Loading Device

During regular operating conditions there is ample external load at the mine to absorbe any regenerated energy from the coasting of a locomotive down hill when there is no power being consumed by the railway proper; but to provide for a condition where the regeneration exceeded all the remaining load, an automatic 2400-volt d-c. water rheostat has been provided.

The electrodes of this rheostat are operated by means of a hydraulic cylinder, the control of which is accomplished through a pilot valve worked from a governor operated at the station frequency. Any variation in this frequency or any tendency for a coasting locomotive to speed up the turbine will automatically throw in the water rheostat electrode to a sufficient depth to just balance the load conditions. The water rheostat mechanism is equipped with a compensating device to prevent hunting.

Pump House

The pump house building construction is of particular interest in that it is built at the waters edge and considerable below mean low tide. The building structure is very massive and heavily reinforced in order to withstand the impact of an extremely heavy sea. The general design of this building and arrangement of equipment is shown in Fig. 7.

There are no doors or windows provided. A heavily constructed hatch-way in the roof provides for the installation or removal of apparatus and a smaller hatch-way gives necessary access for inspection.

COMMERCIAL ASPECTS OF ELECTRIFICATION OF STEAM ROADS

By J. G. Barry

Manager Railway Department, General Electric Company

The author writes a concise statement of some of the most prominent advantages to be secured by the railways, manufacturers, farmers, and the public at large by the electrification of our steam railroads.—Editor.

In all probability during the next few years very marked progress will be made in electrification of existing steam railway lines. The economies of operation and the increased facilities secured on the Chicago, Milwaukee & St. Paul Railway mountain divisions, and on the Butte, Anaconda & Pacific Railway installation are so striking as to convince the most skeptical of the advantages of electrical operation; the results obtained on these roads will exert a powerful influence on other lines operating under similar conditions to adopt electrification.

Many indications point to a large increase in operating costs for the railway systems of this country; to offset these increased charges without corresponding reductions in other directions, means that increased charges for service must be made. If, however, economies in fuel, in maintenance, in reduced delays, and in a decreased amount of non revenue freight haulage can be obtained on other roads to the extent that they actually have been on the roads above referred to, a substantial amount can be saved above the return on the investment required for electrification.

While the electrification of steam railway lines is primarily a railway problem, there are other aspects that make it of extreme interest and importance to the entire electrical industry and to the country at large. In Montana and Idaho, as a result of the Milwaukee electrification, the Montana Power Company, from whom the Railway Company purchases power, has extended its distribution system over a territory which previously had not sufficient commercial power possibilities to warrant such extensions. As a result, cheap power is available for lighting and manufacturing purposes in communities that could not otherwise have hoped for these advantages for years to come. The result of this must inevitably be to stimulate both trade and population, which will react favorably to the railway, to the power company and to the states themselves.

It is this broad extension of the use of electric power that must necessarily follow in the footsteps of the electrification of long railway lines that is of prime importance to the electrical industry as a whole; the logical step for any road adopting electrification is to purchase power from outside power companies; and the loads that would be carried would justify central stations of the largest capacity, considerably in excess of the load obtainable from the railroads themselves. This would probably result in the consolidation of numerous small companies in many parts of the country, and the creation and development of power facilities in sections which are now practically undeveloped.

In all such instances, comparatively cheap power would be made available to small urban communities and to agricultural districts, and this must result in the most far reaching benefits to the general public. A plentiful supply of energy at a moderate price will open up, through irrigation, much of the waste land of the west and southwest; manufacture and trade in villages and towns which are now merely trading posts will be stimulated; and the farmer will be enabled to secure many of the comforts of life now possible only to the city dweller and to employ in his work many of the labor saving devices now beyond his reach.

These things make for the general public welfare. Individually, the manufactures of electrical apparatus, the power companies immediately along the lines of the steam railways, and the railways themselves are particularly concerned and benefited.

But the general prosperity and well being of the nation itself is also concerned. Our national life is complex and nearly every vital factor in it is tied together by the transportation systems and is dependent upon them for proper functioning. It is distinctly to the public interest and vital to its welfare that the railways be operated as efficiently and economically as possible and that their development and improvement be continued and encouraged. It is from this standpoint that the possibilities of electrical operation assume a phase of national interest and importance.

SOME ASPECTS OF ELECTRIFICATION FINANCE

By William J. Clark

Manager Traction Department, General Electric Company

A brief outline is made of the financial position of steam railroads. Figures are given to show how operating expenses have been increasing at the same time that revenue has been falling off. Suggestions are made as to ways and means of decreasing the investment charges necessary for electrification by trust certificates and by the purchasing of power from existing central stations so that advantage may be taken of the well recognized economies to be secured by such electrification. It is pointed out that a saner fundamental political policy towards railroads is much needed.—Editor.

Unjust treatment, by public authorities, of capital invested in American railraods has, among its many phases of injury to the future progress and prosperity of the country, done more than all else to retard electrification, as during recent years the railroads have in the main been thus prevented from undertaking more in a financial way than to care for the essentials to the operation of their immediate service. So the finance of electrification or of other important betterments has been seriously handicapped. This situation is more clearly pictured by the following statement, which has been specially prepared by an eminent steam railway authority for quotation herein:

"The most practical service which you electrical men can perform is to understand the financial situation of the railways, to recognize frankly their needs and to co-operate in re-establishing their credit. No man is ever in better business than when he is endeavoring to strengthen the purchasing power of his customer.

"A few simple computations will show the financial drift. In 1907 the operating expenses of the steam roads of the country per mile of line was $7687. This had risen to $8109 in 1915. The average annual wages of railway employees in 1907 were $641. This had increased to $826 in 1915. Taxes per mile of line in 1907 were $357 and in 1915 $534. The ratio of operating expenses to operating revenue in 1907 was 67.5 and in 1915 70.6—this in spite of the fact that in 1907 the roads had been hauling enormous increases of tonnage, whereas in 1915 a prolonged spell of starvation had got most of them down to hardpan.

"The result of this tendency is seen in the amounts which the roads of the country on the average had left after deducting operating expenses and taxes. This figure per mile of line in 1907 was $3339 and in 1915 had fallen to $2834. One of the uses to which this remainder has to be put is the payment of interest. Many of the roads during these eight years greatly increased their investment per mile of line. The roads as a whole (1907-15) increased tons of freight car capacity per mile of line from 67,033,324 to 92,225,541; number of locomotives from 55,388 to 65,099, and miles of track per mile of line from 1.44 to 1.56. This says nothing of the great investment in terminals and the substitution of steel for wooden passenger cars. Another item which comes out of the remainder which I am talking about is additions and betterment out of income without any increase of capitalization. Finally there is decrease in the item of dividends on stock and surplus, which are the indications consulted by those who advise investors in order to determine the financial condition of a company.

"In short, railway credit has been impaired by a rise in expenses not accompanied by a proportionate increase in revenues. To remedy that situation the railway managers invite and in my judgment deserve your co-operation. They say that if regulation which affects interstate commerce could all be centered at Washington two grand results would be promised. First, needless duplication of expense to the roads arising from regulation by 48 states would be saved to the roads and to the public; second, the Interstate Commerce Commission could then be held responsible for the total financial results of the rates which they fix and of the expenses which Congress compels, and hence the country would at all times have a servant whose function it would be to watch for untoward tendencies in condition of the roads and act with promptness and decision in the public interest."

The economic advantages of electrification have now been so thoroughly demonstrated that railroad financiers and executives are fast becoming convinced of their existence, but as indicated by the foregoing quotation this alone cannot provide the funds required to undertake extensive electrification projects, for to readily accomplish this securities issued for such purpose, must be made more attractive to investors than the great majority of railroad issues have been since governmental oppression has so seriously threatened their stability and prospective financial return.

Seemingly, therefore, the only ways in which railroad electrification can be greatly facilitated in this country, are these:

(a) By improvement of fundamental political conditions, thoroughly impressing the true financial situation of the railroads and the growing inadequacy of their facilities upon the people at large, making it clear to all that governmental authorities, supposedly acting in accordance with public demand, are responsible therefor, but in so doing have greatly injured the public interests; which condition should be remedied by the public itself.

(b) Under present prevailing conditions provide methods of finance for electrification, which will more strongly appeal to investors than do those available through the sale of ordinary issues of railroad securities, thus placing the finance of electrification in a different category than are nearly all other forms of extensive railway betterment.

(a) is a public duty incumbent upon every good citizen, which, however, has been sadly neglected by most of them. But as electric public utilities have endured and are still suffering from the effects of misguided public sentiment in ways similar to those that have been inflicted upon the steam railraods, necessity for such action is brought directly home to the electric fraternity.

The accomplishment of (b) is already well advanced; this principally through the rapid evolution and expansion of the central electric station industry along broader lines than is ordinarily appreciated by railroad men or others.

Extensive railroad betterments, other than the acquisition of additional rolling stock, are of course fixed in their character and therefore must usually be financed through the issue and sale of railway stock or bonds, for which, so far as stock at least is concerned, a favorable market does not exist at the present; while in many other instances legal restrictions prevent the making of further bond issue in a form which is attractive to investors.

Additional rolling stock, whose earning power is apparent, can be and is favorably financed through the issue of trust certificates or equipment obligations for which the equipment is pledged and whose principal is, in due course, paid out of increases in earnings thus made possible.

The popularity of this class of security is constantly evidenced by stock exchange quotations, while past financial experience has demonstrated that such trust certificates, as a class, have been the most reliable form of railroad investment.

Until recently, however, railroad men have considered it impractical to broadly apply this principle to the finance of electrification projects, believing that their corporations would in such connection be forced to finance the cost of power stations, transmission lines, substations and other forms of fixed investment. But from the day when Mr. Samuel Insull first pointed out and demonstrated the true economies of central station load factors, transmission, distribution, and sale of electrical power, a radical change was wrought in such regard; this to the great advantage of the railroad companies and consequently to the public.

Since then, Mr. John D. Ryan has directly exemplified the same truths on an extensive scale through arranging for the Montana Power Company to furnish current to operate the electrified divisions of the Chicago, Milwaukee & Puget Sound Railroad, relieving the latter from the finance of a goodly portion of the fixed investment required, and in so doing also avoided unnecessary duplication of electrical generating plants and transmission systems throughout an extensive territory.

To be more explicit upon what has just been outlined:

As is well known by those familiar with the electrical industry, experience has demonstrated that with a generating plant of the same character and capacity, a central station company can, under ordinary working conditions, produce current at less cost than can a railraod company for its own individual uses. This because the former, from a greater diversity of power supplied, will have a higher load factor than does the latter. It will usually be found also that, to a greater or less extent, existing transmission and distribution systems of central station companies can be utilized for electrified railroad operation, or can be so expanded in connection with electrification as to enable the generating companies to supply additional current to others than the railroad. This condition, of course, contributes further toward making it possible for central station companies to furnish current to the railroads at favorable rates.

To take full advantage of what is possible in this last-mentioned respect, certain of the largest and most progressive central station companies stand ready to finance and furnish all of the fixed essentials to electrified railroad operation, other than the comparatively unimportant items of working conductors, rail bonding, and local feeders. So the one essential to electrification, which the railroads would be called upon to finance when dealing with them, is electrified rolling stock. True, this is the largest item involved in electrification but it can be financed by the issue of equipment obligations such as have been mentioned. Where central station companies are ready to make this possible for the railroad companies, the prospective financial return to the railroads upon their investment for electrification purposes will, in nearly every instance, be most attractive. When it is remembered that electrification is popular with the public, and that its introduction does evidence progressive railway management, can it not be considered to possess, in addition to the economic advantages now demonstrated, elements which will operate toward the creation of a more just public sentiment as regards the railroads than now exists.

NOTES ON RAILWAY ELECTRIFICATION

By A. H. Armstrong

Chairman Electrification Committee, General Electric Company

The author, from a wide experience in electrification engineering problems, writes some interesting and most useful notes. He emphasizes the importance of dealing with the whole problem broadly rather than becoming enthusiastic over a single element of the whole scheme, and gives some logical reasons for the success of the direct-current locomotive. The data presented concerning the amount of non-revenue freight hauled in the shape of fuel for steam locomotive operation are of particular significance.—Editor.

During the term of years that the electric locomotive was on trial, and before it had carried conviction to both the designing engineer and railroad operator, it was natural that its physical characteristics should be most actively discussed. It was found early that steam engine construction as a precedent failed to meet the necessities of this new type of motive power, and that radical departure from established forms of construction was necessary in order to best utilize the larger possibilities available. With the growing appreciation of release from the traditional restrictions of steam engine construction, the electric locomotive took shape in widely differing forms during this developing period, and drew its power supply from a miscellaneous assortment of conducting, distributing and generating systems. Some of the experiments met with instant and continued success, obvious failure claimed a few, while others, after years of development spent upon them, cannot yet be finally classified as a complete success and duplicated in other installations, or proved a failure and relegated to the scrap heap upon which progress builds the advances of the future.

Laying the foundation stones of such a gigantic structure as the electrification of our steam railway lines calls for the broadest possible treatment of the needs of the problem, supplemented by a prophetic view of the possible future state of the art as foreshadowed by the universally recognized successes of the present. The locomotive, contact, distributing and power generating systems all form part of a completed whole and abnormal development of any one cannot but result in seriously disturbing the balance of the others. As a good example for illustration may be cited the adoption in certain instances of electric locomotives that demand single phase power supply at 25 cycles or even lower frequency, while general power distribution is universally accomplished by balanced three phase circuits. In certain restricted localities, 25-cycle power is available and can be purchased single-phase at the expense of installing suitable phase balancers and synchronous condensers, to correct the voltage unbalancing and poor power-factor that might otherwise prove disastrous to the success of supplying railway, lighting and industrial power from a common bus. The record of sales of the manufacturing companies for the past several years, however, indicates very clearly the tendency toward 60-cycle power generation and distribution. In fact, west of Chicago and all through the mountain districts where electrification holds out its greatest promise of return, no 25-cycle power is available, while 60-cycle transmission lines are being rapidly extended over wide areas and fed from generating stations of large capacity. Even in the east, the higher frequency power supply is increasing in a faster ratio than the lower, so that the prospective 25-cycle single-phase power user appears to be confronted with the alternative of financing and operating his own isolated power house with the attendant disadvantages that may go with it, or of purchasing 60-cycle power with the necessary substations that are sometimes held up as such a serious handicap to the success of the direct locomotive.

Electric power cannot always be advantageously purchased along the railroad right of way and in certain instances a railroad company power house is necessary to the success of the project. No one can reasonably deny, however, that in this age of combining the resources of similar interests, it would be of great future advantage to install the same frequency apparatus as that in service in the immediate vicinity. While not so serious as the handicap of differing track gauge, it is very important that a new power supply shall conform in frequency, and if possible also in voltage, to the adjoining installations with which it may some day be advantageously connected and operated in common. An electric locomotive that requires single phase 25-cycle power supply carries with it the present and probable future handicap of not fitting in with the rest of the picture, and from the view point of power generation and distribution the single-phase current type of electric locomotive must be considered an abnormal development.

Among others, two far reaching facts have been demonstrated by the Chicago, Milwaukee & St. Paul electrification.

1. The direct current motor locomotive operating at 3000 volts can successfully haul both passenger and freight trans-continental trains over mountain grades with a modest expenditure in the cost of substations and copper.

2. The direct current motor locomotive fed through synchronous motor-generator sets can be supplied with power from general purpose transmission lines without causing interference with other loads carried over the same lines.

The fourteen substations supplying 440 route miles of the Chicago, Milwaukee & St Paul electrification have a total capacity of 59,000 kw. and provide ample capacity for the largest daily tonnage movement with one motor-generator set reserved as a spare in each substation. It has also been demonstrated that in cases of emergency, a substation can be shut down and power fed through from the two adjoining substations and all trains moved by operating at half speed with motors in series. The expenditure in substations, trolley and feeder copper on the St. Paul electrified zone appears ample to take care of all normal and emergency operating needs and yet amounts to only approximately 25 per cent of the total cost of electrification.

The railway load has been taken on by the Montana Power Company without causing any interference with its lighting and industrial load. This fact is the more remarkable considering the ragged load curve necessarily produced by heavy trains operating at infrequent intervals over a very broken profile. Both units of the synchronous motor-generator sets permit a reversal of their normal functions when power returned by regenerative braking of down grade trains is not locally absorbed by other trains running between the adjoining substations. Under all conditions of operation, the power-factor of the substation load is approximately 100 per cent or slightly leading, thus constituting a most desirable load notwithstanding the fluctuating character of the load curve.

The necessity of treating the engineering problem of electrification broadly has been dwelt upon somewhat at length as it seems to the writer to be sometimes obscured by too great enthusiasm over the attractive claims of some one piece of apparatus that after all constitutes but one item of expense in the cost of installing and operating an electrified railway. The facts available justify making the general statement that any track carrying tonnage enough to warrant electrification can be equipped and operated for less money with direct-current locomotives and motor cars than with any alternating-current motor equipment thus far developed. And the reason for this rests largely in the fact that the direct-current motive power equipment fits in admirably, not only with the requirements of general railroad service but utilizes to best advantage the generating and transmission facilities in universal use throughout the country.

We are all willing to pay full tribute to the wonderful manner in which the engineering problems of electrification have been met and successfully overcome. The expense to the manufacturers of research and experimental work has been tremendous but it has resulted in perfecting the electric locomotive in twenty years to the point where its fitness for general haulage service is admitted as superior to that of the steam engine itself, notwithstanding the fact that the present state of development of the steam engine may be partly credited to the growing competition of the electric locomotive. With full acknowledgement that the engineers have made it possible to place the electric locomotive upon the rails of our trans-continental roads, we now look to the railway operator to determine the economic and operating return upon the investment made. Unfortunately, many of the steam road tracks electrically equipped are in the nature of tunnels and terminals, and in certain instances impose an additional burden of operating expense upon the road. The more extensive installations, however, are giving evidence of attractive savings in operating expenses and improved service over the previous steam engine operation.

The designing engineer may be fully informed of the technical points of construction and performance but the electric locomotive will not come into its own until the railway operator fully grasps from personal experience what it means in the handling of traffic to have at his disposal a type of motive power that gives release from many of the limitations inherent in steam engine operation. All the advantages of electric operation must pass the final test of economic return upon the additional capital charge incurred. Some of the more apparent savings can be readily determined. For example, the annual cost of power can be contrasted with the previous cost of coal as charged on the books, but in this connection few roads make any allowance for transportation charges on company freight and the price of coal carried on the books is often the cost at the mines or point of delivery to the right of way.

The actual cost to the railroad company of the fuel consumed on the steam engines presents an interesting study from the standpoint of electric operation. The cost of hauling company coal from mines to the several coaling stations is readily determined as is also the expense incurred at these stations. What is not so apparent, however, is that this coal retraces its journey, this time on the engine tender, and that the annual ton mile movement of company coal in cars and on tender may readily reach 10 per cent of the total gross ton miles carried over the rails. As an example, consider the performance of a Mikado engine on a 2 per cent grade. The following data apply:

Weight on drivers	220,000 lb.
Total weight of engine	280,000 lb.
Weight of tender	180,000 lb.
Total weight engine and tender	460,000 lb.
Tractive effort due to 2 per cent grade	40 lb.
Tractive effort due train resistance	6 lb.
Coeff. of adhesion taken	20 per cent
Tractive effort at 20 per cent of driver weight	44,000 lb.
Total hauling capacity 2 per cent grade	956 tons
Rated load behind tender	726 tons

After deducting the engine and tender weight of 230 tons from the total moving capacity of 956 tons there remains only 726 tons that can be hauled behind the tender.

$$\text{Ratio tender to trailing load} = \frac{726}{90} = 12.4$$

per cent

In other words, the non-revenue tender ton mileage on a 2 per cent grade with a Mikado engine of the above capacity will demand running one additional train in every eight, just for the purpose of carrying the necessary coal and water consumed on the engine. The Mallet engine with its greater weight is not in such bad case; but it is a fair statement that steam engine operation of the mountain divisions of our trunk lines demands the equivalent addition of one train in every ten run, just to furnish coal and water to the boilers.

The electric economist may take advantage of this credit in several ways, but perhaps less complication will result from considering that the company coal and tender ton mile movement of steam engine operation becomes revenue tonnage with electric locomotives. Not only can the electric locomotive haul heavier trains at higher speeds on the ruling grade, but its freedom from coal and water necessities inherently raises the average train tonnage some 10 per cent with no increase whatever of driver weights.

In view of the increasing demands of labor there is no question but that the future of our railroads depends upon increasing both the weight and average speed of trains. Increasing traffic has so crowded certain tracks as to seriously restrict the daily tonnage movement and the relief afforded by electrification can be secured, in many instances, with less capital expenditure than by adding more tracks, reducing grades or building tunnels at enormous cost. Even after such expensive improvements are made, there is no gain made in methods of operation if the steam engine is retained with its attendant handicaps.

The expediency of electrification may therefore be summed up as desirable from two standpoints.

1. Increased track tonnage capacity provided by reason of heavier trains, higher speeds and reduction in the number of daily train movements.
2. The cost of electrification in many cases investigated is found to be considerably less than the cost of corresponding improvements with continued steam engine operation and there is, also, a return upon the additional capital charge incurred for electrification of from 15 to 20 per cent resulting from the savings in operating expense over steam operation.

Here then, is the economic force that is pushing the electric locomotive on public attention: Relief from track congestion can be found by electrifying for less money expenditure than in any other way, and in addition such economies in operation are secured as to pay a very attractive return upon the investment.

The construction engineers have accomplished the hardest part of their task. They have developed the electric locomotive to the point of a successful operating machine, possessing great reliability in service, very efficient in its conversion of electric into mechanical power and capable of hauling the heaviest trains at the highest speeds permitted by the profile and alignment of the track. The railroad operator has yet to be heard from, partly because no considerable stretch of track has been in operation until recently, but largely because it takes time to jar him loose from the traditions of a life time of service behind the steam engine.

PROGRESS OF HIGH VOLTAGE DIRECT CURRENT RAILWAYS

By G. H. Hill

Assistant Engineer Railway and Traction Department, General Electric Company

The author shows the economic reasons that led to the adoption of higher potentials in railway work and points out that it is the inherent characteristics of higher potential direct-current apparatus that have led to its extensive adoption for interurban railways, and also, for the heaviest kinds of steam railroad electrification.—Editor.

Statistics, covering the progress in the art or industry measured by the extent of its use from year to year, are not only interesting and instructive, but if favorable, help inspire confidence in the stability of the industry and to secure the participation and co-operation of capital for continued progress.

A close study of the accompanying tabulated data of high voltage direct-current railways clearly indicates that the favorable showing is the outcome of general and successful use, and is not the result of local enthusiasm or individual prejudice. The installations are widely distributed and include all varieties of service. The results accomplished have stood the critical analysis of independent engineers and have exceeded the expectations of practical operators. In no case has the high voltage direct-current system been abandoned. On the contrary many roads have been converted from 600 volts d-c. or single-phase to high tension direct-current and in no case has the system failed to meet the economic success anticipated. Emphasis can especially be placed on the freedom from apparatus failures and low maintenance as contributing a large measure of the practical success.

The advent of the high voltage direct-current electric railway dates from 1907 when the first interurban line was equipped with 1200-volt apparatus.

Up to this time electric railways had experienced a phenomenal growth not alone in city service but also in suburban and interurban extensions.

The 600-volt system was universally accepted as the standard and the electric apparatus comprising it had been developed to a high state of perfection. Enthusiasm in electric railway construction was at high pitch and on every hand the city systems were being rapidly extended to the suburbs and in many cases elaborate interurban lines were built and being planned.

It soon became apparent, however, that promoters of these interurban projects had in many cases been too optimistic in their expectations of creating traffic and that new forms of competition, for which the automobile is chiefly responsible, were making such heavy inroads on the income that the financial outlook of the electric interurban was not a satisfactory one.

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

Compiled by GENERAL ELECTRIC COMPANY
Railway and Traction Engineering Department

Schenectady, N. Y. Oct. 1, 1916 W. D. B.

	PERMANENT WAY				OVERHEAD CONSTRUCTION					POWER			ROLLING STOCK								
					Trolley or Third Rail		Transmission Line			Generating Stations	Substations		Motor Car Equipment					Pass. Trailers	Locomotives		
	Length of Route	Length of Track (Single Track Basis)	Miles of 600-Volt City Operation	Track Gauge S.—4 ft. 8½ in. Weight of Rail	Type	Voltage	Voltage	Frequency	Phases	Number, Capacity and Type of Generator Equipment	No. of Subs.	Type, Capacity and Voltage of Apparatus	Number Motor Cars	Weight Eq'p't Tons	Principal Motor Equipment	Free Running Speed	Seating Capacity	Number	Number	Weight Eq'p't	Motor Equipment
Aroostook Valley Ry. Co., Presque Isle, Maine	32	38	0	S-70	Direct Suspension	1200	11,000	60	3	Power purchased from Maine & N. Brunswick El. Pr. Co.	2	(4) TC-6-200-1200-600/1200 H.R. Transformers G.E.	4 1 Ex.	30 30	(4) G.E. 217-600 (4) G.E. 205-600 Volts	30	50	Fgt.	1	40	(4) G.E. 206-600 Volts
Butte, Anaconda & Pacific Ry., Butte, Mont.	30	114	0	S-85	11 Point Catenary Trolley	2400	100,000	60	3	Power purchased from Montana Power Co. (Hydro Elec.)	2	(7) 1000-kw. Syn. M.G. Sets, 1200/2400 Volts G.E.	0	...	....	..	..		28 3	80 40	(4) G.E. 229-1200 Volts (2) G.E. 229-1200 Volts
Canadian Northern Ry., Montreal, Can.	10	30	0	S-90	Catenary Trolley	2400	11,000	60	3	Power purchased from Montreal Lt., Ht. & Pr. Co.	1	(2) 1500-kw. Syn. M.G. Sets, 1200/2400 Volts-11,000 Volts G.E.	8	80	(4) G.E. 239-1200 Volts	50	70		6	83	(4) G.E. 229-1200 Volts
Central California Traction Co., Stockton, Cal.	69	71	7	S-75	Third Rail and Catenary	1200	60,000	60	3	Power purchased from Western States Gas & Elec. Co.	3	(1) 300-kw., (2) 500-kw. and Syn. M.G. Sets, 1200 Volts, G.E.	8	38	(4) G.E. 205-1200 Volts	45	46 50	2	3	41 46	(4) G.E. 205-1200 Volts
Charles City Western Ry., Charles City, Iowa	25	30	0	S-70	Direct Suspension	1200	2,300	60	3	Power purchased from Cedar Valley Pr. Co.	1	(2) 300-kw., 1200-volt M.G. Sets, 2300-volt G.E.	4	11 21 28	(3) (2) G.E. 217 (1) (4) G.E. 217	30	34 52	...	1	35	(4) G.E. 205-600 Volts
Chicago, Milwaukee & St. Paul Ry.	440	650	0	S-90	Catenary Double Trolley	3000	100,000	60	3	Power purchased from Montana Pr. Co. (Hydro Elec.)	14	(23) 2000-kw. M.G. Sets 9–1500-kw. M.G. Sets, 1500/3000 Volts G.E.	......	...	....	..	..	...	30 12 2	282 300 70	(8) G.E. 253-1500 Volts (4) G.E. 255-1500 Volts
Chicago, Milwaukee & St. Paul Ry., Great Falls Terminal	4	7	0	S-90	Catenary Trolley	1500	6,600	60	3	Power purchased from Montana Pr. Co. (Hydro Elec.)	1	1–300-kw., 1500-volt M.G. Set, 6600-volt G.E,	......	...	....	..	..		1	50	(4) G.E. 207-750 Volts
Davenport & Muscatine Ry., Davenport, Iowa	30	30	4	S-70	Catenary Trolley	1200	33,000 Y	60	3	Power purchased from Moline-Rock Island Mfg. Co.	2	(4) 300-kw., 1300-volt M.G. Sets G,E.	6 1 Ex.	32	(4) G.E. 217-600 Volts	39	52	0	....	..	
Fort Dodge, Des Moines & So. Ry., Boone, Iowa	120	145	5	S-70	Direct Suspension	1200	22,000 △	25	3	6500-kw. Curtis Turbine 4000-kw. Curtis Turbine	6 1 Port	(8) 400-kw., 600-volt Syn. Conv. (2 in Series) (1) 300-kw., 1200-volt Syn. Conv. G.E.	10	42	(4) G.E. 205-600 Volts	45	50	8	7 4	40 60	(4) G.E. 206-600 Volts (4) G.E. 251-600 Volts
Grand Rapids, Holland & Chicago Ry., Grand Rapids, Mich.	45	77	5	S-60 S-70	Direct Suspension	1200	20,000	30	3	Power purchased from Consumers Pr. Co.	1	(2) 500-kw., 1200-volt Syn. Con. G.E.	10	35	(4) W-333-600 Volts	60	55	0	0	..	....
Hocking-Sunday Creek Traction Co., Nelsonville, Ohio	14.8	15.2	0	S-70	Direct Suspension	1200				Power purchased from Hocking Pr. Co., 2300-volt, 60-cy.	1	(2) 200-kw., 600-volt Syn. Con. West	3	23.5	(4) W-324-600 Volts	42	48	0	0	..	... .
Indianapolis & Louisville Traction Ry. Co., Scottsburg, Ind.	41	41	Traffic Rights 75	S-75	Direct Suspension	1200	none			4 (300-kw.) 600/1200-volt D-C. Engine Driven Generators	0	Direct Feed	10	34	(4) G.E. 205-600 Volts	53	50	0	0	..	....
Iowa Ry. & Lt. Co., Cedar Rapids, Iowa	28	28		S-70	Direct Suspension	1200	16,500	60	2	Eng. Drive A.C. 7000-kw., Turbine Units 10250-kw., 2300-volt, 2-phase	2	(1) 500-kw., 2-unit, 600/1200-volt Syn. M.G. Set (1) 500-kw., 600/1200-volt Syn. Con. G.E.	5	45	(4) G.E. 205-600 Volts	41		5	1	50	(4) G.E. 207-600 Volts
Jefferson Co. Traction Co., (Eastern Texas Elec. Co.), Beaumont, Texas	20	20	4	S-70	Catenary	1200	none			Power purchased from Beaumont & Pt. Arthur Lt. & Pr. Co., Sub. in P. H.	2	2-Syn. M.G. Sets, 60-cycle, 2300-volt, 1200-volt, d-c. G.E.	6 1 Ex.	30	(4) G.E. 233-600 Volts	45	46	4	0	..	....
Kansas City, Clay Co. & St. Joseph Ry.	72	74	9	S-70	Catenary	1200	33,000	25	3	Power purchased from Metropolitan St. Ry. Co., St. Turbine.	3	(6) 500-kw., 750-r.p.m., 1200-volt Syn. Con. Con. (1500 Volts incl.) West	22 5	41	(4) G.E. 225-750 Volts (4) W-327-750 Volts	60	66	0	0	..	....
Lake Erie & Northern Ry., Ontario, Can.	54	56	1	S-85	Catenary Trolley	1500	20,000	25	3	Power purchased from Hydro Elec. Pr. Commission of Co.	3	(3) 500-kw., 1400-volt Syn. Con. (1 Portable Cand., G.E.	6	40	(4) W-85-h.p., 750 Volts	45	70	3	2	60	(4) W. 562-D-5, 750 Volts
London & Port Stanley Ry., London, Ont.	24	30	0	S-70	Catenary	1500	13,200	25	3	Power purchased from Ontario Hydro Elec. Pr. Com.	2	(4) 500-kw., 1500-volt Syn. Con., West.	6	51	(4) G.E. 225-750 Volts	50	56	6	3	63	(4) G.E. 251-750 Volts
Maryland Electric Ry. Co., Annapolis, Md.	25.3	32.3	0	S-80	Catenary	1200	13,200	25	3	Power purchased from Consol. Gas, Elec. Lt. & Pr. Co.	2	(4) 300-kw. Syn. Con., 1200-volt, d-c., West.	12 1 Ex.	40	(4) W-317-A-4, 600 Volts	45	52	0	1	52	(4) W-562-600 Volts
Michigan Ry. Co., Kalamazoo-Grand Rapids Allegan-Battle Creek	92	95	4	S-80	Third Rail Overrunning Catenary	2400	70,000	30	3	Power purchased from Consumers Pr. Co., Jackson, Mich.	2	(8) 500 kw., 1200/2400-volt Syn. Con. (2 in Series) G.E.	8 6	70 65	(4) G.E. 239 (2) G.E. 239-1200 Volts	70 50	52	Fgt.	4 Exp.	55	(4) G.E. 239-1200 Volts
Michigan Ry., Flint-Bay City	46	46	5	S-80	Third Rail Overrunning Direct Suspension	1200	20,000	60	3	Power purchased from Consumers Pr. Co., Jackson, Mich.	2	(4)500-kw., 1200-volt, d-c.; 5000-volt a-c. Syn. Motor Generator Sets G.E.	12	40	(4) W-333-600 Volts	60	55	0	0	..	....
Michigan United Traction Co., Jackson, Mich.	150	150	0	S-70	Overrunning Third Rail Direct Suspension Trolley	1200	44,000	60	3	Power purchased from Consumers Pr. Co., Jackson, Mich.	3	(9) 500-kw., 1200-volt, d-c.; 5000-volt, a-c. Syn. Motor Generator Sets G.E.	40 4	45	(4) W-333-600 Volts (4) G.E. 254-600 Volts	60	55	5	0	..	....
Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wisc.	135	135	47	S-80	Catenary Trolley	1200	13,200 38,000	25	3	Part of an Extensive System	6	(12) 300-kw. } Syn. Con., 600-volt, 2 in Series (5) 500-kw. } G.E.	11 15	43.5 39.5	(4) G.E. 205-600 Volts (4) G.E. 207-600 Volts	45	64	59	0	..	....
Nashville-Gallatin Inter. Ry., Nashville, Tenn.	27	27	3.5	S-70	Direct Suspension Trolley	1200	33,000 Y	60	3	Power purchased from Nashville Ry. & Lt. Co.	1	(3) 200-kw., 600-volt Syn. Con., 2 in Series, G.E.	4 1 Ex.	38	(4) G.E. 205-600 Volts	40	50	0	0	..	....
Oakland, Antioch & Eastern Ry., San Francisco, Cal.	118	118	4	S-70	Catenary	1200	11,000	60	3	Power purchased from Great Western Pr. Co.	5 1 Port	(6) 750-kw., 1300-volt Syn. M.G. Sets; 11,000-volt, a-c., West. (1) 300-kw., 1200-volt Syn. M.G., G.E.	3 G.E. 15 W.	40	(4) G.E. 205-1200 Volts (4) W-322-600 Volts	55	50	18	2 2 2	49 62 35	(4) W-308-B, 600 Volts (4) W-321-600 Volts (4) G.E. 205-1200 Volts
Ogden, Logan & Idaho Ry., Ogden, Utah	97	97	5	S-70	Catenary	1500	44,000	60	3	Power purchased from Utah Power & Lt. Co.	3 1 Port	(4) 500-kw., 1500-volt Syn. M.G. Sets; 2300-volt, a-c., West.	18	45	(4) W-334-750 Volts	50	76	7	3	50	(4) W-562-A, 750 Volts
Oregon Electric Ry., Portland, Ore.	154	180	25	S-70 S-75	Catenary	1200	60,000	33	3	Power purchased from Portland Ry. & Lt. Co.	8 1 Port	(6) 500-kw., 600/1200-volt Syn. Con. (7) 500-kw., 1200-volt Syn. Con. G.E.	53 8 Ex. 1 W.	45	(4) G.E. 205 (4) G.E. 222-600 Volts (4) W-321-600 Volts	45	62	28	6 4	60 50	(4) G.E. 212-600 Volts (4) G.E. 207-600 Volts
Orleans & Kenner Ry., New Orleans, La.	11.6	12.5	4.3	S-70	Catenary	1200	6,600	60	3	Power purchased from N.O. Ry. & Lt. Co., New Orleans	1	(2) 200-kw., 600-volt Syn. Con., 2 in Series, West.	4	32.5	(4) W-50 h.p., 600 Volts	40	52	0	0	..	....
Pacific Electric Ry., Los Angeles, Cal.	57	91.5	1.7	S-70	Catenary	1200	15,000	50	3	Power purchased from Pacific	5	(5) 1000-kw., 1200-volt Syn. M.G. Sets;	24	54	(4) G.E. 254-600 Volts	60	60	0	10	65	(4) W-308-600 Volts

POWER — Substations: No. of Subs.	Type, Capacity and Voltage of Apparatus	ROLLING STOCK — Motor Car Equipment: Number Motor Cars	Weight Eq'p't Tons	Principal Motor Equipment	Free Running Speed	Seating Capacity	Pass. Trailers: Number	Locomotives: Number	Weight Eq'p't	Motor Equipment	Control (Pass.): Type A=Auto. NA=Non-Auto. K=Cylin.	Multiple Unit Operation	Single or Double End Operation	Speed on Half Voltage	Heaters	Air Brakes: Type of Air Brakes	Type of Compressor	Capacity—Ft./Min.	Voltage	Date Started High Voltage Operation	Previous System of Operation	Chief Points Connected
2	(4) TC-6-200-1200-600/1200 H.R. Transformers G.E.	4 1 Ex.	30 30	(4) G.E. 217-600 (4) G.E. 205-600 Volts	30	50	Fgt.	1	40	(4) G.E. 206-600 Volts	M-NA (2) K	Yes	D	Half	1200	St. & St. Auto. G.E.	C.P.-22 C.P.-29	24	600	July 1910	Steam & New Exten.	Presque Isle, Caribou, Washburn, Swedcn
2	(7) 1000-kw. Syn. M.G. Sets, 1200/2400 Volts G.E.	0	...	....	..	..		28 3	80 40	(4) G.E. 229-1200 Volts (2) G.E. 229-1200 Volts	......	.....	..	....	2400 Elec. Hot Air	W. St. & Auto.	C.P. 26	100	600	June 1913	Steam	Butte, Anaconda Mines & Smelters
1	(2) 1500-kw. Syn. M.G. Sets, 1200/2400 Volts-11,000 Volts G.E.	8	80	(4) G.E. 239-1200 Volts	50	70		6	83	(4) G.E. 229-1200 Volts	M NA	Yes	D	Half	2400 Volts Elec. Hot Air	Comb. St. & Auto. G.E.	C.P. 33	100	2400	Bldg.	New Steam Terminal	Montreal, through Tunnel to Mt. Royal
3	(1) 300-kw., (2) 500-kw. and Syn. M.G. Sets, 1200 Volts, G.E.	8	38	(4) G.E. 205-1200 Volts	45	46 50	2	3	41 46	(4) G.E. 205-1200 Volts	M NA	Yes	D	Half	1200	West. G.E. Comp.	C.P. 22	24	600	June 1908	New	Stockton & Sacramento
1	(2) 300-kw., 1200-volt M.G. Sets, 2300-volt G.E.	4	11 21 28	(3) (2) G.E. 217 (1) (4) G.E. 217	30	34 52	...	1	35	(4) G.E. 205-600 Volts	K R-200	No	D	Half	1200	St. & Auto. Straight G.E.	C.P.-29 C.P.-30	27 30	1200	July 1915	Steam	Charles City & Marble Rock
14	(23) 2000-kw. M.G. Sets 9–1500-kw. M.G. Sets, 1500/3000 Volts G.E.	......	...	....	..	..	...	30 12 2	282 300 70	(8) G.E. 253-1500 Volts (4) G.E. 255-1500 Volts	......			....	Oil Fired Steam	W. St. & Auto.	(2) C.P. 34	24 150	3000	Dec. 1915	Steam	Harlowton, Montana to Avery, Idaho
1	1-300-kw., 1500-volt M.G. Set, 6600-volt G.E.	......	...	....	..	..		1	50	(4) G.E. 207-750 Volts	......	.....	..	....		W. St. & Auto	(2) C.P. 29	24 27	1500	Feb. 1915	Steam	Great Falls Yards and Terminal Station
2	(4) 300-kw., 1300-volt M.G. Sets G,E.	6 1 Ex.	32	(4) G.E. 217-600 Volts	39	52	0	....	..		K	No	S	Half	....	West. D-2-K	W.	18	1200	Aug. 1912	New	Davenport, Muscatine
6 1 Port	(8) 400-kw., 600-volt Syn. Conv. (2 in Series) (1) 300-kw., 1200-volt Syn. Conv. G.E.	10	42	(4) G.E. 205-600 Volts	45	50	8	7 4	40 60	(4) G.E. 206–600 Volts (4) G.E. 251-600 Volts	K	Yes	S	Full	Hot Water	West. St. & Auto.	C.P. 28	25	600	Sept. 1911	600 Volts	Fort Dodge, Boone, Des Moines & Rockwell City
1	(2) 500-kw., 1200-volt Syn. Con. G.E.	10	35	(4) W-333-600 Volts	60	55	0	0	..	....	M NA	Yes	S	Full	Hot Water	West.	Dyna. Comp.	25	1200	May 1915	600 Volts	Grand Rapids, Holland & Lake Resorts Macatawa and Saugatuck
1	(2) 200-kw., 600-volt Syn. Con. West	3	23.5	(4) W-324-600 Volts	42	48	0	0	..	... .	HL	Yes	D	Half	Hot Air	W.-A.M.M.	W. D.-2K.	25.3	1200	May 1915	500 Volts	Nelsonville & Athens
0	Direct Feed	10	34	(4) G.E. 205-600 Volts	53	50	0	0	..	....	M-NA	Yes	S	Full	Hot Water	Emergency Straight G.E.	C.P. 22	24	600	Oct. 1907	New	Seymour & Sellersburg & Indianapolis & Louisv., via 600 Volts
2	(1) 500-kw., 2-unit, 600/1200-volt Syn. M.G. Set (1) 500-kw., 600/1200-volt Syn. Con. G.E.	5	45	(4) G.E. 205-600 Volts	41		5	1	50	(4) G.E. 207-600 Volts	M-K	Yes	D	Full		G.E. Straight Air	C.P. 28	25	600	Operated at 600 Volts	600 Volts	Cedar Rapids, Iowa City & Toledo
2	2-Syn. M.G. Sets, 60-cycle, 2300-volt, 1200-volt, d-c. G.E.	6 1 Ex.	30	(4) G.E. 233-600 Volts	45	46	4	0	..	....	K	No	S	Half	....	....	W.	25	600	1914	New	Beaumont & Port Arthur
3	(6) 500-kw., 750-r.p.m., 1200-volt Syn. Con. Con. (1500 Volts incl.) West	22 5	41	(4) G.E. 225-750 Volts (4) W-327-750 Volts	60	66	0	0	..	....	M-A HL-A	Yes	D	Half	Hot Water	Comb. St. & Auto. G.E.	C.P. 29	25	1200	Jan. 1913	New	Kansas City, St. Joseph & Excelsior Sprg.
3	(3) 500-kw., 1400-volt Syn. Con. (1 Portable Cand., G.E.	6	40	(4) W-85-h.p., 750 Volts	45	70	3	2	60	(4) W. 562-D-5, 750 Volts	West. A-B	Yes	D	Half	1500 Volts	West Automatic	Dyna. Comp.	25	1500	Feb. 1916	New	Galt, Brantford, Simcoe & Port Dover
2	(4) 500-kw., 1500-volt Syn. Con., West.	6	51	(4) G.E. 225-750 Volts	50	56	6	3	63	(4) G.E. 251-750 Volts	M-NA	Yes	D	Half	Hot Water	Comb. St. & Auto. G.E.	C.P. 29	25	1500	Aug. 1915	Steam	London, St. Thomas & Port Stanley
2	(4) 300-kw. Syn. Con., 1200-volt, d-c., West.	12 1 Ex.	40	(4) W-317-A-4, 600 Volts	45	52	0	1	52	(4) W-562-600 Volts	H-L-F NA	Yes	D	Half	Hot Air	W.-A.M.M.	D.-2K.	25.3	1200	Jan. 1914	6600 Volts, 1φ & Steam	Baltimore & Annapolis
2	(8) 500 kw., 1200/2400-volt Syn. Con. (2 in Series) G.E.	8 6	70 65	(4) G.E. 239 (2) G.E. 239-1200 Volts	70 50	52	Fgt.	4 Exp.	55	(4) G.E. 239-1200 Volts	M-NA	Yes	S	Full	Hot Air	Comb. St. & Auto. G.E.	C.P. 28	25	60	May 1915	New	Kalamazoo, Grand Rapids, Allegan & Battle Creek
2	(4)500-kw., 1200-volt, d-c.; 5000-volt a-c. Syn. Motor Generator Sets G.E.	12	40	(4) W-333-600 Volts	60	55	0	0	..	....	HL	Yes	S	Full	1200 Volts	West. A.M.M.	Dyna. Comp.	25	1200	May 1914	New & 600 Volts	Flint & Saginaw Bay City
3	(9) 500-kw., 1200-volt, d-c.; 5000-volt, a-c. Syn. Motor Generator Sets G.E.	40 4	45	(4) W-333-600 Volts (4) G.E. 254-600 Volts	60	55	5	0	..	....	HL	Yes	S	Full	1200 Volts	West. A.M.M.	Dyna. Comp.	25	1200	Operated at 600 Volts	600 Volts	Kalamazoo, Battle Creek, Jackson, Lansing, Owosso
6	(12) 300-kw. } Syn. Con., 600-volt, 2 in Series (5) 500-kw. } G.E.	11 15	43.5 39.5	(4) G.E. 205-600 Volts (4) G.E. 207-600 Volts	45	64	59	0	..	....	M NA	Trailers Only	D	Full	Hot Water	West. D.-3 N.			600/1200	Mar. 1910	3300 Volts Single-phase	Milwaukee E. Troy Burlington & Watertown
1	(3) 200-kw., 600-volt Syn. Con., 2 in Series, G.E.	4 1 Ex.	38	(4) G.E. 205-600 Volts	40	50	0	0	..	....	K	No	S	Half	Hot Air	G.E. Straight	C.P. 29	25	1200	Apr. 1915	New	Nashville & Gallatin
5 1 Port	(6) 750-kw., 1300-volt Syn. M.G. Sets; 11,000-volt, a-c., West. (1) 300-kw., 1200-volt Syn. M.G., G.E.	3 G.E. 15 W.	40	(4) G.E. 205-1200 Volts (4) W-322-600 Volts	55	50	18	2 2 2	49 62 35	(4) W-308-B, 600 Volts (4) W-321-600 Volts (4) G.E. 205-1200 Volts	M-NA W-HL	Yes	D	Full	1200 Volts	West.	Dyna. Comp.	2x25	1200	Sept. 1913	New	Oakland, Antioch, Sacramento & San Francisco
3 1 Port	(4) 500-kw., 1500-volt Syn. M.G. Sets; 2300-volt, a-c., West.	18	45	(4) W-334-750 Volts	50	76	7	3	50	(4) W-562-A, 750 Volts	West. HL-NA	Yes	D	Half	1500 Volts	West. A.M.M.	Dyna. Comp.	32	1500	Apr. 1915	New	Ogden, Logan & Preston
8 1 Port	(6) 500-kw., 600/1200-volt Syn. Con. (7) 500-kw., 1200-volt Syn. Con. G.E.	53 8 Ex. 1 W.	45	(4) G.E. 205 (4) G.E. 222-600 Volts (4) W-321-600 Volts	45	62	28	6 4	60 50	(4) G.E. 212–600 Volts (4) G.E. 207-600 Volts	M-A	Yes	D	Full	Hot Water 1200 Volts	West. D-3		35	1200	Aug. 1912	600 Volts & New	Portland, Salem, Albany & Eugene
1	(2) 200-kw., 600-volt Syn. Con., 2 in Series, West.	4	32.5	(4) W-50 h.p., 600 Volts	40	52	0	0	..	....	HL	Yes	D	Full	None	West Automatic	......	..	600	Operated at 600 Volts	New	New Orleans & Kenner
5	(5) 1000-kw., 1200-volt Syn. M.G. Sets;	24	54	(4) G.E. 254-600 Volts	60	60	0	10	65	(4) W-308-600 Volts	M-A	Yes	D	Full	1200	West.	Dyna	35	1200	May	600 Volts	Los Angeles, San Bernardino &

Oregon Electric Ry., Portland, Ore.	154	180	25	S-70 S-75	Catenary	1200	60,000	33	3	Power purchased from Portland Ry. & Lt. Co.	8 1 Port	(6) 500-kw., 600/1200-volt Syn. Con. (7) 500-kw., 1200-volt Syn. Con. G.E.	53 8 Ex. 1 W.	45	(4) G.E. 205 (4) G.E. 222-600 Volts (4) W-321-600 Volts	45	62	28	6 4	60 50	(4) G.E. 212-600 Volts (4) G.E. 207-600 Volts	M-A	Yes
Orleans & Kenner Ry., New Orleans, La.	11.6	12.5	4.3	S-70	Catenary	1200	6,600	60	3	Power purchased from N.O. Ry. & Lt. Co., New Orleans	1	(2) 200-kw., 600-volt Syn. Con., 2 in Series, West.	4	32.5	(4) W-50 h.p., 600 Volts	40	52	0	0	..	....	HL	Yes
Pacific Electric Ry., Los Angeles, Cal.	57	91.5	1.7	S-70 S-75	Catenary	1200	15,000	50	3	Power purchased from Pacific Lt. & Pr. Corp. & So. Cal. Edison Co.	5	(5) 1000-kw., 1200-volt Syn. M.G. Sets; 15,000-volt, a-c. G.E.	24 3 44	54 44	(4) G.E. 254-600 Volts (4) G.E. 222-600 Volts (4) W-333-600 Volts	60	60	0	10	65	(4) W-308-600 Volts	M-A HL-A	Yes
Piedmont & Northern Lines, Charlotte, N. C.	125	125	10	S-80	Catenary	1500	2,400 13,200 2,000 44,000	60	3	Power purchased from Southern Pr. Co., (Hydro Elec.)	8 1 Port	(12) 500-kw., 1500-volt, 3-unit M.G. Sets (6) 250-kw. Syn. Con., 2 in Series, for 1500-volt, West.	31 2	42	(4) W-321-750 Volts (2) G.E. 217-750 Volts	45	60	0	6 W. 6 G.E.	55 64	(4) W-308-750 Volts (4) G.E. 212-750 Volts	West. HL R-200	Yes
Pittsburgh & Butler St. Ry. Co., Pittsburgh, Pa.	33	33	5	5 ft. 2½ in. 80	Catenary	1200	22,000	25	3	(1) 1500-kw., (2) 750-kw., Turbine Generator Sets, 6600 volts. West.	2	(4) 300-kw., 1200-volt, Syn. Con., G.E.	13	38	(4) G.E. 225-600 Volts	47	48	0	0	..	....	M-NA	Yes
Pittsburgh, Harmony, Butler & Newcastle Ry.	71	82	4	5 ft. 2½ in. 80	Direct Suspension Double Trolley	1200	13,200	60	3	(2) 1500-kw., Turbine Generators, 13,200 G.E. also purchase Duquesne Lt. Co.	4	(6) 400-kw., 1200-volt, 3-unit Syn. M.G. Sets (1) 500-kw., 1200-volt, 3-unit Syn. M.G. Sets; G.E. (2) 250 kw., Syn. Con., 2 in. Series (2) 500 kw., 1200-volt, 3 unit and (2) 200-kw., 2-unit, 600-volt Syn. M.G. Sets, 2 in Series, West.	22 G.E. 7 W.	35 32	(4) G.E. 205-600 Volts (4) W-322-600 Volts	45	60	51 Fgt.	0	..	....	M-A	Yes
Salt Lake & Utah Ry., Salt Lake City, Utah	67	67	0	S-75	Catenary Trolley	1500	44,000	60	3	Power purchased from Utah Pr. & Lt. Co.	4	(12) 250-kw. Syn. Con., 750-volt, 2 in Series, 1 spare, West	18 2	44 11½	(4) W-334-E-750 Volts (2) W-530-750 Volts	50	62	0	1	40	(4) W-334-E-6, 750 Volts	HL-NA R-200	Yes
Shore Line Electric Ry. Co., Saybrook, Conn.	56.4	68	10.3	S-70	Catenary and Direct Suspension	1200	11,000	25	3	(2) 1500-kw., Turbine Generator, 11,000-Volt, G.E. Saybrook	2	(8) 200-kw., 600-volt Syn. Con., 2 in series, G.E.	14 2 8 W.	30	(4) G.E. 217-600 Volts (4) G.E. 205-600 Volts (4) W-327-600 Volts	43	44	0	0	..	....	M-NA HL-NA	Yes
So. Cambria Ry. Co., Johnstown, Pa.	23	24	0	S-70	Direct Suspension Double Trolley	1200	none			(2) 300-kw., 600/1200-Volt, (2) 500-kw., 600/1200-volt, Engine Driven Gen., G.E.	0	Direct Feed	8 G.E. 2 W.	38	(4) G.E. 205-600 Volts (4) G.E. 217-600 Volts	43	46	0	0	..	....	M-A K	Yes No
So. Illinois Ry. & Pr. Co., Harrisburg, Ill.	15	17	0	S-80	Catenary Trolley	1200	33,000	60	3	(2) 1000-kw., 2300-volt Curtis Turbine at Muddy	1	(2) 300-kw. Syn. M.G. Sets, 1200-volt, located in P.H., G.E.	5	40	(4) G.E. 205-600 Volts	41	46	2	0	..	....	M-NA	Yes
So. Illinois & St. Louis Ry., Harrisburg, Ill.	60	60	0	S-80	Catenary Trolley	1200	33,000	60	3	Purchased from So. Ill. Ry. Co., Pr. Station at Muddy	2	(10) 300-kw., 650-volt Syn. Con., operate 2 in Series, G.E.	5 5	48 40	(4) G.E. 240-600 Volts (4) G.E. 233-600 Volts	41	46	8	2	60	(4) G.E. 212-600 Volts	M-NA	Yes
Southern Pacific Co., Electric Division, Portland, Ore.	146	162	3	S-75 S-90	Catenary	1500	13,200 60,000	60	3	Power purchased from Portland Ry., Lt. & Pr. Co.	3 1 Port	(7) 500-kw., 1500-volt Syn. M.G. Sets, G.E. (4) 500-kw., 750-volt Syn. Con. West., 2 in Series	33 5 Ex.	46	(4) G.E. 205-750 Volts	45	60	11	3	60	W-308-750 Volts	M-A	Yes
So. Pacific Railroad (Oakland, Alameda & Berkeley Div.)	118	138	0	S-80	Catenary	1200	13,200	25	3	(2) 5000-kw. Turb. Gen. West. (1) 2500-kw. 60/25-cycle Freq. Ch. Set G.E. Pr. also pur. Gt. Western Pr. Co.	3	(20) 750-kw., 600-volt Syn. Con., 2 in Series, G.E.	81 10	50½ 30	(4) G.E. 207-600 Volts (4) W-337-600 Volts	40 27	88 116 52	40				M-A HL	Yes
Southern Traction Co., Dallas, Texas	158	158	5	S-70 S-80	Catenary	1200	66,000	60	3	Power purchased from Texas Pr. & Lt. Co.	6 1 Port	(4) 400-kw., 1200-volt Syn. M.G. Sets (6) 400-kw., 600/1200-volt Syn. M.G. Sets, G.E.	22 6 Ex.	41	(4) G.E. 225-600 Volts	66	56	12	2	25	(4) G.E. 225-600 Volts	M-NA	No
Southwestern Traction & Pr. Co., New Iberia, La.	14	14	0	S-60	Catenary	1200	none			(1) 200-kw. 1200-volt d-c. Gen. Engine Driven Gen. Elec.	0	Direct Feed	3	26	(4) G.E. 217-600 Volts	36.5	46	0	0	..	....	K	No
Texas Traction Co., Dallas, Texas	76	76	0	S-70	Catenary	1200	33,000	60	3	Purchased from Texas Pr. & Lt. Co. also own 2400-kw. G.E. Turbine	6 1 Port	(4) 300-kw., 500-volt Syn. Con. (7) 200-kw., 600-volt, 2 in series, G.E.	0		....				0				
Tidewater So. Railroad Co., Stockton, Cal.	33	33	0	S-65	Catenary	1200	16,500	60	3	Power purchased from Sierra & San Francisco Pr. Co.	2	(4) 200-kw., 600-volt Syn. Con., 2 in series, West.	3	30	(4) G.E. 201-600 Volts	43	40	0	1	40	(4) G.E. 207-600 Volts	M-A	Yes
Toronto Suburban Ry., Toronto, Can.	49	56	3	S-70	Catenary	1500	25,000	25	3	Power purchased from Toronto Pr. Co.	3	(4) 500-kw., 1500-volt Syn. Con., G.E.	6	45	(4) G.E. 240-750 Volts	52	56	0	0	..	....	M-K	Yes
United Rys., Portland, Ore.	20	27	0	S-60 S-90	Catenary	1200	60,000	33	3	Power purchased from Portland Lt. & Pr. Co.	1	(2) 500-kw., 600-volt Syn. M.G. Sets in Series, West.	7	40	(4) G.E. 73 and 205 (4) G.E. 205-600 Volts	46	62	3	1	40		M-A	Yes
Valparaiso & Northern Ind. Ry., Valparaiso, Ind.	46	46				1200	2,200	60	3	Part of Mahoning & Shanango Ry. & Lt. Co. Lines (Rp. Ry. & Lt. Prop.)	1	(3) 300-kw., 600-volt Syn. Con., 2 in Series, G.E.	......	...	....				0				
Washington, Baltimore & Annapolis Elec. R.R. Baltimore, Md.	61	103	14	S-80	Catenary	1200	33,000	25	3	Power purchased from Potomac Elec. Pr. Co.	4	(15) 300-kw., 600-volt Syn. Con., 2 in series, G.E.	53	40	(4) G.E. 205-600 Volts (4) G.E. 233-600 Volts	46	54	0	3	45	(4) G.E. 207-600 Volts	M-A	Yes
Waterloo, Cedar Falls & Northern, Waterloo, Iowa	60	65		S-72	Catenary	1200	40,000	25	3	(2) 1500-kw., (1) 3000-kw. Turbine Generator	4	(4) 500-kw. 1300-volt, Syn. Con., Allis Chalmers Co.	8 5	47 32	(4) W-333-600 Volts (4) W-317-600 Volts	60	52		5	60	(4) W-308-600 Volts	HL	Yes
Willamette Valley Southern Ry.	30	32	0	S-60	Catenary	1200	57,100	60	3	Power purchased from Portland Ry. & Light Co.	2	(2) 500-kw. Syn. M.G. Sets, 1200-volt, West	3	34	(4) G.E., 240-600 Volts	40	58	3	1	50	(4) G.E. 207-600 Volts	M-NA	Yes
Foreign High Voltage D-C. Railways, General Electric																							
Bethlehem Chile Iron Mines Co., Tofo, Chile	15	24	0	S-100	Catenary	2400	2,300	60	3	(2) 3500-kw., 2300-volt Turbine Generator, General Electric	1	(2) 1000-kw., 3-unit, 2400-volt, d-c., Syn. M.G. Sets, 2300-volt, a-c., G.E.	0	...	....	..	..	...	3	120	(4) G.E. 263-1200 Volts	......	....
Imperial Railways, Japan	20	40	4	42 in.	Caten[illegible]y	1200	11,000	25	3	(3) 1500-kw., 11,000-volt Gas Eng. Alternators Dick. Kerr.	1	(2) 1000-kw., 3-unit, 1200-volt Syn. M.G. Sets, Siemens	40	40	(4) G.E. 244-600 Volts	46	45	14				M-A	Yes
South Manchurian Ry., China	25	25	0	S-50 S-80	Cate[illegible]y	1200	2,300	60	3			(3) 400-kw., 1200-volt Syn. M.G. Sets, G.E.	2	35	(2) G.E. 205-1200 Volts	25			3	40	(4) G.E.206-600 Volts	M	No
Victorian Rys., Melbourne, Australia	150	325	0	85 5 ft., 3 in.	Catenary	1500	20,000	25	3	(6) 10,000-kw. Parsons Turbine	15	Syn. Con., 750 to 3000 kw. each. Total, 65,000 kw.*	400	50	(4) G.E. 237-750 Volts	52	70	400	0	..	....	M-A	Yes

*Subject to change.

4 from Port- . Co.	8 1 Port	(6) 500-kw., 600/1200-volt Syn. Con. (7) 500-kw., 1200-volt Syn. Con. G.E.	53 8 Ex. 1 W.	45	(4) G.E. 205 (4) G.E. 222-600 Volts (4) W-321-600 Volts	45	62	28	6 4	60 50	(4) G.E. 212-600 Volts (4) G.E. 207-600 Volts	M-A	Yes	D	Full	Hot Water 1200 Volts	West. D-3		35	1200	Aug. 1912	600 Volts & New	Portland, Salem, Albany & Eugene
d from N.O. New Orleans	1	(2) 200-kw., 600-volt Syn. Con., 2 in Series, West.	4	32.5	(4) W-50 b.p., 600 Volts	40	52	0	0	..	....	HL	Yes	D	Full	None	West Automatic	......	..	600	Operated at 600 Volts	New	New Orleans & Kenner
l from Pacific . & So. Cal.	5	(5) 1000-kw., 1200-volt Syn. M.G. Sets; 15,000-volt, a-c. G.E.	24 3 44	54 44	(4) G.E. 254-600 Volts (4) G.E. 222-600 Volts (4) W-333-600 Volts	60	60	0	10	65	(4) W-308-600 Volts	M-A HL-A	Yes	D	Full	1200	West. Automatic	Dyna Comp.	35	1200	May 1914	600 Volts	Los Angeles, San Bernardino & Riverside
d from Sou- Co., (Hydro	8 1 Port	(12) 500-kw., 1500-volt, 3-unit M.G. Sets (6) 250-kw. Syn. Con., 2 in Series, for 1500-volt, West.	31 2	42	(4) W-321-750 Volts (2) G.E. 217-750 Volts	45	60	0	6 W. 6 G.E.	55 64	(4) W-308-750 Volts (4) G.E. 212-750 Volts	West. HL R-200	Yes	S	Half		West Variable Release	Dyna. Comp.	25	1500/750	May 1912	New & Single-phase	Charlotte, Greenville, Spartansburg, & Anderson
(2) 750-kw., erator Sets, st.	2	(4) 300-kw., 1200-volt, Syn. Con., G.E.	13	38	(4) G.E. 225-600 Volts	47	48	0	0	..	....	M-NA	Yes	D	Full	Hot Water	G.E. Straight Air	C.P. 28	25	600	Aug. 1913	6600 Volts Single-phase	Pittsburgh & Butler
rbine Gener- .E. also pur- ne Lt. Co.	4	(6) 400-kw., 1200-volt, 3-uoit Syn. M.G. Sets (1) 500-kw., 1200-volt, 3-unit Syn. M.G. Sets; G.E. (2) 250 kw., Syn. Con., 2 in. Series (2) 500 kw., 1200-volt, 3-unit and (2) 200-kw., 2-unit, 600-volt Syn. M.G. Sets, 2 in Series, West.	22 G.E. 7 W.	35 32	(4) G.E. 205-600 Volts (4) W-322-600 Volts	45	60	51 Fgt.	0	..	....	M-A	Yes	S & D	Half Full	Hot Water	G.E. Emer. Straight	C.P. 22 30 28	24 25	600 600/1200	July 1908	New	Pittsburgh, Butler, Harmony & Ellwood City, Beaver Falls & New Castle
from Utah	4	(12) 250-kw. Syn. Con., 750-volt, 2 in Series, 1 spare, West	18 2	44 11½	(4) W-334-E-750 Volts (2) W-530-750 Volts	50	62	0	1	40	(4) W-334-E-6, 750 Volts	HL-NA R-200	Yes	D	Full	1500 Volts	West. St. & Auto.	Dyna. Comp.	37	1500	July 1914	New	Salt Lake City, Provo & Payson
rbine Gener- -Volt, G.E.	2	(8) 200-kw., 600-volt Syn. Con., 2 in series, G.E.	14 2 8 W.	30	(4) G.E. 217-600 Volts (4) G.E. 205-600 Volts (4) W-327-600 Volts	43	44	0	0	..	....	M-NA HL-NA	Yes	D	(14) Half (8) Full	1200 Volts	Emer. St. & Auto. G.E.	C.P. 29–28	25	600/1200	Sept. 1910	New	New Haven & New London
0/1200-Volt, 0/1200-volt, Gen., G.E.	0	Direct Feed	8 G.E. 2 W.	38	(4) G.E. 205-600 Volts (4) G.E. 217-600 Volts	43	46	0	0	..	....	M-A K	Yes No	D	Full	Hot Water	Emer. St. Air G.E.	C.P. 22 D.-2K.	24	600	1910	New	Johnstown & Ebensburg
0-volt Curtis ddy	1	(2) 300-kw. Syn. M.G. Sets, 1200-volt, located in P.H., G.E.	5	40	(4) G.E. 205-600 Volts	41	46	2	0	..	....	M-NA	Yes	D	Half	Hot Water	Comb. St. & Auto. G.E.	C.P. 29	25	1200	Sept. 1913	New	Eldorado, Harrisburg, Carriers Mills
So. Ill. Ry. n at Muddy	2	(10) 300-kw., 650-volt Syn. Con., operate 2 in Series, G.E.	5 5	48 40	(4) G.E. 240-600 Volts (4) G.E. 233-600 Volts	41	46	8	2	60	(4) G.E. 212-600 Volts	M-NA	Yes	D	Half		Comb. St. Auto. G.E.	C.P. 29	25	1200	Bldg.	New	Harrisburg, Marion Junc., Johnson City, Benton
from Port- Pr. Co.	3 1 Port	(7) 500-kw., 1500-volt Syn. M.G. Sets, G.E. (4) 500-kw., 750-volt Syn. Con. West., 2 in Series	33 5 Ex.	46	(4) G.E. 205-750 Volts	45	60	11	3	60	W-308-750 Volts	M-A	Yes	D & S	Full	1500 Volts	West.	Dyna. Comp.	35	600/1500	Jan. 1914	Steam & New	Portland, Oswego, McMinville, Forest Grove
b. Gen. West. 5-cycle Freq. Pr. also pur. . Co.	3	(20) 750-kw., 600-volt Syn. Con., 2 in Series, G.E.	81 10	50½ 30	(4) G.E. 207-600 Volts (4) W-337-600 Volts	40 27	88 116 52	40				M-A HL	Yes	D	Half		West. A.M.M.	West.	35	1200	Apr. 1911	Steam	Oakland, Alameda & Berkeley
from Texas	6 1 Port	(4) 400-kw., 1200-volt Syn. M.G. Sets (6) 400-kw., 600/1200-volt Syn. M.G. Sets, G.E.	22 6 Ex.	41	(4) G.E. 225-600 Volts	65	56	12	2	25	(4) G.E. 225-600 Volts	M-NA	No	5-D 23-S	Full	1200 Volts	West. A.M.N. G.E. Comp.	C.P. 29	25	600	Oct. 1913	New	Dallas, Waco & Corsicana
00-volt d-c. Driven Gen.	0	Direct Feed	3	26	(4) G.E. 217-600 Volts	36.5	46	0	0	..	....	K	No	D	Half		Straight Air G.E.	C.P. 29	25	1200	May 1912	New	New Iberia & Jeanerette
Texas Pr. & n 2400-kw.	6 1 Port	(4) 300-kw., 500-volt Syn. Con. (7) 200-kw., 600-volt, 2 in series, G.E.	0		....				0												Operated at 600 Volts	600 Volts	Demson, Sherman, Dallas, McKinney
from Sierra o Pr. Co.	2	(4) 200-kw., 600-volt Syn. Con., 2 in series, West.	3	30	(4) G.E. 201-600 Volts	43	40	0	1	40	(4) G.E. 207-600 Volts	M-A	Yes	D	Half	1200 Volts	West.	Dyna. Comp.	35	600/1200	Nov. 1913	New	Stockton & Modesta
from Tor-	3	(4) 500-kw., 1500-volt Syn. Con., G.E.	6	45	(4) G.E. 240-750 Volts	52	56	0	0	..	....	M-K	Yes	S	Half	1500 Volts	Comb. St. & Auto., G.E.	C.P. 28	25	750	Bldg. 1916	New	Toronto, Georgetown & Guelph
from Port- Co.	1	(2) 500-kw., 600-volt Syn. M.G. Sets in Series, West.	7	40	(4) G.E. 73 and 205 (4) G.E. 205-600 Volts	45	62	3	1	40		M-A	Yes	D	Full	1200 Volts	West. Auto.	West.	35	600/1200	Jan. 1913	600 Volts, D-C.	Portland & Wilkesboro
& Shanango Lines (Rp. .)	1	(3) 300-kw., 600-volt Syn. Con., 2 in Series, G.E.	......	...	....				0											.	Operated at 600 Volts	600 Volts	Valparaiso, Cheston & Porter
from Poto- o.	4	(15) 300-kw., 600-volt Syn. Con., 2 in series, G.E.	53	40	(4) G.E. 205-600 Volts (4) G.E. 233-600 Volts	45	64	0	3	45	(4) G.E. 207-600 Volts	M-A	Yes	D	Half	Hot Air	West. G.E. Comp.	C.P. 29	25	1200	Feb. 1910	6600 Volts, 1φ & Steam	Washington, Baltimore & Annapolis
) 3000-kw. tor	4	(4) 500-kw. 1300-volt, Syn. Con., Allis Chalmers Co.	8 5	47 32	(4) W-333-600 Volts (4) W-317-600 Volts	60	52		5	60	(4) W-308-600 Volts	HL	Yes	S	Full	Hot Water	West. A.M.M.	Dyna. Comp.	38	1200	Sept. 1914	New & 600 Volts	Waterloo & Cedar Rapids
from Port- ht Co.	2	(2) 500-kw. Syn. M.G. Sets, 1200-volt, West	3	34	(4) G.E., 240-600 Volts	40	58	3	1	50	(4) G.E. 207-600 Volts	M-NA	Yes	D	Full	1200 Volts	West. Auto. Air	Dyna. Comp.	25	1200	Jan. 1914	New	Oregon City, Beaver Creek, Mt. Angel
0-volt Tur- , General	1	(2) 1000-kw., 3-unit, 2400-volt, d-c., Syn. M.G. Sets, 2300-volt, a-c., G.E.	0	...	....	..	..	...	3	120	(4) G.E. 253-1200 Volta	......	.....	..	....	....	West. St. & Auto.	C.P. 34	150	2400	Bldg. 1916	New	Tofo & Iron Mines
00-volt Gas s Dick. Kerr.	1	(2) 1000-kw., 3-unit, 1200-volt Syn. M.G. Sets, Siemens	40	40	(4) G.E. 244-600 Volta	46	46	14				M-A	Yes		Full		G.E. Comb. St. & Auto				1915	Steam	Tokio, Yokobama
		(3) 400-kw., 1200-volt Syn. M.G. Sets, G.E.	2	35	(2) G.E. 205-1200 Volts	26			3	40	(4) G.E.206-600 Volts	M	No	D	Half			C.P.	25	1200	1914	Steam	Fushun, Colliery
sons Turbine	16	Syn. Con., 750 to 3000 kw. each. Total, 65,000 kw.*	400	60	(4) G.E. 237-750 Volts	52	70	400	0	..	....	M-A	Yes	D	Half		G.E. Comp.	C.P. 29	27	1500	Bldg. 1916	Steam	Melbourne & Suburbs

*Subject to change.

The generally increasing burdens due to new conditions and increasing demands of the public made the situation more and more acute. It became very apparent that to meet these new conditions it was imperative that some means should be evolved to lower the necessary investment and overhead charges if further extension of the electric interurban was to be made economically possible.

The new single-phase system was put forward as a solution and was immediately siezed upon rather extensively, but was not fulfilling its early promises because of a multitude of engineering difficulties and apparatus failures.

The 1200-volt system not only showed the necessary economic advantages but inherited the confidence derived from the long experience with its 600-volt prototype.

It embodied no new and untried theories and did not require the devoted nursing of over-enthusiastic patrons.

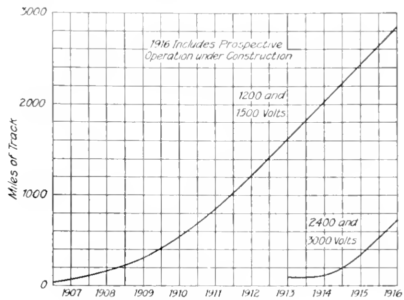
From the first it demonstrated its superior fitness and was generally adopted both for new roads and in place of other existing systems. As shown by the accompanying chart, the increase of mileage of the 1200- and 1500-volt roads (which may for present purposes be considered as of the same family) has been steady and continuous even through recent years of general business depression.

Today it is unusual to have any question raised as to the proper equipment for interurban lines. The 1200-volt system is standard just as the 600-volt system is standard for city lines.

The history and experience with the interurban problem naturally develops faith and enthusiasm for a similar application of direct-current principles to the still more important field of railway electrification. The experience of previous years had prepared railway engineers to better appreciate the economical relation between the unit demand for power and the supply voltage and had as well fitted them to produce apparatus suited to operate at higher potentials. It was realized that the large locomotives and heavy train units required for steam railway electrification both demanded and permitted higher operating potentials.

The first installation of 2400-volt equipment was on the Butte, Anaconda & Pacific Railway in 1912. The engineering features and designs involved some new elements and extensions of previous practice, but there was nothing fundamentally new and untried and the engineering problem was chiefly a matter of capacity.

This installation was made not so much to demonstrate the engineering accomplishment as the economic fitness and those most interested in the outcome were the railway officials who were formulating vast projects necessarily based on improved methods of propulsion over the most important lanes of the nation's traffic. The tremendous importance of a correct judgment



Growth in Miles of Track of High Potential Direct Current Railway

required the elimination of all exaggerated enthusiasm. The decision in favor of direct-current was the result of not only the highly successful demonstration but of the most searching inquiry and comparison with all other possible systems.

The practical results as well as the comparative possibilities were critically analyzed by the officials and engineers who had the heavy responsibility for transcontinental railroad operation and the decision must be accepted as beyond the possibility of prejudice or partisan enthusiasm.

The immediate practical success of the 2400- and 3000-volt apparatus resulted partly from the inherent ruggedness and flexibility of direct-current designs as well as from the absence of radically new features of construction.

The locomotives, although larger and more powerful than any yet constructed, adhered to the simple, rugged and thoroughly tried mechanical arrangement of motor drive and truck structure. Much study and many trials have been made in all parts of the world to find a driving connection between the motors and the driving axles that is superior to direct gearing. Preconceived limitations as to the unsuitability of simple gearing for heavy torque and a rather theoretical impression that an electric locomotive should follow steam locomotive practice led to trial construction using diagonal side rods, jackshafts and parallel rods of various forms. It may be that some such arrangements are necessary or desirable in certain situations but it is also very clear that direct gearing is amply able to accomplish all that can be needed for locomotives of great capacity, equal to handling the heaviest transcontinental trains. The use of twin gears, making the full strength of the gear teeth available; spring drive in the gears cushioning the hammer blow on the teeth and equalizing the stress between the gears; and advances in the quality of the gear steel, are the chief improvements over former practice that completely determined the suitability of the direct gear arrangement to this heavy duty.

Practical service amply emphasizes the excellence of direct gearing and demonstrates its superiority to other forms of drive.

Another feature that serves to mark the adaptability of direct-current is the regenerative braking which has been put into successful use on the Chicago, Milwaukee & St. Paul locomotives.

This is a feature that previously had been considered particularly suited to polyphase alternating-current motors exclusively. The control arrangement for regenerative braking, as well as the results accomplished on the Chicago, Milwaukee & St. Paul locomotives, are fully covered elsewhere in this issue and will be recognized in keeping with the simplicity and effectiveness of the direct-current system.

Particular attention is directed to the flexibility of this system of braking. The ability to utilize the electric brake over a wide range of speed and its ease of control make it far more useful than polyphase system of braking which is limited to a single speed.

The overhead contact system for the 3000-volt direct-current system retains the good features of the flexible construction previously used and adds to it increased current capacity. Its appearance, effectiveness and practical operation leave no room for criticism.

The substation apparatus corresponds closely with established practice and is perfectly adapted to the reverse transmittal of energy incident to the regenerative braking of the trains.

It is particularly instructive to note that in spite of may previous theoretical adverse comparisons with other systems the direct-current system, as actually installed and in successful service, compares most favorably with concurrent installations as to the spacing of substations, the kilowatts of substations per mile of track and the total cost of substations.

The Chicago, Milwaukee & St. Paul electrification has hardly been in operation long enough to give accurate statistics as to the economic results but the operating officials of the Railway are most optimistic and favorable expectations are justified.

As to the probability of developing still higher voltage systems it can only be repeated that 3000 volts seems to be adequate for the heaviest trunk line traffic and is likely to represent the true economic balance between cost of substations and feeder copper on the one hand and cost of locomotives on the other, and as well to present the greatest flexibility and the lowest operating charges. But 5000 or 6000 volts direct-current is a possibility if there arises a real field of usefulness for this further extension of the direct-current family.

RECENT DEVELOPMENTS IN SPRAGUE GENERAL ELECTRIC PC CONTROL

By F. E. Case

Railway Equipment Department, General Electric Company

The author describes the recent improvements made in the PC control, which have been brought about by a careful study of the apparatus in actual operation. He also describes briefly the different forms developed for equipments of various capacities, noting in each case their special features.—Editor.

In the October 1915 number of the General Electric Review, Mr. C. J. Axtell had an article on PC control for railway service, giving several good views of the controller which had been developed at that time. Since then, the controller illustrated in that article has been re-arranged to give greater accessibility for installation and inspection, and other controllers have been designed to meet different requirements.

The principle of operation of the PC controller has proved very satisfactory and but few changes have been found necessary, these being in minor parts. The use of a cam shaft, rotated by a pinion and rack driven by "On" and "Off" air pistons which are electrically controlled, for closing and opening the contactor elements of the controller, has demonstrated that this is a simple and reliable means of operation.

Combining the contactors, line breaker, overload relay, notching relay and reverser in a single structure has resulted in a material reduction in weight, and in the space occupied under the car. This single unit design permits the installation at the factory of the necessary inter-connecting cables for both control and power circuits, thereby reducing to a minimum the labor of mounting under a car and connecting up.

One of the main features of the PC controller is that the control circuits for automatic current limit acceleration are much less complicated than in previous systems of automatic control using either magnetically or pneumatically operated contactors. This is owing to the definite sequence of contactor operation produced by the cam shaft, and to the consequent elimination of a large number of interlock switches necessary with individually operated contactors of previous controls.

Another feature peculiar to the PC controller is that it is less complicated in its electrical connections for automatic acceleration than for non-automatic or hand acceleration. The reverse is true with controls using individually operated contactors, as the connections for automatic acceleration require a very materially increased number of interlocking switch contacts on contactors to provide a proper sequence of operation.

Many railway men have said that while theoretically automatic acceleration was preferred on account of better power efficiency, decreased shocks to equipment parts and passengers, and less effort on the part of the motorman, the additional complication, as compared with non-automatic operation, more than offset these advantages. As the automatic PC control secures the desired results without the complication in circuit connections heretofore found necessary, there is every reason to believe that it will be largely adopted for city and interurban car service, as well as on elevated, subway and electrified steam roads, which have already accepted automatic acceleration.

An additional feature of the PC controller, which makes automatic acceleration still more generally practicable, is the ability of the motorman to quickly cut out the current limiting action should the progression of the controller be arrested on a resistance step, due to an unusual motor current. This point is highly desirable on city and interurban cars operating under conditions of sharp curves, steep grades and heavy loads, where the ordinary current setting of the accelerating relay, although suitable for normal accelerations, is sometimes too low to permit proper starting. Under these conditions the current limit relay may be held up by the motor current, and the controller then cannot turn on further unless means are provided for re-establishing the notching up circuit of the controller irrespective of the position of this relay. With the new control, when progression of the PC controller is arrested by the relay, the motorman merely pushes a small supplemental lever located on the top of the master controller, which permits the motor controller to take another step. Should it be necessary, he can repeat this operation until the controller has turned fully on.

It is becoming more generally recognized, where abnormal forces can be applied to the

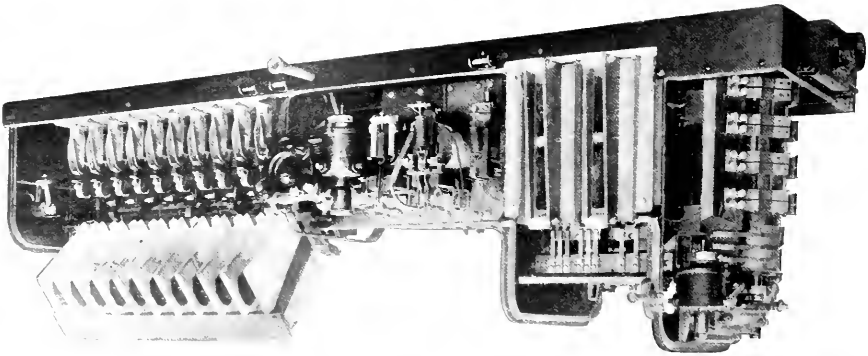


Fig. 1. Front View of PC-10 Controller

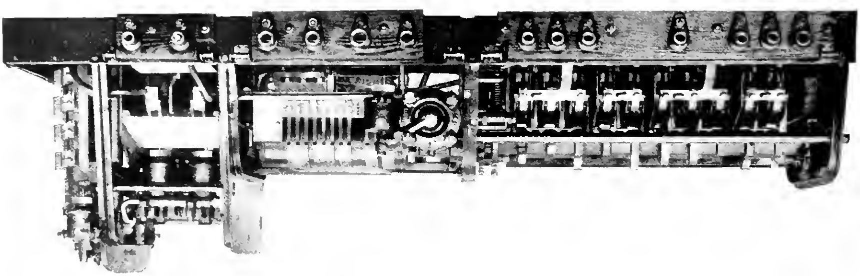


Fig. 2. Rear View of PC-10 Controller

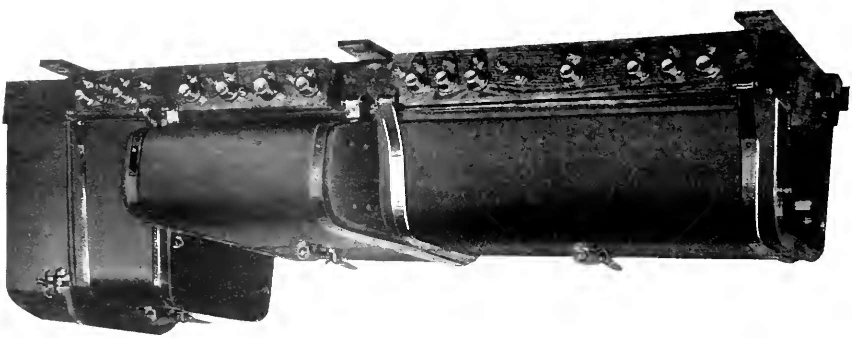


Fig. 3 Rear View of PC-10 Controller, Covers on

detriment of electrical apparatus, that limiting devices of some kind are desirable. This is equally true in the industrial and railway applications of electric motors. In consequence of this, it is believed that the PC controller, with its freedom from the circuit complications of previous controls, should fill a long felt requirement.

Figs. 1, 2, 3, 4 and 5 show various views of the re-arranged controller known as the PC-10. Two hundred of these controllers are now being furnished the Interborough Rapid Transit Company, of New York.

In the original form of the PC controller, the reverser was located between the line breakers and the cam operated contactors. In the present form, the reverser has been placed at the end of the controller, thereby facilitating the connection of incoming motor leads and also permitting much easier inspection, as the removal of the end cover exposes all of the parts. It can be readily seen from the illustrations that the re-arrangement of parts has resulted in a material improvement.

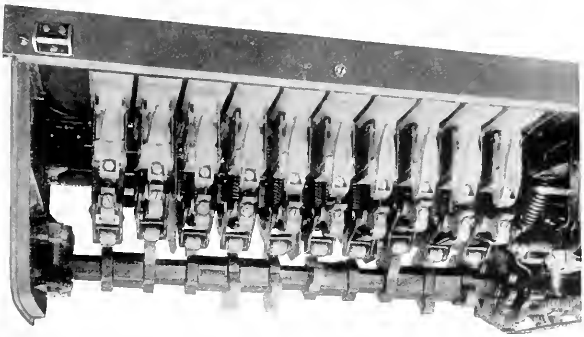


Fig. 4. Contactors of PC-10 Controller, with Arc Chute Removed

The PC-10 controller has a maximum capacity for two 250-h.p., 600-volt motors and the same general form of controller, the PC-11, is made for operation with four 150-h.p. motors. In this case, besides having a four-motor reverser, a cutout switch is provided for removing either pair of motors from the circuit, leaving the remaining pair properly connected for series and parallel operation.

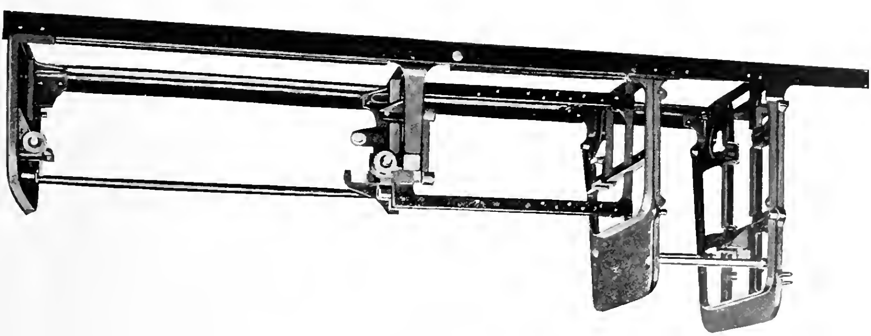


Fig. 5. Skeleton Frame of PC-10 Controller

A small PC controller has been developed for use with four motors of a maximum capacity of 70 h.p. each, to take care of lighter service than that for which the PC-11 controller was designed. This controller is the PC-5, illustrated in Fig. 6. Its weight is approximately one-half that of the larger controller, and its dimensions such

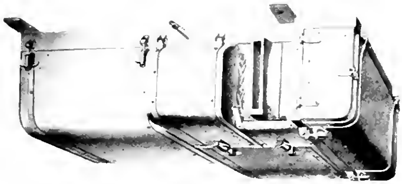


Fig. 6. Type PC-5 Controller

as to readily permit installation under cars provided with 24-inch wheels. The method of operation is identical with that of the larger controller, and the parts controller, and it is possible to cut out either pair of motors after opening a small door. The covers are easily removed for exposing all of the operating parts for inspection. The same master controller is used as with the larger controller, the circuit connections and amount of control current required being the same.

The PC-101 controller has been developed for 1500-volt systems. This controller uses the same contactor elements and operating parts as the 600-volt controller, with increased insulation suitable for this voltage. The general arrangement of the cam operated contactors, line breakers, reverser, relays and motor cutout switches, is similar to that of the 600-volt controller, but the outside dimensions of the controller have been somewhat increased to permit the use of more insulation and to provide proper spacing of parts carrying 1500-volt currents.

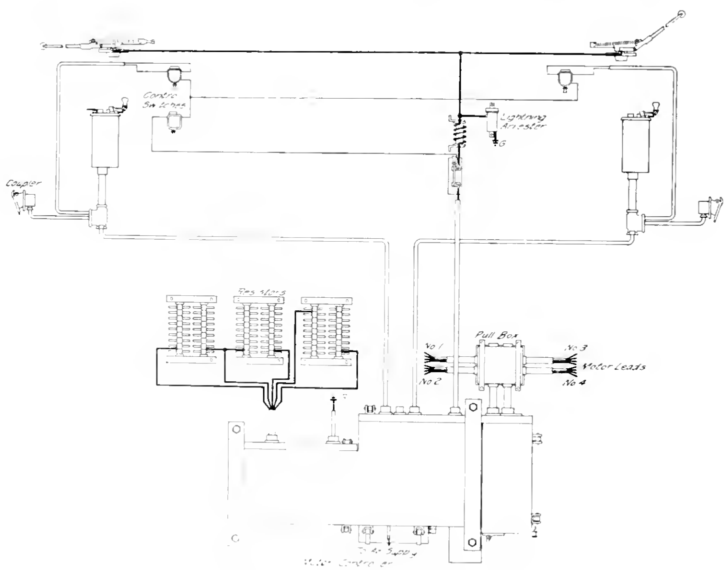


Fig. 7. Arrangement of PC Controller with Equipment on Car

are similar, but of lighter construction on account of the decreased duty required. This controller is also of the automatic type, containing a current limit relay for governing the acceleration. A cutout switch is provided in the reverser compartment at the end of the

PC control can be operated from either a high or a low voltage source on account of the very small amount of energy required.

The 124 PC controllers furnished the Interborough Rapid Transit Company last year, and the 200 now being supplied are arranged for operation from a 32-volt storage battery circuit. Equipments have been supplied to other roads for operation at line potential, resistance tubes being used to cut down the voltage at the magnet valve coils.

In turning off, the natural time element of the air driven cam shaft is considerably greater than that of the line breakers, and in consequence, the latter take all of the arcing. These line breakers have an extremely powerful and well arranged magnetic blowout, which promptly extinguishes the arc without undue burning of the contacts. As in the other forms of PC controller, this one is also designed for current limit acceleration.

The arrangement of all PC control apparatus on the car with its control circuit cables has been carefully studied with a view to simplifying the equipment as a whole, and Fig. 7 shows what has been accomplished in this direction. Cables connect directly from the coupler sockets to the master controllers and from the latter to the motor controller, instead of separate connection boxes being used between the couplers and master controllers as with older types of control. Both the new master controller and the PC controller have ample space for the additional set of incoming cables.

The master controller shown in Fig. 8 was designed for use with the PC-5, 11 and 101 controllers for automatic current limit acceleration. It is of very light weight and, although small and compact, the parts are very accessible. The cylinder construction is of the "hex" shaft type with wrapped insulation, as used in large drum controllers. Separate power and reverse handles are provided, as well as a third handle which actuates the contacts for producing the step by step movement of the motor controller when the current limit relay is held in its open position by the motor current.

Before developing the first PC controller for car service, considerable experience had been obtained with cam operated contactors in other places. A notable instance was on the Butte, Anaconda & Pacific 2400-volt locomotives, where a series-parallel switch containing eleven cam operated contactors was employed. The resistance steps were secured by means of magnetically operated contactors of the Sprague General Electric Type M control type, but the transfer from series to parallel connection of the motors was produced by means of this pneumatically operated switch.

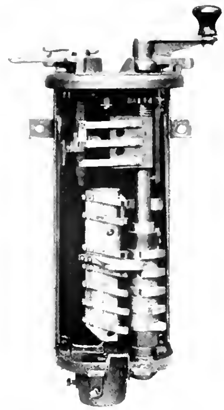


Fig. 8. Master Controller

This switch reduced the number of operating coils and produced a definite sequence of contactor operations during the transfer, so that it was not necessary to employ numerous interlock contacts in the control circuit for preventing irregular actuation of the contactors. The successful operation of this locomotive control led to the use of the same type of series parallel switch in the Chicago, Milwaukee & St. Paul locomotives, and further gratifying results have been obtained.

The present PC controller is really, therefore, a development of this series-parallel switch, incorporating with it the contactors necessary for cutting out the starting resistance step by step and adding control circuit parts for accomplishing this feature.

GIVE THE OPERATOR A JOB

By Cassius M. Davis

Railway and Traction Engineering Department, General Electric Company

The author shows how economies can be secured in electric railway operation by the use of automatic substations. He presents the subject in a very human way and gives tables relative to the saving in energy, the effect upon schedules, a hypothetical case, comparative cost and operating expenses, and finally summarizes the results obtained by the use of manual and automatic control.—Editor.

Many electric railway companies are finding it profitable to employ the otherwise idle time of their substation operators in such ways as either to bring in revenue or at least to reduce expenditure. The picture of the substation man reading a magazine with his feet on the desk is being rapidly "dissolved" into one where the work bench replaces the desk and the man's attention is fixed upon a lathe or upon an armature coil he is repairing. The latter looks more businesslike, to say the least, and certainly is more remunerative to both employer and employee.

The railways can go one step farther. What does the average substation operator do when he works, especially in the interurban substation? He cuts in and out machines at specified times whether there is load or not. He closes the circuit breakers when they open, due to an over zealous motorman trying to make up time. He keeps the substation log, if there is one. He sweeps out the building and blows out the machines—sometimes. Aside from these duties he is a comparatively free man. To be sure, many operators must be baggage and ticket agents, and perform various incidental duties, but they belong to another category.

If these are the chief duties of substation operators, why cannot some scheme be worked out which will mechanically or electrically perform them? Human intelligence is no longer necessary to watch the water tank and start the pump when it becomes empty; a float switch accomplishes this. Neither is constant human effort necessary to weave an intricate design in a fabric; the perforated "card" does this. The starting of the water pump is merely the response to load demand and the weaving of the design is the accomplishment of a purpose through a succession of steps. Until recently railways have found it necessary to employ intelligent substation attendants, but modern ingenuity has developed a means of substation control which renders such intelligence unnecessary.

The way it is done is quite simple. The switches the operator throws by hand are replaced by those electrically operated. The order in which they are closed or opened is determined by a slowly revolving cylinder.

Thus, starting and stopping the apparatus could easily be effected without the attention of the operator. But how about closing the circuit breakers after the motorman has exceeded the acceleration limit? One way is not to let the breakers open; or, rather, not to entirely disconnect the feeder from the bus. A little resistance could be inserted which would limit the accelerating current to a reasonable value. This resistance could be cut out after normal conditions had again been reached.

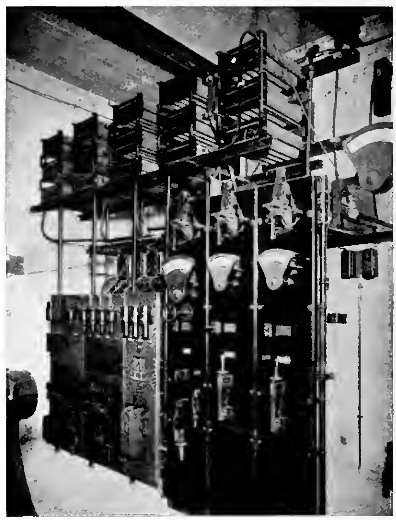


Fig. 1. Automatic Railway Substation. Direct-current Panels and Automatic Equipment which Supersedes Them

Keeping the log has already been reduced to a science by the advent of numerous graphic meters and indicators, while sweeping out the building and blowing out the machines still remain unsolved!

It is not difficult, then, to see how a railway substation can be made to function naturally whether the operator is there or not. Why not take the operator away and put him on the repair or line gang; where possibly he can earn more money and the company save something? This is possible and practical in the automatic railway substation.

Granting the expense of operators can be greatly minimized,—it naturally cannot be entirely eliminated, since the apparatus must be inspected—there is another item of expense which may be reduced—the power bill.

The most economical scheme of operation is to start up the substation when there is a demand for power and to shut it down when this demand disappears. To operate otherwise means a constant waste of energy in heating the machines and churning the air.

If the railroad operates a car-an-hour schedule for twenty out of the twenty-four hours, it is safe to say most of the substations really carry an appreciable load only 50 to 60 per cent of the time. The remaining 40 to 50 per cent of the time they are running light,

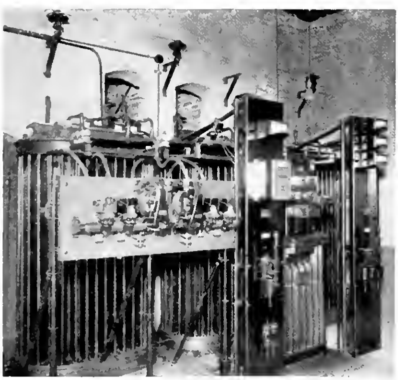


Fig. 2. Automatic Railway Substation. Alternating-current Starting and Running Contactor Panel. Superseded Hand-operated Panels to the Right

or nearly so. Taking the light load losses at 4 per cent. a 500-kw. substation would waste 20 kw. for eight or ten hours, or 160 to 200 kw-hr. per day; or further $292.00 to $365.00 per year at one half a cent per kw-hr. This is, say roughly, one third the yearly wage of an operator. Hence it appears that placing a man in a substation is about as inefficient a way to utilize him as could be imagined.

We have hinted at the means provided to operate a substation automatically—the electrically controlled switches and the revolving

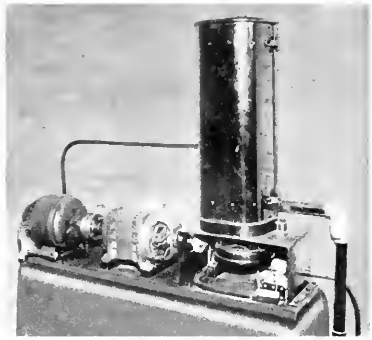


Fig. 3. Motor-driven Drum Controller with Polarizing Generator Direct Connected

cylinder. The demand for the power is indicated by a drop in trolley voltage. The contact-making voltmeter may be used to start the cylinder moving. When the demand ceases, the substation delivers little or no current and a current relay will register the fact, disconnecting the machine from the system. It then remains but to correlate and supplement these devices by the use of contactors and other relays to obtain a practical, operative equipment.

Figs. 1 and 2 show clearly how the equipment looks when placed beside an old switchboard manually operated, while Fig. 3 pictures the revolving cylinder driven by a small motor. The resistance which is inserted in circuit during a heavy draft of current appears in the upper part of Fig. 1.

It must be expected that numerous difficulties have to be overcome. The first one is the fixing of the proper polarity if a synchronous converter is started from the alternating-current side. The small direct-current generator shown in Fig. 3 does this when it is connected to the converter field at the proper time. Another difficulty presents itself if we imagine the trolley wire or third rail grounds throwing a heavy overload on the machine. The resistances and several thermostats avert the danger; the resistances limiting the output, and the thermostats shutting down the machine if the temperature becomes dangerous. Other difficulties are obviated in equally efficacious ways.

The complete wiring diagram for a certain installation is presented in Fig. 4 and the details of operation may be studied thereform. To simplify matters and to give the sequence of operation at a glance, reference to Fig. 5 should be made. Here the load-carrying circuits are shown in heavy lines and the principal control circuits in light lines. A dot in one of the squares of the tabulation under the diagram indicates the correspondingly numbered device is closed at that point in the sequence. The complete wiring diagram shows various interlocking circuits which prevent false operations should any device fail to function properly.

A question frequently asked is: Does not the substation shut down every time the motorman throws off the power? No, because relay No. 3 has a time delay which keeps it closed as long as five minutes, if necessary, after it is de-energized. Another question: Is not a large quantity of energy lost in the limiting resistance? No, to this also. Experience has shown that as much as 4 kw-hr. is "wasted" per day in a 300-kw. equipment. And at that, it really is not "wasted" since experience has also shown that the cushioning effect of this resistance has not only reduced the wear and tear on the substation apparatus, but it has practically eliminated flashovers of the car motors, thus materially decreasing their maintenance.

Some very interesting problems present themselves for solution where a railway is operated automatically. The economical spacing of substations, their capacity, and the amount of feeder copper installed, all hinge upon the production of a nice balance between first costs and between annual operating expenses. Assuming given conditions of traffic, the greatest dividends are possible on the railroad costing the least to install and operating at the least expense. Now, since the automatic substation can operate trains on the same schedule with less energy than one manually controlled, and since the attendance expense account is greatly reduced, it is evident new balances can be struck and these bear investigating.

It is a fact that even manually operated substations are cheaper than the feeder copper between them; that is, down to a point where the number of substations per mile of track is greater than present practice indicates. It is

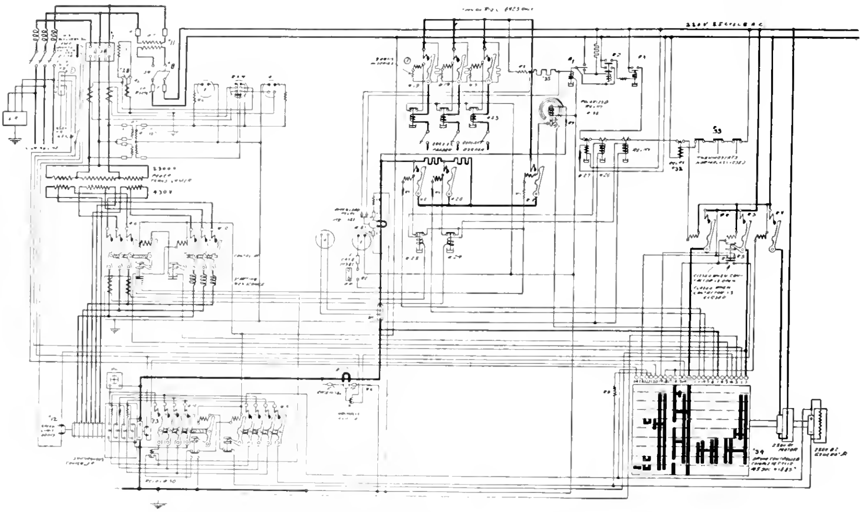
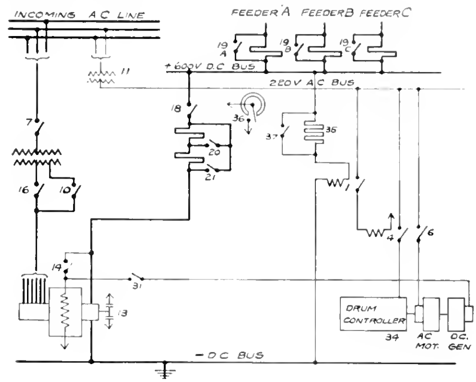


Fig. 4. Complete Wiring Diagram of Typical Automatic Railway Substation

the expense of operating them that keeps them at a respectable distance. With a lower operating cost and smaller power bill, it seems that a little feeder copper might be saved and possibly more substations installed with a net reduction in first cost, or at least a reduction in operating expense. Some roads already in existence have found it convenient to cash in a quantity of feeder metal and have enough money left after buying automatic equipment to make some needed improvements. With attendantless substations in the field, old ideas regarding electric railroading must be modified to meet the new situation.

A few figures will show the general tendency toward a reduction in annual expenditures. Each individual road must be judged upon its own merits, but the figures given below will serve as a guide, and modifications can be made applicable to specific cases. It goes without saying that the expense of attendants can be materially decreased, but is there a saving in power worth mentioning? To show that there is, Table I has been prepared. This estimate is based upon the car schedules shown in Fig. 6.

Before leaving Fig. 6 some interesting things should be noticed. One train sheet shows 120-minute headways and the other 60-minute. Each is divided into three schedules of different layovers. The time each sub-



	SEQUENCE	1	4	6	7	10	13	14	16	18	19A	19B	19C	20	21	31	36	37	REMARKS
1	SHUT DOWN										●	●	●					●	CONTROLLER "OFF"
2	LOW D.C. VOLTAGE	●	●	●							●	●	●					●	" STARTS
3	1ST CONTROLLER POSITION	●	●	●	●						●	●	●					●	OIL SWITCH CLOSED
4	2ND " "	●	●	●	●	●					●	●	●					●	STARTING TAP
5	3RD " "	●	●	●	●	●	●				●	●	●					●	SYNCHRONOUS SPEED
6	4TH " "	●	●	●	●	●	●				●	●	●			●	●	●	POLARITY FIXED
7	5TH " "	●	●	●	●		●	●	●		●	●	●				●	●	FULL VOLTS SELF EXCITED
8	6TH " "	●	●	●	●		●	●	●	●	●	●	●				●		ALL RESISTANCE IN
9	7TH " "	●	●	●	●		●	●	●	●	●	●	●	●			●		PART RESISTANCE OUT
10	8TH " "	●	●	●	●		●	●	●	●	●	●	●	●	●		●		ALL RESISTANCE OUT
11	9TH " "	●	●		●		●	●	●	●	●	●	●	●	●		●		CONTROLLER STOPS "RUN"
12	LIGHT OVERLOAD FEEDER "A"	●	●		●		●	●	●	●		●	●	●	●		●		19B OR 19C OPEN ON
13	MEDIUM " " "	●	●		●		●	●	●	●		●	●	●			●		FEEDERS "B" OR "C"
14	HEAVY " " "	●	●		●		●	●	●	●		●	●				●		CORRESPONDINGLY
15	UNDER LOAD			●	●		●				●	●	●				●	●	CONTROLLER STARTS
16	SHUT DOWN										●	●	●					●	" STOPS "OFF"

Fig. 5. Simplified Wiring Diagram and Table showing Sequence of Operations

TABLE I

AUTOMATIC CONTROL

Energy Economies

Headway between cars		120 min.	60 min.
Length of road	mi.	50	50
Schedule speed	m.p.h.	25	25
Weight of cars	tons	30	30
Number of stops per mile		0.5	0.5
Capacity of substation converters	kw.	300	300
Length of operating day	hr.	18	18
Total car miles per day		900	1800
Energy consumption per car mile	kw-hr.	1.7	1.7
Total energy per day at cars	kw-hr.	1530	3060
Total energy per day high-tension side substation	kw-hr.	1860	3720
Total substation hours possible (5 substations)	hr.	90	90
Total substation hours actual running	hr.	30	52
Total time substations are not running	hr.	60	38
Running light losses per substation	kw.	15	15
Energy saved per day, automatic operation	kw-hr.	900	570
Energy saved per year, automatic operation	kw-hr.	328500	208000
Total energy per day, manual operation	kw-hr.	2760	4290
Value of energy saved per year at ½ cent per kw-hr.		$1642	$1040
Energy saved, automatic operation		32.5 per cent	13.3 per cent

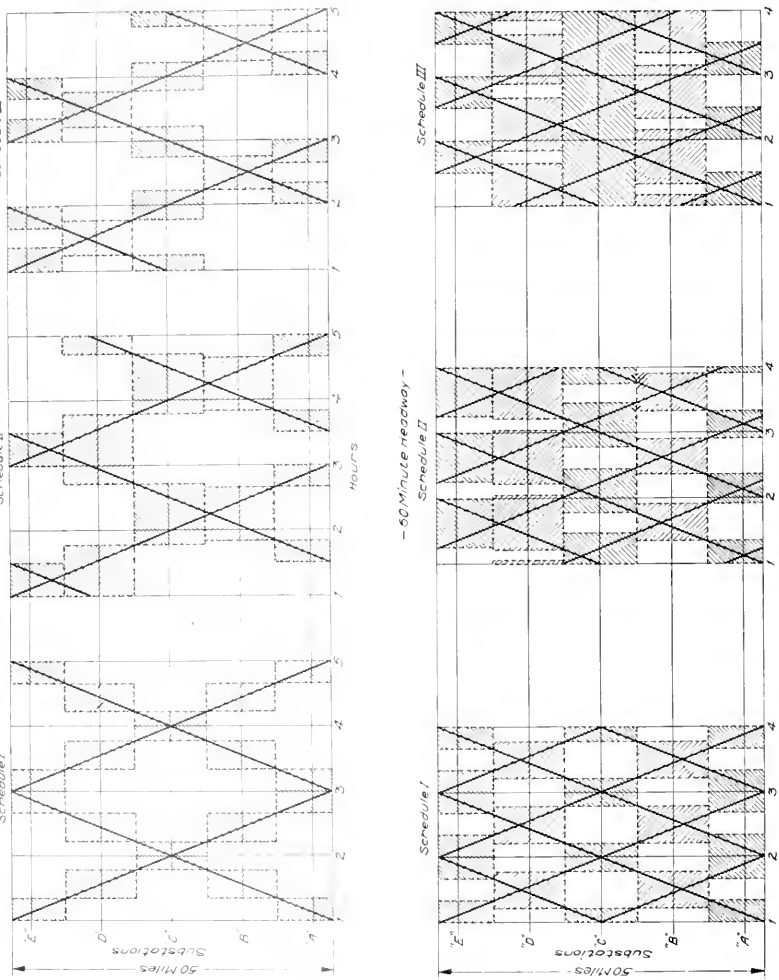


Fig. 6. Train Sheet Showing the Effect of Schedule upon Time of Substation Operation

station carries more than one half the car load is indicated by the shaded portions. If the substations operate automatically these shaded portions indicate when the substations are running. The rest of the time they are shut down. This forms a very convenient method of determining the number of hours per day the running-light losses of a substation could be eliminated by automatic operation. From these train sheets Table II can be made. The curious point to be noticed is that for 120-minute headways more power can be saved with a layover of 60 minutes, and that for 60-minute headways more power can be saved with no layovers. Fortunately enough too, it will be observed in each case that conditions for minimum time of running correspond to maximum efficiency conditions on the substations. In Schedule I of 120-minute headways, only one substation out of the five carries two cars at a time, while Schedule III shows two of the substations so loaded. Again, in Schedule I of 60-minute headways three substations carry two cars each, while with any other arrangement of cars circumstances are not so favorable. The railway efficiency expert may find something of interest here, and raise the all day efficiency of even manually operated substations.

Returning to Table I, it is seen an energy saving of over 30 per cent is possible on roads operating cars every two hours, and a saving of over 10 per cent for cars one hour apart. To be sure these estimates are based upon hypothetical car services, but where a "paper" saving as high as that indicated is possible the means of attaining it should be seriously considered.

It is to be expected that the more infrequent the car service the greater the energy saving, but it is on the railways having just such a service that the power bill is the largest in proportion to the total operating expenses. The same is true with regard to the item of substation attendance. The interurban road running few cars per day presents, then, the immediate future for the automatic substation.

To make the case complete, further evidence should be introduced. Let us assume an electric railway already running. The general specifications appear in Table III. In order to bring out the effect of the size of feeder, two cases are assumed, one where a 4/0 feeder reinforces the trolley conductor, and the other where a 500,000 c.m. feeder is used. The latter is evidently over feedered.

The items of cost and expense appear in Table IV and it will be noted two methods of application of the automatic feature are included. In either case, and either method, a distinct saving accrues, the relative amounts being given in the Summary, Table V.

The tabulations bring out a valuable point; viz., the greatest economy in operation sometimes is attained by merely converting the substations already in operation, and other times by increasing the number of substations. It depends upon conditions. Naturally a road that is overfeedered would show a large saving, but it would do this much under manual operation.

Taxes and the cost of land have not been included in these calculations on account of their varying values. To make the comparison complete these items should, of course, be considered.

TABLE II

EFFECT OF SCHEDULE UPON TIME OF AUTOMATIC SUBSTATION OPERATION

Minutes of Substation Operation per Hour

	Substation	A	B	C	D	E	Total Substation Minutes Per Hour
	Headway 120 Minutes						
Schedule	I—No layovers	20	27	13	27	20	107
	II—30- and 90-minute layovers	20	25	28	32	15	120
	III—60-minute layovers	20	18	25	17	20	100
	Headway 60 Minutes						
Schedule	I—No layovers	40	35	26	35	40	175
	II—15- and 45-minute layovers	25	35	40	50	45	195
	III—30-minute layovers	30	50	60	50	30	220

Thus far nothing has been said about the broad question of reliability of the automatic apparatus. This subject will bear thought, and since it defies accurate numerical calculation, making capitalization difficult if not impossible, its value can only be judged by argument.

In the manually controlled substation the apparatus and its proper operation is dependent upon the human element and its vagarious efficiency. The exceptional operator uses such keen judgment and conducts his duties with such accuracy and dispatch that he soon gets his job, and we are therefore not concerned about him in this discussion. But the average operator of the desk and magazine type mentioned early in this article must receive our attention. The monotony of his work soon hardens him to a state of semi-coma. If he gets his machines on the line at specified times (whether or not the load conditions require them) and keeps his breakers closed, the major portion of his day's work is done. It is only in times of stress when things do not run smoothly that he is called upon to exhibit quick and accurate judgment. Many stories have been told—some not without their humorous side—of operators performing fearful and wonderful feats during times of trouble and excitement; feats for which the men themselves would truthfully disclaim credit and vigorously deny having done. Mr. E. E. F. Creighton in Trans. A.I.E.E. for 1912 discusses several such performances.

Knowing these conditions, the railroads must nevertheless place their apparatus under such circumstances. It is not to speak disparagingly of the operators that this statement is made—they are human.

Fallibility is not unknown in electrical or mechanical devices, and although the scheme of automatic operation includes several protective features, and the circuits are carefully interlocked, yet it may be possible to imagine a combination of conditions which might result in a traffic delay. But such a combination is improbable. One thing is certain; that as long as the devices are kept in working order, events in operation can only take place in one particular (and proper) sequence no matter how rapidly the conditions may change. And furthermore, this sequence will take place with the same speed and precision regardless of the stress of circumstances.

TABLE III

MANUAL CONTROL

Data for Assumed Road

Physical Characteristics		
Length of road.	mi.	50
Schedule speed	m.p.h.	25
Weight of cars . .	tons	30
Headway between cars	min.	120
Number of stops per mile		0.5
Number of substations		5
Capacity of substation converters	kw.	300
Length of operating day	hr.	18
Car miles per day.		900
Energy consumption per car mile	kw-hr.	1.7
Total energy per day at cars	kw-hr.	1530
Total energy per day high-tension side substation .	kw-hr.	1860

Cost and Operating Expenses

	Normal Feeder	Over Feedered
Size of feeder (copper) 44 miles	4 0	500,000
Original cost of substations at $40.00	$60,000	$60,000
Original cost of feeder installed	41,000	82,000
Total cost	101,000	142,000
Maintenance of substations at $200.00	1,000	1,000
Substation attendance at $75.00	9,000	9,000
Interest and depreciation at 10 per cent	10,100	14,200
Power at 1/2 cent per kw-hr..	5,037	4,770
Total operating expenses (approximate	25,000	29,000

The same cannot be said under human control.

All the relays and contactors making up the automatic equipment are devices which have been standard for a number of years and used extensively in power stations and industrial applications. They have all proven their ability to function successfully. It is only their application to railway work which is novel. The automatic substation still retains the usual lightning protection. If a lightning stroke were severe enough to damage the apparatus, it would do so whether an attendant were present or not. There is a bare possibility that on systems prone to severe short circuits on the direct-current side, the current on this side would rise so rapidly that the machine would be subject to momentary danger until the protective resistance was inserted. In such cases complete protection could be provided by the use of a quick opening switch or contactor, or by the use of a small amount of inductance in the direct-current circuit.

With all its trimmings the automatic substation is less complicated than the multiple unit car it feeds. The service it gives equals in continuity its manual predecessor.

We have already seen the application of automatic substations as a means of saving energy and diminishing the expense of operators. There are many other ways that losses may be saved or inordinate financial outlays averted. A few may be enumerated.

There are roads still running on the now obsolete and highly inefficient booster scheme. The amount of feeder conductor which can be turned into cash capital is something

TABLE IV

AUTOMATIC CONTROL

Comparative Costs and Operating Expenses, on Basis of: First, using Present Number of Substations; and, Second, Using More Substations and Taking Down the Feeder

	CASE I NORMAL FEEDER		CASE II OVER FEEDERED	
Number of substations	5	9	5	9
Size of feeder	4/0	None	500,000	None
Weight of feeder copper	150,000	0	356,000	0
Cost of conversion of present substations	$16,500	$16,500	$16,500	$16,500
Cost of new substations (200 kw.) at $46.00	......	36,800	......	36,800
Total cost	16,500	53,300	16,500	53,300
Credit for feeder removed at 25 cents	......	37,500	......	89,000
Approximate initial investment	16,500	16,000	16,500	*
Maintenance of substations	1,000	1,800	1,000	1,800
Substation inspectors at $100	2,400	3,600	2,400	3,600
Interest and depreciation at 10 per cent	11,800	11,800	15,900	7,000
Power at ½ cent per kw-hr. (1860 kw-hr. per day)	3,400	3,400	3,400	3,400
Total operating expense (approximate)	19,000	21,000	23,000	16,000

* There is a balance of $35,700.00 after paying for all the automatic equipment. This is applied as a credit to the original cost of the installation and the interest and depreciation is based upon the new cost figure.

TABLE V

AUTOMATIC *VERSUS* MANUAL CONTROL

Summary

	MANUAL CONTROL		AUTOMATIC CONTROL			
	Orginial		Case I Normal Feeder		Case II Over Feedered	
Size of feeder—44 miles	4/0	500,000	4/0	None	500,000	None
Number of substations	5	5	5	9	5	9
Initial cost	$101,000	$142,000	$117,500	$117,000	$158,500	$106,300
Annual operating expenses	25,000	29,000	19,000	21,000	23,000	16,000
Saving in operating expenses	.....	.....	6,000	4,000	6,000	13,000
Years to pay for auto. equip.	.....	.....	2 to 3	4 to 5	2 to 3	Credit
Saving in operating exp. per mi.	.....	.....	$120	$80	$120	$260
Saving in operating expense	.....	.....	24 per cent	16 per cent	24 per cent	52 per cent

enormous, to say nothing of the improved voltage conditions at the cars, with consequent improvement of schedule.

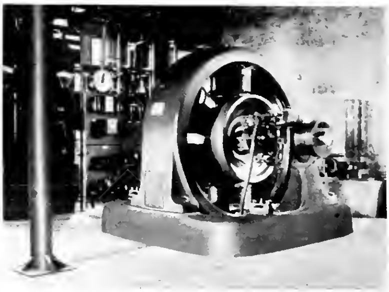
Should the unexpected happen and the service on the railway increase after the initial installation, the most economical remedy would be the automatic substation, one placed between each present substation. It is possible these could have units smaller in capacity than the original.

Centers of excursion traffic present admirable locations. Portable substations to bring the power supply near temporary loads such as gravel pits, road-side quarries, etc., are now more practical than ever, since they can be made automatic and operate only when the trains move.

A feature of the load limiting resistance which should not be overlooked is its value in reducing peak demands on the system. A power contract placed on a peak demand basis can now be rewritten to the advantage of the railway.

Finally, the building which houses an automatic substation can be compact and reasonably constructed. Living quarters, so frequently necessary, are no longer required. Provision for heating and the attendant fuel expense can be reduced to nothing. Windows may be small and high.

Much has been said so far of what *might* be done, what savings *might* be made. Has anything actually been done to warrant these statements? Yes. Four substations are now in regular operation and before this article is read six or seven more will have been started. The scheme therefore is practical and it works. The manufacturers are building six more railway equipments to say nothing of three others to control waterwheel generators and one to control a synchronous condenser. These last, by the way, indicate that the field of application is not limited to railways, but this is another story. Accurate figures of savings are not yet available although one road claims economy of energy considerably beyond that estimated in the accompanying tabulations. All of which goes to show several of the railway companies—and they are not all confined to the interurban field—see the light. They give the operator a job.



Automatic Railway Substation

MODERN CAR EFFICIENCY

By J. F. Layng

Railway Traction and Engineering Department, General Electric Company

The writer presents a strong argument for the replacing of old equipments with new when conditions are such that radical economies can be secured. He cites a special instance where the adoption of lighter modern equipments effects very handsome savings and pays very large returns on the additional investment. His arguments are based on figures which are incorporated in the article.—Editor.

The business of any concern is seldom coming in at a steady rate month after month and year after year; it is either increasing or decreasing in volume. With any of our great modern industrial institutions their business has grown to the present large proportions owing to the fact that the managements have been progressive and willing to make changes in methods, plant equipment, and in the general conduct of the business. Such changes are made to enable them to successfully meet the newer conditions by having a general constructive policy. If we enter into any modern up-to-date machine shop we see that practically all of the tools have been installed within the past few years, and that those which are turning out most of the work are up-to-date heavy machines adapted for high speed work.

Another example of change in equipment is that of the steel corporations. Fifteen years ago the tonnage of any particular mill was but a small fraction of what it is today with a modern up-to-date plant, which is adapted to the cutting of cost on a tonnage basis. As we glance back over the financial history of the steel corporations, the wisdom of such wholesale change in plant equipment can not be doubted. The success of these companies has only been secured by the willingness to make wholesale changes, and it seems that many electric railway systems in this country should carefully consider the making of changes in order to give transportation at a lower cost. Some of the railway companies have adopted this policy and modern light weight equipment is being operated successfully, and by the use of this type of equipment properties which would have either no net earnings, or very small net earnings, have been turned into reasonably profitable companies.

Our railway officials have so much statistical information before them that it would seem, at times, it is not properly analyzed so that the full benefit of what can be done in the cutting of costs is not realized.

Recently, the writer was called upon to assist in investigating the operating conditions of a railway company which operated both city and interurban service; serving quite a number of rapidly growing communities. Lately there was a change in the management and the new manager was the type of man who wished to analyze, not only the costs which he had before him, but also to analyze the operating conditions. The object of the analysis was to determine if the equipment which was being operated was entirely suitable for the work which was in hand. He called a conference of his Efficiency Engineer, Superintendent of Transportation and Master Mechanic to determine what would be the best method to properly analyze the conditions as they existed at that time. After this investigation had proceeded in a preliminary way it developed that the interurban service was not interurban service at all, but was merely a high speed suburban service, approximately two stops per mile. For some short distances it was necessary to operate schedule speeds of 19½ miles an hour, but the stops where this high speed was necessary was reduced to approximately 1½ stops per mile. In reviewing the equipment it was found that some of the cars were geared for free running speeds as high as 48 miles an hour when operating on 600 volts or approximately 40 miles an hour when operating on 500 volts.

There are a variety of operating conditions which this company has been called upon to fulfill and after reviewing all of the service data and the equipments which are now operating, it was decided that it is feasible to operate a car equipped with four 35-h.p. motors and 26-in. wheels which will weigh approximately 40,000 pounds complete without live load. The car which was selected as the ideal car would have a seating capacity of 60 passengers. The gearing which would be used will give 30 miles per hour free running speed on 500 volts. The following table will give the schedule possibilities of the equipment for different stops per mile when compared with the present equipment which will average a free running speed of 40 miles per hour:

Stops per Mile	Schedule Speed when Free Running Speed is 30 M.P.H	Schedule Speed when Free Running Speed is 40 M.P.H.
0.5	25	31
1.5	18.5	20.5
2	16	17
3	14	15
4	12	12.5

From this table it will be seen that the new cars will practically have all of the schedule possibilities of the older equipments for the service in which they will be operated. However, there are some short stretches of from 2 to 3 miles where the present cars are operating at a higher speed than the newer cars will be capable of, but at the same time the new cars will be able to move more rapidly in congested districts and in this way the running time from terminal to terminal will be maintained with some modification of the running time on points between terminals.

It is interesting to note that this company has 31 cars which are used in the interurban service. A general summary of the savings that will be effected is as follows:

Power	$40,754.18
Car maintenance	20,698.52
Track maintenance	8,700.00
Total annual saving	$70,152.70

The cars which are now operating require a power house capacity of 3500 kw. Substitution of the modern light weight cars will reduce the power house capacity required to approximately 2000 kw. At a moderate estimate the 1500-kw. power house capacity could be valued at $60 per kw. or an installation cost of $90,000. The savings represented by the interest on this sum have not been included in the annual savings enumerated. In addition to this, providing the modern light weight interurban cars are not purchased, the growth of the communities which are served by the railway companies is such that it will be necessary to start tram operation which will make it necessary to install additional substations and feeder copper, which will not be capitalized in the general method which will be pursued in explaining how the annual savings of over $70,000 can be made on these equipments.

The new moderate weight cars can be purchased for approximately $7000 each and it is fair to assume that those which are now operating will salvage for at least $1000 each. This salvage is extremely low. On this basis the new cars will have a net cost of $6000 each, which for the total of 31 cars will represent an expenditure of $186,000. The annual savings of $70,152.70 will represent 38.5 per cent interest on this investment. Of course this percentage will be greatly increased providing the additional cost of power house, feeder copper and substation equipments were capitalized.

In reviewing the cars in service it was found that there were four classes of cars to be considered. For the convenience of explaining just how the savings were arrived at these cars were divided into series A, B, C and D. When the new car is mentioned it is designated as Class "X."

Class "A" Cars

The series includes 9 cars which weigh 56,000 lb. complete with all equipment. With 40 passengers these cars will weigh complete with live load 61,600 lb. or 30.8 tons, which is equivalent to 7.7 tons per motor. These cars are equipped with four 90-h.p. motors and 33-in. wheels. With 20 lb. friction and on 500 volts these cars will have a free running speed of 40 m.p.h. In order to appreciate the amount of energy used by this type of car, the following tabulations have been made when the cars are making different number of stops per mile with the maximum schedule which can be obtained under these conditions.

Stops per Mile	Watthours per Ton Mile	Kw-Hr. per Car Mile
0.5	75	2.31
1.5	102	3.14
2	112	3.46
3	130	4.02
4	142	4.38

By substituting Class X car equipped with four 35-h.p. motors, and 26-in. wheels, the total weight of the car with 40 passengers will be 46,920 lb. or 23.46 tons, which is equivalent to 5.87 tons per motor. This will give a free running speed of 30.2 m.p.h. The power consumption of this class of car will be as follows:

Stops per Mile	Watthours per Ton Mile	Kw-Hr. per Car Mile
0.5	50	1.17
1.5	65	1.52
2	72	1.69
3	82	1.92
4	90	2.11

The average stops per mile of the interurban cars in all classes of service is approximately two per mile. On this basis, the saving in power will be 1.77 kw-hr. per car mile. During the month of May 1916, all cars of Class A made a total of 49,290 car miles. This would give 591,480 car miles per year. The average voltage at the car on the system is less than 450 volts, which would mean that the power delivered to the car would cost at the least calculation one cent per kw-hr. All of the power readings as given above are figured as power at the car and do not include transmission, substation and line losses. The total savings of the power on the basis of 1.77 kw-hr. per car mile are 1,046,919 kw-hr., which at one cent per kw-hr. would have a value of $10,469.19.

The cost of maintaining all classes of cars including all small city cars and interurban cars is $15.90 per 1000 car miles. On a conservative method of figuring the large interurban cars will cost not less than $20 per 1000 car miles for car maintenance. The cars of the X class will cost $10 per 1000 car miles. With this maintenance the savings for a year on all cars of this class will be $5,914.80. This is on the basis of operating 591,480 car miles per year.

With the lighter cars the maintenance on the track, special work and structures will be much less than that which is now obtained, and as is shown in another portion of this article the annual track maintenance saving that can be made with this series of cars is $2,209.80.

If the present cars are continued in service to meet the traffic demands, with train operation, the need of additional substation apparatus and feeders is shown by the accelerating currents. To accelerate one of the Class A cars at 1½ m.p.h.p.s., 472 amperes are required. With the two-car train this figure is 944 amperes. With a Class X car arranged as previously described, when accelerating at 1½ m.p.h.p.s., 286 amperes are required. With a two-car train this value is 572 amperes. This shows the Class A car will take 65 per cent more current to accelerate than the new car.

A tabulation of the savings which are made by substituting the new car for the present Class A cars is as follows:

Power reduced 1.77 kw-hr. per car mile.	
Annual saving in power 1,046,919 kw-hr.	
Accelerating current Class A car 65 per cent greater than proposed car.	
Annual value of power at 1c. per kw-hr.	$10,469.19
Saving in car maintenance.	5,914.80
Saving in track maintenance	2,209.80
Total.	$18,593.79

There are nine cars in this series, and a new Class X car costs approximately $7000. It is assumed that the salvage value of the present cars is $1000 each. This leaves a net cost of the new cars of $6000 or $54,000.

The annual saving as shown above pays 34.3 per cent interest on this investment.

Class "B" Cars

There is a total of fourteen cars of this class to be considered. These cars complete with all equipment weight 68,000 lb. and with 40 passengers complete with a live load they weigh 73,600 lb., which is equivalent to 36.8 tons, or 9.2 tons per motor. These cars are equipped with four 90-h.p. motors and have 33-in. wheels. With 20-lb. friction and on 500 volts these cars will have a free running speed of 40 m.p.h. The energy for different stops per mile for a car of this class will be as follows:

Stops per Mile	Watthours per Ton Mile	Kw-Hr. per Car Mile
0.5	75	2.76
1.5	102	3.75
2	112	4.12
3	130	4.79
4	142	5.22

By substituting the Class X car, it can be seen that the average power consumption will be reduced from 4.12 kw-hr. per car mile to 1.69 kw-hr. per car mile, which gives a reduction of 2.43 kw-hr. per car mile. All of the Class B cars which have been enumerated operated during the past year 1,080,354 car miles. On this basis the power saving would represent 2,625,270 kw-hr., which at 1c. per hw-hr. would have a value of $26,252.70. The savings in the maintenance on the new car figuring on the basis of $10.00 per 1000 car miles would be $16,202.78. The saving in track maintenance due to the lesser weight would be $4,628.40.

When accelerating at $1\frac{1}{2}$ m.p.h.p.s., the accelerating current is 568 amperes for a single car, and for two cars 1136 amperes. Since the Class X car takes 286 amperes per car, and the Class B will take 568 amperes, it will be appreciated that the present cars of this class take 98.5 per cent more current.

Summary of Savings

Annual saving in power	$26,252.70
Car maintenance	10,202.78
Track maintenance	4,628.40
Total	$41,083.88

There are fourteen cars in this service, which at a net replacing cost of $6000 each would represent $84,000. The annual saving represents 49.7 per cent interest on this investment.

Class "C" Cars

These cars weigh complete with all equipment 68,000 lb. Including 40 passengers the weight complete with load will be 73,600 lb. or 36.8 tons, or 9.2 tons per motor. These cars are equipped with four 90-h.p. motors with 33-in. wheels. On 500 volts these cars will have a speed of 37 m.p.h. The energy for different stops per mile for a car of this class will be as follows:

Stops per Mile	Watthours per Ton Mile	Kw-Hr. per Car Mile
0.5	65	2.39
1.5	87	3.2
2	96	3.53
3	112	4.12
4	125	4.6

Since there are two stops per mile as an average the energy will be 3.53 kw-hr. The Class X car will use 169 kw-hr. per car mile; there will be a saving of 1.84 kw-hr. per car mile.

This particular class of car for a year would operate 177,270 car miles for which the current savings would represent 215,776 kw-hr. which at 1c. per kw-hr. would represent $2,157.76. The savings in track maintenance would represent $530.70. The accelerating current per car when accelerating $1\frac{1}{2}$ m.p.h.p.s. would be 540 amperes, or for a two-car train 1080 amperes. With the Class X car the accelerating current would be 286 amperes per car. Therefore, the accelerating current of the present cars would be 88.5 per cent greater.

The summary of savings is as follows:

Power reduced 1.84 kw-hr. per car mile.
Annual power savings 215,776 kw-hr.

Annual savings in power	$2,157.76
Saving in car maintenance	1,172.70
Saving in track maintenance	530.70
Total savings	$3,861.16

The net cost of two cars is $12,000. On this basis the annual interest is 31.1 per cent.

Class "D" Cars

There are six cars in this series which weigh completely equipped 58,640 lb. With 40 passengers this weight with live load will be 64,240 lb. or 32.12 tons, or 8.03 tons per motor. These cars are equipped with four 65-h.p. motors and 33-in. wheels. On 500 volts, it will have a free running speed of 30 m.p.h. The energy for different stops per mile for a car of this class will be as follows:

Stops per Mile	Watthours per Ton Mile	Kw-Hr. per Car Mile
0.5	50	1.60
1.5	64	2.05
2	70	2.24
3	81	2.60
4	89	2.76

With an average of 2 stops per mile it will be noted that these cars require 2.24 kw-hr. per car mile. The new car requires 1.69 kw-hr. per car mile, which is a saving of 0.55 kw-hr. per car mile. All cars of this class operate 340,824 car miles annually. The energy saving for this mileage is 187,453 kw-hr., which at 1c. per kw-hr. represents $1,874.53. The reduction in car maintenance which will be obtained by using the new car is $10 per 1000 car miles. Therefore this saving represents $3408.24. Track maintenance saving due to the lesser weight of car will be $1,331.10.

The accelerating current for this type of car when accelerating at $1\frac{1}{2}$ m.p.h.p.s. is 368 amperes, while the current for the new car is 286 amperes. This shows that the accelerating current for the present cars is 28.6 per cent greater.

A summary of the savings is as follows:

Power saving 0.55 kw-hr. per car mile.
Annual saving in power 187,453 kw-hr.

Annual value of power at 1c. per kw-hr.	$1,874.53
Car maintenance saving	3,408.24
Track maintenance saving	1,331.10
Total	$6,613.87

The six new cars have a net cost of $36,000. Therefore, the saving represents 18.35 per cent interest on the investment.

TRACK MAINTENANCE

In order to determine a correct value to assign to the lesser track maintenance which will necessarily take place when such lighter equipments are used and also to properly proportion the maintenance between the different series of cars used, the following data have been tabulated:

Class A Cars:	During the month of May operated 49,290 car miles.
Class B Cars:	During the same period operated 75,257 car miles.
Class C Cars:	During the same period operated 19,545 car miles.
Class D Cars:	During the same period operated 28,402 car miles.

The weight of these equipments without passenger load for each of the different series of cars are respectively 56,000, 68,000, 68,000 and 58,640 pounds. Assuming that the average car mileage throughout the year is the same as during the month of May and by multiplying the yearly mileage by the weight we obtained the total pound miles that were operated by each class of car. By proportioning this, we find that the value to use for each of the different classes of cars will be as follows:

Class A Cars	25.4 per cent
Class B Cars	47.1 per cent
Class C Cars	12.2 per cent
Class D Cars	15.3 per cent

The total maintenance of track including overhead and signals during the past year was $153,000. After deducting $66,000 for overhead and removing snow and ice, etc., we have $87,000 for direct track maintenance.

By substituting the new cars this maintenance will be reduced at least 10 per cent, or $8700 per year. It is generally recognized that the heavy cars of any system are those which cause the most rapid depreciation of special work, rail joints and structures. The present cars of the different classes enumerated will weigh 40, 70, 70 and 46.6 per cent respectively more than the new cars. It will, therefore, be readily appreciated that the figure as used will be exceptionally low.

Proportioning the maintenance on a percentage basis as previously outlined, we find the credit which should be given for the lesser track maintenance for the

Class A Cars	$2,209.80
Class B Cars	4,097.70
Class C Cars	1,061.40
Class D Cars	1,331.10

It will be seen that this analysis of operating conditions is different from that which we usually find and it would seem as if this is a good logical method to follow.

After reviewing the figures which have been enumerated it will be seen and readily appreciated that the proper thing for a railway company to do, that has equipments of the character which have just been enumerated, is to sell the equipment which is now operating for whatever money can be secured, and to purchase new equipment. The savings which have been shown will pay a very profitable interest on the investment and it is a mistake to continue the operation of equipment which has served its usefulness. The new cars will not only give a more reliable but a more satisfactory all round, up-to-date service.

A LIGHT WEIGHT RAILWAY MOTOR
(THE GE-258)

By G. L. Schermerhorn

Railway Motor Department, General Electric Company

This is a detailed description of a new light railway motor. Special provision is made to insure good ventilation; a novel feature is the use of ball bearings.—Editor.

During recent years many railway managers and engineers have seriously considered the use of light weight cars in order to materially reduce operating expenses and improve the service. Such cars have also been considered in connection with jitney competition. Lines using the common form of heavy car to handle comparatively light travel might be operated at increased profit provided lighter cars and equipments were used. Railway motor equipments, car bodies and trucks in common use at the present time are in general too heavy and to expensive in first cost and subsequent maintenance of equipment and track to effect the greatest economy in operation. Motor sales at this time point to a very extended use of the light car in various classes of service.

To meet the demand for a light, sturdy, efficient, low cost motor the GE-258 railway motor has been designed and placed on the market. Up to the present time seven hundred eighty-five of these motors have been sold and are being used in many different roads throughout the country. In order to meet the general demand the motor has been developed in two forms *A* and *B*. The Form *A* is suitable for use with 24 inch wheels and four inch axles: the Form *B* can be used on either 30 or 33 inch wheels and axles up to 4 1/2 inch diameter. The armatures, field windings, brush holders, bearings and other internal parts are alike for the two forms.

Fig. 1. A New Light Weight Railway Motor

The motor is rated at 25 h.p. for one hour at 600 volts. It will operate continuously at inputs of 32.4 amperes 300 volts, 34.9 amperes 450 volts, and 35.2 amperes 600 volts, without the temperatures of the motor windings or commutator exceeding 65 deg. C as measured by thermometer.

The weight of the motor complete with gearing, gear cover, axle linings, and collar is 885 pounds for the Form *A* and 995 lb. for the Form *B*.

In order to secure the high continuous capacity as indicated above and at the same time produce a motor of light weight, advantage was taken of the fully ventilated type of design which has been introduced during the past few years. The motor operates with conservative armature speeds although somewhat higher than have commonly been used in earlier designs of motors. An increase in armature speed serves two purposes, first, to reduce the weight, and second, to obtain a greater amount of air through the motor, thereby increasing the continuous rating.

Although the armature speed is somewhat higher than commonly used, the car speeds remain normal, this being accomplished by the use of a higher gear ratio. In order to obtain strength and good life for this type of gearing, heat treated, high grade material is used.

The GE-258 motors have been in actual service only a few months, but it will be of interest to state that after 20,000 miles the teeth of the pinions and gears have taken on a bright polish and show very little wear.

The gear covers are made of pressed steel in two halves, bolted together to a two point suspension. Each half is pressed from a sheet in one piece, making the case exceedingly light and at the same time very rigid.

The general motor design follows the standard G.E. box frame type, as shown in illustration Fig. 1. The air intake shield is shown removed from the motor, exposing the ventilating holes through the magnet frame. Cooling air enters under the shield and through the holes in the shield and frame, as shown. The air is expelled by the fan through ventilating holes at the pinion end of the motor as shown in Fig. 2. The axle bearings are of the standard oil and waste lubricated type. The motor is provided with a lug on its front side suitable for spring suspension on the truck.

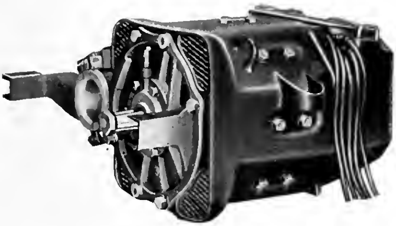


Fig. 2. Pinion End of Motor Showing Ventilating Holes

A distinctive feature of the motor is the adoption of ball bearings for the armature. Experimental motors of various sizes equipped with different types of ball bearings, operating in actual service for a period of from three to ten years, proved ball bearings to be entirely practical.

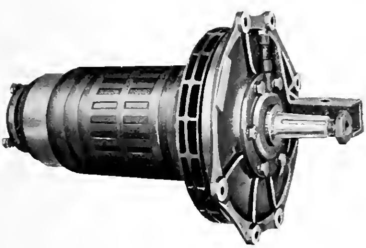


Fig. 4. Armature, Fan and End Frame Head

The decision to use ball bearings in this motor was based directly on the good results obtained in these tests. Fig. 3 shows the arrangement of the bearing at the pinion end of frame. Fig 4 shows the armature complete with bearings and pinion end frame head. Particular attention is called to the form of construction shown which enables the armature to be removed from the motor frame complete with bearings. This permits the armature and bearings to be examined or overhauled while on a bench or suitable rack, thereby greatly eliminating the possibility of dirt getting into the bearing. This feature is of particular importance since it was found that in previous designs dirt was liable to get into the bearings due to the fact that the bearings were assembled at the time the armature was being placed in the magnet frame.

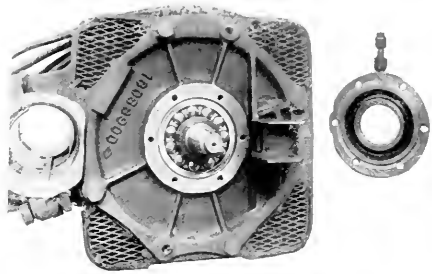


Fig. 3. Arrangement of Ball Bearing

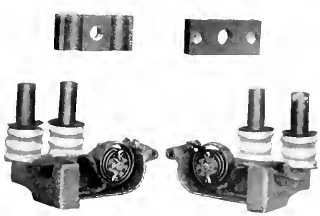


Fig. 5. Brush Holder

The bearing design adopted in this motor eliminated the necessity of a separate frame head at the commutator end of the motor, the outer raceway of the bearing with its housing being fitted into a bored recess in the solid end wall of the magnet frame.

The brush holders are of the latest type, held in position by means of insulated studs clamped to the end wall of the magnet frame. The brush holder springs are of the phosphor bronze clock spring type. The holder was designed with a view to eliminating all unnecessary parts and to allow repairs or adjustments to be made with the greatest ease. A general view of the brush holder is shown in Fig. 5.

The system of ventilation used is the same as is employed in other types of G.E. railway motors, notably the GE-247. Air enters the commutator end of the frame, passes in parallel paths through ventilating ducts in the armature core and over the field coils, being expelled by means of the large diameter fan through the frame openings at the pinion end. Experience has shown that this form of ventilation produces the highest continuous capacity. This system of ventilation has been used in actual service about two years. Experience indicates that predictions of serious trouble due to water and dirt entering the motor through the ventilating intake holes have not come true.

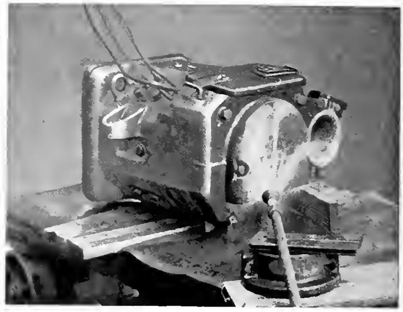
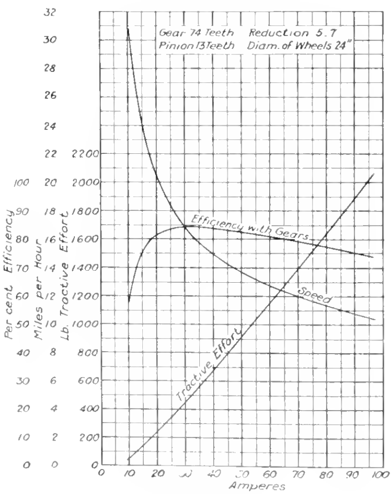
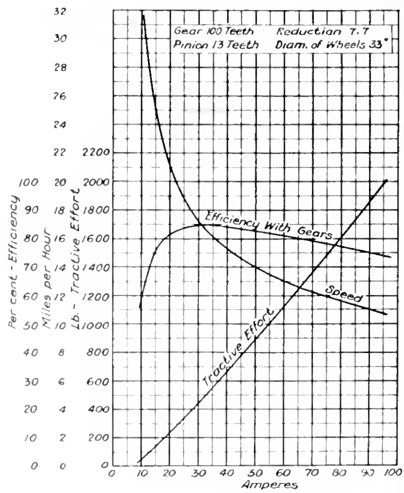


Fig. 6. Water Test, with Motor Running Light, 625 Volts on Armature, 1650 R.P.M.



GE-258-A



GE-258-B

Figs. 7 and 8. Speed, Torque, and Efficiency Curves

Approximately twenty-seven hundred motors having the GE-258 type of ventilation have been sold to date, a large majority of which have been placed in service. They are operating with complete success.

Fig. 6 shows a shop test made for several hours with this motor. It will be noted that water from a hose was directed against the openings in the frame while the motor was operating at 625 volts. No injury resulted to the motor windings or commutator.

Speed, torque and efficiency curves are shown in Figs. 7 and 8.

The following table gives the service performance of the GE-258 motor when handling four or five tons per motor on 24 in. wheels and 500 volts. The temperature rise of the motor when operating the schedules given is very low, thus indicating a very conservative electrical design. The same schedules will be maintained with the GE-258-B motor on 30-in. wheels at the same voltage.

SCHEDULE SPEED, GE-258-VOLT MOTOR A-1 AND A-3

Trolley potential 500 volts. Diam. of wheels 24 inches. Acceleration and braking 1.5 miles per hour per second. Duration of stops 10 seconds. Coasting for distance of 230 feet. Straight level tracks. Schedule speeds are 10 per cent less than theoretical values to allow for delays due to grades, curves, slow-downs or other factors affecting schedules.

Stops per Mile	Gear Ratio	Tons per Motor 4	Tons per Motor 5
2	5.7	14.8	14.3
2	4.8	15.8	15.4
3	5.7	13.2	12.8
3	4.8	14.4	14.0
4	5.7	11.9	11.5
4	4.8	12.2	12.0
5	5.7	10.7	10.5
5	4.8	11.1	10.8
6	5.7	9.8	9.6
6	4.8	10.1	9.9
7	5.7	9.1	8.9
7	4.8	9.4	9.2
8	5,7	8.5	8.3
8	4.8	8.7	8.5
10	5.7	7.7	7.5
10	4.8	7.8	7.6
Max. free running speed 4-motor equipment	5.7	22.6	21.0
	4.8	25.0	23.7

Maximum free running speed of 2-motor equipment approximately 90 per cent of above.

ENGINEERING EFFICIENCY IN RAILWAY OPERATION

By J. C. Thirlwall

Railway and Traction Engineering Department, General Electric Company

The author points out the constant vigilance on the part of the railway management that is necessary to make sure that the maximum possible efficiency of a system is not impaired by lack of co-operation between different departments and by the retention of equipment that is either obsolete or unsuited to the particular service in which it is operating. He cites examples where considerable economies could be effected by changing the equipment.—Editor.

In the construction of a new electric railway, all details of track, overhead lines, stations and rolling stock are planned as a coördinate whole by the engineer in charge, and as a result the physical portions of the property function in a more efficient manner when the road first commences operation than is usual several years later. This results from several causes, some unavoidable and some which might be avoided. The impossibility of maintaining equipment and lines at their original efficiency, and changes in traffic conditions, may be classed among the factors which are unpreventable; so may increased costs of material which often force a road to continue equipment in service after it has become inadequate for the increased duties that changed conditions have imposed upon it, for lack of the money required to replace it, even when the advantages of new equipment are fully recognized.

But a lack of proper coordination between the different departments of the company may be responsible for many losses which could be classed as preventable. The typical railway organization has separate departments in charge of rolling stock, of track, of overhead lines, and of stations; with a separate and distinct organization handling traffic. Even with men of exceptional ability in their own fields in charge of these different departments, a lack of thorough cooperation often exists that hampers the efficiency of the organization as a whole. For instance, through lack of sufficient power or because of insufficient feeders or proper bonding, the most economical schedule speeds cannot be maintained; or contrawise, by the insistence of the transportation department on unnecessarily high speed equipment both the maintenance of rolling stock and the cost of power is run up to abnormal and excessive values.

The constantly rising cost of railway operation, due to a steady advance in both material and labor costs, makes it imperative that every operation be conducted on the highest possible plane of efficiency and emphasizes the need of engineering coördination, and is tending to create a demand for a special executive, the Transportation Engineer, an engineer whose training is broad enough so that he understands the relative importance of each of the separate departments of his company, and can see to it that the demands of the transportation or claim departments are met in the most economical and efficient manner. His duties should be to aid the general manager in determining the allotment of expenditures for maintenance, renewals, replacements, and new equipment; to investigate service conditions; to advise on the type of cars best suited to various lines, etc.; to do, in short, what consulting engineers are so frequently called upon to do, and which, through his more intimate knowledge of local conditions, he should be able to do in a better fashion than an outside consultant. On all large properties the duties of the general manager, whose province it usually is to supervise the various department heads and coördinate their recommendations, are so numerous and complex that he often cannot find time for the investigation of the details of the work of the various departments; and with human nature as it is, the strongest or most aggressive subordinate will often have his recommendations adopted at the expense of some other department, even where some other program might be to the general interest.

Equipment engineers frequently observe conditions of this sort; consulting engineers who study railway systems are continually calling attention to the results where intelligent cooperation on the properties they investigate is lacking.

Some specific instances of conditions personally observed by the writer on roads where he has had occasion to work on equipment propositions form the basis for the foregoing observations, and may be referred to without in any way disparaging or criticizing the managements of the properties referred to. So long as the human tools with which all executives have to work remain fallible, errors will be made and the attainment of 100 per cent efficiency is further off in the human machine than in the mechanical. Almost every railway manager will admit that there are many details in the operation of his lines that could be improved; almost always there is some good reason why it has not been corrected. It may be lack of funds; it may be legislative restrictions; it may be labor union prejudices; or merely public sentiment. But there are, too, very frequently, details which can be corrected without conflicting with any of these things, and which a trained engineer will see sooner than anyone else.

I have in mind one fairly large system which operates under widely varying conditions a considerable trackage of city, suburban and interurban lines. It is, like many other properties, a system formed by the consolidation of many separate roads, and hence it inherited cars and equipment of widely varying types, and also schedules and operating conditions which varied as widely.

The operators, under the circumstances, pursued a very sensible course at this juncture in securing the services of an able engineer who laid out a comprehensive plan of power distribution, of equipment assignment, and of schedule speeds, particularly on the suburban and interurban lines, and the operating efficiency of the road at this time was placed on a high plane. Recently, however, they have become convinced that radical changes are necessary if they are to continue on a paying basis. Studies made by their own organization and by consulting engineers have revealed a surprising degree of inefficiency in many phases of operation—too slow schedule speeds, unsuitable and inefficient equipment, excessive power losses, abnormally high maintenance costs, together with excessive depreciation of much of the physical property. All in all it was apparent that tremendous annual savings in operating costs could be made, and the fundamental reasons for the loss in efficiency that had developed in a few years may be of general interest, for similar conditions exist or are in process of becoming existant on a very large number of roads. To some extent it is simply the result of conditions changing so rapidly that the operation cannot keep pace; in some respects it is due to a lack of engineering coördination.

The original cars which were used on the suburban and interurban portions of the lines were for the most part cars weighing about 36,000 lb. and equipped with four 40-h.p. motors, geared for fairly moderate speeds, about 28 miles per hour on 500 volts. The stops at this time on the longer runs probably did not exceed one per mile, and on the suburban lines about $2\frac{1}{2}$ per mile. But as people settled along the railway lines, and the suburban population increased, the car loads became heavier and heavier, and the number of stops increased to a marked extent, until today they average $2\frac{1}{2}$ per mile on the interurban runs and from 4 to 5 per mile on the suburban.

The increased traffic necessitated larger cars, and a type which became a standard for some years was one which weighed about 48,000 lb. and was geared for about 30 m.p.h.

The increased number of cars in service, the greater weight of the cars themselves and of the loads they carried, the greater number of stops and the higher free running speeds, all worked together to very radically increase the power consumption. The capacity at the primary sources was built up in proportion to this increased demand, and some additions were made in the number of substations and in their capacity. But the copper in the transmission and distribution systems was not increased to the same extent, with the result that on all of the longer lines and on many of the shorter ones, there was a very excessive drop—voltage at the car frequently running as low as 200 volts, for long distances.

This, of course, led to complaints on the part of the transportation department, for the low voltage reduced the free running speeds of the cars to such a degree that it was impossible to maintain schedules. The proper remedy, in view of the fact that the bulk of the mileage made by the cars was in service that required a free running speed of only about 25 m.p.h., would have been to add more copper to the lines and to bring up the voltage to a normal value of at least 450 volts. Instead, the cars were speeded up by putting on higher speed gear ratios on the motors, which brought the free running speed on the portions of the line where 500 volts was obtained to about 33 m.p.h., and on some cars more recently purchased, to about 35 m.p.h. This, in turn, increased the current consumption still more, and caused a still further line drop, which to a large extent, offset the increased speed of the motors. Thus, the schedules were not appreciably improved, but power costs were very considerably increased. In addition, the motors and controllers were badly overloaded on many of these lines, and maintenance costs became excessive.

Had the line voltage drop been decreased by the addition of more copper, it is fairly certain that the car speeds would have been so much increased, that lower speed gear ratios could have been used on the motors, and the savings in power and maintenance would have paid a very liberal rate of interest on the cost of the copper used. Moreover, the depreciation, in this case, would have been far less than it is now; that is, copper line deteriorates far more slowly than electrical machinery. The transportation department was unquestionably justified in demanding higher speeds; schedules today are too slow to secure the maximum traffic, or to keep platform costs down to a normal figure. But the point is, that a wrong method of attempting to increase speeds was adopted, and one that no consulting engineer of broad experience and through knowledge of local conditions would have suggested. The results were heavy increases in the total cost of operation with no appreciable decrease in traffic expenses.

A similar instance may be found in the subject of car design. From some standpoints, it is simpler for both the transportation and the mechanical departments to have a single type of car and of motor equipments, a car that can be used interchangeably on any and every line of the system. But on a large property where service on the various lines differs widely, the disadvantages of a universal type of equipment are very great. For interurban lines all over this country it has been demonstrated that a fairly large car, running at moderately high speeds on rather long headways, is best suited to the service and most economical. For congested traffic in large cities, a similar sized car, but of lighter weight and using smaller motors geared for lower speeds, is the best, as shown by their practically universal application.

For smaller cities, where big cars can only be operated on long headways (except at the expense of too great an operating ratio), smaller, extremely light weight cars are best suited, and if one-man operation is desired a special type for this purpose is preferable.

In this case, since so large a part of the service called for a car of large capacity to handle the morning and evening loads, the attempt was made to design a universal car, using the same motors for all services, with two gear ratios, one suited for the highest speed lines and the other for the city lines, and the cars which had the high speed equipment were used indiscriminately on lines which actually required the inherent speed they possessed (under the low average voltage conditions), and on many others where even under existing conditions a slower speed equipment would have been equally satisfactory and much more economical.

The logical method under these condition would have been to carefully study the characteristics and service on each line; to have divided them all up into three or four broad classes; and to have purchased cars and equipment specially suited to each of these classes, and confined cars so selected to the service for which they were best suited. This procedure would have resulted in a lower first cost for equipment purchased; in reduced maintenance both of equipment and of track; in reduced power cost; and probably in platform expense.

These are but two instances of what lack of intelligent co-operation or of proper engineering analysis and coordination may cost an operating company—many others will suggest themselves as actually existent on many properties, or as logical possibilities. The electric railways have been going through a period of dropping earnings and of rising expenses. Competition with the jitney car, the larger auto bus, or the private automobile is now and will continue to be a check on earning capacity. A steady advance in both the material and the labor market tends to keep operating costs on a rising plane. Increased fares are still, in most communities, a rosy Utopian dream.

Under these circumstances, the development of a transportation engineering department headed by a man who has been trained to co-relate the various factors entering into the cost of service would appear a logical step for all roads large enough to maintain such a department, and the engineering staffs of the manufacturing companies could render considerable assistance along these same lines. Such help as they can render is always and gladly placed at the disposal of any railroad which desires it.

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 benfit 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. Adress letters of inquiry to the Editor, Question and Answer Section, General Electric Review, Schenectady, New York.

TRANSFORMER: BUZZING SOUND

(185) What causes a buzzing sound in transformers when lightning arresters are charged?

The buzzing sound which occurs in transformers when aluminum cell lightning arresters are being charged is caused by the relatively high-frequency charging current drawn through the transformers from the line by the arresters. If no charging resistances are used the sound will be especially pronounced. If, however, such resistances are used the sound is likely to be noticeable only at the starting and stopping of the charge. F.R.F.

AUTOTRANSFORMERS: OPERATION, VOLTAGE AND CAPACITY

(186) (a) Would it be permissible to operate three autotransformers in the relation shown in Fig. 1?

(b) Would grounding the neutral of the low-voltage line or of the high-voltage line affect the possibility of operation?

(c) What would be the tap voltages necessary for a transformation from 30 kv. to 50 kv. and the capacity of the autotransformers to deliver 600 kv-a. each at 50 kv.?

(a) and (b) Under certain conditions of grounding it would be thoroughly feasible to operate autotransformers as shown. These conditions and those others which would prevent operation are described in the following:

(I) *Low-tension line isolated: Autotransformer neutral isolated.*

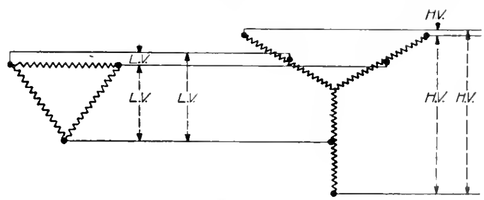
(1) A triple-frequency voltage exists between the low-voltage line and its neutral which causes the potential stress that is induced in the autotransformers to be increased 20 to 50 per cent, depending upon the flux density in the iron. The increase in the insulation stress from winding to core of the autotransformer occurs at the neutral, not at the line ends of the winding. Therefore, the presence of the triple-frequency voltage is not serious for, although the average potential stress on the insulation is increased, the maximum stress is not affected.

(2) A ground at X, Fig. 2, places the low-voltage lines B and C at a potential above ground approximately equal to 0.57 times the high-voltage plus 0.43 times the low-voltage. This, for 30 kv. low-tension and 50 kv. high-tension, equals $0.57 \times 50{,}000 + 0.43 \times 30{,}000 = 41{,}400$ volts.

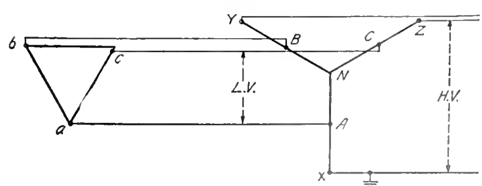
(II) *Low-tension line isolated: Autotransformer neutral grounded.*

(1) The triple-frequency voltage, which is present as in Case (I), is now exerted across the line insulation to ground. This is particularly dangerous if the autotransformer is connected to a system having considerable electrostatic capacity. Electrostatic capacity between line and ground causes a charging current in which the third harmonic is prominent; this intensifies the triple-frequency voltage by reacting upon it. Potential peaks equal to three times normal might easily result from this interaction at ordinary iron densities; at very low densities and at saturation density, however, the danger is less. It is instructive to note that the charging current necessary to produce these abnormal voltages is not large.

(2) A ground at A, Fig. 3, causes AN to collapse; A, N, and X are reduced to ground



(186) Fig. 1



(186) Fig. 2

potential and the remaining phases receive open-delta excitation at 1.73 times the normal flux density. This increased excitation is represented by the dotted lines. B and C are placed at low-voltage potential above ground.

(3) A ground at X produces the same result as a ground at A.

(III) *Low-tension neutral grounded: Autotransformer neutral isolated.*

(1) A triple-frequency voltage is present as in Case (I). However, since the autotransformer neutral is isolated there is no danger of the triple-frequency voltage being intensified.

(2) A ground at A, Fig. 4, short circuits the "a" phase of the low-voltage system.

(3) A ground at X, Fig. 4, results in a distortion of and inrease in the voltage induced in the autotransformer, as illustrated in Fig. 5. The low-voltage system does not receive an abnormal voltage nor is it subjected to abnormal insulation stress.

(IV) *Low-tension neutral grounded: Autotransformer neutral grounded.*

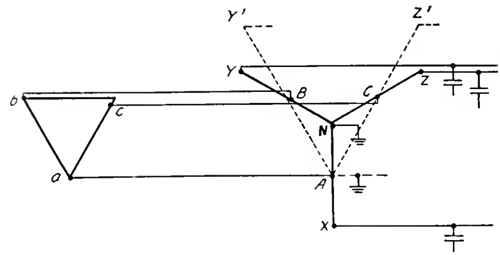
(1) A triple-frequency voltage is present but it is much reduced by the triple-frequency current which flows through the ground connections. The amount of reduction in the triple-frequency voltage depends somewhat upon the resistance of the ground circuit.

(2) A ground at A, Fig. 6, short circuits the "a" phase of the low-voltage system.

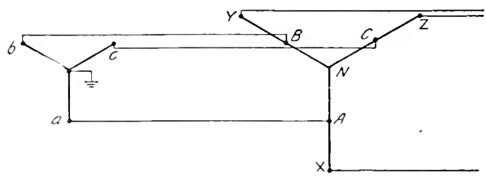
(3) A ground at X, Fig. 6, shrot circuits the NX phase of the autotransformer and also the "a" phase of the low-voltage system by reactance of the autotransformer. The potentials of B and C cannot rise above normal values.

Certain practical limitations have been ignored in the discussions of these four Cases, I, II, III and IV, for the sake of relatively presenting each for theoretical comparison with the others. The most noticeable departure in practice occurs in Cases II (2) and III (3). If the normal flux density is about 80 kilolines per square inch in Case II (2), Fig. 3, the magnetizing current required to produce the increase of 73 per cent in flux density will be so great as to cause a line reactance drop sufficient to considerably reduce the voltages applied to the autotransformer. The diagram as given, however, applies rigidly in all cases wherein the normal flux density is so low that when a ground occurs the cores will not become super-saturated. Similarly, the values XY and XZ given in Case III (3), Fig. 5, are much greater than those that would occur in practice on account of the excessive flow of magnetizing currents caused by the ground at X.

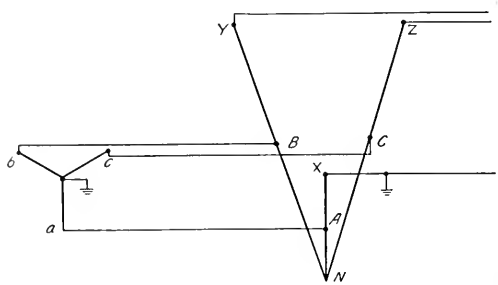
From the analysis of the four cases, it may be concluded that it is permissible to operate with the autotransformer neutral isolated, provided the low-voltage system is insulated to withstand the voltage stress which occurs when one high-voltage line is grounded, Case I (2) Fig. 2. This will usually be the case if the ratio of transformation is small. If the autotransformer



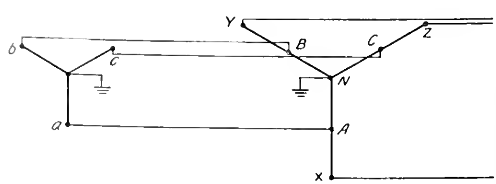
(186) Fig. 3



(186) Fig. 4



(186) Fig. 5



(186) Fig. 6

neutral is grounded three single-phase autotransformers should not be used; a three-legged core-type structure should be employed in order to limit the danger of intensifying the triple-frequency voltage.

Wherever the ratio of transformation is large, autotransformers are but slightly more economical than straight transformers and, on the other hand, the former possess some decided disadvantages as have been described.

(c) The over-all high-tension and low-tension voltages of the autotransformers shown in Fig. 1 are 50 kv. and 30 kv. respectively. Therefore, the voltage per leg high-tension is $50{,}000 \div 1.73$ (or $\sqrt{3}$) $= 28{,}900$; and the voltage per leg low-tension is $30{,}000 \div 1.73$ (or $\sqrt{3}$) $= 17{,}300$. Thus the low-tension tapping points are 17,300 volts from the neutral. These points are $28{,}900 - 17{,}300 = 11{,}600$ volts from the line ends of the windings.

The ratio of the capacity of an autotransformer to its output equals the ratio of the difference between its high- and its low-tension voltages to its high-tension voltage.

Since the output of each autotransformer is to be 600 kv-a., the capacity will be

$$\frac{50{,}000 - 30{,}000}{50{,}000} \times 600 = 240 \text{ kv-a.}$$

and the total capacity will be

$$3 \times 240 = 720 \text{ kv-a.}$$

W.W.L.

REACTIVE VOLT-AMPERE INDICATOR: CONSTRUCTION AND CONNECTIONS

(187) How does the construction of the wattless component indicator differ from that of the wattmeter? What are the connections of the wattless component indicator?

In construction, the wattmeter and the reactive volt-ampere indicator* are essentially alike, both being of the electrodynamometer type with a fixed current coil and a movable potential coil. The difference is in the connections. This can best be explained by contrast.

As a wattmeter the current and potential coils are connected in phase; i.e., on a unity power factor circuit the currents in the two coils are in phase. With this connection the instrument indicates the amount of in-phase volt-amperes; i.e., the watts. As a reactive volt-ampere indicator the current and potential coils are connected 90 electrical degrees out of phase; i.e., on a unity power-factor circuit the currents in the two coils are 90 electrical degrees out of phase. With this connection the instrument indicates the amount of 90-electrical-degree out-of-phase volt-amperes; i.e., the reactive volt-amperes.

Because the type of instrument (single-phase or polyphase) to be used and the corresponding connections to be employed depend upon the number of phases in the circuit being measured and upon the load balance between phases, the various conditions will be considered.

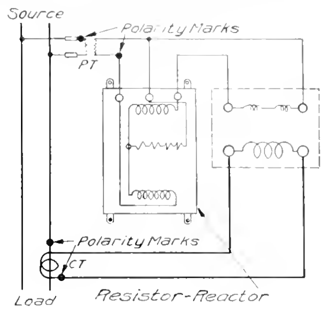
Single-Phase, Two-Wire Circuit

A single-phase wattmeter in connection with a special resistor-reactor box in the potential circuit should be employed to indicate the reactive volt-amperes in a single-phase two-wire circuit. The purpose of the resistor-reactor box is to produce the 90-degree electrical displacement between the current coil and the potential coil. The internal connections of the resistor-reactor box, the reactive volt-ampere indicator, and the complete external connections are shown in Fig. 1.

Two-Phase, Three- or Four-Wire Circuit

A two-phase wattmeter is necessary for indicating the reactive volt-amperes in an unbalanced two-phase, three- or four-wire circuit. On a two-phase three-wire circuit, the current in the potential coil is displaced 90 electrical degrees from that in the current coil in each element of the polyphase instrument by the connections illustrated in Fig. 2. On a two-phase, four-wire circuit, the 90-degree electrical displacement is produced by the connections shown in Fig. 3.

A single-phase wattmeter may be employed, instead of the polyphase wattmeter, to indicate the reactive volt-amperes in a two-phase, three- or four-wire circuit when the phases are well balanced. The 90-degree electrical displacement between the current coil and the potential coil is secured for a single-phase instrument on a two-phase three-wire circuit by the connections shown in Fig. 4 and on a two-phase four-wire circuit by the connections shown in Fig. 5.



(187) Fig. 1

Three-Phase Three-Wire Circuit

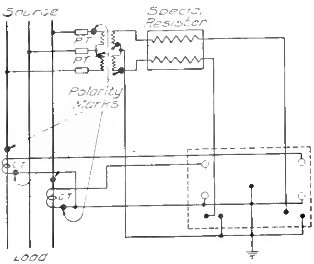
A three-phase wattmeter is required for indicating the reactive volt-amperes in an unbalanced three-phase three-wire circuit. A special resistor box is employed in the potential circuit; its resistance is 15 per cent greater than that used when the instrument is being applied as a wattmeter. The current and potential coils of each element of the instrument are cross-connected between phases to secure the 90-degree electrical displacement in each element. The complete connections are shown in Fig. 3.

A single-phase wattmeter may be used, instead of the polyphase wattmeter, to indicate the reactive volt-amperes in a three-phase three-wire circuit when the circuits are well balanced. The 90-degree electrical displacement of the current and potential coils is obtained through use of the connections shown in Fig. 6.

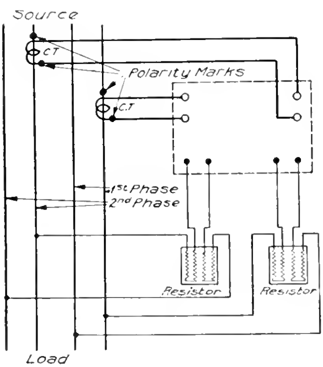
Three-Phase Four-Wire Circuit

A three-phase four-wire wattmeter is required to secure an indication of the reactive volt-amperes in a three-phase four-wire circuit. The method of obtaining the 90-degree electrical displacement

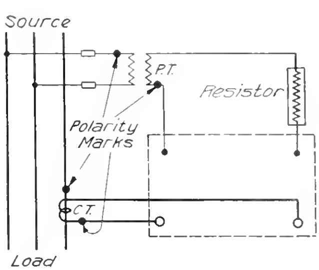
*The A. I. E. E. Standardizing Committee has adopted the term "reactive volt-ampere indicator" to replace the term "wattless component indicator."



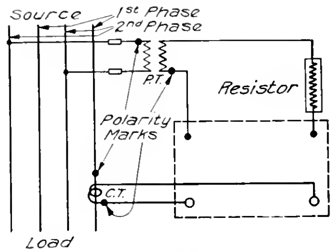
(187) Fig. 2



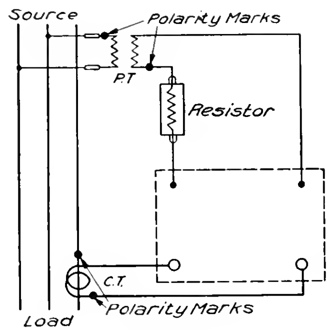
(187) Fig. 3



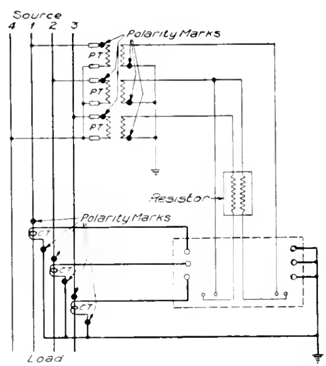
(187) Fig. 4



(187) Fig. 5



(187) Fig. 6



(187) Fig. 7

between the current and potential coils is illustrated in Fig. 7.

Six-Phase Six-Wire Circuit

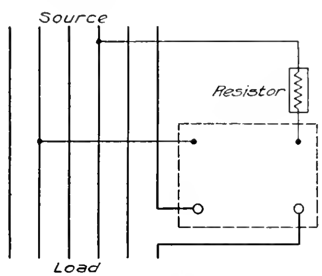
A single-phase wattmeter is the advisable instrument to use for indicating the reactive volt-amperes in a well balanced six-phase six-wire circuit. Employment of the connections shown in Fig. 8 will give the required 90-degree electrical displacement between the current and potential coils.

J. A. H.

WATTHOUR METER: CONNECTIONS

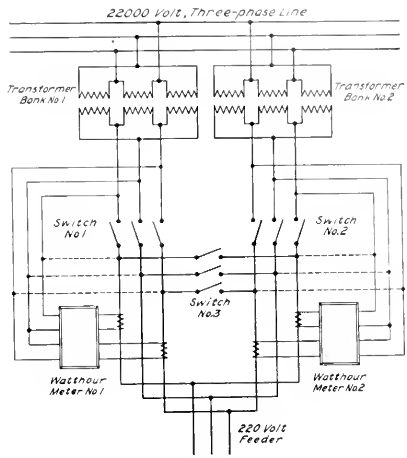
188) The full lines of Fig. 1 represent power and meter connections which were used to enable a high-tension line to supply a feeder through two banks of transformers operating in parallel or through either bank operating alone. The tie line in which switch No. 3 is located would not have been necessary under ordinary conditions. In this installation, however, lines "Switch No. 1-to-Feeder" and "Switch No. 2-to-Feeder" were long and the tie line enabled the copper of both lines to be utilized when only one bank of transformers was supplying the feeder.

With a certain load on the feeder, switches Nos. 1 and 2 closed, and switch No. 3 opened, watthour meter No. 1 measured the energy furnished by transformer bank No. 1, watthour meter No. 2 the energy from bank No. 2, and the sum of the two readings was the input to the feeder. With the load on the feeder unchanged, either switch No. 1 or No. 2 opened and switch No. 3 closed (for single transformer bank operation) the sum of the two meter readings considerably exceeded the previous total. Why should this increase occur?



(187) Fig. 8

The meter potential coil connections are made correctly for parallel operation of the two banks of transformers with or without the tie line, or for either bank operating alone without the tie line, *but not for either bank operating alone with the tie line.* For example, assume switches No. 2 and No. 3 closed and switch No. 1 opened. Under these conditions bank No. 2 carries the entire feeder load, bank No. 1 is alive but delivers no energy, and the energy from bank No. 2 is transmitted to the feeder approximately half-and-half by the two circuits. "Switch No. 2-to-Feeder" and "Switch No. 2-to-Switch No. 3-to-Feeder." It is evident that the current coils of both meters are supplied with current in the correct amount and that the potential



(188) Fig. 1

coils of meter No. 2 are supplied with voltage of the correct value, i.e., load value. (Load value equals the no-load secondary voltage of the transformer bank minus the voltage drop in the bank due to load.) The location at which the potential coil connections of meter No. 1 are made to the power circuit shows that the meter was supplied with the no-load voltage of bank No. 1. This no-load voltage exceeds the load voltage existing in the "Switch No. 2-to-Switch No. 3-to-Feeder" circuit and consequently the meter will read too high.

If the potential coil connections of both meters to the power circuit are changed to the other side of switches Nos. 1 and 2, as shown by the dotted lines, the meters will register correctly under all conditions.

The same reasoning will apply if potential transformers are used between the meters and the power circuits.

E.C.S

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE — Editor, JOHN R. HEWETT — Associate Editor, B. M. EOFF — Assistant Editor, E. C. SANDERS

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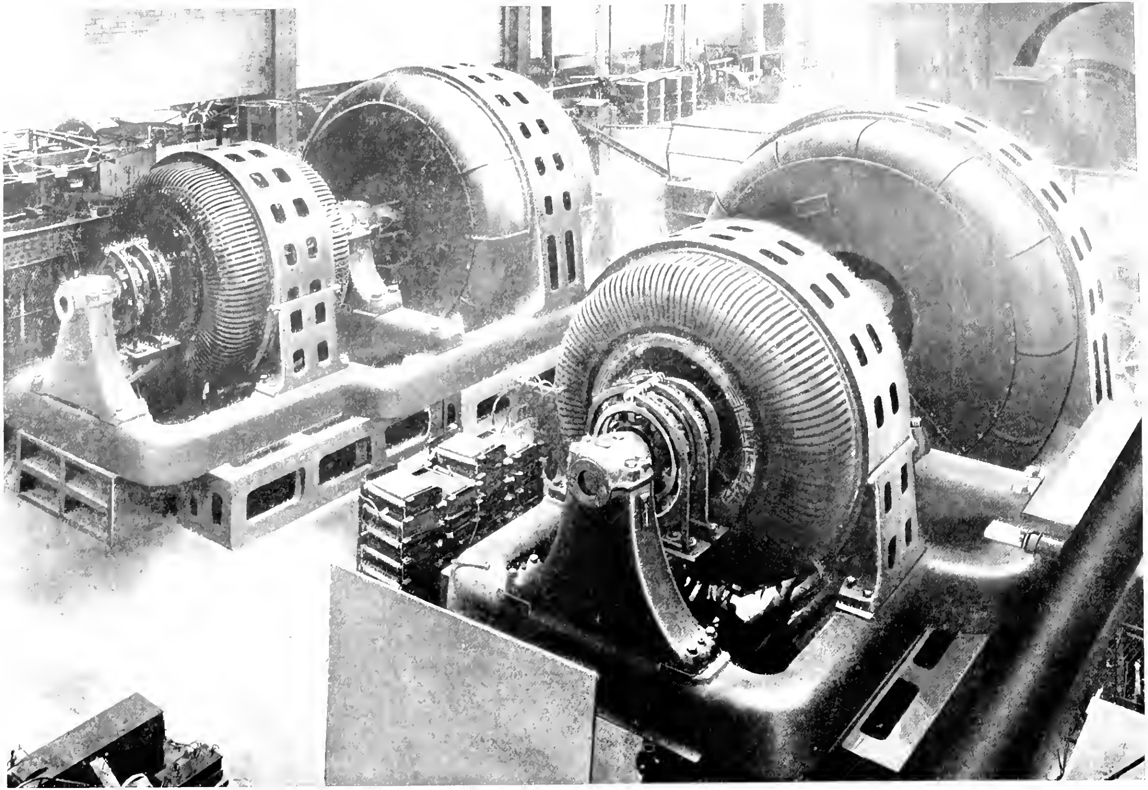


TWO 5000-KW. PHASE CONVERTERS FOR PHILADELPHIA ELECTRIC COMPANY

(See page 1097)

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

We are fortunate this month in being able to publish two contributions from Mr. E. W. Rice, Jr. Both of these are addresses recently delivered, and both appear to us very timely. His address before the Association of Edison Illuminating Companies will already have been read with keen interest by many business men as it sets forth the present status of the electrical industry, which can be taken as a fair barometer for indicating the general business position of the country as a whole.

The present status of the industry is unique: we are passing through a period of unparalleled prosperity, but at the same time we are keenly alive to the fact that the present conditions are due in part, at least, to circumstances over which we have no control and to external conditions which even the keenest business man sincerely hopes will soon cease to exist.

In spite of abnormally good business there are certain accompanying factors which call for careful consideration and some misgivings. Caution is specially necessary in contracting for future business, as the price of labor and materials have both advanced to such a point that future prices for apparatus are absolutely indeterminate.

The obscurity of the future is not due alone to external conditions, but is in a large measure intensified by domestic political conditions. It is in this connection that we find Mr. E. W. Rice's address to young engineers so timely.

In this address he tells the younger generation of engineers that their activities in the future must extend beyond the realms of purely technical problems and that engineers must hereafter take an intelligent interest in framing the laws that are to govern their activities. In these views we most heartily concur

The engineer has revolutionized the whole fabric of our social and economic systems. To be brief: first the introduction of the steam engine and then the invasion of electrical apparatus and appliances into almost every industry have metamorphosed our conditions of living and changed to an unrecognizable extent the relationships between capital and labor and have especially bettered the condition of the working man.

The engineer has, however, been so busy in achieving wonderful accomplishments and at the same time these accomplishments have so broadened the fields of engineering activity that today we find an astonishingly large percentage of all intelligent citizens engaged in scientific and engineering pursuits. The engineer has done his work so well and given such undivided and loyal attention to his task that unfortunately he has been contented to let others control his political destinies.

We are now beginning to awake to the fact that there are forces of ignorance working, some perhaps unwittingly, for the destruction of much that the engineer has built up, but it appears to us that such destructive policies are too often born of selfishness as well as ignorance.

For these reasons it is particularly opportune to call the attention of engineers and all other highly trained men to some of their duties as citizens. These duties must include more than a mere "interest" in politics; they must embrace a willingness to serve their country by assuming the burden of service in the capacity of legislators.

We are optimistic as to the future only because we believe that the Engineer will see his duty and undertake the task. We are encouraged in this belief by the unselfish attitude of those gentlemen on the Naval Consulting Board who are giving their experience and much of their valuable time free to their country as a patriotic duty. We feel that if a persistent call is made for the engineer to broaden his services to the state, this call will be answered.

If we can succeed in getting the scientific, engineering and other highly trained professions fairly represented in our numerous governing bodies, many of the evils that we have suffered from in the past will be eliminated. It is for these reasons that we owe a debt of gratitude to Mr. Rice for calling the attention of the younger generation of engineers to the broader duties they must perform in the future if they are to fill the functions that we must look for from engineers which, hereafter, will not only include the conversion of the resources of nature to the service of man, but also the added duty of protecting the fruits of their labor against all the evils of political ignorance and selfishness.

A DISCUSSION OF PRESENT CONDITIONS IN THE ELECTRICAL INDUSTRY

By E. W. Rice, Jr.

President, General Electric Company

Mr. E. W. Rice, Jr., read the following address before the Association of Edison Illuminating Companies at their annual convention, September 4–7, at Hot Springs, Va., and we are reproducing it in the Review by the courtesy of the Association. Mr. Rice's remarks are of the greatest interest to the profession, as he reviews the status of the electrical industry during these most abnormal times. He shows by actual figures the increases in price of those materials that enter into the construction of electrical machinery; tells of the effect of munition contracts on the present situation, and discusses the postponement of shipping dates and probable deliveries on next year's contracts, as well as the possibility of an increase in prices for 1917.—Editor.

The electrical manufacturing business during the early part of 1913, in common with other business in this country, enjoyed prosperity. A decline, however, set in during the autumn and winter months of 1913-14 which was accelerated by the outbreak of the great European war in August, 1914. Our business did not show marked signs of revival until orders placed in this country for the belligerents had reached a considerable volume. Improvements due to this latter cause was noticeable in the summer of 1915, and by autumn of that year orders, particularly for large apparatus, were being received in unprecedented volume; and while the volume of business during recent months has shown some recession, orders are still being placed at a rate in excess of anything in our previous experience. As far as we have been able to observe, this condition applies not only to our business, but to practically all other business, particularly in the field of machinery and metal products.

The situation which I have described has brought about general manufacturing conditions which are, from a production standpoint, extremely unsatisfactory. Stocks in the hands of manufacturers and dealers in metals and machinery, which were allowed to become depleted owing to the abnormal reduction in business, were quickly exhausted upon its revival. All manufacturers and dealers in such materials and appliances soon became overwhelmed with orders, and consequently there has been for the past year, and still continues to be, the greatest difficulty in obtaining raw materials and equipment, particularly those of a special nature. The demand for copper and brass materials, iron and steel, sheet steel, castings, forgings, etc., has for some time greatly exceeded the capacity of the producing concerns in this country. Promises made by producers of raw materials and machinery and tools, of every description, have been found by sad experience to be extremely unreliable, and this naturally interferes with our schedules of manufacture of finished goods. There is little, if any, evidence of a change in the situation in the immediate future, and we anticipate that tremendous difficulties will continue to be experienced in obtaining raw materials.

As a result of oversold conditions, prices have been advanced to unprecedented figures. For example, copper, which was selling in August, 1914, at about 12.5 cents per pound, rapidly advanced to 28 and 30 cents, and is now holding at about 23 to 25 cents, according to delivery required. Sheet steel for electrical purposes has advanced from 45 to 85 per cent; iron castings, from 15 to 25 per cent; steel castings, from 20 to 25 per cent. Ordinary zinc advanced from 5 cents per pound to 25 cents, or over 500 per cent, but a few months ago it began to react and is now selling at about 8 cents per pound, some 60 per cent above normal; and aluminum has advanced, according to conditions of contracts, from 100 to 250 per cent.

The above materials are the foundation of our business. Other important materials which enter into our manufacture, such as tungsten, mercury, ferro-manganese, asbestos and paper have also greatly advanced. Tungsten, for example, climbed for a time to over 900 per cent, and is now over 250 per cent above normal; mercury advanced over 700 per cent and is now double the normal price; ferro-manganese advanced over 700 per cent; asbestos over 150 per cent, and paper from 50 to 100 per cent.

This remarkable situation is well illustrated by the machine tool market; prices were constantly raised and deliveries lengthened until, some six months ago, the most reputable manufacturers, manufacturing the highest grade of standard tools, began to quote merely nominal current prices subject to an advance in price not to exceed 20 per cent at the time of shipment. I quote a clause which now appears to be the standard with many machine tool builders:—

"The price of machines for 1917 delivery to be that prevailing at the time of shipment with a guarantee that the advance, if any, will not exceed approximately 20 per cent of the current price quoted above, as per our letter of even date."

This is taken from an actual quotation to our company on August 4, 1916. They also informed us that the above prices, named for prompt acceptance only, are subject to change without notice.

The increase in prices of raw materials and machinery has not been permitted to directly affect production unfavorably, as these prices have been met. The fundamental difficulty which has constantly interfered with production schedules has been the inability to get machinery and materials either on time or in sufficient quantities to keep our factories operating in an efficient manner. In some instances materials and machinery which heretofore have been employed have been unobtainable and new materials, machinery and methods have been substituted, all of which has involved delay in production. Even after we had succeeded in purchasing our raw materials, and shipment had actually taken place at the point of manufacture, there was no assurance that the materials would arrive on time. The railroads, as is well known, became so congested that deliveries were slow and uncertain, and complete embargoes were frequently placed upon the delivery of important materials, and always, it would seem, at the most unfortunate time for ourselves and our customers.

The manufacturer, however, needs something more than buildings, machinery and raw materials in order to fill the orders of his customers. He must have labor of good quality and of reasonable and reliable supply, and manifestly it is impossible to cope with the increased volume of business without an increase in the efficiency of labor or an increase in quantity.

It is natural and proper that laborers, both skilled and unskilled, should seek to share in the general prosperity, and we, in common with other manufacturers, endeavored to meet the situation promptly and liberally. In spite, however, of all our efforts the labor situation for the last year has been, and still remains, in a very unsatisfactory condition, especially with reference to high-grade skilled employees and low-grade common laborers. There does not seem to be a sufficiency of either class to meet the demands of production in this country. As is well known, the scale of wages of such employees is abnormally high, which condition has been intensified by competition among the manufacturers themselves. Many manufacturers of war materials have been particularly energetic, even offensive, in their competition for labor and have done much to demoralize the labor situation. Of course, these manufacturers realize that their work is largely of a temporary nature and will not, in most cases, extend beyond the cessation of hostilities in Europe, and naturally they wish to "make hay while the sun shines." To meet the demands, large new shops have been erected, which had to be manned, and in doing this the most ruthless competition has been inaugurated, and is still in effect.

It is also well known that the great decrease in emigration, due to the European war, has created a serious shortage in ordinary labor, and there is a real scarcity of such labor in all parts of the eastern and middle states. Such labor now commands the highest wages ever paid it, and there seems to be no immediate prospect of increase in the supply.

The increase in the price of labor would not in itself affect production adversely; it might, in fact, under proper conditions lead to a stimulation and improvement of production. However, unfortunately, there is every evidence that the efficiency has, temporarily at least, declined and the output per man is lower than it has been heretofore, at a time when it is to the interest of all men engaged in the industry, as well as the employers, to obtain the highest possible output. Unfortunately also for efficient production, it has been apparently impossible to make the needed adjustments without frequent strikes, which in several instances have been of long duration and naturally have interfered seriously with the efficiency and output. Unfortunately, we have not been free from this calamity, having experienced during October and November of last year a strike of six weeks duration at our principal works, in which from 12,000 to 15,000 employees stopped work for the period stated. Deliveries of materials and machinery upon which we were relying have also been interrupted at critical periods by strikes among those from whom we purchase such articles.

EFFECT OF MUNITION CONTRACTS ON THE PRESENT SITUATION

I have been especially asked to say something about the effect of munition contracts on the present situation. The large contracts which have been taken for war munitions have unquestionably affected the general manufacturing situation. They have created a demand for enormous quantities of brass, copper and steel and are largely responsible for the condition in which the producers of such materials find themselves, viz., almost complete inability to fill orders. Munition orders also, without doubt, have had a profound influence upon prices of raw materials required for their manufacture, and the higher level of prices of all materials is, to a considerable extent, due to the demand which orders for war munitions have created. This condition is not confined to materials, but also extends to machine tools. Manufacturers of munitions, both abroad and at home, have ordered machinery, such as lathes, automatic screw machines, drill presses, and other standard lines of tools, in enormous quantities and have overwhelmed the manufacturers. The demand for such machines and tools for the manufacture of munitions has been so great, for a time, as to absorb the entire output of the country, and consequently it has been, and is still, very difficult to obtain tools required for the manufacture of regular lines of product, and this has naturally in turn interfered with our schedules for increased production.

As has already been stated, the creation of large munition plants, and the undertaking of the manufacture of munitions, has created an abnormal demand for labor, and has, in spite of the increase in wages, resulted in an absolute shortage of labor of all kinds.

I suppose, however, that you are particularly interested to learn as to what extent, if any, the manufacture of such material by our company has interfered, or may interfere, with deliveries of our regular product. I frankly admit at once that such contracts as we have taken for munition work have, and will until completed, interfere to a relatively limited extent with our regular business. I may further confess that if we had anticipated the prompt revival of business, to say nothing of the phenomenal increase in our regular business, we would never have undertaken the manufacture of any munitions.

Having made the above statement, however, in the interest of frankness, it is only fair to explain that at the time when these contracts were undertaken many of our departments had been running for some time at from 25 to 60 per cent of their normal capacity. We therefore had an abundance of idle space and tools, and although we had placed in stock, in anticipation of orders, a large amount of material, we felt that we had reached the limit of prudence, and were at the point where we faced a continued decline in our production and the further loss of tried, valuable and skilled employees.

Our entrance into the munition field was therefore undertaken largely with a view of filling some of our vacant space and furnishing work for our employees. Moreover, long before the vacant space that was available for such work was occupied we erected additional buildings and also purchased additional idle factories for the express purpose of providing room for munition work without, as we then thought, any interference whatsoever with our standard work.

I would also state that none of the space which we normally devote to the manufacture of turbines, induction motors or other similar apparatus has been occupied at any time for the manufacture of munitions, and that the total space occupied in munition work of all character is today but three per cent of our total manufacturing space, much less than the proportion in value of our munition orders to orders for our regular product. Moreover, our last important order for munitions was taken over a year ago, and we do not now expect to take any further orders of this nature. The reason why the space occupied and the men employed on munition work is relatively less in proportion to its output in money value than our standard product is that munition work is fundamentally a better manufacturing proposition; it consists of many thousands of articles which are absolutely identical not only in design but in size, which naturally permits of a greater output per man and per square foot than a product that is variable and special, as is our electrical business.

POSTPONEMENT OF SHIPPING DATES ON 1916 CONTRACTS AND PROBABLE DELIVERIES ON 1917 CONTRACTS

I think it can be safely said that most large manufacturers have found it necessary to extend shipment dates on a portion of their 1916 contracts. The difficulties of obtaining raw materials, labor of proper quality and mechanical equipment have, as heretofore stated, interrupted and slowed up manufacturing and created conditions which cannot but result in deferred shipments, on a portion at least, of the output. This is a cause of great anxiety to us as well as to our customers. We are sparing no expense in procuring materials or devising ways and means, as far as may be practicable, to maintain our schedules. In some instances our customers, due to the fact that they have been disappointed in deliveries by contractors for other materials which are needed, have found it possible to permit postponement of our deliveries without adding to their troubles, and have kindly permitted us to postpone such deliveries, which in turn has enabled us to help other customers who were in a different situation.

At this time it is difficult to express a definite opinion as to deliveries on 1917 contracts. We have taken large contracts for delivery in 1917, and in some cases even for 1918. We are contracting for important materials as far in advance as seems to be necessary in order to insure deliveries. In order to be assured of a supply it seems to be necessary to place orders for some materials well into 1917. In such cases we have not hesitated to take the risk.

INCREASED PRICES FOR 1916 AND RELATIVE PRICES FOR 1917

I have also been asked to say something as to increased prices for 1916 and relative prices for 1917. The great increase in the cost of raw materials and labor, as well as other items of expense, have made it necessary for us to increase our prices. We have not, however, advanced our prices more than necessary to cover increased cost of manufacture. In some classes of apparatus, through the skill of our engineers in redesigning, without sacrifice of quality, we have effected economies offsetting, in part at least, the normal increased cost, and in such instances our prices have not been increased to the extent that otherwise would have been necessary.

As to future prices, we are so completely dependent upon the prices which we must pay for raw materials and labor that it is impossible for us to express an opinion which would be of special value. It would almost seem that the high-water mark with respect to prices of raw materials and labor has been reached and, if so, with a continuance of such conditions, future prices of raw materials would naturally remain substantially unchanged. Of course, upon any extended reaction in business, which some authorities assure us will take place upon the cessation of hostilities, prices would naturally decline. However, I am not a prophet and am glad to leave to others better fitted than myself to entertain us with their views as to what the future may bring forth.

I may say, in this connection, that in spite of the uncertainty as to the business outlook after the European war is over, and in disregard of the abnormally high cost and difficulty of construction work, we have started a large amount of building operations which will give us a greatly increased output in the future, provided, of course, that we can secure the necessary materials and men. We should, therefore, be in even better position in 1917 to fill our contracts on time.

It has been suggested that the large profits on munition contracts have established a precedent which may have a bearing upon the electrical business. I do not share in this view, as the electrical business is highly competitive, and in normal times the volume of demand is less than the combined facilities of all the manufacturers. On the other hand, the demand for munitions has far exceeded the existing facilities of every description and prices have been high in consequence.

I am glad to state that in spite of all the difficulties with materials, labor, transportation, etc., which have made it impossible for us to realize the full output of existing facilities, nevertheless, our manufacturing organization has succeeded in not only maintaining but in greatly increasing our output as compared with previous years, although, as already stated, this increased production has unfortunately only been obtained at a great increase in cost, which let us hope is temporary in character.

In conclusion I wish to express my hearty appreciation of the opportunity to talk to you this evening. I have been enjoying the meetings of the Edison Association for about a quarter of a century. It is my mature judgment that it would scarcely be possible to exaggerate the importance and value of the contributions of this Association to the success of the electrical industry of which we form a part and are all vitally interested.

At your meetings have been gathered the pioneers of the industry. Revolutionary discoveries and inventions have here received their first introduction to the public. Constructive criticism, free and frank discussion, sincere and effective co-operation between manufacturer and members has resulted in such practical progress as to be the wonder of the world. Meetings have been eagerly looked forward to from year to year and have proved the greatest stimulus to increased effort. It has been a privilege and a joy to thus work together for so many years. The result stands as an unbroken record of continuous expansion of the industry in volume and in the variety and number of its useful applications to the service of the public, a constant reduction in the cost of the manufactured product, all accompanied by a most remarkable improvement in the quality and in the character of the service rendered to each other and to the public. By manufactured product I mean, of course, to include not only the product of the manufacturer of electrical machinery and devices, but also that of the central station which supplies electrical energy and light to the public.

We hear much said nowadays about setting business free, and men may differ as to the truth of the claim or even as to the exact meaning of the expression. But there can be no question as to what the men of the electrical industry have done. They have created a business valued at hundreds of millions, even billions of dollars, given employment to hundreds of thousands of men and women, and conferred untold benefits, comforts and luxuries upon millions of human beings. If the past is a promise of the future, then indeed the electrical industry has a most brilliant and useful future. I believe that it has, yet I must admit at times to a feeling of uncertainty akin to despondency. For this wonderful business which you have created has expanded until it touches the lives of millions of the people; men who know nothing of its origin or nature have risen and are attempting by political methods to control and regulate it. I sometimes tremble lest the "valor of ignorance" should prevail over the wisdom of experience and our progress be thus stopped. This indeed would prove a public calamity. The remedy is, as has been many times suggested, the proper education of the public, and through it of our political rulers as to the character and value of our work.

I am happy to note that you are aroused to the dangers that beset you, and I have confidence that those who have created and guided this wonderful industry will not fail to co-operate and take all such steps as may be necessary for protection from the attacks of the ignorant and indolent and all other similar enemies.

EFFECT OF THE TYPE "C" LAMP ON PUBLIC STREET LIGHTING

By John West

C. H. Tenney & Co., Boston, Mass.

The author's statements and tables show the result of much careful consideration. The data are particularly useful since they are derived from a thickly populated section. It is interesting to note that during the eight years considered in the paper the total revenue from street lighting has increased 33 per cent, and that this increase has been secured during a period when the efficiency of lamps has been greatly improved, and the incandescent lamp has become an important factor in street lighting. This paper was read before the New England Section of the National Electric Light Association at Pittsfield, October, 1916.—Editor.

The street lighting phase of central station operation is seemingly demanding more and more attention with the progress of the art. The successful development of the nitrogen-filled tungsten lamp, commonly known as the Type "C" Mazda, is undoubtedly one of the greatest advances that has ever been made in street lighting methods, and must very materially affect street lighting practice.

In the old days we had the arc lamp, to which was added the carbon filament incandescent, used to provide a low intensity of illumination for the outlying districts, and, frequently, to help out the arc lamp. Next came the addition of the comparatively efficient tungsten filament incandescent lamp, with its resulting increase in light, the accent of importance gradually seeming to shift from the arc lamp to the tungsten filament incandescent, especially in the smaller communities. As we review the development of the older types of incandescent lamps we see they have made possible a type of illumination which would have been commercially impractical with the old arc lamp, and in this way has developed a field of their own. The addition of the Type "C" lamp to our street lighting materials offers an illuminant surpassing in efficiency all the older types of incandescent lamps, and actually encroaches into the field of the arc lamp.

The effect of this Type "C" lamp, which seems certain to entirely supersede all the present types of illuminants in many communities, is surely a matter of great interest to central stations. It seems premature to attempt to prophesy at this time what effects this new lamp will have upon street lighting, and the best that is hoped for is that an expression of the tendencies which have been observed during the comparatively short time that this lamp has been available will excite a discussion which will be mutually beneficial to all concerned.

The relative importance of public street lighting to the total income of the central station is brought out by the following figures, which have been taken from the reports of the Massachusetts Gas & Electric Light Commission, which include the distributing companies in that state. It is thought that these figures will be fairly representative of the existing conditions in New England.

These statistics very strikingly present the interesting fact that while the percentage of street lighting revenue to the total income received by the central station is a slowly decreasing value, it is of equal importance to note that, in the face of a marked increase in the efficiency of illuminants during the period considered, the income from street lighting has actually increased approximately 33 per cent. During this 33 per cent increase in street lighting revenues, we find that the total income of the central stations has been increased approximately 71 per cent for the same period, which has been due to the rapid growth in the uses of electricity in domestic and industrial life.

While it seems natural to expect that, when considered in the relation of percentage to total income, street lighting revenues will continue to slightly decrease, on account of the fact that the extensive domestic and industrial uses of electricity have not even approached a point of saturation, the very nature of this class of business requires that it be contracted for on relatively long terms, and being independent of conditions which affect the incomes from other sources makes this street lighting business of material importance to central stations; and the tendency seems to be that revenue from street lighting will continue to increase.

The increasing use of the incandescent lamp for street lighting is pointedly brought out by the above figures. In the eight years under consideration we find that the revenues for street lighting by incandescent lamps has increased over 150 per cent, while on the other hand the revenues from street lighting by arc lamps have remained practically stationary, dropping off about 6 per cent.

The most significant point about these statistics is that the total increase in street lighting revenues, amounting to 33 per cent in the eight years, has been due to incandescent lighting, with a loss of 6 per cent in arc lighting revenue to be made up besides. This is of particular interest when it is considered that the first revenues were based on the inefficient carbon filament lamps, which have in the period considered all been replaced by the more efficient Mazda and Type "C" lamps. It is believed that for the period considered in these figures, very few installations of Type "C" lamps are included, however.

It is very strikingly brought out that the changes in public street lighting practice are being made along the lines of the utilization of the smaller and more flexible types of illuminants. With the older types of lamps there has always been a gap between the field of the arc and the incandescent lamp which it has never been possible to economically and effectively bridge. The Type "C" lamp presents an illuminant surpassing in efficiency the older types of both incandescent and arc lamps, and is flexible in rating up to the size where it comes into active competition with the high efficiency modern arc lamps. In other words, we have available a line of public street lighting illuminants flexibly rated from the smallest size to the largest size demanded, and operating at an efficiency consistent with the size of the units.

It seems very certain that the Type "C" lamp is bound to make a very radical change in street lighting practice. The effect of the application of this new lamp on any particular community depends entirely upon how efficient and effective the system of illumination has been heretofore. The opportunity is offered to the community of maintaining their existing standard in regard to either expense for street lighting or for the amount of illumination afforded. If the same expense is to be devoted to street lighting with this new type of lamp, an increased quantity and quality of illumination will result, while on the other hand, the same amount of illumination may be provided with a decrease in the expense. The opportunity is also open for the community to increase the amount of illumination and expense, and with the Type "C" lamp it is possible to get a relatively large return in illuminating value for the money expended. With these new lamps the major portion of the expense is due to the investment necessitated by the distribution system and the fixtures; the energy to operate the lamp adds little to the expense.

It seems to be the present tendency for a community to be willing to spend approximately the same amount of money which they have in the past and take advantage of the increased illumination which the Type C lamp offers. Taking as an example the case of the ordinary small city, we find that the business section, under conditions previous to the development of this new lamp, would be lighted at a high intensity with a modern high efficiency magnetite arc. An intermediate zone surrounding the business section is ordinarily lighted with the old type of carbon enclosed arc, and the outlying districts, on account of the expense involved, are lighted with a "beacon" system of illumination at low intensity, using a relatively small incandescent lamp of, say, 60 candle-power.

To wisely take advantage of the new Type "C" lamp, a procedure somewhat along the following lines seems to be the present tendency. The old carbon enclosed arc lamp would be discarded and replaced with Type "C" lamps, using an increased illumination in the zone bordering on the business section and tapering off into a smaller lamp as the outlying districts are approached. The same wattage might be provided in the outlying districts as heretofore, advantage

Year	Revenue from Street Arcs	Per Cent	Revenue from Street Incandescents	Per Cent	Total Revenue from Street Lights	Per Cent Street Ltg. Revenue to Total Income
1908	$1,479,422	75	$488,582	25	$1,968,004	18.9
1909	1,450,637	73	522,032	27	1,972,669	18.7
1910	1,400,028	71	575,252	29	1,975,280	17.6
1911	1,418,436	68	675,677	32	2,094,113	17
1912	1,418,850	64	783,778	36	2,202,628	16.2
1913	1,409,141	60	921,802	40	2,330,943	15.4
1914	1,390,625	55	1,130,847	45	2,521,472	15
1915	1,387,566	53	1,228,995	47	2,616,561	14.7

being taken of the increased illumination obtained with the new type of illuminant.

It has been observed in one of the many cases where the above general outline has been followed that an amount of illumination nearly 115 per cent in excess of the amount provided for under the old contract was obtained, with a decrease in revenue of several per cent. It seems to be the general tendency, however, to take advantage of the increased illumination obtainable with the Type "C" lamp at approximately the same expense as the community was under for street lighting heretofore.

The proper method of street lighting is coming to be recognized as an exact science, and a matter for the Illuminating Engineer. Too often in the past the application of illumination has been made for reasons more political than for the best interests of the town or city, and the central station has suffered blame for ineffective illumination for this very reason. With the present knowledge of street lighting in the hands of competent illuminating engineers—private, and those maintained by the manufacturing companies—there is no reason why any community should not be equipped with the most effective lighting which they feel they can afford. These men can accurately determine the standard of illumination actually required for utilitarian reasons, and are in a position to educate the public to this standard which is demanded by the increasing amount of traffic and the increasing standard of residential and commercial lighting. It seems safe to say that at the present time there are few cities whose illumination is comparable with what they ought to have. While it is not anticipated that the general application of the Type "C" lamp at the present time will have much effect upon the central stations' revenue for street lighting service one way or another, it is along the lines of increased illumination that it is expected an increase in the revenue from this class of service will result in the future.

It is suggested that the possibility of supplying up-to-date information with regard to the amount of illumination used by the various cities be discussed. It seems that some arrangement could be made whereby data on this subject, arranged in connection with the population and miles of streets lighted, and the sizes and spacing of units, could be presented through the channels of the Commercial Section. This information, if up-to-date, would certainly be of value when a street lighting contract is under consideration, for many reasons.

With the utilization of these new types of illuminants for street lighting, there must be developed a satisfactory rate to cover the new service offered. A good many new rates have been made for the Type "C" lamp, and a good many more will have to be made in the next few years; and in view of the importance of this subject, it behooves us to consider the rate situation very carefully.

The rates charged for street lighting remain in a peculiar position as compared with the rates which it has been found necessary to charge for other classes of service.

The consideration of the theoretical cost to serve in connection with street lighting rates reveals the fact that practically nothing has occurred to justify a reduction of rates. The reason for this lies in the fact that the street lighting business is as much apart from the other lines of the company's activities as would be the business of supplying steam for heating buildings. Street lighting invariably precedes other business into undeveloped territory, and still maintains itself on the peak load of the station as it always has. While it is true that the cost of generating energy has probably been reduced appreciably, due to larger and more efficient machinery being required to take care of the increasing business in other lines, the energy cost of supplying public street lighting is a relatively small portion of the total cost for that service, and as the efficiency of illuminants increases, that proportion of the total cost for energy is a decreasing figure. The entire street lighting system, beginning at the busbar, is available for public street lighting purposes only, and there has been no opportunity for saturating the investment required with energy sold for other purposes, to bring about a reduction in rate, as has been made possible in other lines of business. Considering the increased price of materials, labor, etc., it would seem that it would cost more to serve the same street lighting system at the present time that it would ten years ago.

It is within the memory of most of us that the rates charged for electricity used for lighting and power purposes have been reduced to nearly half. This fact has been widely advertised and has reflected on public street lighting rates in a demand for a reduction in prices charged for this class of service. In a few cases so-called experts have been employed by the cities to bring about a reduction in these lighting rates, and the method employed has been to estimate the cost of supplying the service upon some arbitrary basis most favorable to the so-called expert. An opinion written by the Massachusetts Board of Gas and Electric Light Commissioners in 1912 on this subject is of interest in this connection and seems to represent the general stand that is taken. The opinion follows:

"The company's customers may be broadly divided into two groups,—those who are dependent upon the company for their supply and those who may readily supply themselves in other ways or by other forms of power. To the first the company may dictate the price controlled only by motives of business expediency, its own sense of justice and its duty as a public servant. To the second the company must so fix the price as to secure the customer's business, or else go without it. The variety and wide range of the prices offered by the company is ample evidence of its recognition of these facts. The city with respect to its municipal arc system plainly belongs to the first class."

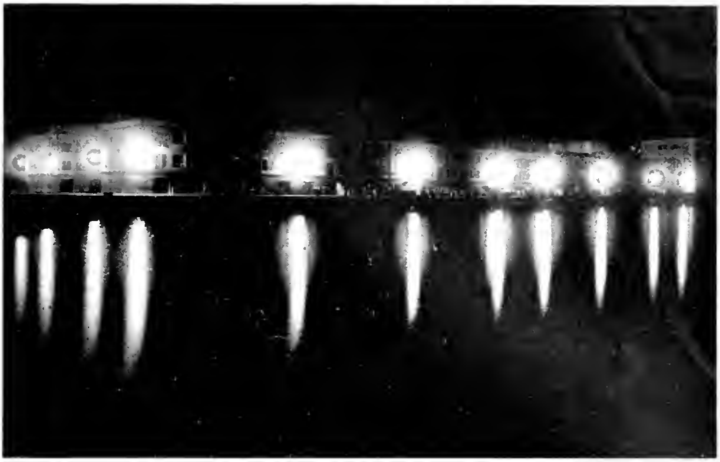
The expense of employing these so-called "experts" never seems commensurate with the results obtained. In the final analysis, where the central station must be considered as a servant of the public, an apportionment of the burdens of service to the best advantage of the public is what is most to be desired. Increasing earnings are universally taken care of by rate reductions in that class of business where they are most advantageous to the community. It is suggested that it be borne in mind in offering rates for new street lighting units on the necessarily long term contract basis which is necessary to protect the central station for the investment required and for the municipality to obtain the most favorable rates, that the tendencies of the cost of service are toward an increase, on account of the rising cost of labor, materials, supplies, etc., and that rate making for street lighting units should be governed accordingly.

While the majority of prices for public street lighting are quoted on a candle-power basis, there seems to be a few central stations that have departed from this standard. It is suggested that a discussion of the basis, upon which street lighting rates should be made, would be of advantage from the standpoint of uniform rate schedules.

APPENDIX

Analysis from Selection of 108 Typical New England Cities, Taken to Show Present Day Practice in Use of Illuminants for Street Lighting

Classification of Population	1000-5000		5000-10,000		10,000-25,000		25,000-50,000		50,000-100,000		Over 100,000			
Municipalities	19		15		33		22		8		11			
Lamp	No. of Units	Per Cent of Total	No. of Units	Per Cent of Total	No. of Units	Per Cent of Total	No. of Units	Per Cent of Total	No. of Units	Per Cent of Total	No. of Units	Per Cent of Total	Total No. of Units	Per Cent of Total
Flaming Arc Lamp	15	0.4					185	2.2	54	0.4	254	0.7	508	16
Magnetite														
6.6 amp.			5	0.1	190	1.4			406	3	8,182	22.9	8,783	93.5
5 amp.			58	0.8	107	0.8	1317	15.3	100	0.7	2,081	5.8	3,663	22.2
4 amp.	57	1.4	374	5.5	634	4.6	414	4.8	727	5.4	2,914	8.2	5,120	16
Total	57	1.4	437	6.4	931	6.8	1731	20.1	1,233	9.1	13,177	36.9	17,566	47
Enclosed Carbon Arc			60	0.9	1,275	9.3	1,659	19.3	499	3.7	696	2	4,189	19.6
Type "C" Mazda														
1000 c-p.	10	0.3	12	0.2	89	0.6			50	0.4	161	0.5	322	25.1
600 c-p.	79	2	143	2.1	231	1.7	448	5.2	945	7	571	1.6	2,417	33.8
400 c-p.	37	1	50	0.7	264	1.9	245	2.8	1,020	7.5			1,616	51
250 c-p.	142	3.5	16	0.3	605	4.4	215	2.5	75	6	594	1.7	1,647	50.5
	268	6.8	221	3.3	1,189	8.6	908	10.5	2,090	15.5	1,326	3.8	6,002	13.7
Mazda Lamps Below 250 c-p.	3643	91.4	6058	89.4	10,385	75.3	4081	47.9	9,598	28.7	20,270	56.6	54,035	15.1
Total	3983	100	6776	100	13,780	100	8564	100	13,474	71.3	35,723	100	82,300	100



New Commonwealth Fish Pier, Boston, Mass., Lighted by 1000-Watt Mazda C Lamps in Enclosing Globes

View in Hartford, Conn., Lighted by Mazda C Lamps

THE CONDENSATION PUMP: AN IMPROVED FORM OF HIGH VACUUM PUMP

By Irving Langmuir

Research Laboratory, General Electric Company

The author describes two new types of condensation pumps in which a blast of mercury vapor carries the gas into a condenser. The method of bringing the gas into the blast is based on a new principle; the action of the pump being due to the fact that *all* atoms of mercury striking a glass surface are condensed, practically none being reflected. It is because of the action of the pumps being based upon this principle that they are named condensation pumps.—Editor.

In a recent article in the *Physical Review** the writer described a new form of mercury vapor vacuum pump, which was characterized by its extreme speed and the high degree of vacuum attainable. The preceeding paper was merely a preliminary announcement of the new type of pump and no attempt was made to describe more than one form of the pump. In fact it was stated that "In a subsequent paper the writer will describe in more detail other modifications of mercury vapor pumps, some of which have marked advantages in simplicity of construction and reliability of operation over that shown here."

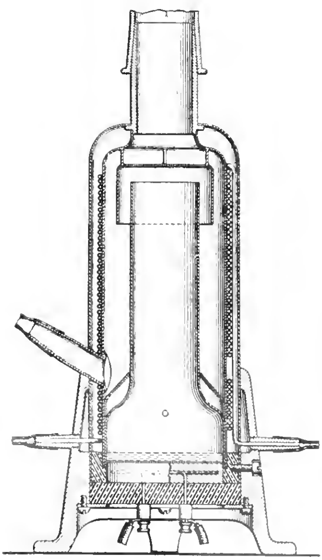


Fig. 1

The object of the present paper is therefore to describe these improved pumps. Before doing this, however, it will be desirable to describe the original pump.

The original type of pump is shown diagramatically in Fig. 1.

In this device a blast of mercury vapor passes upward from the heated flask A through the tubes B and C into the condenser D. Surrounding B is an annular space E connecting through F and the trap G with the vessel to be exhausted. The tube C is enlarged into a bulb H just above the upper end of the tube B. This enlargement is surrounded by a water condenser J from which the water is removed at any desired height by means of the tube K which is connected to an aspirator. The mercury condensing in D and H returns to the flask A by means of the tubes L and M. The tube N connects to the "rough" or "backing" pump which should maintain a pressure considerably lower than the vapor pressure of the mercury in A.

This pump operated extremely satisfactorily but was rather difficult to make. Trouble was frequently experienced by some liquid mercury collecting at the bottom of the annular space E. This mercury by being in contact with the hot tube B gave off vapor which produced a blast passing upwards into the annular space E. Some of this mercury vapor flowed out along the tube F and interferred with the free passage of gas from F into the pump.

This difficulty may be avoided by the construction shown in Fig. 2. A circular trough, separated from B, is provided in which the mercury may collect before flowing out through M. This prevents the mercury from being heated to a temperature high enough to give off troublesome quantities of vapor. In pumps of the type shown in Fig. 1 the difficulty could be easily overcome by directing a jet of air against the glass walls

* Langmuir, Phys. Rev., 8, 48 (1916).

of the annular space *E* just below its junction with *F*. Tilting the apparatus slightly so that the mercury drained out more readily into the tube *M* also proved useful.

The Improved Type of Glass Pump

To completely avoid these difficulties the design shown in Fig. 3 was adopted. In this pump, mercury vapor from the flask *A* is carried through the thermally insulated tube *B* to the nozzle *L*. The vessel to be exhausted is connected to *R*. The gas from this vessel passes through the trap *G* and the tube *F* into the annular space *E*. At *P* this gas comes into contact with the mercury vapor blast issuing from the nozzle *L* and is thus forced *outward* and *downward* against the walls of the tube *C* and is finally driven down into the space *D* from which it escapes into the rough pump connection *N*. The mercury which condenses on the sides of the water-cooled tube *C* passes back through the tube *M* into the boiler *A*.

By this construction none of the mercury which condenses passes into the annular space *E* and thus the troublesome blast of mercury into the tube *F* is wholly avoided. The glass blowing work on this type of pump is also much less difficult than on the earlier type.

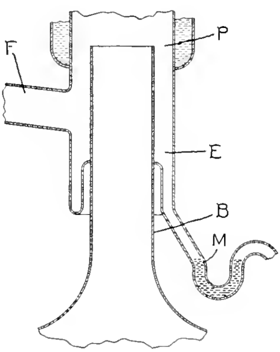


Fig. 2

In the pump shown in Fig. 1 a part of the mercury vapor condensed on the walls of the enlargement *H*, but the larger part passed up into the air-cooled condenser *D*. In the newer pump (Fig. 3), the enlargement of the tube *C* and the second condensing chamber are eliminated entirely. This greatly simplifies the construction without materially affecting the operation of the pump. It is true that the speed of operation appears to be somewhat higher in the type containing the enlargement, but the speed of these pumps is usually so excessive even without the enlargement that a further increase in speed serves no useful purpose.

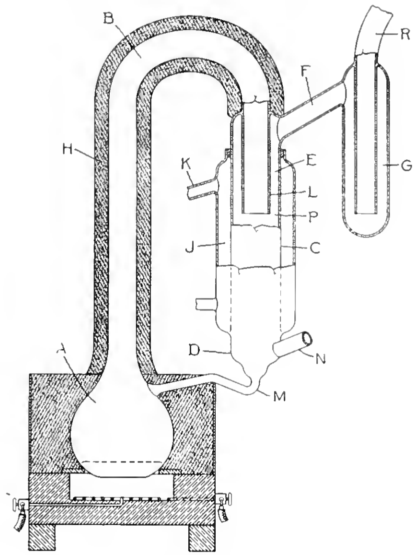


Fig. 3

In order that the pump may function properly it is essential that the end of the nozzle *L* (Fig. 3) shall be located below the level at which the water stands in the condenser *J*. In other words, the overflow tube *K* must be placed at a somewhat higher level than the lower end of the nozzle as is indicated in the figure. The other dimensions of the pump are of relative unimportance. The distance between *L* and *D* must be sufficiently great so that no preceptible quantity of gas can diffuse back against the blast of mercury vapor, and so that a large enough condensing area is furnished.

The pump may be made in any suitable size. Some have been constructed in which the tube *B* and the nozzle *L* were one and a quarter inches in diameter while in other pumps this tube was only one-quarter of an inch in diameter and the length of the whole pump was only about four inches. The larger the pump the greater is the speed of exhaustion that may be obtained.

Operating Characteristics

In the operation of the pump the mercury boiler A is heated by either gas or electric heating so that the mercury evaporates at a moderate rate. A thermometer placed in contact with the tube B, under the heat insulation, usually reads between 100 and 120 degrees C. when the pump is operating satisfactorily. Under these conditions the mercury in the boiler A evaporates quietly from its surface. No bubbles are formed so there is never any tendency to bumping.

Unlike Gaede's diffusion pump, there is nothing critical about the adjustment of the temperature. With an electrically heated pump in which the nozzle L was $7/8$ in. in diameter, the pump began to operate satisfactorily when the heating unit delivered 220 watts. The speed of exhaustion remains practically unchanged when the heating current is increased even to a point where about 550 watts is applied.

The back pressure against which the pump will operate depends, however, upon the amount and velocity of the mercury vapor escaping from the nozzle. Thus in the case above cited, with 220 watts, the pump would not operate with a back pressure exceeding about 50 bars,* whereas with 550 watts back pressures as high as 800 bars did not affect the operation of the pump.

General Theoretical Considerations Regarding Vacuum Pumps

Vacuum pumps are characterized principally by three factors.

1. *Back pressure* against which the pump may be operated. This is the pressure on the exhaust side of the pump as for example at N in Fig. 3.

2. *Speed of the Pump.* Gaede has defined, S, the speed of a vacuum pump by the equation

$$S = \frac{v}{t} ln \frac{p_2}{p} \qquad (1)$$

where t is the time required for the pump to reduce the pressure from p_2 to p in a vessel having the capacity v. The speed is thus measured in cu. cm. per second.

In the case of a piston pump this is approximately equivalent to the piston displacement per second.

3. *Degree of Vacuum Attainable.* This is the lower limit to the pressure which may be obtained in a closed vessel connected to the pump.

For convenience we shall refer to the back pressure acting on the pump as the ***exhaust pressure*** while the pressure at which the gas enters the pump we shall call the ***intake pressure***.

Most mechanical pumps of the piston type are built to exhaust at atmospheric pressure. But mechanical rotary pumps are frequently designed to be used in series with "rough pumps" in which case they operate with an exhaust pressure of a few hundredths of a megabar. (1-5 cm. of mercury).

Newer forms of pump such as Gaede's molecular pump and diffusion pump require still lower exhaust pressures, (approximately 10-100 bars, roughly, 0.01 to 0.1 mm. of mercury). Such pumps are always used in series with good mechanical pumps.

The type of mercury vapor pump shown in Fig. 3 operates with exhaust pressures ranging from 50 to 800 bars depending upon the amount of heat supplied to the boiler A

With the exception of Gaede's molecular pump, which gives a maximum speed of about 1300 cc. per second, mechanical high vacuum pumps have not had speeds exceeding 100 or 200 cc. per second. Gaede's rotary mercury pump for instance gives a speed of about 120 cc. per second. In nearly all cases the speed of a pump is practically independent of the exhaust pressure against which it operates unless this is raised above a certain rather critical value at which the pump ceases operating satisfactorily.

With most types of vacuum pump the degree of vacuum attainable depends to a large extent on the exhaust pressure used. This is usually due to leakage back through the pump. In the Gaede molecular pump, operating at low pressures, there is a strict proportionality (about 50000:1) between the exhaust pressure and the lowest attainable intake pressure.

When a pump has lowered the pressure nearly to its limiting value the speed of *exhaustion* decreases even though the ***speed of the pump*** remains the same. If S is the "speed of the pump" and E is the speed of exhaustion then for a pump with which the lowest attainable pressure is p_o we may define E and S as follows:

$$S = v \frac{d \ ln \ (p - p_o)}{dt} = \frac{v}{p - p_o} \frac{dp}{dt} \qquad (2)$$

*The bar is the C.G.S. unit of pressure: one degree per sq. cm. One bar is equal to a pressure of 0.00075 mm. of mercury or about one-millionth of an atmosphere.

$$E = v\frac{d\ ln\ p}{dt} = \frac{v}{p}\frac{dp}{dt} \qquad (3)$$

From these we obtain

$$E = S\left(1 - \frac{p_o}{p}\right) \qquad (4)$$

The "speed of the pump" S thus defined usually remains practically independent of the pressure. If $p_o = 0$ is the limiting value of the pressure then the "speed of exhaustion" E is identical with S the speed of the pump. In other cases the speed of exhaustion decreases as the pressure approaches p_o and becomes zero when the limiting pressure is reached.

In operating vacuum pumps of high speed it is essential to use tubing of large diameter between the pump and the vessel to be exhausted if full advantage is to be taken of the speed of the pump. Knudsen* has calculated according to the kinetic theory the rate at which gases at low pressures can flow through tubing and has thoroughly checked these theoretical results by careful experiments.

Knudsen considered especially the "molecular flow" of gases through tubes at pressures so low that the collisions of the gas molecules with each other are of relatively rare occurance as compared with the collisions between the gas molecules and the walls of the tubes. This molecular flow takes place at pressures at which the "mean free path"** of the molecules is large compared to the diameter of the tube.

Knudsen finds that the quantity of gas q which flows per second through a tube is given by the equation:

$$q = \frac{p_2 - p_1}{w\sqrt{\rho_1}} \qquad (5)$$

The quantity of gas q is measured by the product of volume and pressure; Thus

$$q = \frac{d\ (pv)}{dt} \qquad (6)$$

The pressure is preferably to be expressed in bars (dynes per sq. cm.). ρ_1 is the density (grams per cubic cm.) of the gas at unit pressure. From the gas law $pv = RT$ it is easily seen that the density of a gas is given by

$$\rho = \frac{pM}{RT} \qquad (7)$$

where M is the molecular weight, T is the absolute temperature and R is the gas constant 83.15×10^6 ergs per degree. If we place $p = 1$ we obtain

$$\rho_1 = \frac{M}{RT} \qquad (8)$$

In equation 5, W is the "resistance" which the tube offers to the flow of gas.

Knudsen finds that it is equal to

$$W = \frac{3}{8}\sqrt{\frac{\pi}{2}}\int \frac{O}{A_1}dl = 0.4700\int \frac{O}{A_2}dl \qquad (9)$$

where A is the area and O is the perimeter of the cross section of the tube. For circular tubes of diameter D and length L this becomes

$$W = \frac{6}{\sqrt{2\pi}}\frac{L}{D^3} = 2.394\frac{L}{D^3} \qquad (10)$$

In the case of openings in thin plates Knudsen† gives

$$W = \frac{\sqrt{2\pi}}{A} = \frac{2.507}{A} \qquad (11)$$

where A is the area of the opening.

Combining equations 5, 8, 10 and 11 gives, for long circular tubes:

$$q_1 = \frac{\sqrt{2\pi}}{6}\sqrt{\frac{RT}{M}}\frac{D^3}{L}(p_2 - p_1) = 3809\sqrt{\frac{T}{M}}\frac{D^3}{L}(p_2 - p_1) \qquad (12)$$

and for openings in plates:

$$q_2 = \sqrt{\frac{RT}{2\pi M}}A\ (p_2 - p_1) = 3638\sqrt{\frac{T}{M}}A\ (p_2 - p_1) \qquad (13)$$

These equations are strictly accurate only when the diameter of the tube or opening is very small compared to the mean free path. From Knudsen's experimental data, however, it may be shown that as long as the mean free path is not less than 0.4 of the diameter of the tube, the equation 12 gives results accurately within about 5 per cent. With air at room temperature and at a pressure of p bars the mean free path λ is $\lambda = 8.6/p$ centimeters.

Thus in the case of a tube one centimeter in diameter the equation 12 would be accurate within 5 per cent for all pressures below about 21 bars.

At higher pressures the quantity of gas flowing through a tube becomes much greater than that calculated by equation 12. For these higher pressures the flow may be

* Ann. Physik., *28*, 76 (1909).

** See Dushman Gen. Elec. Rev., *18*, 1042 (1915).

† Ann. Physik., *28*, 999 (1909).

calculated from the viscosity η by Poisseuille's equation:

$$q_3 = \frac{\pi}{128} \frac{D^4 p}{\eta L} (p_2 - p_1) \qquad (14)$$

where q is expressed in the same units as in equation 5. This equation is of a totally different form from those applicable at low pressures. To make this clearer let us apply these equations to the case of air at room temperature, ($M = 28.8$; $T = 293$). The viscosity η of air at 20 deg. C, is $181. \times 10^{-6}$ (C.G.S. units). Equations 12, 13 and 14 thus become

$$q_1 = 12130 \frac{D^3}{L} (p_2 - p_1) \qquad (12a)$$

$$q_2 = 11700\, A\, (p_2 - p_1) \qquad (13a)$$

$$q_3 = 136 \frac{D^4}{L} p\, (p_2 - p_1) \qquad (14a)$$

With a tube one cm. in diameter and 10 cm. long with a difference of pressure $(p_2 - p_1)$ of 1 bar we find $q_1 = 1213$ cc. per second, and $q_3 = 13.6 \times p$ cc. per second. These represent the quantities of gas flowing through the tubes measured in terms of the volume which the gas would occupy at one bar pressure. If the volumes of gas were measured at atmospheric pressure (10^6 bars) the volumes would be one-millionth as great. In other words, at very low pressures 0.001213 cc. of gas per second would flow through the tube, while at atmospheric pressure ($p = 10^6$) 13.6 cc. per second would flow or more than 10,000 times as much gas.

This indicates the relatively enormous resistance which tubes offer to the passage of gases at very low pressures. It should be noted, however, that this resistance increases as the pressure is lowered only until the state of molecular flow is reached while for lower pressures the resistance remains constant.

Let us now consider a pump having a speed S_1 connected to a vessel of volume V by means of a tube of diameter D and length L. What will be the rate at which the vessel is exhausted?

We will assume that the volume of the tube is negligible compared to the volume of the vessel, and that the limiting pressure for the pump is $p_o = 0$. We obtain from (2) and (6)

$$S_1\, p_1 = \frac{d\,(pv)}{dt} = q \qquad (15)$$

in which p_1 is the pressure at the pump intake and q is the quantity of gas which flows per second through the tube.

Now the pump, connected through the tube, exhausts the vessel V at a rate which is less than if the pump were directly connected to the vessel. The pump and tube together, however, constitute a system which is the equivalent of a pump of lower speed, say S_2. The rate at which gas leaves the vessel to enter the tube is thus $S_2 p_2$ where p_2 is the pressure in the vessel. This is also equal to q the rate at which the gas passes through the tube. Thus we have

$$S_2 p_2 = q \qquad (16)$$

Solving (15) and (16) for p_1 and p_2 and substituting in (5), we obtain

$$\frac{1}{S_2} = \frac{1}{S_1} + W\sqrt{\rho_1} \qquad (17)$$

The quantity $W\sqrt{\rho_1}$ represents the resistance to flow offered by the tube. The quantity $1/S_1$ must also be of the nature of a resistance—the resistance of the pump to the passage of the gas through it. That is, the pump itself may be looked upon as the equivalent of a very large, perfectly exhausted vessel connected to the apparatus to be exhausted by a tube offering a certain resistance. Knudsen has already defined the term resistance of tube by equation (9) and it is desirable to retain this definition, since resistance thus defined is a function only of the dimensions of the tube and not of the kind or temperature of the gas flowing through it.

By analogy with electrical usage, we may thus define $W\sqrt{\rho_1}$ as the "impedance" of the tube. This "impedance" will depend on the temperature and nature of the gas in a way not entirely dissimilar to the way impedance depends on frequency. The quantity $1/S_1$ is thus to be called the "impedance" of the pump, and $1/S_2$ is the "impedance" of the pump and tubing in series.

In this way we may calculate the speed of exhaustion through complicated systems in much the same manner as the calculations are made for electrical circuits. The effect of two tubes or more in series is obtained by adding their "impedances." With tubes in parallel, their "admittances" (reciprocal of impedance) are added.

Since it is usually more convenient to deal with the speed of a pump rather than with its reciprocal, it will also be convenient to express the characteristics of tubes in terms of their "admittance." This is a quantity of the same kind as S, the speed of the pump. In general, the "admittance" of a tube or opening may be defined by

$$S = \frac{q}{p_2 - p_1} \tag{18}$$

Thus the admittance may be calculated for any case from equations 5, 12, 13, 14, 12a, 13a or 14a, merely by placing $p_2 - p_1 = 1$. As an illustration, in the case of a tube 1 centimeter in diameter and 10 centimeters long, with air at room temperature, we find from (12a) and (14a) that the admittance of the tube is 1213 cc. per second at low pressures and $13.6 \times p$ cc. per second at high pressures.

If we place such a tube in series with a high vacuum pump having a speed $S = 1213$ cc. per second, it will evidently cut the effective speed of the pump down to one-half its former value, namely, 606 cc. per second.

Thus, with a pump which has a speed $S = 4000$ cc. per second (and such speeds are easily attainable with mercury vapor pumps), if we wish to use a tube which does not reduce the effective speed by more than 10 per cent, we must use a tube which has an "admittance" of at least 36,000 cc. per second. From equation (12a), we see that for a tube of this kind D^3/L must be at least 2.97. Thus if a tube 30 cm. long is to be used, the diameter must be at least 4.5 cm. in diameter.

These results indicate how seriously the speed of a mercury vapor pump may be limited by the resistance of the tubing unless this is of very great size.

We have thus far considered the action of the pump in lowering the pressure in a vessel. This process cannot go on indefinitely, for the pressure finally becomes lowered to a point at which the leakage of gas into the apparatus prevents a further decrease of pressure. A stationary condition is then reached.

The leak which limits the pressure may be in the pump itself, or in the vessel being exhausted. The first case is equivalent to that we have already considered, in which there is a lower limit p_0 to the pressure attainable by the pump. The rate of flow of gas into the pump is then $S_1 (p_1 - p_0)$.

The gas leaking into the vessel does not, in general, pass through the walls of the vessel, but is given off from the walls of the vessel or from bodies within it. Let q_2 be the rate at which such gas escapes into the vessel. Then when a stationary condition has been reached, this rate will be equal to the rate at which the gas is being removed by the pump, namely, S_2 p_2 where S_2 may be calculated from the speed of the pump S_1 and the "admittance" of the connecting tube. The lowest pressure obtainable in the vessel is thus

$$p_2 = \frac{q_2}{S_2} \tag{19}$$

This equation shows that the degree of vacuum which may be reached, even by a pump for which $p_0 = 0$ is limited by the speed of the pump and the size of tubing between the vessel and the pump.

Measurements of pressure by various forms of supersensitive vacuum gauges* have shown that the rate of evolution of water vapor from glass surfaces at room temperature is such that pressures below 0.2 bar could not be obtained even when using a molecular pump ($S_2 = 870$ cc. per second) continuously for an hour. In this case we can calculate by equation 19 that the rate of evolution q_2 must have been 170 cc. (of gas at 1 bar pressure) per second. This corresponds to 0.00017 cc. of gas at atmospheric pressure per second, or 0.62 cc. of water vapor per hour. In this case the surface of glass was about 1800 sq. cm.

After heating the glass for half an hour or more to 360 deg., this evolution of water vapor (at room temperature) is reduced many thousand fold, but even then it is not avoided entirely. The limit to the pressure actually attainable by means of mercury vapor pumps seems to depend entirely upon this evolution of gas from the walls of the vessel and tubing, and not upon any inherent limitation in the pump itself.

Since the mercury vapor pumps are used in series with a rough pump, it is of interest to know what the speed of the rough pump should be to allow the mercury vapor pump to operate at maximum efficiency. Suppose we have a mercury vapor pump having, together with its connecting tubing, the effective speed S_2. Let this be connected to a vessel V containing gas at a pressure p_2. We have seen that the speed of mercury vapor pumps is practically independent of the exhaust pressure so long as this does not exceed a certain critical value, say p_c. Thus, to obtain the full effectiveness of the pump, it is only necessary to have a rough pump having sufficient speed (S_0) to maintain a pressure lower than p_c. Under these conditions the quantity of gas per second being delivered by the mercury vapor pump is S_2 p_2, and this must be equal to the quantity

* See for instance, Dushman, Phys. Rev., *5*, 224 (1915).

removed by the rough pump, namely $S_0 \, p_c$ from which we find

$$S_0 = \frac{p_2 \, S_2}{p_c} \qquad (20)$$

In other words, the maximum speed of the mercury vapor pump may be realized if the speed of the rough pump is less than that of the mercury vapor pump in the ratio $p_2 : p_c$.

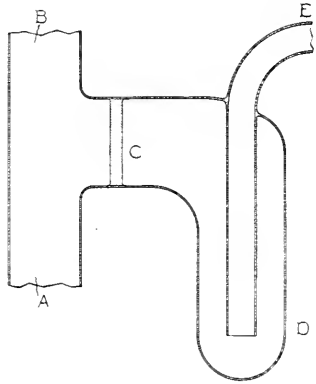


Fig. 4

Ordinarily, the pressure p_c for a mercury vapor pump is about 200 bars, so that if it is used to exhaust a vessel at ten bars pressure the speed of the rough pump need not exceed one-twentieth of that of the mercury vapor pump. The only advantage, then, in using a faster rough pump is that the maximum speed may still be obtained even with pressures higher than 10 bars.

In case the speed of the rough pump is not sufficient to maintain a pressure lower than p_c, then the mercury vapor pump will not operate at maximum speed, but will deliver gas to the rough pump at such a rate that the pressure on the exhaust side of the mercury vapor pump will remain substantially constant at p_c. Thus the speed of the mercury vapor pump under these conditions will vary with p_2 according to the equation

$$S_2 = \frac{p_c}{p_2} S_0$$

THEORY OF THE OPERATION OF THE CONDENSATION PUMP

For a number of years the writer has been convinced that the collisions between gas molecules and a solid or liquid body against which they may strike, are in general almost wholly inelastic. Each molecule which strikes a surface thus *condenses* on the surface instead of rebounding, although it may subsequently re-evaporate. This condensation takes place just as well at high temperatures as at low, but at high temperatures the re-evaporation may occur so soon that it is difficult to detect the condensation. In this case the condensed molecules constitute an adsorbed film. The condensed particles, before they re-evaporate, are held to the surface by the same kind of forces as those which hold solid bodies together. This leads to a theory of adsorption which is in excellent agreement with experimental facts.

A general review of the above theory and of the evidences supporting it, has recently been published.*

It was by a direct application of these ideas that the writer was led to construct a high speed mercury vapor pump.

Gaede†, in connection with a study of the diffusion of gases through mercury vapor at low pressures, devised a new form of high vacuum pump which he has called the "diffusion pump." Before describing the mercury vapor diffusion pump, Gaede illustrates the principles underlying the action of such pumps by means of the water vapor pump shown diagramatically in Fig. 4. A blast of steam passes through the tube *AB*, past the porous clay diaphragm *C*. The vessel to be exhausted is connected to the tube *E* and the appendix *D* is cooled by a mixture of ether and solid carbon dioxide. Steam diffuses through the diaphragm from left to right and is condensed at *D* and is thus prevented from passing into *E*. On the other hand, the air in the vessel to be exhausted into *E* and *D* and diffuses through the diaphragm from right to left into the steam, where it is carried away by the blast of steam. By a pump of this type Gaede was able to obtain an X-ray vacuum in about two hours. The great fault of this pump was its slow speed.

Gaede develops a simple theory of the pumps which use a clay diaphragm and finds that the speed can be increased either by increasing the surface of the diaphragm or by decreasing its thickness. If the thickness could be made zero, according to this simple theory, the speed would become infinite.

* The Evaporation, Condensation and Reflection of Molecules and the Mechanism of Adsorption. Phys. Rev. *8*, 148 (1916).

† Ann. Physik, *46*, 357 (1915)

He concludes that his equation does not apply to this case, and therefore proceeds to derive another, based on the kinetic theory. According to this theory, a porous diaphragm is equivalent to a large number of openings of dimensions comparable with the mean free path of the molecules. Gaede therefore calculates the rate at which one gas diffuses into a small hole in a thin plate out through which a second gas is escaping. In this way he finds that the first gas diffuses in at a maximum speed when the size of the opening is approximately equal to the mean free path of the second gas.

He thus determines the construction which will give a *diffusion* pump of the maximum speed. The design adopted for the mercury vapor diffusion pump is essentially that shown in Fig. 5. A blast of mercury vapor passes up through the tube AB past the narrow circular slit C. A part of the mercury vapor passes out through this slit and condenses on the water cooled surface D. The gas from the vessel to be exhausted passes through E and *diffuses into the slit C against the escaping blast of mercury vapor.* After it enters C it is carried away from the slit by the blast of mercury vapor and is thus effectively prevented from returning back through the slit.

It is evident that the speed with which the gas from E diffuses into the slit will have a maximum value for some particular width of slit. If the slit is too wide, the blast of mercury vapor escaping from it will be of such a volume that the gas molecules will not be able to diffuse appreciably against it. Gaede calculates and then shows experimentally that the maximum speed is obtained when the width of the slit is made approximately equal to the mean free path of the molecules in the mercury blast AB.

In the actual operation of the pump, Gaede finds it best to use such a pressure of mercury vapor that the maximum speed is obtained with a slit width of 0.012 cm. The maximum speed then obtainable is $S = 80$ cc. per second.

Such relatively low speeds are inherent in pumps in which the gas must diffuse in through an opening against a blast of mercury vapor.

While constructing and operating a Gaede diffusion pump, it occurred to the writer that this serious limitation of speed could be removed if some other way could be found to bring the gas to be exhausted into the stream of mercury vapor. The action of a pump such as Gaede's diffusion pump really consists of two rather separate steps:

Process I. The process by which the gas enters the blast of mercury vapor.

Process II. The action of the blast of mercury vapor in carrying the admixed gas along into a condensing chamber from which it cannot return to the vessel being exhausted.

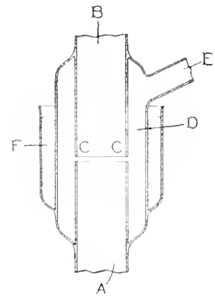


Fig. 5

The great advantage of the diffusion pump over all previous pumps lay in the remarkable effectiveness of the Process II. The limitations of the diffusion pump were imposed by the Process I.

Now the Process II in the diffusion pump is essentially similar to that used in commercial steam ejectors. In such ejectors, however, the Process I does not depend on diffusion, but on the lowering of pressure caused by the high velocity of the jet, in accordance with hydrodynamical principles (Bernoulli effect). The gas in an ejector is thus sucked into the jet because the *pressure in the jet is lower than that of the gas* in the vessel being exhausted. As the velocity of the mixed gases decreases in the expanding part of the ejector C (in Fig. 6), the pressure gradually increases up to that in the condensing chamber D.

Since the pressure in the jet must always be considerable, it is evident that the Bernoulli effect cannot be directly utilized to obtain a high vacuum. According to the kinetic theory also, the molecules in a jet of gas passing out into a high vacuum must spread laterally, so that there would be no tendency for a gas at low pressures to be drawn into such a blast.

In fact, it is easy to see that an ejector such as is shown in Fig. 6 could not be used to produce a high vacuum. Suppose, for instance, that a blast of mercury vapor passes through the tube A and escapes from B into the exhausted chamber C, and condenses at D. A large fraction of the atoms of mercury vapor escaping from B will have

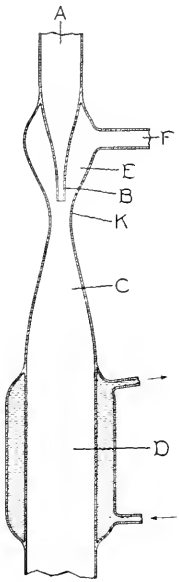


Fig. 6

transverse velocity components, so that they will strike the walls of the outer tube at K. These will condense, but the heat liberated will cause the walls to assume a temperature comparable with that of the mercury vapor blast. The condensed mercury will therefore evaporate approximately as fast as it condenses. The atoms which evaporate are just as likely to leave the surface in a direction towards E as toward C. Therefore a large fraction of the mercury vapor which strikes the wall K will pass into the tube E and out through F, so that it will completely prevent the entrance into E of a gas at low pressure. Experiments have subsequently proved that this is exactly what happens when it is attempted to operate an ejector at very low pressure. Not only does the device fail to pump, but it is often impossible to get any gas to pass through the device, even when there is a pressure of 100 bars or more at F and the pressure at D is held at 1 bar or less.

This reasoning indicates that the Bernoulli effect cannot be used to draw the gas into the blast (Process I). The main reason for this failure is the blast of gas which originates at K by the re-evaporation of the condensed mercury. If this re-evaporation could be prevented, the blast of gas from K to E would disappear and the gas from F would therefore meet no obstacle in passing into E and entering the stream of mercury vapor at K.

If it had been assumed that the mercury atoms striking K were *reflected* into E, then there would be no obvious means of preventing this reflection. But the work previously referred to had convinced the writer that reflection did not occur, and therefore indicated that to avoid this blast of mercury vapor into E it would only be necessary to cool the walls of the outer tube at the point K.

In this way, the blast of gas into E is made to disappear and the gas from F therefore passes into E and towards K. Beyond the nozzle B the molecules of this gas are struck by the atoms of mercury escaping from B and are *forced outward* (not drawn inwards) against the walls of the outer tube at K. The gas molecules are then subjected to a continual bombardment from mercury atoms which have velocity components in the direction towards C. If the walls of the tube C are also water-cooled, the gas which enters at F is thus pushed along the walls of C and is finally driven into the condenser D.

This was the reasoning which led to the construction of the type of pump shown in Fig. 1. The very first pump constructed operated perfectly satisfactorily and gave a speed of about 1800 cc. per second.

The action of the pump is based on radically different principles from that of the ejector. The most essential element in the operation seems to be the condensation of the mercury vapor at K and the maintainence of a temperature in this region so low that the condensed mercury does not re-evaporate. It is therefore suggested that pumps based on this principle should be called *Condensation Pumps*.

The distinction between the condensation pump and the ejector is clear when we realize that in the ejector there is no necessity for cooling the walls of the tube at K, Fig. 6, whereas the condensation pump entirely fails to operate unless this is done. Furthermore the effectiveness of the ejector depends on the flare of the tube C between K and D whereas this flare is entirely unnecessary in the condensation pump. In fact since a large portion of the mercury vapor condenses on the walls at K it is rather desirable to have a *decreasing cross section* between K and D. In the form of pump shown in Fig. 1, this contraction above the point P, Fig. 1, was actually employed. Subsequent experiment showed that it was unnecessary to provide two condensing chambers as in Fig. 1, but that the pump could be simplified as in Fig. 3.

If this later form of pump is examined during operation, it is seen that when there is a high vacuum on the intake side of the pump, practically no condensation of mercury takes place on the walls of the condenser C above the level of the point P. In other words, *all* the atoms of mercury vapor leaving the end of the tube L have downward velocity components and therefore cannot pass up above the point P unless they first strike some body not having the corresponding downward velocity. If, however, the walls of the condenser are allowed to become heated then the mercury atoms from L collide with mercury atoms evaporating from the walls (which do not have downward velocity) and as a result of these collisions a large faction of this mercury vapor is deflected upward into the space E. This prevents gas from F from reaching the point P where it might be acted on by the direct blast from L.

When a small flow of gas is allowed to enter through R so that the intake pressure is maintained at about 100 bars, it is interesting to observe that the line of demarcation below which the condensation occurs loses its sharpness, and that a considerable quantity of mercury vapor condenses above the point P. This is due to the collisions between the mercury atoms from L and the gas molecules which are driven in close to the walls of the condenser C.

Another interesting fact may be observed by watching the operation of the condensation pump. The greater part of the mercury vapor which escapes from L condenses on the walls of C within a couple of centimeters below the end of the nozzle L. This indicates that the mercury atoms radiate out from the end of L in all directions and show no particular tendency to continue to move in the direction in which the nozzle is pointed. This is essentially different from what happens in injectors or ejectors. It is well known that when steam escapes from a straight tube into the open air, the jet of steam continues to move in a nearly straight line for a considerable distance from the nozzle before it mixes to a large extent with the air. This effect evidently entirely disappears at very low pressures. This fact is in accordance with the kinetic theory of gases. At very low pressures the density of

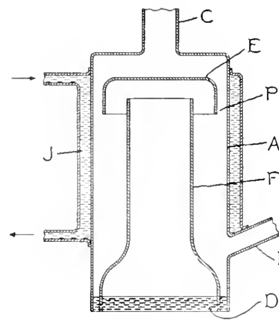


Fig. 7

the mercury vapor is extremely small whereas the viscosity of the gas is practically as great as at atmospheric pressure. The frictional effects of the walls therefore entirely predominate over the inertia effect which at higher pressures leads to the jet formation.

Some special pumps have been built to operate by a combination of the injector and condensation pump principles so that very much higher exhaust pressures may be used. In this way it has been possible to operate a single mercury vapor pump producing as high a vacuum as the ordinary type of condensation pump, but exhausting at a pressure of about 20 mm. of mercury. Further development work will be necessary, however, before these pumps become as satisfactory as a condensation pump backed up by a mechanical pump.

Condensation Pumps Built of Metal

The condensation pump lends itself admirably to construction in metal.

One type of pump which has proved relatively simple in construction and efficient in operation is shown diagramatically in Fig. 7. A metal cylinder A is provided with two openings B and C, of which B is connected to the backing pump and C is connected to the vessel to be exhausted. Inside of the cylinder is a funnel shaped tube F

which rests on the bottom of the cylinder *A*. Suspended from the top of the cylinder is a cup *E* inverted over the upper end of *F*. A water jacket *J* surrounds the walls of the cylinder *A* from the level of *B* to a point somewhat above the lower edge of the cup *E*.

Mercury is placed in the cylinder as indicated at *D*. By applying heat to the bottom of the cylinder the mercury is caused to evaporate. The vapor passes up through *F* and is deflected by *E* and is thus directed downward and outward against the water-cooled walls of *A*. The gas entering at *C* passes down between *A* and *E* and at *P* meets the mercury vapor blast and is thus forced down along the walls of *A* and out of the tube *B*. The mercury which condenses on the walls of *A* falls down along the lower part of the funnel *F* and returns again to *D* through small openings provided where the funnel rests upon the bottom of the cylinder.

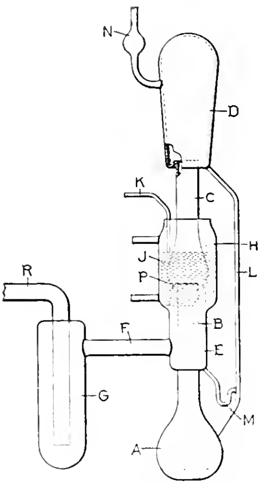


Fig. 8

A more detailed drawing of the pump as actually constructed is shown in Fig. 8.

Pumps of this type have been made in several different sizes. A pump in which the funnel *F* is 3 cm. in diameter and the cylinder *A* is 7 cm. in diameter gives a speed of exhasution for air of about 3000 cc. per second and will operate against an exhaust pressure of 200–600 bars depending on the amount of heat supplied to the mercury. The energy consumption ranges from 100 to 500 watts.

Very small pumps have also been constructed in which the tube *F* is only 0.6 cm. and the cylinder *A* is only 2 cm. in diameter. This type of pump gives a speed of about 200 cc. per second.

Degree of Vacuum Obtainable

The condensation pump resembles Gaede's diffusion pump in that there is no definite lower limit (other than zero) below which the pressure cannot be reduced. This is readily seen from its method of operation. A lower limit could only be caused by a diffusion of gas from the exhaust side (*N* in Fig. 3) back against the blast of mercury vapor passing down from *L*. The mean free path of the atoms in this blast is of the order of magnitude of a millimeter or less and the blast is moving downward with a velocity at least as great as the average molecular velocity (100 meters per second for mercury).*

The chance of a molecule of gas moving a distance about 4.6 times the mean free path without collision is only one in a hundred. To move twice this distance the chance is only 1 in 100^2, etc. If the mean free path were one millimeter the chance of a molecule moving a distance of 4.6 cm. against the blast without collision would be 1 in 10^{20}. In other words, an entirely negligible chance.

However, if with any particular design of pump it should be found that gas does leak back against the blast of vapor, it is a simple matter to increase the pressure in the blast or increase the distance against which the gas must pass back through the blast. Thus the construction adopted in Fig. 1, may be adopted where only a small part of the mercury is condensed close to the nozzle from which the vapor escapes, while the greater portion travels a considerable distance before condensing.

As a matter of fact even in the type of pump with a single condensing chamber such as shown in Fig. 3 and 7, there is evidence that the back diffusion is absolutely negligible under all normal operating conditions. Thus if a vessel is exhausted to 0.001 par (the lowest pressure readable on a McLeod gauge) while a good vacuum is maintained on the exhaust side of the pump, it is found, when the pressure on the exhaust side is gradually raised, that the vacuum remains unchanged on the intake side until a relatively high pressure

* This is apparent when we consider that no appreciable number of atoms pass up into the space *E*.

such as 200–600 bars on the exhaust side is reached. A very slight further increase in the exhaust pressure then causes a very great increase in pressure on the intake side. This result indicates that when comparatively low exhaust pressures such as 50–100 bars are used, the limiting pressure on the intake side, if it exists at all, must be extraordinarily low.

Of course it must be realized that the condensation pump like any mercury pump does not remove mercury vapor from the system to be exhausted. The vapor pressure of mercury vapor at room temperature is in the neighborhood of 2 bars. By inserting a trap such as that indicated at G (in Fig. 3) between the pump and the exhausted vessel, this vapor pressure may be lowered. The following table gives the vapor pressures of mercury corresponding to different temperatures and indicates how completely mercury vapor may be eliminated by cooling the trap.

Temp. Deg. C.	* Vapor Pressure of Hg in Bars
−180 deg. C.	2.3×10^{-24}
−78	4.3×10^{-6}
−40	0.0023
−20	0.029
−10	0.087
0	0.25
+10	0.65
+20	1.6
+30	3.7

* These vapor pressures are calculated from the formula

$$\log p = 11.27 - \frac{3243}{T}$$

which is obtained from data given by Knudsen (Ann. Physik., *29*, 179 (1909).

For a very large number of experiments the presence of mercury vapor is not injurious. By use of solid CO_2 or liquid air the mercury vapor may be entirely eliminated.

As has been pointed out previously, the vacuum actually attainable by the condensation pump is usually determined (according to equation 19) by the rate at which gases are given off by the walls of the vessel being exhausted.

By means of a new type of vacuum gauge devised by Dr. A. W. Hull of the research laboratory, pressures as low as 10^{-5} bar obtained by the condensation pump have already been measured. There is little doubt but that pressures very much lower than this can be and have been obtained by cooling the bulb to be exhausted in liquid air so as to decrease the rate at which gases escape from the walls.

Summary

Two new types of condensation pump are described, one built wholly of glass and the other wholly of metal.

In these pumps a blast of mercury vapor carries the gas into a condenser. This action is similar to that in a steam ejector and in a Gaede diffusion pump. The method by which the gas is brought into the mercury vapor blast in the condensation pump is based on a new principle which is essentially different from that employed in the steam ejector or Gaede diffusion pump. In the new pumps the gas to be exhausted is caught by the blast of vapor and is forced by gas friction to travel along a cooled surface. By maintaining this surface at such a low temperature that the condensed mercury does not re-evaporate at an appreciable rate, it is possible to keep the mercury vapor from escaping into the vessel being exhausted. The action of this pump therefore depends primarily upon the fact that *all* the atoms of mercury striking a mercury covered surface are condensed (no matter what the temerature), instead of even a fraction of them being reflected from the surface. It is for this reason that the term condensation pump is proposed.

The condensation pump is characterized by extreme speed (3000–4000 cc. per second, or even more, if desired), by simplicity and reliability, and by the absence of lower limit (other than zero) to which the pressure may be reduced. By the aid of this pump pressures lower than 10^{-5} bars have been produced and measured.

To obtain the full benefit of the high speed of these pumps, it is necessary to use connecting tubing of very large size. Equations are given by which the effect on the speed of exhaustion produced by tubing of any given dimensions may be calculated.

THEORY OF THE SINGLE-PHASE ALTERNATING-CURRENT MOTOR

Part I

By W. C. K. Altes

Induction Motor Department, General Electric Company

The shunt compensated repulsion motor is a combination of the repulsion motor and the single-phase induction motor, in which the high starting torque of the repulsion motor and the limited no-load speed and flat torque-speed characteristics of the induction motor are retained. A preliminary description of how this is effected is first given, and this is followed by a comprehensive discussion of the theory of the individual component motors. In the second and concluding installment the theory of each of the following motors is discussed: shunt compensated single-phase induction motor, shunt compensated repulsion motor, series compensated repulsion motor, and compound compensated induction motor.—Editor.

Constant Speed Single-phase Motor

The constant speed single-phase motor (Type RI) which has been developed by the General Electric Company can be classified as the shunt compensated repulsion motor or the repulsion induction motor. It is a combination of a repulsion and an induction motor, possessing the desirable characteristics of each of the two elements. The characteristics of the repulsion motor are high starting torque, high no-load speed and a large variation of the speed with the load. The characteristics of the single-phase induction motor are no starting torque, a limited no-load speed equal to the synchronous speed, and a small variation of the speed with the load. The repulsion motor is unsuitable for general purposes on account of its high no-load speed and large variation of the speed with the load; the single-phase induction motor is equally unsuitable on account of its lack of starting torque. A combination of the two types of motors makes it possible to take advantage of the desirable characteristics of both. It is merely necessary to sacrifice a part of the repulsion motor starting torque in order to secure the limited no-load speed and the flat torque-speed characteristics of the induction motor.

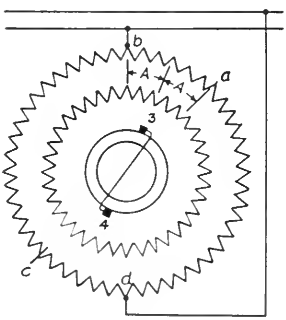


Fig. 1

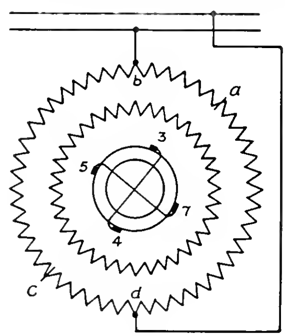


Fig. 2

The repulsion motor is represented diagrammatically in Fig. 1. It consists of a single-phase stator winding connected to a single-phase line, and an armature winding connected to a commutator on which slide two brushes 3 and 4, which are connected together. The axis *bd* of the stator winding is displaced over an angle *A* with respect to the axis of the armature circuit, which follows the axis of the brushes 3 and 4. We can resolve the stator winding into two components, one of which (the motor field turns *ab-dc*) is perpendicular to the armature circuit, and the other (the stator turns of transformation *da-cb*) follows the axis of the armature circuit. The stator turns of transformation are in inductive relation to the armature circuit and induce a current in the armature winding which flows between brushes 3 and 4 and neutralizes the current in the stator turns of transformation. The current flowing in the motor field turns excites the motor field flux, which, if we neglect the hysteresis, is in time phase with the current. The current and flux relations are essentially the same as in the d-c. series motor with neutralizing winding, with the difference that both current and flux pulsate with line frequency, so that a pulsating instead of a continuous torque is exerted. When the armature starts to rotate due to this torque, a voltage of rotation will be induced between brushes 3 and 4. As these brushes have a common connection, the current in the armature circuit will assume such a time phase and value that the resultant ampere turns yielded by the currents in both the stator transformation turns and the armature circuit produce a flux which by alternation induces a voltage that balances the rotation voltage. This voltage of alternation is also induced in the stator turns of transformation, and if we desire to keep the line current constant we have to raise the applied line voltage accordingly. The principal differences between the repulsion motor and single-phase series motor are the presence of a flux (which we will call flux of transformation) changing with the speed and working along the axis of the transformation turns, and the difference in time phase and amount between the armature and stator ampere turns of the repulsion motor, leaving the resultant ampere turns which excite this flux of transformation.

If we add to the motor of Fig. 1 another set of short circuited brushes 5 and 7, the axis of which is perpendicular to the axis of brushes 3 and 4 (see Fig. 2), a current will flow through the armature circuit formed by the brushes 5 and 7 which will neutralize the current in the motor field turns so that the motor field flux disappears but for the small amount maintained by the leakage reactance and resistance of the armature circuit. Hence this motor will exert scarcely any torque. When brought up to speed the flux of transformation will induce between the brushes 5 and 7 a rotation voltage which gives rise to an armature current yielding a flux which induces by alternation a voltage balancing this rotation voltage. This flux works again as motor field flux, inducing a rotation voltage in the armature circuit 3–4, and exerting torque by reacting on any energy current which flows in the circuit 3–4. The operation is essentially the same as that of the single-phase induction motor with squirrel cage armature.

If we do not short circuit the brushes 5 and 7 but connect them to a reactance, more or less of the field will be left, according to the amount of this reactance, and we will retain more or less of the repulsion motor's starting torque. This reactance at the same

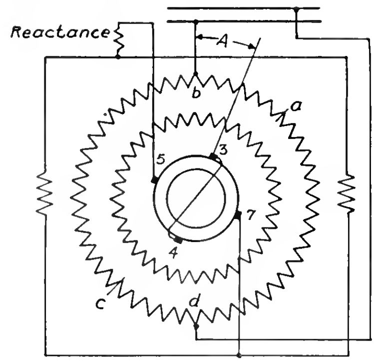


Fig. 3

time raises the no-load speed above the synchronous speed, as it limits the flux excited along the axis of the brushes 5–7. This flux induces the rotation voltage between the brushes 3 and 4, and it is clear that in order to get the same rotation voltage the speed has to be increased according to the decrease of flux. We can also insert between the reactance and the circuit 5–7 a voltage derived from the line, which has been represented in Fig. 3. As in the circuit 5–7 the rotation voltage and the voltage of alternation balance each other when the motor is running near synchronous speed, this voltage will have to overcome the resistance drop only, and we thus excite the field with a watt current, which offers the possibility of improving the power-factor of the motor. This is done on the Type RI constant speed motor.

Having explained in a preliminary way the principle of operation of the constant speed motor, we will develop in more detail the theory of the motors of which it is the combination.

The Single-phase Repulsion Motor

The theory of the single-phase repulsion motor can be developed in a way similar to that in which the theory of the single-phase series motor was developed. (See GENERAL

Electric Review of February, 1916, Page 115.)

In Fig. 4 we have shown a machine consisting of a stator S and a rotor R, both made up of punchings. The rotor is mounted in bearings. The stator is provided with a

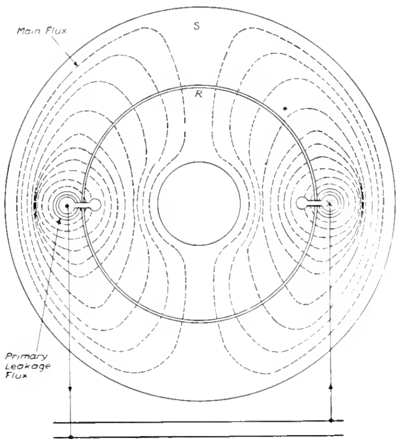


Fig. 4

coil having W_1 turns, which is connected to an a-c. source of supply. The rotor is provided with a coil having W_2 turns, and has been

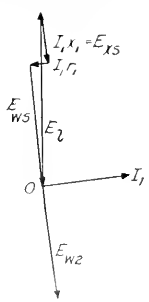


Fig. 5

left open. When a current I_1 is flowing through the stator coil, the ampere turns will yield a magnetic flux passing through both the stator and rotor iron and surrounded by the rotor coil. We will call this the main flux, or "the flux of transformation." It is represented in Fig. 4 by dotted lines. Further, a small magnetic flux will be yielded which is only surrounded by the stator coil. We will call this the primary leakage flux. It is represented in Fig. 4 by full lines. Due to the alternating nature of these magnetic fluxes, both the main flux and the leakage flux will induce in the stator coil voltages lagging 90 degrees in time phase behind the flux and proportional to the number of turns of the coil, the value of the flux, and the frequency of alternation.

The voltage induced in the stator coil by the main flux we will call E_{ws} and the voltage induced in the stator coil by the primary

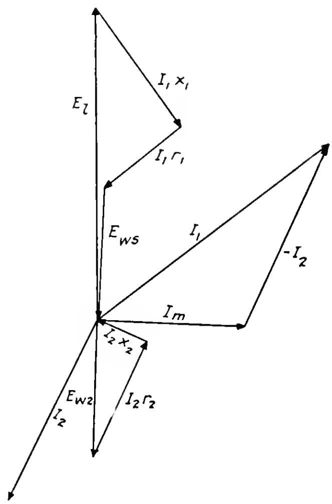


Fig. 6

leakage flux E_{xs}. If we neglect the hysteresis losses in the iron, which would cause the flux to lag behind the current by which it is yielded, the flux will be in time phase with the current I_1, and E_{ws} will lag 90 degrees behind I_1. A large part of the path of the leakage flux is formed by the air spaces of the slot openings and the air gap, so that this flux will be independent of the saturation in the iron and therefore proportional to the current. We can, as is customary, substitute for the voltage E_{xs} induced by the leakage flux the product of current and primary leakage reactance, so that $E_{xs} = I_1 x_1$. The resistance of the coil will further cause a resistance drop $I_1 r_1$, where r_1 is the resistance of the stator coil. Fig. 5 gives the vector diagram for the different voltages described above in their time relation to the current. The line voltage E_l required for driving the current I_1 through the stator coil under these conditions should be equal and opposite to the vector sum of $I_1 x_1$, $I_1 r_1$ and E_{ws}. We have further shown in Fig. 5 the voltage E_{w2} induced in the rotor coil by the main flux. This voltage has the same time phase as the voltage E_{ws} induced in the stator coil, and will be equal to E_{ws} when the number of turns W_2 of the rotor coil is equal to the number of turns W_1 of the stator coil, and

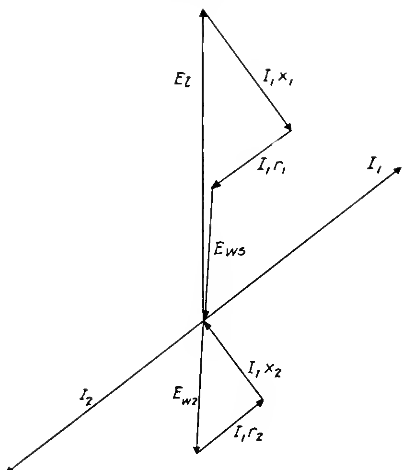


Fig. 7

the axis of both stator and rotor coil have the same direction. (See Fig. 4.)

As soon as we short circuit the rotor coil the voltage E_{w2} induced in it will cause a current I_2 to flow, which is limited by the resistance drop $I_2 r_2$ and leakage reactance drop $I_2 x_2$ of the rotor coil. The ampere turns excited by the current I_2 in the rotor coil will counteract the ampere turns of the stator coil, and the flux of transformation will be excited by the vector difference of the rotor and stator ampere turns. Fig. 6 gives the vector diagram for the machine covered by Fig. 4 with short circuited rotor coil. If we neglect the magnetizing current I_m which is required for exciting the small flux of transformation, then I_2 is equal and opposite to I_1 and the diagram can be represented by Fig. 7.

Those readers who are familiar with the theory of the stationary transformer will realize that Figs. 2, 3 and 4 represent the well known diagrams for the transformer with open and closed secondary.

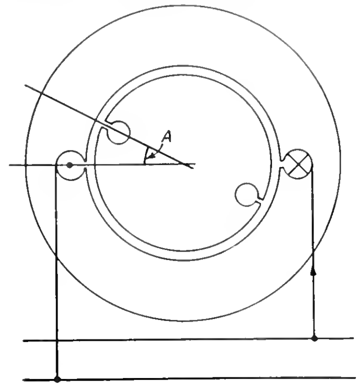


Fig. 8

In Fig. 8, we have shown the rotor shifted A degrees clockwise from the position of Fig. 4. The magnetomotive force *MMFS* resulting from the current I_1 flowing through the turns of the stator coil can be resolved into two components, one of which, *MMFS cos A*, follows the axis of the rotor coil, and the other *MMFS sin A* is perpendicular to the axis of the rotor coil. (See Fig. 9.) The component *MMFS cos A* is in inductive relation and the component *MMFS sin A* is in non-inductive relation to the rotor coil. If

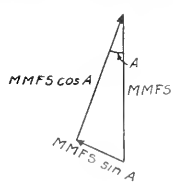


Fig. 9

we short circuit the rotor coil and apply to the stator coil a voltage E_l of such magnitude that a current I_1 will flow through it, a current I_2 will flow through the rotor coil, and have such a value that the vector sum of I_1 and I_2 gives as resultant the small magnetizing current I_m required for exciting the flux of transformation which induces the voltage E_{w2}, balancing both the leakage reactance and resistance drop in the rotor. *MMFS sin* A, yields a flux at right angles to the axis of the rotor coil which we will call motor field

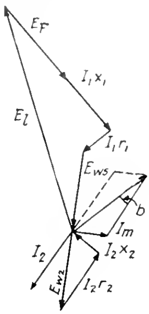


Fig. 10

flux *F*. The direction of the motor field flux *F* is perpendicular to the axis of the turns of transformation W_1 *cos A*, hence cannot induce any voltage by pulsation in this winding. The flux *F*, however, induces in the W_1 *sin A* stator coil turns, the axis of which coincides with that of the flux, a voltage E_f. The line voltage E_l has moreover to overcome the primary reactance drop I_1x_1 and the primary resistance drop I_1r_1. Fig. 10 gives the vector diagram of these different voltages in relation to the currents. Fig. 11 gives the same diagram, except that the magnetizing current I_m has been neglected. Hence we have

$$I_1W_1 \cos A = I_2W_2 \text{ or if}$$
$$W_1 = W_2$$
$$I_2 = I_1 \cos A$$

which equation is based on the fact, that the magnetomotive force *MMFS cos* A of the stator coil along the axis of the rotor coil is equal and opposite to the *MMF* of the rotor coil.

In accordance with Laplace's law a pull is exerted on each side of the rotor coil due to the repulsion between the current in the coil and the flux yielded by *MMFS sin* A. This pull has been represented by the arrows *a* and *b*. As the flux is perpendicular to the axis of the coil, *a* and *b* are tangent to the circumference of the rotor (see Fig. 12) and their full value, and not a component only, will produce the torque. The torque is proportional to the field flux, the number of rotor turns, and the component of the rotor current in time phase with the field flux; i.e., if we neglect both the hysteresis and the magnetizing current I_m, $I_2 = I_1 \cos$ A, as proved before.

If we neglect the saturation of the iron, the field flux will be proportional to I_1W_1 *sin* A = *MMFS sin* A and the torque will be proportional to $I_1^2W_1^2 \sin A \cos A = \frac{1}{2} I_1^2W_1^2 \sin 2A$. Fig. 13 shows how the torque and motor field flux will vary when, with different brush positions A, a constant line current is maintained, and the saturation of the iron, the hysteresis losses, and the magnetizing current I_m are neglected. The field flux, which is proportional to $I_1W_1 \sin A$, will move on the field flux circle and is zero for A = 0 and maximum for A = 90 degrees. The torque, which is proportional to $\frac{1}{2} I_1^2$, $W_2^2 \sin 2A$ will move on the torque circle. The torque is zero for A = 0 and *A* = 90 degrees, and maximum for A = 45 degrees. The torque can also be expressed in synchronous watts. If we call the voltage induced in the armature by the motor field flux with full frequency E_{r2}, the torque in synchronous watts will equal $E_{r2}I_2 \cos b$ (in which *b* is equal to the angle between primary and secondary current (see Fig. 10); or if we neglect I_m, in which case $b = 0$ and $I_2 = I_1 \cos$ A, the torque in synchronous watts $= E_{r2}I_1 \cos$ A.

It is clear that the rotor will move clockwise when turned clockwise over a small angle from the position in which *A* = 0. The position in which A = 0 is usually called the

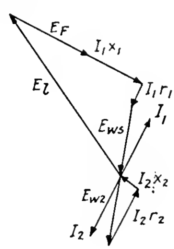


Fig. 11

"live neutral," and the position for which A = 90 degrees the "dead, or false neutral." In both positions the motor will not develop torque.

Instead of equipping both rotor and stator with a single coil, a distributed winding can be used, covering either a part or the entire circumference. In Fig. 1 we have shown fully distributed stator and rotor windings. Moreover, the rotor winding has been connected to a commutator on which can slide two brushes connected together and spaced 180 degrees apart. The axis of the rotor winding will follow the line through the brushes and the axis of the stator winding goes through b and d. If we shift the brushes clockwise over an angle A, the same torque and current relations will be obtained as explained for Fig. 12, the only difference being that the brushes can be kept stationary and the armature can rotate without the torque and current relation being changed, provided we vary the line voltage in order to balance the counter e.m.f. induced by rotation through the motor field flux. The stator winding can be resolved into two components, viz., the section a-b/d-c, the axis of which is, perpendicular to the axis of the rotor winding and the section d-a/c-b, the axis of which follows the axis of the rotor winding. The total stator winding has W_1 turns and a distribution factor $\frac{2}{\pi}$; hence the effective turns of the stator are

$$W_1\,eff = \frac{2}{\pi}\,W_1$$

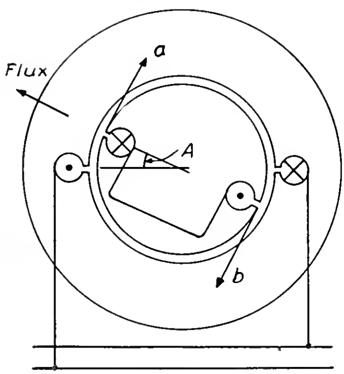


Fig. 12

The component perpendicular to the axis of the rotor winding has $\frac{2\,A}{\pi}\,W_1$ turns and a distribution factor $\frac{1}{A}\,sin\,A$, i.e., a total number of effective turns.

$$\frac{2\,A}{\pi}W_1\frac{1}{A}sin\,A = \frac{2}{\pi}W_1\,sin\,A = W_1\,\text{eff.}\,sin\,A.$$

The component which follows the axis of the rotor winding has $\frac{\pi - 2\,A}{\pi}\,W_1$ turns and a

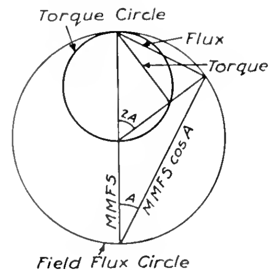


Fig. 13

distribution factor $\frac{2\,sin\left(\frac{\pi}{2} - A\right)}{\pi - 2\,A}$, i.e., a total number of effective turns.

$$\frac{\pi - 2\,A}{\pi}W_1 \times \frac{2\,sin\left(\frac{\pi}{2} - A\right)}{\pi - 2\,A} = \frac{2}{\pi}W_1\,sin\left(\frac{\pi}{2} - A\right)$$
$$= W_1\,\text{eff.}\,cos\,A.$$

Hence we see that *MMFS* gives the same components no matter whether a single coil or a distributed winding is used.

We have found how the torque will vary when a constant current is maintained and the rotor position or the brush position is changed. We can also investigate how the torque and current will vary when a constant line voltage is applied to the stator winding and the brushes are shifted. The problem is to find the brush position and torque for a certain assumed line current. We will neglect the hysteresis losses and the magnetizing current required for exciting the flux of transformation which induces the voltage E_{w2} so that we can apply the diagram of Fig. 11. In Fig. 14 have been plotted curves giving as ordinates the induced voltage and volt amperes, and as abscissæ the current flowing through the stator winding of a single-phase motor having W_1 stator turns. We assume further that we know both the primary and secondary reactance and resistance r_1, r_2, x_1 and x_2.

For the assumed current I_1 we can determine $I_1\,(r_1 + r_2)$, we further know that the reduced brush drop equals approximately

$$e_b = \frac{W_1}{W_2} \times \text{brush drop}.$$

We can determine the total reactive drop

$$E_f + I_1(x_1+x_2) = \sqrt{E^2_l - (I_1r_1+I_1r_2+e_b)^2}$$

and find the field drop

$$E_f = \sqrt{E^2_l - (I_1r_1+I_1r_2+e_b)^2} - I_1(x_1+x_2)$$

and the volt-amperes consumed by the field flux

$$I_1E_f = I_1\sqrt{E^2_l - (Ir_1+I_1r_2+e_b)^2} - I(x_1+x_2)$$

In Fig. 14 we find that to excite a field flux which requires $XB = E_f\ I_1$ volt-amperes a current OX flowing through W_1 turns will be needed. We have a current I_1, hence the field turns are equal to

$$\frac{OX}{I_1} W_1$$

or

$$W_1 \sin A = \frac{OX}{I_1} W_1$$

and

$$\sin A = \frac{OX}{I_1},$$

from which the angle of brush shift can be determined. Further, we find in Fig. 14 that with a flux corresponding to OX the induced voltage in the stator winding will be $XA = E$. If the rotor had the same number of turns as the stator then the rotor current would be $I_1 \cos A$, and hence in accordance with previous equations the torque in synchronous watts would equal $E\ I_1 \cos A$. The voltage E further determines the voltage induced in the coils short circuited by the brushes, on which depends the commutation at starting. In Fig. 15 we have plotted the torque, line current, and voltage E of a single-phase repulsion motor as ordinates with the angle of brush shift as abscissæ, when a constant line voltage is applied to the terminals.

It will be understood that by proceeding in this way, we have used too large a value for both the secondary reactance and resistance drop, which are equal to $I_2\ x_2$ and $I_2\ r_2$ or as $I_2 = I_1 \cos A$, equal to $I_1x_2 \cos A$ and $I_1\ r_2 \cos A$. The primary winding of transformation has $W_1 \cos A$ turns, the secondary $W_2 = W_1$, and hence in the primary circuit this drop appears as

$$\frac{W_1 \cos A}{W_1} I_1\ x_2 \cos A = I_1\ x_2 \cos^2 A \text{ and } I_1\ r_2 \cos^2 A$$

In case we desire to obtain more nearly accurate results we can correct our calculations by using in the above equations $x_2 \cos^2 A$ and $r_2 \cos^2 A$ instead of x_2 and r_2. In that case it becomes necessary to carry out the calculation a few times. The same correction can be made for the brush drop, which really is equal to $e_b = \frac{W_1 \cos A}{W_2}$ brush drop.

If we let the armature rotate, the motor field flux will induce a voltage in the armature conductors proportional to the speed, the number of effective turns of the armature

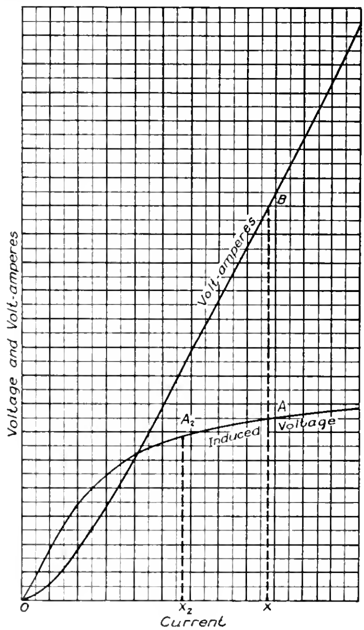


Fig. 14

between the short circuited brushes, and the field flux. As the brushes have been short circuited, a magnetizing current will be required for exciting the flux of transformation which alternates in the axis of the short circuited brushes and which induces by alternation a voltage which just balances the vector difference of the voltage induced by rotation and the secondary impedance drop. The result is that the secondary current will assume such a value and time phase that the vector sum of the secondary ampere turns

$I_2\,W_2$ and the primary ampere turns $I_1\,W_1 \cos A$ is equal to the ampere turns required for exciting the flux of transformation. In order to simplify the calculation we assume that $I_2\,W_2$ equals $I_1\,W_1 \cos A$, thus neglecting the ampere turns required for exciting the flux of transformation, and as before, we neglect the hysteresis losses. Further, it is clear that the flux of transformation will induce a voltage in the stator transformation winding.

By assuming that $I_2\,W_2 = I_1\,W_1 \cos A$, we get an incorrect value for the secondary impedance drop, both in time phase and value. However, this is a small error.

It is possible to determine for a given brush shift A, line voltage E_l and assumed line current I_1, the speed, power-factor, efficiency, torque and output of the motor. We take two perpendicular co-ordinates and as ordinates $OI_1 = I_1$ (see Fig. 16). We set off $OA = I_1\,(r_1 + r_2 \cos^2 A)$ opposite to OI_1, $AC = e_b$, the brush drop, which is also opposite to the current. We make $CD = I_1\,(x_1 + x_2 \cos^2 A)$ equal to the reactance drop lagging 90 degrees behind the current. To determine the field drop, $E_f = DE$ also lagging 90 degrees behind the current, we find with the aid of Fig. 14 for the abscissæ $OX = I_1 \sin A$, the voltage $E = OA$; then $E_f = E \sin A$.

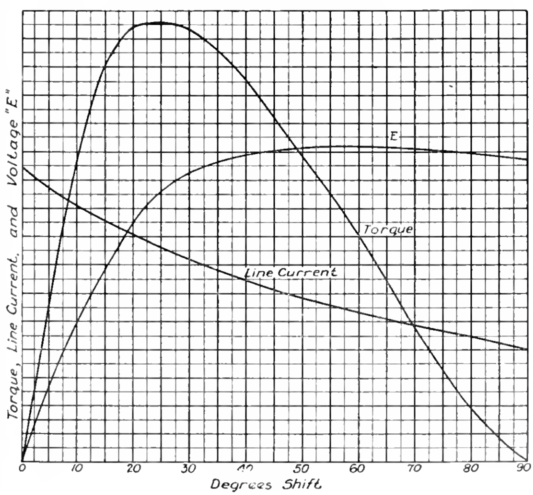


Fig. 15

We further make $ET = E \cos A$, i.e., the voltage which would be induced in $W_1 \cos A$ stator turns at synchronous speed. With the

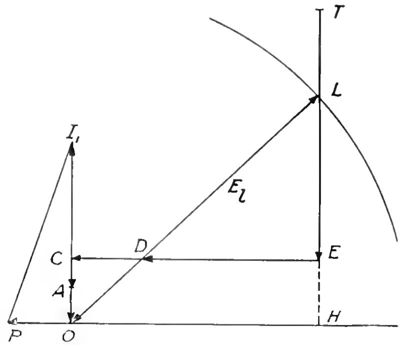


Fig. 16

line voltage E_l as radius and from O as center we describe a circle which intersects ET in L. We thus find that with the assumed line current the rotation voltage that is transformed back to the stator winding can only be equal to EL, and hence the speed in percentage of synchronous speed which the motor can assume equals $S = \frac{EL}{ET}$ and the rotation voltage transformed back to the stator transformation turns equals $EL = SET$.

The power-factor is equal to $\frac{HL}{OL}$. The torque in synchronous watts is equal to

$$I_1\,ET = I_1\,E \cos A.$$

We can calculate the magnetizing current required for exciting the flux of transformation. With the aid of Fig. 14, we find that it takes OX_2 amperes to excite a flux which induces by alternation in W_1 turns a voltage

$$OA_2 = \frac{\cos A}{EL}$$

Hence, with the $W_1 \cos A$ turns which excite this flux it would require $\frac{OX_2}{\cos A}$ ampere. We can resolve the primary current I_1 into two components, one of which, $OP = \frac{OX_2}{\cos A}$ leads

EL over 90 degrees and the other of which is equal and opposite to the secondary current reduced to the primary. The secondary current itself is equal to $\frac{W_1 \cos A}{W_2} \times PI_1$ and if desired we can correct the secondary impedance drop. It is obvious that in order to obtain the exact value of the magnetizing current we should have added to EL both the secondary reactance and resistance drop. This can be easily done, although in most cases this will only slightly alter the results. If we neglect the secondary impedance drop, then the flux of transformation is equal to $S \times F$.

When the repulsion motor is running above synchronous speed then both EL and OP become large, which means that the secondary current will reach very high values, thereby increasing the losses. This explains why the repulsion motor will have a lower no-load speed than the series motor.

The electrical output equals $EL \times I_1$ and the power input $HL \times I_1$, from which the efficiency can be calculated after subtracting the friction and windage losses from the electrical power output.

Commutation

The commutation depends on the resultant value of the different voltages induced in the coils short circuited by the brushes. In order to determine this resultant value, we have to know the different voltages both in value and time phase. These different voltages can readily be determined if we bear in mind the following definitions:

(*a*) A positive current flowing through a winding builds up a north pole at the beginning and a south pole at the end of this winding, the direction of the flux coinciding with the axis of the winding.

(*b*) When a winding rotates through a magnetic flux and the beginning of this winding is displaced less than 180 electrical degrees from the north pole in the direction of rotation, then a positive voltage will be induced, i.e., a voltage which will give rise to a current yielding a north pole at the beginning of the winding. This voltage is proportional to the frequency of rotation, the flux, the number of turns, and the sine of the angle between the north pole and the beginning of the winding; hence it is maximum when this angle is equal to 90 degrees, and zero when the angle is equal to 0 or 180 degrees.

(*c*) When a winding rotates through a magnetic flux and the beginning of this winding is displaced less than 180 electrical degrees from the north pole opposite to the direction of rotation, a negative voltage will be induced, i.e., a voltage which will give rise to a current yielding a south pole at the beginning of the winding.

Referring to Fig. 1, the motor field flux is excited by the line current I_1, flowing through the turns between ab and dc, the beginning of the axis of this winding lying between a and d. The axis of the armature coils short circuited by the brush 3 coincides with the axis of this winding, and hence, due to the alternation of this flux, a voltage will be induced in the coils short circuited by the brush 3, lagging 90 degrees in time phase behind the line current I_1. The beginning of the axis of the stator turns of transformation lies between c and d, and along this axis the flux of transformation, lagging 90 degrees behind the line current I_1, is excited. The direction of rotation of the motor is clockwise the brushes having been shifted clockwise from the live neutral. Hence, the axis of the coils short circuited by the brush 3 is displaced 90 degrees opposite to the direction of rotation with respect to the flux of transformation and in accordance with the previous definitions a negative voltage will be induced by rotation through the flux of transformation, i.e., 180 degrees ahead of the flux of transformation. We thus see that in the coils short circuited by the brushes the voltage induced by alternation of the motor field flux is opposite to the voltage induced by rotation through the flux of transformation.

We have found before that the flux of transformation is equal to S times the motor field flux F. As the voltage induced in the coils short circuited by the brush 3 is proportional to the flux of transformation and the speed, this voltage $e = -c\,S^2F$.

The voltage induced by alternation of the motor field flux is proportional to the frequency and the motor field flux F and is

$$e = cF.$$

The resultant voltage is

$$e \text{ resultant} = cF - cS^2F = e(1 - S^2).$$

On the polyphase series brush shifting motor the voltage induced in the coils short circuited by the brushes is $e_{res} = e(1 - S)$. Hence, with the same field flux and armature, the speed of the polyphase motor can be regulated over a wider range without exceeding the commutation limits than the speed of the single-phase repulsion motor.

At synchronous speed both motors will commutate equally well, as in this case $S=1$ and $e_{res}=0$.

Further, we have to take into account the voltage induced in the coils short circuited by the brushes while passing from one circuit to the other. This voltage, being a reactive voltage, will lag 90 degrees behind the secondary current or 270 degrees behind I_1; hence it is approximately in time phase with the voltage induced by rotation through the transformer flux. This voltage is proportional to the reactance of the armature coils, the current, and the frequency of commutation, and hence it increases with increasing speed and causes the point of ideal commutation, where the resultant of all induced voltages is zero, to occur somewhat below synchronous speed. Above synchronous speed the voltage induced by rotation through the flux of transformation is higher than the voltage induced by alternation of the motor field flux, to which has to be added the voltage resulting from the commutation of the current which increases proportionally with the speed. Hence, it is clear that the commutation is much more sensitive above than below synchronous speed, and for this reason standard motors cannot be run at much more than 15 per cent above synchronous speed when carrying load. By special means, however, it is possible to obtain good commutation when running above synchronous speed. In that case the short circuit of the energy brushes has to be opened and a voltage impressed on them so that only part of the energy is furnished by transformation, and the flux of transformation is reduced to the proper value. We thus obtain the series repulsion motor that has been used for railway work.

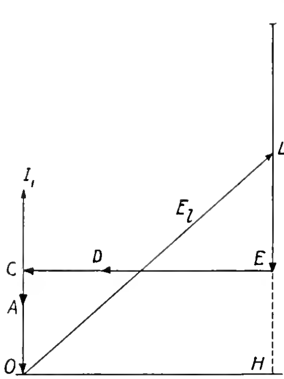


Fig. 17

The Effect of Resistance

If we increase the resistance of either the stator or the rotor winding the resistance drop OA of Fig. 16 will increase, which means that with the same angle of brush shift, current, and line voltage E_l, the points A, C, E and T in the diagram will be further removed from the horizontal, as shown in Fig. 17, and the result is a lower speed. The torque will be unchanged as long as we have the same current and brush shift. The speed of the repulsion motor can therefore be regulated like the direct-current series motor by inserting different values of resistance. This is done on the crane motors which are being developed and also on the Type R repulsion motors for direct connection to fans.

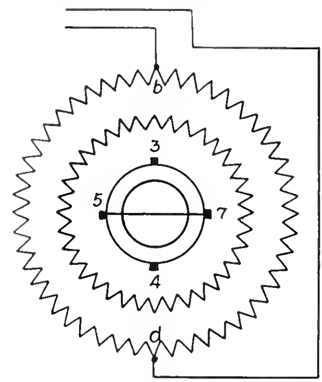


Fig. 18

The Single-phase Induction Motor

In Fig. 18 we have represented an induction motor with commutated armature, having a single-phase stator winding bd, four equally spaced brushes, 3, 4, 7 and 5; 7 and 5 are connected together and are standing in such a position that the axis through them is perpendicular to the axis of the stator winding.

We neglect both the resistance and leakage reactance of the stator winding, the motor core loss, and the leakage reactance of the armature winding. If we apply to the stator winding a voltage E_l, a magnetizing current I_m will flow so that $E_l = I_m X_m$. If X_m represents the mutual inductive reactance of this stator winding.

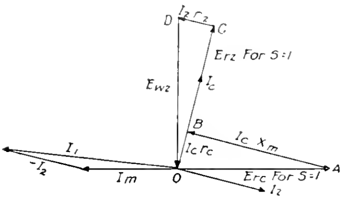


Fig. 19

Assuming that the armature has as many effective turns as the stator winding, the mutual inductive reactance of the armature winding will also be equal to X_m.

The flux of transformation yielded by the magnetizing current I_m will induce between the brushes 3 and 4 by alternation a voltage $E_{w2} = I_m X_m$.

If we drive the armature clockwise, a voltage E_{rc} will be induced due to the rotation through the flux of transformation in the armature winding between the brushes 5 and 7, so that if S is equal to the speed in percentage of synchronous speed, $E_{rc} = I_m X_m S$ and the direction of E_{rc} is opposite to the flux excited by I_m, 5–7, being displaced 90 degrees from the stator winding opposite to the direction of rotation.

As the brushes 5 and 7 have been short circuited, this voltage will give rise to a current I_c which is limited by the resistance r_c of the armature circuit and the mutual inductive reactance X_m. The current I_c excites a flux which in turn induces by rotation in the armature circuit 3–4 a voltage of rotation $E_{r2} = I_c X_m S$.

As the circuit 3–4 is displaced 90 degrees in the direction of rotation from 5–7, E_{r2} will be in time phase with I_c. If we also short circuit the brushes 3 and 4 a current I_2 will flow between these brushes so that the resistance drop $I_2 r_2$ balances the vector difference of E_{w2} and E_{r2}.

At synchronous speed $S = 1$.

$E_{rc} = I_m X_m = E_{w2}$ and $E_{r2} = I_c X_m$

The diagram at synchronous speed is shown in Fig. 19 and has been drawn under the assumption that $r_2 = r_c$, in which case, since the triangles OAB and OCD are equal and similar,

$$I_2 = I_c$$

It further follows from OAB that

$$I_2 = I_c = I_m \sqrt{\frac{X_m^2}{X_m^2 + r_c^2}} \cong I_m$$

and

$$E_{r2} = I_m X_m \sqrt{\frac{X_m^2}{X_m^2 + r_c^2}}$$

It will be noted that the current I_2 flowing between the brushes 3 and 4 is nearly opposite to the magnetizing current I_m, and the stator winding will therefore draw a current $I_1 = I_m - I_2$ from the line, so that the resultant ampere turns yielded by the stator current I_1 and the armature current I_2 excite the flux of transformation. This explains the well known fact that the single-phase induction motor draws a current from the line when running light which is equal to approximately twice the magnetizing current flowing with open circuited armature.

When running at synchronous speed, the current I_2 will not exert any torque, the direction of the current being perpendicular to the e.m.f. of rotation $E_{r2} = OC$. However, the current I_c exerts by reacting on the flux of transformation a generator torque, the angle between I_c and the e.m.f. of rotation E_{rc} being smaller than 90 degrees. If left to itself, the single-phase inducton motor would therefore not run up quite to synchronous speed at no-load, but to a lower speed, so that the current I_2 has such a time phase as to exert a motor torque which balances the generator torque exerted by the current I_c.

This is under the assumption of sine wave distribution of the flux. An armature such as shown in Fig. 18, however, will not excite a sine wave flux, but a triangular shaped one having a distribution factor of $\frac{2}{3}$ instead of $\frac{2}{\pi}$, for the voltage induced by alternation of the flux. For the rotation voltage the factor remains $\frac{2}{\pi}$. Hence, if we call X_m the mutual induction reactance for the voltage of alternation, then the mutual inductive reactance for the voltage of rotation will be equal to

$$\frac{2}{\pi} \times \frac{3}{2} X_m = \frac{3}{\pi} X_m$$

and we find at a speed S, that

$$E_{rc} = \frac{3}{\pi} I_m X_m S$$

$$I_c = \frac{3}{\pi} S I_m \frac{X_m}{\sqrt{X_m^2 + r_c^2}},$$

$$E_{r2} = \frac{3^2}{\pi^2} S^2 I_m \frac{X_m^2}{\sqrt{X_m^2 + r_c^2}}$$

We found before that at synchronous speed the torque exerted by the current I_2 is zero for

$$E_{r2} = I_m X_m \frac{X_m^2}{\sqrt{X_m^2 + r_c^2}}$$

When taking into account the winding factor we will obtain the same voltage E_{r2} for

$$\frac{3^2}{\pi^2} S^2 = 1 \text{ or } S = \frac{\pi}{3} = 1.045.$$

Hence, due to the triangular flux distribution the no-load speed of the induction motor with commutated armature will be raised above the synchronous speed. The generator torque exerted by the current flowing in the circuit 5-7, and the hysteresis, friction and windage losses will often bring this speed down to within $1/2$ to 1 per cent above synchronous speed.

When the motor is loaded then the speed will go down, permitting the current I_2 to change both in time phase and amount and thus the torque required by the load will be exerted.

(To be Continued)

THEORIES OF MAGNETISM

Part V

By Dr. Saul Dushman

Research Laboratory, General Electric Company

In this concluding article of the series the writer discusses Weiss's and Parson's magneton theories, also the difficulties inherent in the present theories of magnetism. The last section deals with magnetostrictive effects.—Editor.

The Elementary Magnetic Moment

The theory of para- and ferromagnetism as developed by Langevin and Weiss involves the conception of an ultimate unit of magnetic moment which we have denoted by **M**. The question as to whether this unit has the same magnitude for different substances has, so far, not been discussed. However, the equations which have been deduced in the previous sections enable us to calculate the value of this elementary moment for a number of cases, and in Part III we carried out such a calculation for oxygen(1) on the assumption that every molecule contains one elementary magnetic moment.

In the case of paramagnetic substances, the value of **M** can be calculated from the relation of Langevin and Curie,

$$\chi = \frac{\mathbf{M}^2 n_o}{3kT} = \frac{C}{T} \qquad (37)$$

where n_o = number of elementray magnets per unit mass.

k = Boltzmann's constant = 1.372×10^{-16} ergs/deg.

C = Curie's constant per unit mass.

For ferromagnetic substances above the critical temperature, it has been shown by Weiss and Foex(2) that this relation assumes the modified form,

$$\chi = \frac{C}{T - \theta} \qquad (46c)$$

From both of these equations it follows that

$$\mathbf{M} = \sqrt{\frac{3kC}{n_o}} \qquad (55a)$$

This equation can be written in a more convenient form for calculation thus: Let us assume that the number of elementary magnets per unit mass is the same as the number of atoms (or molecules, in the case of compounds). The number of atoms per gram atomic weight of any substance (or number of molecules per gram molecular weight) is 6.062×10^{23}. Hence,

$$\mathbf{M} = \sqrt{\frac{3kC.m}{6.062 \times 10^{23}}} = 2.605 \times 10^{-20} \sqrt{C.m} \qquad (55b)$$

where m denotes the molecular or atomic weight.

Table XXI gives the values of **M** calculated according to this equation for a number of paramagnetic substances. The data for oxygen and nitric oxide gases are taken from a recent paper by Piccard and Weiss(3), while some of the other data are taken from Tables VII, VIII and IX, Part II(4). The values of $C.m$ for the paramagnetic salts in aqueous solution are taken from the comprehensive paper on magnetism by du Bois(5) to which reference has been made in previous sections.

The elementary magnetic moment may also be calculated directly from the observed values of the saturation intensity of magnetization at, or near, the absolute zero. According to the theory of Langevin and Weiss, there is no thermal agitation of the molecular magnets at the absolute zero, that is, there is no force tending to oppose the orientation of *all* the magnets in the magnetic field. Hence, the saturation intensity of magnetization ought to attain the

(1) Gen. Elec. Rev., Sept., 1916, p. 743.
(2) Gen. Elec. Rev., Oct., 1916, p. 819.
(3) Compt Rend. 155, 1234.
(4) Gen. Elec. Rev., Aug., 1916, p. 672.
(5) Rapports du Congres International, 2, 496 (1900).

TABLE XXI

Substance	C	m	$\mathbf{M}\times 10^{20}$	$\mathbf{M}$ (0.185 $\times 10^{-20}$)
Oxygen	0.0310	32.0	2.59	14.0
Nitric oxide	0.0137	30.0	1.67	9.0
Palladium	0.00152	107	1.05	5.7
$FeSO_4.7H_2O$	0.0110	278	4.56	24.7
$MnCl_2$	0.0300	126	5.06	27.3
Magnetite	0.00445	230.5	2.64	14.2
	0.00682		3.27	18.8
	0.0105		4.04	21.9
	0.0180		5.31	28.7
Nickel	0.0066	58.7	1.62	8.8
	0.00555		1.49	8.0
Cobalt	0.0217	59.0	2.95	15.4
	0.0182		2.70	14.6
Iron	0.0395	55.8	3.87	20.9
	0.0273		3.22	17.4
	0.072		5.22	28.2
	0.0046		1.32	7.1

Salts in Aqueous Solution	$C.m$	$\mathbf{M}\times 10^{20}$	$\mathbf{M}$ (0.185 $\times 10^{-20}$)
$\frac{1}{2}\,Cr_2\,(SO_4)_3$	1.74	3.44	18.6
$CrK\,(SO_4)_2$	1.83	3.52	19.1
$CrNH_4\,(SO_4)_2$	1.76	3.45	18.7
$Cr\,(NO_3)_2$	1.83	3.52	19.1
MnF_2	4.38	5.45	29.5
$MnCl_2$	4.48	5.51	29.8
FeI_2	3.74	5.05	27.2
$FeSO_4$	3.70	5.01	27.1
$FeCl_3$	3.95	5.18	28.0
$FeBr_3$	4.32	5.41	29.3
$\frac{1}{2}\,Fe_2\,(SO_4)_3$	4.41	5.47	29.6
CoF_2	3.02	4.53	24.5
$CoCl_2$	3.06	4.56	24.6
$CoSO_4$	2.97	4.49	24.3
$Co\,(NO_3)_2$	3.06	4.56	24.6
NiF_2	1.30	2.97	16.0
$NiCl_2$	1.30	2.97	16.0
$Ni\,(NO_3)_2$	1.29	2.96	16.0
$CuCl_2$	0.48	1.80	10.0
$CuBr_2$	0.46	1.77	9.6
$CuSO_4$	0.48	1.80	10.0
$Cu\,(NO_3)_2$	0.48	1.80	10.0

greatest possible value at this temperature. In the previous section we denoted the value of I_s at $T=O$ by I_m. It therefore follows that

$$I_m = n\mathbf{M}$$

where n = number of magnets per unit volume.

$$= 6.062\times 10^{23}\times\frac{\text{Density}}{\text{Atomic Wt.}}$$

Or,

$$6.062\times 10^{23}\times\mathbf{M}=\frac{I_m\times\text{Atomic Wt.}}{\text{Density}}\qquad(56)$$

The right-hand side of this equation is designated as the *magnetic moment per gram atom or gram mol.*

Table XXII gives the values of the saturation intensity as determined by Weiss and Kammerlingh Onnes for the case of iron, nickel, cobalt and magnetite, together with the values of **M** derived from these.

The values of I_m were extrapolated from those of I_s at 20.3 deg. abs. There seems to be, however, a lack of agreement among different investigators about the exact values of I_s. It will be observed that the values at room temperature as given in the above table are different from those given in Tables IV and V, Part I(6). Furthermore, there is every reason to believe that the values given by Weiss and Onnes for iron and nickel are much too low. J. Kunz(7) in 1910 gives the values of I_s ($T=293$) and I_m for iron as 1900 and 2120 respectively, while E. H. Williams in 1912, uses the values 1750 and 1950 respectively. The saturation intensity has been measured for different metals in Kunz's laboratory by W. Stifler(8) and P. W. Gumaer(9). Their results as summarized in the paper of E. H. Williams(10) are given in Table XXIII together with the values of **M** as calculated by means of equation (56).

(6) Gen. Elec. Rev., May, 1916, p. 357.
(7) Phys. Rev., *30*, 359 (1910).
(8) Phys. Rev., *33*, 268 (1911).
(9) Phys. Rev., *35*, 288 (1912).
(10) The Electron Theory of Magnetism.

TABLE XXII

Substance	Density	I_s at Room Temp.*	I_s at $T=20.3$**	*** ($I_m\times$Atom. Wt. / Density)	$\mathbf{M}\times 10^{20}$	$\mathbf{M}\times 10^{20}$ / 0.185
Iron	7.862	1706	1742	12,410	2.04	11.03
Nickel	8.79	479	505	3,381	0.56	3.01
Cobalt	8.712	1412		(9,650)	1.56	8.90
Magnetite	5.252	476.5	504	7,417	3.70	20.00

* Journ. de Phys., 9, 373 (1910).
** Journ. de Phys. 9, 555 (1910).
*** Physikal. Zeitsch. 12, 935 (1911).

TABLE XXIII

Substance	$I_0(T=293$	I_m	**M** $\times 10^{20}$	$\frac{\mathbf{M}\times 10^{20}}{0.185}$
Fe	1750	1950	2.29	12.4
Ni	500	570	0.63	3.4
Co	1421	1435	1.60	8.7
Fe_3O_4	430	490	3.55	19.2
Heusler Alloy No. 1		518	3.55*	19.2
Heusler Alloy No. 2		533	4.23*	22.9

* These values have been calculated by a method suggested by Kunz to which reference is made below.

Kunz has suggested a third method of calculating **M** which depends upon a knowledge of the critical temperature and the magnitude of the constant, K, of the intrinsic molecular field (see Part IV of this paper). For the details of this derivation, the reader must, however, be referred to the publications of Kunz and his students.(11)

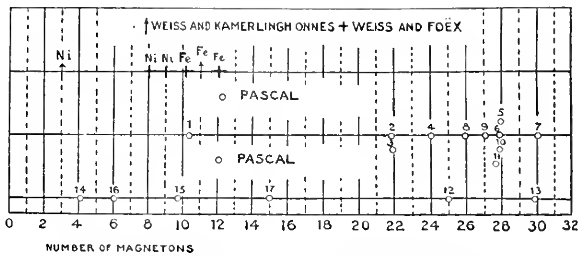
Weiss' Magneton Theory

The investigations of numerous physicists have shown that in considering quantities of electricity, we ultimately arrive at a unit of electric charge whose magnitude, as determined by the most accurately available methods, is 1.591×10^{-20} em.u. All electric charges are multiples of this unit charge. Nowhere else is this result exhibited more strikingly than in the brilliant experiments of Prof. R. A. Millikan on oil drops. These oil drops could be made to acquire a greater or smaller charge at the will of the experimenter, and the magnitude of the change as measured in each case, was a simple multiple of the above unit.

Now the question arises, is it possible to obtain a similar unit of magnetic moment? The values of the elementary magnetic moments as calculated above vary for the different substances, and often for the same substance, according to its state. If there is a unit of magnetic moment, it ought to show up as a greatest common divisor of *all* the values tabulated above.

In order to determine this ultimate unit of magnetic moment, Weiss compared the values of **M** as deduced from the saturation intensities at the absolute zero (I_m), since, as has already been explained above, the theory of ferromagnetism leads to the conclusion that at extremely low temperatures, where presumably thermal agitation has practically ceased, all the elementary magnets ought to become aligned in even a weak magnetic field, and the intensity of magnetization would therefore be the sum of all the unit magnetic moments contained in a unit volume.

Weiss observed that the greatest common divisor of the values of **M** for iron and nickel is 0.185×10^{-20}. This is contained 11 times in the magnetic moment of iron, and 3 times in that of nickel (see last column Table XXII). Hence, Weiss concluded that this



1-11. Various salts of iron.
12. Cobalt chloride.
13. Manganese sulphate.
14. Permanganate of potassium.
15. Cupric sulphate.
16. Cuprammonium sulphate.
17. Uranous sulphate.

Fig. 22

quantity gives the magnitude of the ultimate unit of magnetic moment, and gave it the name "magneton." In a similar manner, it was concluded that in the case of magnetite (Fe_3O_4) there are 20 magnetons for every group consisting of $3Fe$ and $4O$ atoms. In experimenting with cobalt, Weiss and K. Onnes were unable to saturate the metal and thus obtain its magnetic moment. The value (9650) given in Table XXII for the magnetic moment per gram atom is not considered by them as very reliable. But from an invsetigation of nickel-cobalt alloys, Bloch deduced the moment of the cobalt atom to be 8.925 magnetons, while Preuss got from the study of iron-cobalt alloys the value 8.97 magnetons.

For the determination of the number of magnetons per molecule in the case of paramagnetic substances, Weiss used the values derived from the Curie constant. The last column of Table XXI gives the value of the number of magnetons, calculated in this manner. The diagram in Fig. 22 is a sum-

(11) See citations above.

mary of results obtained from a study of different salts of iron and other paramagnetic salts in solution. "The vertical lines are drawn one magneton apart. The circles and arrows indicate by their position horizontally the number of magnetons in the molecule of the substance. It is to be noted how often the circles come on the vertical lines and how rarely they miss them." A large number of other salts have also been investigated by Weiss and his students.(12) In most cases the result of dividing **M** by 0.185×10^{-20} is an integer or nearly so. These results have therefore been taken by Weiss to be in confirmation of his theory that there exists an ultimate unit of magnetism comparable to that already found for electric charges.

Further consideration, however, of the quantitative data and their physical significance leads to conclusions that are quite at variance with Weiss's magneton theory. Firstly, there are a very large number of cases in which the value of the magneton number is not a whole number, and if we are to adhere to Weiss's theory, we must either discard the experimentally derived values of the Curie constants, or else conclude definitely that the method used in calculating **M** is not valid. The latter alternative is synonymous with casting doubt on the whole of Langevin's theory.

Furthermore, the magneton numbers themselves are so large, that it is only necessary to assume slight inaccuracies in the experimental values of the Curie constant in order to make the numbers come out integral values. A critical examination of the data on which Weiss has based his integral values leads to the conclusion that in more than one case there has been an unconscious smoothing out of experimental values in order to obtain the desired result. Thus the Curie constant for salts in solution varies with the concentration of the dissolved substance. Under these conditions, are we justified in taking that value which will lead to an integral magneton number? The argument used by Weiss is quite similar in this respect to that advanced early in the history of chemistry by those who wished to prove that all the elements are composed of either hydrogen or some proto-element. From the fact that the atomic weights of most elements are whole numbers or nearly so, it was assumed that the atoms of all elements are made up of atoms of hydrogen and it was, in fact, advocated that the atomic weights ought to be integral values. Careful determination of the atomic weights have, of course, led to the discarding of this theory; but nevertheless similar ideas crop up from time to time in chemistry and physics—have their little day and then vanish.

There are, however, even more serious objections to Weiss's magneton theory. According to this theory, we must assume that these unit magnets or magnetons are arranged linearily in the atom in rows such as N/S–N/S–N/S etc. In the case of an iron atom at ordinary temperatures we would have to assume 11 such magnets all in a row. It is true that a similar theory of atomic structure was suggested by Ritz to explain certain observed regularities in the spectra of different elements, but such a structure is difficult to reconcile with an immense number of other facts that we know and which are correlated by the atomic models of Thomson, Rutherford and Bohr.

Criticism of Weiss-Langevin Theory

As a matter of fact the very fundamental assumption of the electron theory of magnetism have been questioned by some investigators. According to the classical theory of electrodynamics, an electron rotating in an orbit must radiate energy continuously. In consequence its orbit would become smaller and smaller and finally the electron would fall into the positive nucleus. This objection led Thomson to discard a theory of atomic structure in which the electrons are rotating around a positive nucleus, and instead he postulated a positively charged sphere with stationary electrons distributed inside it. This accounted very well for the periodic properties of the atoms. But with such a model it is impossible to account for the fact that alpha particles have been observed to travel through thin metal foil, and that occasionally one or more of these particles is apparently thrown back towards the point from which it originated, just as a comet coming near the sun is not pulled into it but thrown back in a parabolic orbit. These facts led Rutherford to the conclusion that the atom cannot be impenetrable, for in order to account for these so-called phenomena of scattering, it is necessary to assume that the alpha particle passes within a distance of 1×10^{-13} cm. from the positively charged center of the atom. Bohr took up Rutherfords suggestion and showed that by introducing the quantum theory of energy radia-

(12) Full details are given by Weiss in his paper in Physikal. Zeitschrift, 12, 935 (1911).

tion it is possible to account for an atom consisting of a positive nucleus with electrons rotating round it in one or more rings. That is, Bohr frankly discards the classical theory of electrodynamics and introduces assumptions which appear equally necessary in order to account for a large number of other phenomena.

At first glance, such a theory of electrons rotating around a positive nucleus lends additional support to the electron theory of magnetism. But further consideration shows that here again we meet with difficulties. It will be remembered that in order to account for the fundamental distinction between dia- and paramagnetic substances, Langevin assumes that in the case of the former the resultant magnetic moment of the electrons is zero, while in the case of the latter the revolving electrons possess a resultant magnetic moment. In a magnetic field the electronic orbits tend to set themselves in such a direction that their magnetic fields tend to oppose that of the external field—hence the phenomenon of diamagnetism. But in the case of paramagnetic substance, we have apparently a resultant orbit which is, as it were, a little permanent magnet, and this tends to set itself along the lines of force of the external field, thus leading to paramagnetism. Wherein lies the difference between the two kinds of orbits?

Langevin himself has frankly recognized this situation, and writes as follows:

"Since the individual currents due to the other electrons present in the molecule neutralize one another just as in a purely diamagnetic body, it follows that, in magnetic molecules, *one or more electrons are sharply separated from the rest and are alone responsible for the magnetic properties, while all the electrons co-operate to produce diamagnetism.*

"These are perhaps the very same electrons, situated in the outer part of the system forming the molecule, that play a part in chemical actions, where we know that electrons equal in number to the valence come into action. That would account for the profound influence of the state of molecular association, physical or chemical, upon paramagnetism, and its virtual lack of effect upon diamagnetism."

The theory of Langevin and Weiss leaves however, a large number of other facts unexplained. It has already been shown that temperature has, in general, no effect on the susceptibility of diamagnetic substances, while that of paramagnetic substances decreases with increase in temperature (Curie's law). Nevertheless, there are a large number of exceptions to these rules, and the contrary is even true in some cases. (See Tables X and XI, Part II). According to Langevin's theory diamagnetism is a fundamental property of the atom, while paramagnetism is in some manner dependent upon the particular arrangement of atoms in the solid state. But what about the paramagnetism of oxygen and nitric oxide gases—in which case it is necessary to conclude that paramagnetism is an essential property of each molecule? How shall we explain the fact that the amalgams of iron and cobalt are as strongly magnetic in proportion to their concentration as the pure metals? "This can hardly be explained except by supposing that magnetism is, in the last resort an atomic property, and that the largeness of the magnetism of iron and its congeners is due to some peculiarity of atomic structure. This conclusion is supported by the experiments of St. Meyers and others, from which it results that atomic magnetism is a periodic function of the atomic weight, and is in some very close connection with the atomic volume."(13)

The latter statement must be somewhat modified in view of more recent work by Honda and Owens (see Part III). It has recently been shown by St. Meyers that the magnetic susceptibilities of isotopes is the same. Thus the magnetic property must depend only upon the total number of electrons in the atom, or the nuclear charge.

Let us mention briefly some other facts which have been mentioned in previous sections, and which are inexplicable from the point of view of the Langevin-Weiss theory:(14)

"1. The formation of Heusler's ferromagnetic alloys from copper, manganese, and aluminum, no one of which by itself is usually more than slightly magnetic, either positively or negatively.

"2. The existence of manganese as paramagnetic or ferromagnetic according to past treatment.

"3. The change of tin from a diamagnetic to a paramagnetic state. When gray tin, which is diamagnetic, is heated its negative specific susceptibility grows greater and at 35 deg. C. reaches zero. It continues to rise with the temperature up to 50 deg. A further increase of temperature fails to affect it until the tin melts at 232 deg., when it

(13) G. A. Schott, Phil. Mag., *15*, 172 (1908).
(14) G. F. Stradling, Journ. Frank. Inst., *180*, 173 (1915).

suddenly drops to a value below zero and the liquid metal, a diamagnetic substance, retains this negative susceptibility as it rises still further in temperature.

"4. The formation of iodide of mercury and potassium, a paramagnetic substance from three diamagnetic elements."

To the facts mentioned by Stradling, we can add some others.

5. The relation between molecular constitution and diamagnetic susceptibility, as shown by Pascal and Oxley.

6. The fact that some substances have recently been discovered which can be either dia- or paramagnetic according to the field strength. The name metamagnetic has been suggested for this group.

7. Lastly, there is a large group of facts which the electron theory leaves unaccounted for. These facts are ordinarily classified under the heading of magnetostrictive phenomena and deal with the numerous interactions between strain and magnetism. We shall discuss these phenomena in a subsequent section but it must be emphasized in this connection that so far as the writer is aware, only the slightest attempt has been made to explain magnetostrictive effects by the electron theory.

It must be confessed that destructive criticism of any scientific theory is not a very difficult undertaking, and while in order to be strictly fair, as far as possible, we have mentioned all the above facts which would tend to discredit the electron theory of Langevin and Weiss, the fact nevertheless remains that this theory (if we leave out of account the latter's theory of the magneton) represents a marked advance in our grasp of the complex domain of magnetic phenomena. Whether the ultimate theory of magnetism be evolved along the lines suggested by Langevin, or along some new lines, the theory has performed a splendid service in correlating a large number of observations and provides us with the stimulus for carrying on further experiments towards the solution of the question as to the ultimate nature of magnetism.

Experiments of Barnett, Einstein and de Hass

Within the last couple of years there have been published the results of two investigations on the subject of magnetization by rotation which lend very much support to the electron theory of magnetism and which therefore ought to be mentioned in this connection. The most comprehensive of these investigations is undoubtedly that carried on by Prof. S. J. Barnett[15] in the period 1909 to 1915.

"In 1909 it occurred to me, while thinking about the origin of terrestrial magnetism, that a substance which is magnetic (and therefore, according to the idea of Langevin and others, constituted of atomic or molecular orbital systems *with individual magnetic moments* fixed *in magnitude and differing in this from zero*) must become magnetized by a sort of *molecular gyroscopic* action on receiving an angular velocity.

"Thus consider a cylinder of iron, with zero magnetic moment in its initial state. *If it is given an angular acceleration about its axis, each individual system, which we may suppose for simplicity to consist of a number of electrons revolving in fixed orbits with constant average velocities about an oppositely charged nucleus, will change its orientation in such a way as to contribute a minute angular momentum, and therefore a minute magnetic moment, parallel to the axis of the cylinder.* This increment of angular momentum of each system is in the direction of the axis of rotation, and the corresponding increment of the magnetic moment is either in this direction or in the opposite direction according as the particles in revolution are positive or negative. *If the revolving electrons are all negative, in conformity with most of the experimental evidence, the cylinder will become magnetized in the direction in which it would be magnetized by an electric current flowing around it in a direction opposite to that of the angular velocity imparted to it.* This corresponds to the direction of magnetization of the earth and the sun."

Developing the theory of this effect quantitatively, Barnett shows that the intrinsic intensity of rotation to be expected is

$$H = 2\,\frac{m}{\epsilon}\,\Omega \qquad (57)$$

where Ω is the angular velocity of rotation, and ϵ/m denotes the ratio of charge to mass for the electron.

"This is on the assumption that the negative electron alone is effective. According to this, all substances would be acted upon by precisely the same intensity for the same angular velocity.

"If some or all of the positive ions also have orbital motions, proportionality with angular velocity will evidently still exist, but

(15) Phys. Rev., 6, 240 (1915). The writer is responsible for italizing certain sentences.

the coefficient of Ω will be reduced in magnitude or even changed in sign, and the intensities acting on different substances may differ for the same value of Ω. If the influence of the negative electrons is preponderant, the value in (57) gives the maximum magnitude of H, attained when the negative electrons alone are effective.

"The relation of proportionality must hold also between the angular velocity and the *magnetic flux density* and *intensity of magnetization*, which are very minute and therefore proportional to the intrinsic intensity; but *these quantities will depend not only upon the intensity but also upon the material and shape of the rotating body.* Thus in the case of a diamagnetic substance each of the orbits in an atom or molecule tends to change its orientation precisely as an orbit in a magnetic molecule; but no gross magnetic effect can, on the theory advanced here, result, because the geometric sum of the individual magnetic moments of the particle is permanently zero."

That is, according to Barnett, a body composed of magnetic material ought to become magnetized by rotation, while a non-magnetic substance would not show this effect. Furthermore, from the relation between the direction of rotation and that of the resulting magnetic polarity, it is possible to tell whether the magnetization is due to electrons rotating about a positively charged nucleus or to positive ions rotating about a negative charge.

An extended series of experiments on the magnetization of steel rods showed that after all other possible sources of error are eliminated, the effect prophecied by assuming Langevin's theory of magnetism does exist; the coefficient of Ω was found, however, to be only about half of that expected from equation (57), that is the intensity of magnetization per unit of angular velocity was found to be about half that to be expected if the magnetism is due only to rotating electrons. Whether this difference is due to unavoidable experimental errors, or to an actual motion of positive ions cannot be decided with any degree of certainty. Qualitatively, however, the experiment may be regarded as a signal confirmation of the electron theory of magnetism.

During the past year Einstein and de Hass([16]), who were apparently unaware of Barnett's experiments, also attacked the same problem by another method. Instead of attempting to produce magnetization by rotation, they looked for the converse effect, that is, the production of rotation by magnetization.

Consider an electron of charge ϵ and mass m rotating in an orbit of radius r with frequency ν. The magnetic moment of the circuit considered as an Amperian magnet, is

$$\mathbf{M} = \pi r^2 \epsilon \nu \tag{17}$$

On the other hand, the electron rotating around a central nucleus possesses an angular momentum of magnitude.

$$\mathsf{M} = m r^2 2\pi \nu \tag{58}$$

Hence,

$$\mathsf{M} = \frac{2m}{\epsilon} \mathbf{M} \tag{59a}$$

A similar equation holds for each of the orbits in a given mass of metal. Integrating over all these orbits, we obtain the relation

$$\Sigma \mathsf{M} = \frac{2m}{\epsilon} I \tag{59b}$$

where I is the intensity of magnetization. That is, a magnetized substance possesses a moment of rotation about the magnetic axis which is proportional to the intensity of magnetization. Consequently any change in the value of the latter must cause a proportional turning moment in the mass of metal about the magnetic axis. The manner in which Einstein and de Hass have tested out this conclusion is quite simple.

A small soft iron cylinder was suspended by a fiber along the axis of a solenoid, and alternating current (produced by a commutator) passed through the latter, thus magnetizing the cylinder in alternate directions at any desired frequency. According to the theory, this ought to produce in the iron cylinder a tendency to turn, first in one direction, and then in the other direction, but under ordinary conditions these deflections would be damped out very rapidly by the fiber used for suspension. The frequency of the alternating current was therefore varied until the natural period of oscillation of the iron cylinder about its axis coincided with that of the alternating current used to energize the solenoid. This is, of course, an application of the idea of resonance, and as a result, a regular resonance curve was obtained with the deflection at a maximum for a definite frequency of the alternating current, and the results obtained were actually found to be in splendid quantitative agreement with equation (59b).

([16])Verhand. d. deutsch. Physikal. Ges., *17*, 152 (1915).

Parson's Magneton Theory of the Structure of the Atom

In view of the difficulties inherent in the ordinary electron theory of magnetism as postulated by Langevin, it is of interest to mention rather briefly a new theory of the structure of the atom which has very recently been put forward by A. L. Parson[17], and which represents an attempt to explain not only a large number of the facts of para- and diamagnetism mentioned in the present paper, but also a number of other properties of atoms and molecules.

Parson states the problem which he has attempted to solve as follows: "A theory giving a complete account of magnetic phenomena must, in its final deductive aspect, proceed in certain logical steps. First it must provide a sub-atomic mechanism that would actually be expected to produce in a general way, the external magnetic phenomena that are observed for gross matter. Secondly, it must include a fairly detailed view of the structures of the different atoms, so as to explain their different magnetic properties. And lastly, the combining properties which it gives to the atoms must be such that the explanation can be extended to the magnetic properties of all kinds of molecules and solid aggregates of atoms and molecules.

"Hitherto no theory of magnetism has attempted to go further than the first step, even that has been incomplete. The present theory, on the one hand, is of so definite and far-reaching a character that it is able, in a certain sense, to cover the whole ground. It is true that very little is known as yet about the magnetic properties of the atoms themselves, but what is known is explained by it. Again, while the theory gives a good account of the magnetic changes that may be expected to accompany chemical changes, it has up to the present yielded very little in explanation of ferromagnetism. This phenomenon, after all, is generally recognized to be due to a fortuitous alignment, which can occur only in favorable circumstances, of the magnetic effects of separate atoms or molecules, and the problems connected with it, when regarded from the present fundamental point of view, are of a higher order of difficulty altogether than the problems of paramagnetism; the two stand in much the same mutual relation as the problem of the structure of a solid bears to that of a simple molecule. This has been emphasized by Curie and Weiss."[18]

The fundamental assumption of Parson's theory is that "the *electron is itself magnetic*, having in addition to its negative charge the properties of a current circuit whose radius (finally estimated to be 1.5×10^{-9} cm.) is less than that of the atom (about one-tenth), but of the same order of magnitude. * * * * It may be pictured by supposing that the unit negative charge is distributed continuously around *a ring which rotates on its axis with a peripheral velocity of the order of that light*. * * * * * * * This rotation of a ring-shaped negative charge is intended to replace the usual conception of rotating rings of electrons in providing that orbital motion of electricity which is required by all theories of the magnetic and optical properties of atoms."

This rotating ring of negative electricity is designated by Parson as the *magneton*. The magneton thus possesses both a negative charge and mass (of the same value as the classical electron) and in addition, a permanent magnetic moment. The value of the latter can readily be calculated from the above assumptions.

$$\mathbf{M} = Ai = \frac{\pi r^2 \times \epsilon c.}{2\pi r}$$

where c = velocity of light = 3×10^{10} cm. sec.$^{-1}$
r = radius of ring = 1.5×10^{-9} cm.

Hence,

$$\mathbf{M} = 3.5\times10^{-19} \text{ e.m.u.}$$

It will be observed that this is much larger than that of the iron atom (2.3×10^{-20} according to Table XXIII), and about two hundred times as great as that of Weiss's magneton. But as Parson shows the magnetic moment per atom of any element can never even approach this value owing to interactions between the different magnetons constituting each atom.

These magnetons are distributed in a uniformly charged positive sphere of electricity and according to their number and arrangement in this sphere they give rise to atoms possessing the different chemical and physical properties by which we ordinarily differentiate them as elements. Thus the *magneton number* is the most significant property of any atom. It will be remembered that according to Rutherford and Bohr the properties of the atoms depend almost entirely upon the *atomic number* or charge on the nucleus. Parson would transfer this importance to the magneton number. For

(17) A Magneton Theory of the Structure of the Atom. Smithsonian Institute Publication No. 2371, Nov. 29, 1915.
(18) Pp. 62-3, loc. cit.

elements of low atomic weight, the magneton number is much higher than the atomic number, and it is only in the case of elements of higher atomic weight (above *Fe*, *Co* and *Ni*) that the two numbers become practically equal.

Now let us consider how the different arrangements of magnetons can give rise to diamagnetic or paramagnetic properties.

The hydrogen atom is assumed to have the simplest possible constitution, that of a single magneton in a positive sphere. Diagrammatically the atom may be represented as in Fig. 23 (a). The H_2 molecule must then be represented either as in Fig. 23 (b) or 23 (c). "These two configurations are equally satisfactory from a chemical point of view, but magnetically their properties would be very different. The magnetons are pulled away from the centers of their positive spheres (owing to magnetic attraction), and the fact that the H_2 molecule does not combine with more H atoms is accounted for by the obstructing action of the positive spheres, which prevent other magnetons from coming as close to these two magnetons as they are to one another."(19)

The helium atom is assumed to contain eight magnetons distributed at the points of a cube in such a manner that they form closed magnetic circuits. Thus the top four would be arranged as in Fig. 23 (d) while the lower four magnetons would have the directions of their currents reversed. Such an arrangement would be free from magnetic moment and therefore its presence in the atom would make for diamagnetism.

In fact in all cases where we have diamagnetic atoms, we must assume that the magnetons are arranged symmetrically in space in such a manner that they form a closed magnetic circuit. The reasons for assigning eight magnetons arranged as above, to the helium atom seem to be firstly, to account for its chemical inertness and secondly, for its exceedingly high diamagnetic susceptibility, although four or six magnetons could be arranged in a similar manner to produce the same result.

In the case of other atoms, Parson assumes that a certain number of magnetons corresponding to the valency of the element is distributed symmetrically near the surface of the positive sphere, while the rest form a closed system of eight, or multiples of eight magnetons similar to that present in the helium atom. Thus the atom of nitrogen has thirteen magnetons with five of these distributed near the surface (to account for the maximum valency of nitrogen in such compounds as N_2O_5), and similar considerations hold for the other elements.

When we pass from the consideration of the chemical properties to the magnetic

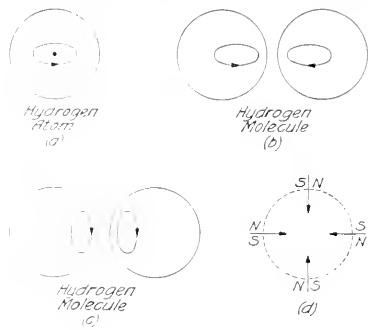


Fig. 23

properties, the explanation of the different effects exhibited by various elements as given by Parson is as follows:

"The presence of free magnetons (that is those not bound together in the cubical arrangement described above) would make for paramagnetism; but would not necessarily succeed in producing it in all cases, for even 'free' magnetons may form fairly stable groupings of intrinsic magnetic moment, such as

$$\frac{N\ S}{S\ N} \text{ for two, } \frac{S}{N}{}^{N}\!/\!{}_{S}^{\ }\ {}_{S}\!\backslash{}^{S}_{N}$$

for three, and so on. It must always be borne in mind that the observed magnetic effect is the difference between the separate paramagnetic and diamagnetic effects, as Langevin points out; and unless it is large in proportion to the number of magnetons in the atom, it gives very little clue to the absolute value of either of them. (This explains those cases where diamagnetism seems to be dependent on temperature.)"(20)

There is an additional cause of difficulty in drawing any conclusion as to the probable para- or diamagnetism of an element from its magneton number. Thus the free magnetons may interfere with one another's orientation, both in the same atom and neighboring atoms. For we must always remember that

(19) P. 16.
(20) P. 65

the magnetons not only exert magnetic effects upon each other, but also electrostatic effects.

Parson finds it much easier to deduce the magnetic properties of compounds. For instance, the ordinary salts of *Fe*, *Ni* and *Co* which are assumed to contain free magnetons are strongly paramagnetic, "While the complex salts of *Fe* and the cobaltamines, in which presumably, these free magnetons are bound, are very slightly paramagnetic, or more often, diamagnetic."

In the limits of a review such as the present, it is extremely difficult to give a clear abstract of Parson's theory. But perhaps, the above remarks may serve to give some conception of the main assumptions of the theory and its bearing on the explanation of magnetic phenomena. There is no doubt that the theory can be critisized for some of its assumptions, such as that of eight magnetons in a helium atom, whereas we know that the alpha particle possesses only two positive changes; but nevertheless the theory is suggestive and has just that element of plausibility to make it interesting.

It would take us much beyond the scope of this paper to compare at length the magneton theory of the atom with the now classical theories of J. J. Thomson, Rutherford and Bohr. Such a comparison may, however, lead to more definite ideas as to the essential reasons upon which each theory is based and the points wherein they can be made to agree. In such a case it may be possible to pick out from each theory certain elements, and by combining them all, develop a conception of atomic structure that will be in more satisfactory agreement with all the facts that we know.

MAGNETOSTRICTIVE EFFECTS

As has been stated above, the theories of magnetism so far proposed have been of great value in correlating a large number of magnetic phenomena, but a glance at the classification given in Table II of Part I is sufficient to show that a large number of phenomena are not even considered by any of these theories, let alone explained in a satisfactory manner. Yet these phenomena are really remarkable in themselves and it may be that a more comprehensive theory of the ultimate nature of magnetism will be attained by means of observations in these fields than in those already discussed in the present paper. In the following sections we shall attempt to outline briefly some of the outstanding facts which are comprised under the headings of "magnetostrictive effects."

We may define the magnetostrictive effects as "those in which we find reciprocal relations between the magnetic properties and the changes of dimensions. Thus, if a piece of ferromagnetic substance is magnetized, it will change its dimensions and contrariwise a mechanical change in the dimensions of the same specimen produces changes in the magnetic qualities of the substance."(21)

In 1842, Joule discovered that an iron rod changed its length when subjected to a magnetic field whose direction was parallel to the axis of the rod. This variation in length with change in magnetic field strength was found to be an increment up to a certain value of the magnetic field beyond which the rod appeared to contract. Later investigators (notably Bidwell) showed that if sufficiently strong magnetic fields were used, the bar actually became shorter than when in its unmagnetized state.(22)

This phenomenon has therefore been designated as the Joule effect. Fig. 24 illustrates typical results obtained by H. G. Dorsey(23) in the case of a number of iron-carbon alloys. *PI* was an alloy containing only 0.058 per cent carbon, while the alloys *A*1, *A*2, *A*3 and *A*4 contained gradually increasing amounts of carbon (from 0.68 to 0.98 per cent). In the case of nickel and cobalt, magnetization is usually accompanied by contraction, even in strong magnetic fields, as shown in Fig. 25.(24)

Joule and others have also carried out interesting experiments upon the changes in length due to magnetization when wires or rods are subjected to tension. Increased tension appears to have the effect of diminishing the maximum elongation and hastening the contraction. The state of hardness of the metal has a profound influence on the relation between change in length and magnetic field strength. S. R. Williams who has done a great deal of work in this field has observed that the maximum elongation occurs at about the same field strength as that at which the third stage, as Ewing calls it,(25) occurs in the induction curve, and also the most rapid rate at which the elongation occurs, appears at the same field strength as that of the most rapid change in the induc-

(21) S. R. Williams, School Science and Mathematics, *5*, 474 (1915).
(22) S. R. Williams, Phys. Rev. *32*, 281 (1911).
(23) Phys. Rev. *30*, 698 (1910).
(24) Chas. W. Burrows, Correlation of the Magnetic and Mechanical Properties of Steel; Bull. Bur. Standards *13*, 174 (1916).
(25) See Part II, GENERAL ELECTRIC REVIEW, Aug., 1916, p. 668

tion."(26) These observations are illustrated in Fig. 26.

We also owe to Joule the discovery that a transverse magnetic field produces changes in dimension. In order to get a transverse field imposed upon an elongated specimen of iron, Joule sent an electric current through an insulated wire inside an iron pipe. The circular magnetic field about the wire in the pipe produced a field normal to the length of the pipe whose change in longitudinal dimension was to be measured. From the experiments of Williams(27) it may be concluded that in general the transverse effect is the reverse of the longitudinal effect, that is, contraction in a longitudinal field is usually accompanied in the same specimen by elongation in a transverse field. An exact quantitative reversal is, however, not obtained.

The volume changes accompanying magnetization have been investigated by Knott, Nagaoka and Honda, and others.(28) But the results obtained vary greatly with the state of the metal and its previous history.

Some years before Joule's discovery, Wiedemann found that if a vertical wire is magnetized longitudinally and a current is then passed through the wire, the lower end of the wire, if free, twists in a certain direction, depending upon circumstances. Maxwell has explained the phenomenon as a special case of the Joule effect, but some comparative experiments by S. R. Williams on the Joule and Wiedemann effects in the same specimens of steel tubes lead him to the conclusion that there is apparently no simple relation between the two effects.(29)

It has been pointed out by J. J. Thomson(30) that on dynamical principles there must be a reciprocal relation between the changes of dimension produced by magnetization and the changes of magnetization attending mechanical strain. The following comparison shows the complete reciprocity of the observed effects.

Iron

Magnetization produces increase of length in weak fields, decrease in strong fields. (Joule effect).

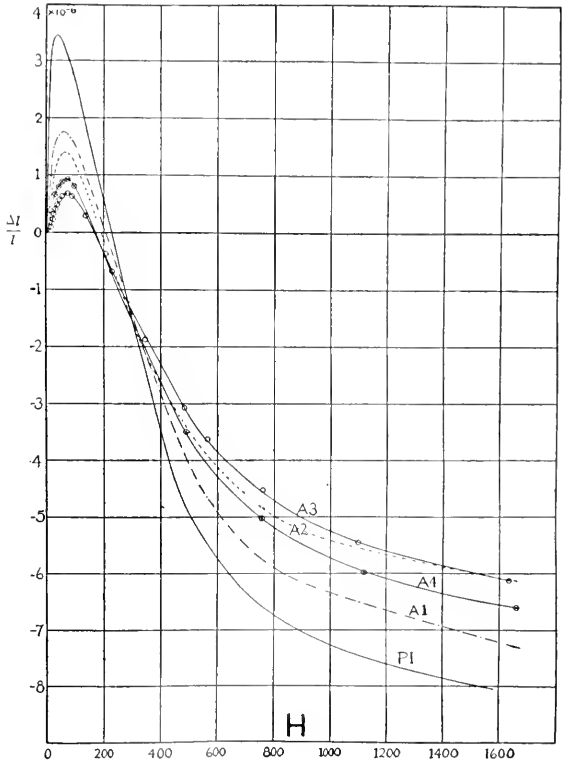


Fig. 24

Tension produces decrease of magnetization in weak fields, increase in strong fields.

(26) School Science and Mathematics, *5*, 474 (1915); also Phys. Rev. *34*, 258 (1912). (27) Phys. Rev. *4*, 498 (1914).

(28) Reference to literature on this point as well as the other magnetostrictive phenomena will be found in the article on Magnetism, Encycl. Britan., 11th Ed., Vol. *17*, p. 338; also in the papers by S. R. Williams, H. G. Dorsey and Chas. W. Burrows, to which reference has already been made above. An excellent summary of observations dealing with magnetostrictive effects is also to be found in L. Greatz's Handbuch der Elektrizitaet und des Magnetisms, Vol. 1, pp. 270-288.

(29) (Phys Rev. *32*, 281, (1911).

(30) Applications of Dynamics to Physics and Chemistry, p. 47; quoted in Encycl. Brit., Vol. *17*, p. 341, article "Magnetism."

Cast Cobalt

Magnetization produces decrease of length in weak fields, increase in strong fields.

Tension produces decrease of magnetization in weak fields, increase in strong fields.

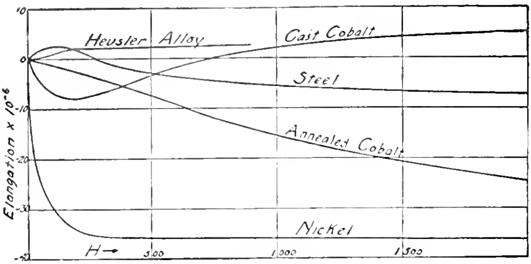


Fig. 25

Nickel and Annealed Cobalt

Magnetization produces decrease of length in all fields. Tension produces decrease of magnetization in all fields.

The last statement is well illustrated by Fig. 27([31]) which shows the effect of tension and compression upon the magnetization curve of nickel.

The so-called Villari effect is really a case of the reciprocal Joule effect. It was discovered by Villari in 1868 that the susceptibility of an iron wire was increased by stretching when the magnetization was below a certain value, but diminished when that value was exceeded. This phenomenon has been termed by Lord Kelvin, the "Villari reversal," and the value of the intensity of magnetization at which tension produces no effect on the susceptibility is known as the "Villari critical point." A number of illustrations of this effect will be found in Ewing's book on Magnetic Induction.

The Wiedeman effect also has its reciprocal on the observation that when a rod of soft iron, exposed to longitudinal magnetizing force is twisted, its magnetism is reduced by torsion to either direction.

In all these magneto-strictive phenomena, the changes of magnetism consequent upon alternating changes of dimensions or vice versa are found to exhibit hysteresis, thus indicating that certain re-arrangements of the ultimate magnetic units must accompany all these effects and that these operations take time to occur. As has been pointed out by S. R. Williams, the most striking study of the relations between magnetization and mechanical stress is that any theory of ferro-magnetism to be comprehensive "must harmonize a mechanical effect with a straight induction effect." In this connection it is of interest to observe also the statement made by Burrows that "the experimental evidence seems to point to the conclusion that there is one and only one set of mechanical characteristics corresponding to a given set of magnetic characteristics, and conversely there is one and only one set of magnetic characteristics corresponding to a given set of mechanical characteristics." This would indicate again that any theory of ferromagnetism which would be satisfactory must co-ordinate mechanical effects with a straight induction effect.

CONCLUSION

When we consider the mass of observations recorded in the above chapters and compare them with the theories postulated in explanation of them, we must confess to a feeling of extreme dissatisfaction with our present

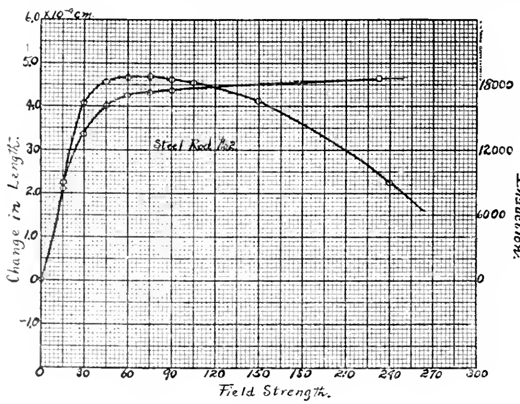


Fig. 26

([31]) Chas. W. Burrows, loc. cit.

views on the subject of magnetism. Here we have a field of physics at which investigators have toiled for almost a century, and what are the results? An enormous number of disconnected facts; a few scattered theories which attempt to correlate a comparatively few observations, and a feeling of helplessness when one attempts to grasp a larger group of these facts from any single point of view.

There is no one who feels more than does the writer himself, how inadequate is the treatment of the subject of magnetism which has been given in the present series of articles. A great many points have been omitted or passed over very superficially which to some readers, might have appeared worth while discussing at greater length. The only reason for such omissions is that if the writer had attempted to make the series of articles as comprehensive as he would have liked them to be, they would never have been finished.

Should, however, any reader feel, after patiently floundering through the mazes of Curie's law; Langevin's theory of para-

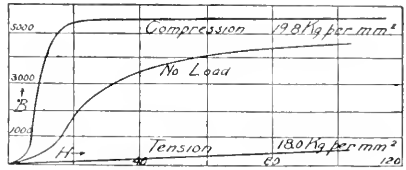


Fig. 27

magnetism, and Parson's magneton theory of atomic structure, that his interest in the subject of magnetism has been stimulated, then the writer will feel that his efforts have borne ample fruit.

PRACTICAL EXPERIENCE IN THE OPERATION OF ELECTRICAL MACHINERY

PART XX (Nos. 79 TO 81)

By E. C. Parham

Construction Department, General Electric Company

(79) FREQUENT MOTOR STARTING

Some of the elaborations occasionally given in an effort to define troubles with electrical appliances are more of a hindrance than a help.

In one instance, the statement was made concerning an induction motor which was giving heating trouble that "the longer the motor runs the cooler it gets." On viewing this rather startling statement, it is not very evident how the temperature of an operating motor could ever get below that of the surrounding air. In justice to the author of the statement, however, it must be said that the statement was true to a certain extent because the motor did cool considerably after it had survived the starting conditions to which it was subjected. The motor was belted to a blower that supplied air to the cupola of a foundry. The damper of a blower should be closed when the motor is being started, in order to prevent a load developing during this period. Not until the motor has attained full speed is the damper to be opened the desired amount. Instead of this procedure, the motor was being started with the damper fully opened. As a result, the speed would not reach a reasonable value on the starting side of the compensator, and on throwing the compensator to the running side the motor fuses would blow. After several renewals of fuses the motor could be made to reach full speed. In the meanwhile the motor of course was heating excessively from the repeated attempts to start it. After the speed had attained maximum value, the abusive conditions no longer existed and the motor would cool to the temperature corresponding to the steady load that it was carrying. With the adoption of the no-load method of starting, all trouble ceased.

(80) WATTMETER CONNECTION

In measuring the power absorbed by an alternating-current circuit, the product of the indications of a voltmeter and an ammeter will not give the correct rate of power absorption unless the voltage and the current are exactly in phase. These instruments indicate effective voltage and effective current, respectively, without regard to their phase-relations. Therefore, although the phase relation of the voltage and current may be such that one is near zero at the same instant that the other is near maximum, the product of the voltmeter and ammeter readings will be the same as if maximum voltage and maximum current occurred at the same instant. The reading of a wattmeter, however, depends upon the interrelation of the instantaneous values of the voltage and current; that is, upon the product of the current value and voltage value that exist at the same instant, and for all instants within the time duration of the measurement. A wattmeter, then, will indicate the true rate of power absorption at the time of reading the instrument, if it is itself correct and its connections to the circuit are made properly.

An operator stated that although he knew his generator (quarter-phase) was supplying enough lamps to at least half load it, two wattmeters which he had recently installed indicated no appreciable absorption of power. Investigation showed that the alternator terminals were connected to the external circuit in the proper sequence, but that the wattmeter connections were such that the potential coil of the meter (whose current coil was connected in series with No. 1 phase) was connected across No. 2 phase, and that the potential coil of the meter (whose current coil was connected in series with the No. 2 phase) was connected across the No. 1 phase. The result of this confusion of connections was that the currents in the two coils of each meter were displaced exactly 90 degrees from each other. Under this condition, the relation of the current reversals in the two coils of a wattmeter are such that the moving element tries to move first in one direction and then in the other; these tendencies in opposite directions alternate so rapidly that the moving element will not move.

When adjusting commercial wattmeters, it is essential that they be adjusted so as not to indicate absorption of power unless power actually is being absorbed. In other words, even with voltage applied to the potential coil and a 90-degree phase relation current flowing through the current coil, the meter indication should be zero. In order to obtain test voltages and currents that are exactly 90 degrees apart in phase, it is customary to connect the current coil of the meter in series with one phase of a quarter-phase generator and the potential coil across the other phase of the same machine.

(81) MOTOR WAS TOO COLD

The speed value marked on the name plate of continuous-current motors generally refers to the speed (full load) at which the motor runs after the field has attained the normal temperature corresponding to a continuous application of normal voltage; in other words, the speed at which the armature will turn when the fields are as hot as they will ever be except under abnormal voltage conditions. Heating the field winding of course increases its resistance; this resistance increase causes a decrease in the field current, thereby weakening the field, lowering the counter e.m.f. of the armature, increasing the armature current, and raising the armature speed. For most applications it is not necessary that a motor turn at exactly its rated speed; in fact, it is not usual to find a motor operating at such speed because it is rare that a motor operates at exactly full load. When a motor does not operate at the speed desired, the necessary change can generally be obtained by shifting the brushes; commutation, however, places a limit on the extent to which this may be carried out Where special conditions are to be met, they should be described when ordering the motor so that a machine can be selected to suit them. It is a common occurrence for the local surroundings of a motor to be such that the motor operates at a temperature that gives a field resistance, hence speed, which exceeds that desired. It is seldom, however, that local temperature conditions are such that the field does not heat enough to give the required speed.

A 1000-r.p.m. continuous-current motor proved to be unsatisfactory because its speed could not be raised above 925 r.p.m. It was necessary that the speed be 1000 r.p.m. An inspector was called to investigate, and he ascertained that in a former application of the motor its speed had been 1000 or more and that it was on this account that the motor had been transferred to duty in a cold-storage room where the temperature was maintained at the freezing point or below. At this temperature the field resistance was so low, the field current so high, and therefore the field strength so great, that the counter e.m.f. held the armature current down to a value that was insufficient to give the speed required.

As the low speed was due to insufficient field resistance, under the unusual conditions, the logical remedy was to increase that resistance. This was done by connecting part of an old generator field rheostat in series with the fields. Approximately the desired speed was thus obtained. The further refinement of shifting the motor brushes backward a bar was also made use of.

SINGLE-PHASE POWER PRODUCTION

By E. F. W. Alexanderson

Consulting Engineer, General Electric Company

G. H. Hill

Assistant Engineer, Railway and Traction Department, General Electric Company

The authors show that there is a general tendency toward the centralization of power stations and that it is highly desirable that the essential features of power stations be standardized. It is pointed out that the production of single-phase power should not interfere with this general scheme, and means are suggested for producing single-phase power without limiting the usefulness of the station. Both the mode of operation and the theory of phase converters are discussed with reference to their adaptability for producing single-phase power from polyphase circuits. This paper was presented before the A. I. E. E. at Philadelphia, on October 13th, 1916.—Editor.

In view of the universal use by power companies of polyphase generation and transmission of electric power for general purposes, the production and delivery of single-phase power must be considered as a special problem.

No power company would or could afford to install a single-phase plant unless its sole purpose was to furnish power to a load that requires single-phase. In other words, it is settled that polyphase generation and transmission is most efficient, flexible, and economical, and the problem presented to power companies when the demand for single-phase power appears is how this may best be produced or derived from their polyphase system.

Indeed it may be well to extend the problem to cover those cases where such large amounts of single-phase power are required as to apparently justify a special power house and to generate and transmit by polyphase and derive the single-phase when and where needed.

Probably the strongest argument for such a view is the practical wisdom in standardizing the electric systems of the country so that they may be tied together as occasion and opportunity permit, with a minimum of elaborate and power consuming transforming apparatus. This idea of consolidation and co-operation has recently been given serious attention by many of our ablest men who appreciate the great value of diversified loads and the greater economic efficiency to be obtained by covering the greatest field possible from a common source of electric power supply.

The rapid growth of electric power systems makes this a most practical consideration. There are enough differences between electric transmission systems as they now exist without introducing still further complications.

Differences in voltage can not be avoided, but to equalize this does not entail great loss of efficiency or undesirable features.

Differences in frequency are more serious and the decision as to the most desirable frequency for general use has resulted in adopting a variety of frequencies in different localities. As we now look upon 60 cycles as standard, the use of 50–40–30–25 and possibly other frequencies can not but be regarded as unfortunate since practical considerations will sooner or later force the systems having odd frequencies to seek means to free themselves from the handicap they entail. There are many excellent systems and stations using 25-cycle power and the reasons for adopting 25 cycles were good and sufficient when they were established. Without, therefore, criticising the engineering of these plants it may be stated that they could be duplicated today with 60-cycle apparatus for less than the orginal cost and with a distinct gain in general economic usefulness and value.

It seems a logical and highly practical conclusion that general policy should be opposed to the establishment to any considerable extent of power systems having peculiar or special features making them inefficient in connection with other systems in the vicinity.

Single-phase power may be obtained by—

1. Separate generating and distribution systems for single-phase and polyphase load.
2. Polyphase generation and distribution of single-phase load between the phases so that in effect the load becomes a polyphase load.
3. Polyphase generation and transmission with motor-generator sets at substations.
4. Mixed single-phase and polyphase load furnished by the same distribution system in combination with methods for correcting the unbalancing effect of the single-phase load.

The first method comes under the head of special and abnormal development, already discussed. It has, besides the disadvantages mentioned, the further disadvantage, as regards the generator, of increased size, weight and lower efficiency as compared with polyphase generators. Single phase generators have been built only for 25 cycles or lower and to a limited extent for special purposes. As compared with other ways of obtaining single-phase power this method seems to offer the least promise of general usefulness.

The second method has the advantage of the polyphase alternator. It is generally used for incandescent lighting distribution and for power and heating where the unit of energy capacity is small and adapted to division between the phases so as to result in very little, if any, unbalancing. It has been proposed and used to a limited extent for heavy single-phase loads, but the difficulty of preserving even an approximate balance between phases makes this method insufficient for large power requirements. It has the further disadvantage of requiring generators of the same frequency as that which the load demands.

The third method has the advantage of entire freedom as to generator and transmission and permits a single-phase load of any frequency or power-factor to be drawn from any standard polyphase system without disturbing the balance or regulation. It provides means, moreover, of improving the power-factor of the system by synchronous motors and from the power system standpoint is the most desirable of all methods when large unit amounts of single-phase power are demanded. It is the only method of producing low-frequency single-phase power from a 60-cycle system. The only objection that is made to this method is the cost of motor-generator sets and the cost of attendance.

The first cost of equipment, it is true, is greater than static transformers alone, but this is balanced to some degree by lower costs at the power station and in the transmission line, and is fully justified in a large power system since it makes it possible to combine the single-phase load with the general load and obtain the benefit of a higher load factor.

The cost of attendance is frequently made negligible by so locating the substations that the attendant may have other duties. The expense of attendance in any case is a small percentage of operating costs and can be entirely eliminated by introducing automatic devices to start and switch the motor and generator, such as are coming into successful use for direct-current rotary converters, waterwheel generators and other rotating apparatus.

This disadvantage, moreover, largely disappears when, as usually happens, a system of single-phase generation is connected to other systems through motor-generator sets for interchange of power.

No. 4 is in general respects the same as No. 2 with the addition of a relatively new development known as the "phase converter" which preserves the balance of the system even when large blocks of single-phase power are taken from the system. Its use greatly extends the possibility of connecting single-phase loads directly to a polyphase system provided the frequency does not have to be changed.

The use of phase converters is relatively recent and perhaps not very well understood. This makes it of interest to discuss the method of balancing and the apparatus employed more in detail.

THEORY OF PHASE CONVERSION

The earliest known form of phase conversion is splitting the phase by induction and capacity. In this case the energy of one phase is stored for a fraction of a cycle and released again so as to make the same energy active in another phase. All methods of phase conversion, therefore, involve the storage of energy. Even the phase conversion of wattless currents necessarily involves storage of energy. The expression "wattless energy" is not such a contradiction as it has sometimes been claimed to be. When energy is wattless it means that the energy delivered during one portion of a half cycle is returned during the other portion of the same half cycle; therefore the average energy flow is zero. But at the same time we must not forget that even if a current is completely wattless there is a real energy flow in both directions. Thus if we wish to change the phase of the current, whether energy current or wattless current, we must provide means for storing the momentary energy flow for a time corresponding to the change of phase that is to be effected.

The method of storing energy in inductances and condensers is very convenient for high-frequency currents but has not up to the present found much practical application for low-frequency power current. There is, therefore, for phase conversion on a large scale, only one type of apparatus that can be considered, namely, a rotating machine which stores the energy in the mechanical inertia of the rotor.

In order to arrive at an understanding of the physical functions of phase conversion with a rotating machine, several different points of view are possible, as sometimes one and sometimes another is more helpful in arriving at direct conclusions. The following three methods of looking at the problem may be helpful.

(1) Phase Converter Considered as a Motor-Generator

The phase converter is built as a quarter phase induction motor or synchronous motor with a squirrel-cage; one phase is a motor phase and the other phase is a generator phase. The input of the motor phase is equal to the output from the generator phase, not only in the average value of the power flow but in the instantaneous value of energy flow which is delivered and returned during the same half cycle. The only difference between the energy flow in the two phase windings of the converter is that the momentary values of current, volts and energy are delayed ¼ cycle in one winding in relation to the other. The squirrel-cage is the medium for the transfer of energy, and the mechanical mass of the rotor provides the energy storage. In order to make it possible to store the energy in the rotor, there must be corresponding changes of speed and therefore the rotor must go through a cycle of speed change during each half cycle of the alternating-current flow. This speed change of the rotor is evidenced by the vibration which is a characteristic of any single-phase machine. The speed change of the rotor has, however, nothing to do with the electrical functions of the machine in performing as a phase converter. If we could couple the rotor to a flywheel of infinite weight so that the speed change would be zero, the converter would perform in the same way.

Having thus explained how it is conceivable that the phase converter operates as a motor-generator, it remains to explain what means are provided for making it perform in this way; in other words, what causes the energy flow in the two phases to vary the same cycle of momentary values although delayed ¼ cycle in time. Various means can be provided for producing the desired energy flow and will lead to different types of phase converters. Broadly, it can be stated that whatever means are provided, the result of these means must be the desired flow of currents through the windings, and therefore the means must consist in providing the necessary electromotive forces to cause these currents to flow through the windings.

One method of providing these electromotive forces is to use an auxiliary generator which impresses the desired electromotive force on the windings. Instead of a generator any other convenient source of electromotive force may be used such as a transformer or an induction regulator. Another method is to connect the windings of the converter with reference to the source of power and the load in such a way that the electromotive forces are furnished automatically by the source of power.

The first method leads to the phase converter connected in shunt to the line and is the type that has been adopted in the phase balancer stations of the Philadelphia Electric Company; and for the sake of brevity this type may be referred to as the shunt converter. The function of the shunt converter is to transfer energy from one phase to another in a polyphase system so as to neutralize the effect of single-phase load drawn from the same system in another place. The second method of producing the desired flow of current in the system leads to the series converter. In this type of converter the single-phase circuit is in series with one phase of the converter. The series converter, as applied for changing from single-phase power to polyphase power, is described in a paper by one of the authors in 1911. This same arrangement is well adapted for change of polyphase to single-phase power and this method is in some cases preferable to the shunt converter. The function of the series converter is not to correct for a single-phase load that has been placed on a polyphase line but to change the single-phase load into a polyphase load before it is connected to the line.

(2) The Phase Converter Considered as a Polyphase Generator

This second point of view is more artificial than the first, but is more helpful in analyzing the function of the phase converter. For the purpose of such analysis a well-known mathematical artifice is made use of. A single-phase current can be considered as resolved into two polyphase components with opposite phase rotation. One of these polyphase components has the same phase rotation as the power system and constitutes a legitimate load on the power system. The other component, which has the opposite phase rotation, is the one that causes the unbalancing of voltage, heating of generators and motors connected to the system, etc. The function of the phase converter is to neutralize this component of the single-phase load which has opposite phase rotation. From these considerations it becomes evident how the phase balancing can be accomplished. This function consists in providing a machine which feeds into the system a polyphase current which has opposite phase rotation to the system, and is equal and opposite to the component of the single-phase load we wish to neutralize. It is now evident how the phase balancer ought to be constructed. The converter should be a polyphase machine, not necessarily synchronous but preferably so in order not to draw lagging current from the system, and means are to be provided for forcing a current to flow through the windings of the phase machine which has opposite phase rotation to the system. The currents of opposite phase rotation are to be regulated in magnitude and phase corresponding to the single-phase load. One convenient way of producing such adjustable polyphase currents is to provide a polyphase generator with its field controlled by suitable regulators. These considerations lead to the design of the shunt converter with direct connected balancer and regulators, such as used by the Philadelphia Electric Company. The construction of these phase balancers is illustrated on page 1048. The sets consist of a main converter and an auxiliary balancing machine which is controlled by automatic regulators. The main converter is mechanically connected to a generator which is called a balancer. The function of this balancer is to circulate polyphase currents of the desired phase and magnitude in the windings of the converter. This auxiliary generator is small compared to the converter because its output is used only to overcome the losses and inductive drop in the windings of the main converter.

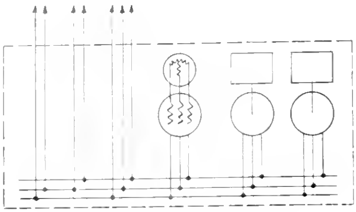
(8) The Phase Converter Considered as a Transformer

This point of view is also more artificial than the first one, but it is helpful in understanding and analyzing the functions of the series converter. The two stator windings of the phase converter are considered as the primary and secondary of a transformer. The squirrel-cage rotor is a medium for transferring the current from the primary to the secondary and the characteristics of the phase converter as a transformer differs from the ordinary transformer only by the fact that the time phase of the secondary is ¼ cycle from the time phase of the primary. This displacement of time phase is due to the time required for the squirrel-cage to rotate through the angle corresponding to the location of the primary and secondary windings of the stator. The function of the series converter is easiest explained in connection with a quarter-phase system, but it is obvious that it can be used in a three-phase system by the use of a Scott transformer connection. The object in the use of the converter is to distribute the single-phase load equally in the two phases of the quarter-phase system. If the problem were to distribute the single-phase load in two circuits of a single-phase system, it is easy to see how this could be done by the use of a series transformer. The single-phase load might be put directly in series with one circuit through the intermediate of a series transformer. If this transformer has a ratio of 1:1, the current would be equally distributed on the two circuits at all loads. The two phases of the quarter-phase system differ from the two circuits of the single-phase system for our present purpose only by the relative time phase. However, if the phase converter may be used as a transformer which changes the time phase of the current between its primary and its secondary to the desired degree, it can be used as a series transformer between the single-phase load circuit and one of the phases of the quarter-phase system in the same way and with the same characteristics as stated above with reference to the ordinary series transformer used to distribute the load on two circuits of the single-phase system. Carrying the analogy between the phase converter and the transformer still further, we can trace the source of the electromotive force required to force equal and opposite currents to flow in the primary and secondary windings. This electromotive force is derived directly from the primary circuit. To cause a current to flow through a winding there is required a voltage and this voltage is evidenced by the impedance drop in the winding. From the theory of transformation we have become in the habit of regarding the impedance of the primary and secondary windings of a transformer as a single impedance, which for the sake of convenience can be said to be located in either the secondary or primary windings. In either case we assume that a certain amount of the primary voltage is used up to overcome the impedance drop of the transformer windings. This impedance drop is evidenced by the voltage drop on the terminals of the secondary winding. The same considerations apply to the use of the converter as a series transformer. The ratio of current transformation is for all practical purposes constant at all loads at which the transformer can be used. The voltage drop on the secondary side is the sum of the impedance drop in the primary and secondary winding. In the case of the phase converter, the impedance drop includes the drop in the squirrel-cage, which is the transfer medium. However, we are also in the habit of measuring the impedance of the induction motor windings on the primary side and look upon the impedance in the stator and the rotor as concentrated in the stator winding. We therefore find that the impedance of a converter when considered as a transformer is the same as the stationary impedance of the same machine measured as an induction motor at standstill. From this analogue, we have a right to expect the following characteristics of the series converter and these conclusions are in entire agreement with practical measurements. The change of a single-phase load into polyphase load is automatic and results in a *perfect distribution of current in the two phases at all loads* The voltage delivered to the single-phase circuit has a slight drop with increasing load and has characteristics with reference to current and power-factor as would be obtained by placing an impedance in series with the single-phase circuit equal to the impedance of the windings of the converter.

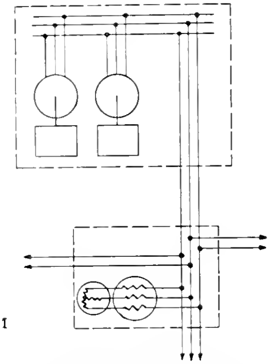
Applications of Phase Converter

In regard to efficiency and size, the phase converter can be considered as being in the same class as the synchronous condenser. In fact it has substantially the same structure, the difference being that the squirrel-cage which is usually employed in the synchronous condensers to counteract hunting becomes in the phase converter the main rotor winding, while the field winding of the synchronous condenser is reduced to a small winding sufficient to carry the no-load excitation. Due to the similarity in structure the same machine can act as a synchronous condenser and phase converter at the same time if the windings are proportioned for this purpose. The fact that the machines can be designed so that they are useful as synchronous condensers and phase converters simultaneously is worth consideration in the application of the methods of phase conversion, as several methods of application are possible. In the first place, it is possible to place the phase converters either in the power house or at any desired place of the distribution system. Synchronous condensers may be needed on distribution systems for the sake of counteracting low power-factor, and such synchronous condensers can if desired be designed so that they can in addition be used as phase balancers in order to make it possible to draw single-phase load from the same system. If, on the other hand, the main load is synchronous converters with unity or leading power-factor it may be more practical to locate the phase balancers in the power stations. The single-phase load is usually of low power factor and the lagging current of the single-phase system may be furnished either to the single-phase distribution system by single-phase synchronous condensers or may be furnished in the power house by polyphase machinery after the whole kv-a. of the single-phase load has been converted to polyphase. In the latter case, the phase converter can be used for power-factor correction as well as phase conversion, but it must then be large enough to convert the whole single-phase kv-a. at a low power-factor and furnish polyphase current to correct for this power-factor; whereas in the other case where the single-phase power-factor is corrected for by synchronous condensers the phase converter needs to convert only the power component of the single-phase load. The choice between these methods of conversion will depend upon local conditions of expediency.

The shunt converter is of particular value in those cases where it is expected that single-phase load may be drawn from different phases of a polyphase system. In such cases unbalancing of the single-phase load will be partly neutralized and it will be necessary to convert only the difference between the single-phase loads. There are, on the other hand, cases where the series phase converter can be used to best advantage. These are cases where it is desired to convert the single-phase load at the point where it is connected to the polyphase system. The series converter here has the advantage of simplicity, as the arrangement is automatic and no auxiliary generator or voltage regulator is needed. In cases where a single electric welding machine or a single arc furnace is to be fed from a polyphase system, the series

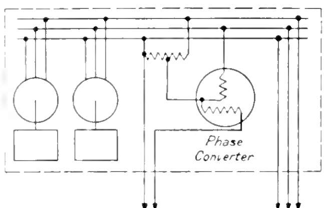


Power House with Polyphase Generators and Shunt Phase Converter

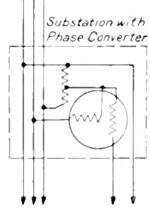


Power System with Polyphase Generator and Shunt Phase Converter in Substation

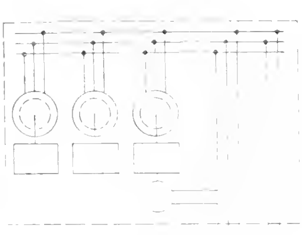
BALANCING SYSTEM A-1



Power System with Polyphase Generators and Series Phase Converters

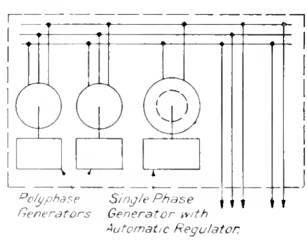


BALANCING SYSTEM A-2



Power House with Special Generators for Mixed Power and Voltage Balancer

BALANCING SYSTEM B



BALANCING SYSTEM C

converter should be recommended. If such an installation has been made with a series converter in order to insure the lowest first cost and it should be desired to add other furnaces to the other phases, the same converter might be used as a shunt converter without any increase of converter capacity but with the addition of suitable regulating devices.

It has been pointed out that a synchronous condenser has a structure suitable for phase conversion. This is also the case with an induction motor or a single-phase turbo-generator; in fact any polyphase machine with a squirrel-cage. Such machines are always connected in shunt to the line and would, therefore, be available as shunt converters whenever desired. If, for instance, a power house is built primarily for furnishing single-phase power from single-phase generators but it is desired to furnish a certain amount of polyphase power in addition, the objection arises that the polyphase voltage is unbalanced in proportion to the single-phase load. In such a case it might be expedient to use the squirrel cage of the turbo-generator as a converter medium by adding suitable regulating devices. The interchange of current between the phases is then already determined by the load conditions, but the electromotive forces necessary to cause this interchange of current appear in the unbalancing of the line voltage. This unbalancing of voltages can be treated with the same method of analysis as has been given for the unbalancing of current. The unbalancing electromotive forces are resolved into their components and the correcting electromotive force may be furnished by a generator driven either from the turbine shaft or by a synchronous motor. This generator has the same character and functions as the auxiliary balancing generator in the phase converter set. A power house for mixed single-phase and polyphase load equipped in this way can be operated in multiple with other power houses using standard polyphase generators.

The methods that may be employed in order to equip a power system so that it can take on mixed single-phase and polyphase load can be classified in the following groups:

(A) The use of standard polyphase generators and phase converters for correcting the unbalanced load. The phase converters may be placed either in the power station or substations and may be:

(1.) Shunt converters, or

(2.) Series converters.

(B) The use of special generators with squirrel-cage windings, adapted for mixed single-phase and polyphase load, and an equipment of automatic apparatus to prevent the unbalancing of voltage that the single-phase load tends to produce.

(C) The use of standard polyphase generators and special single-phase generators connected to the same busbars with automatic means for regulating the governors and fields of the single-phase generators so that they will absorb the entire unbalancing of the current.

The choice between these three methods of balancing a power system with mixed load will depend upon local conditions and expedience. All three methods have the advantage of avoiding duplication of the transformation and distribution system. The first method involving the use of the phase converter introduces the least change in standard polyphase power systems and is adapted for cases where the polyphase load is predominant. The second method is adapted for cases where the single-phase load is predominant, and has the merit of making all the generating units available for both single and polyphase power, as the system may demand. It is thus adaptable to growth and changes in the system, to preservation of good load factor and interconnection with other power systems. The third method does not offer any particular advantages over the two others but is mentioned for the sake of completeness. Its use might be considered in cases where single-phase and polyphase generators are already in use in the same power house and it is desired to use the polyphase distribution system for taking on single-phase load. The efficiency of all three methods may be said as a whole to be on a par. In specific cases some slight advantage may be figured out for each of the systems, but the determining factors will not be so much the inherent efficiency of the electrical apparatus as the difference in load factors and the influence of load factors on steam economy.

For the sake of an easy comparison of the different methods proposed, a tabulated set of diagrams is given showing the essential features of each system.

A TALK TO YOUNG ENGINEERS

By E. W. Rice, Jr.

President General Electric Company

The Schenectady Section of the A.I.E.E. held its first meeting for the season 1916–1917 on Friday evening, October 6th. On this occasion Mr. E. W. Rice, Jr., addressed the meeting, and we here reproduce the substance of his remarks. Mr. O. D. Young was also to have been present, but was unavoidably absent. Mr. Rice was followed by Dr. Whitney who was, as usual, both interesting and instructive in his remarks. We hope that many young engineers who were not present at this meeting will read Mr. Rice's remarks, as they are full of sound reasoning and should help the younger generation of engineers to understand something of the problems, technical, economic and political, that have to be faced during the career of an engineer.—Editor.

I am always gald of an opportunity to speak to engineers, and particularly to young engineers such as I see before me. I wish, first, to congratulate you upon your choice of a profession. I cannot imagine any more interesting work or any greater opportunity for valuable service to the world than that of the engineer. The one man that I truly envy is the engineer, and you engineers who have had the advantages of a modern technical education are certainly most fortunate. Those of you who have made good use of your opportunities are starting your professional career with a theoretical training which was denied to those of us who started in the electrical industry in its early days. However, you will have good use for all your training and for all the wit and wisdom with which you are endowed in your future work, as our industry is no longer small and simple, but has grown to stupendous size and of corresponding complexity. I am sure, however, that I do not alarm any of you in making this statement. I can see that you are full of courage and confidence, and that is a good omen for your own future and the future of our industry.

I wish, however, to say a word about the character of the problems which it seems to me you engineers will have to solve. Of course, much of your work and many of your problems will be similar in character to those which have been in existence since the beginning of the industry, but you will have other and more difficult problems to solve, problems which were possibly largely created by the present and the early workers in your profession. The pioneers of our business were naturally fully occupied with the problems which belong to the beginning and development of any enterprise. The engineer spent his entire time in the solution of his engineering problems, just as the financier and the manufacturer were engrossed in their particular work. It has taken all the time, energy and ability of these men to make discoveries and inventions, to build up the business, to organize it and to administer it.

The work of the last generation of engineers, to which you are now succeeding, has on the whole, I may say, been well done. I will not take the time to describe the results of this work as they are in evidence on every hand and are well known to you all. We have now a magnificient industry employing hundreds of thousands of men, representing an investment of hundreds of millions of dollars, which has added to the confort and joy of existence of millions of men and women throughout the world. This wonderful industry had its commercial beginning less than a third of a century ago, since which time the electric light, the trolley car, the electric motor, the long distance transmission of electrical energy, long distance telephony, and a multitude of other useful electrical devices have been created and have become the common-places of our daily life. It will be your duty, and also your great pleasure, I am sure, to carry on the work which has been already so well begun.

However, I wish to point out that while your technical problems will be similar to those which engaged the time and energies of your elders, that you will have other and additional problems to solve of possibly greater importance, and it is to these problems that I wish briefly to direct your attention. These problems are, briefly, those of economics and those of politics. The engineer has always been knowingly or unknowingly interested in economics but has usually let politics severely alone. The engineer of the future must, however, take an active interest in both subjects.

It is the engineer's business to produce wealth; he does this by making discoveries and inventions, by making better use of material and of labor, by saving by-products and preventing waste, by multiplying the effectiveness of labor as by the invention of labor saving tools and devices, and in other ways too numerous to mention. The net result is, and must be, if he is successful, a constant increase in wealth or in the good things of this world. He is increasing, in other words, the amount of the material wealth which is the basis of our prosperity and even of our existence. I do not think I need to emphasize this point any further; it must be self-evident to you gentlemen.

However, if you have read the newspapers, or have used your eyes, ears and brains, you must have become painfully aware of the fact that there has grown up in this country a large body of men whose business it seems to be to reduce the effectiveness of your work as much as possible. A large and apparently growing class of men seem to act upon the theory that efficient production is undesirable, that production should be limited to the minimum rather than increased to the maximum, and that the cost of production may be constantly and indefinitely increased without damage to industry or their own interests. The fallacy which underlies this theory and practice is, of course, evident to you educated men. It is the fallacy that there is only a limited amount of work to be done in the world and that the less work each man does individually the more work there will be left for the other fellow. These teachers of false economic doctrine and practice seem to assume that it is undesirable to increase the amount of goods produced in the world, that the fewer the goods produced the more there will be to divide. Now, in my judgment, it will be necessary for you gentlemen to make a careful study of this situation and combat in every proper way this false and dangerous practice. Of course you know that the more there is produced in the world the more there will be to divide, and while it may be true that as long as men live there will be a disagreement as to the division of the good things which are produced, it is simply suicide for any of us to adopt practices which restrict or reduce the amount of useful goods produced. I will not take your time to go into this matter in detail; I am sure you are intelligent enough to make your own application, but I do wish to assure you that it is a live problem and one in which every one of you should interest himself. You should try to ascertain the reason for the growth of this suicidal policy, and it will be your duty to help to find a solution of the problem. It is perhaps the most serious problem which faces our country; in fact, it is not limited to this country but is found in every civilized country. It is manifestly impossible for us to continue to make progress unless we all pull together. I do not wish to have you think that those who are now charged with the responsibility of manufacturing and engineering are indifferent to this situation; on the contrary, all progressive companies and individuals are seeking a solution, but we need your help to combat inefficient practices and false doctrines. I think that if we all get the proper point of view we will eventually arrive at a satisfactory solution.

Until comparatively recent times we as a people have been satisfied to confine the activities of our legislatures to the rather well-known and generally accepted sphere of government. However, during the past decade or two there has been a demand for legislation of an entrely novel character; you are familiar with its nature. Statutes of all kinds for the regulation and restriction of business activities, laws of a paternalistic and socialistic nature, have been ground out at a constantly accelerating rate. We have departed a long way from the old fashioned doctrine that "every man should be the architect of his own fortune and the pilot of his own pursuit of hapiness." I do not wish to have you consider this statement as a criticism or as an approval of the existing tendencies. I wish, however, to make this appeal. You engineers have had a good, scientific education; this education should have given you a capacity to look facts in the face; it should have given you a constructive point of view; you should be largely free from prejudice, superstition or false sentiment; you should be only interested in securing what is best, most efficient and just; you should be able to analyze the statements presented and distinguish between facts and fancies; and, above all, your training should have made you intellectually honest. I do not think the country has anything to fear from the conclusions which you will reach, provided you take the time to study the problems that are presented and use the same methods in arriving at a conclusion that you would use in your daily engineering work.

If our Government is to continue to regulate business, and, particularly, if it is to extend the field of its activities into business and institute competition with private individuals, it is essential that the men we elect to our legislatures and to Government offices should be possessed of accurate knowledge of modern business, of which engineering constitutes a most important feature. Modern business is no longer simple, as I have stated; it is highly complex, and, to be successful, demands the highest technical experience, scientific skill, unflagging industry, intellectual honesty, great administrative ability, initiative and resourcefulness to meet the ever changing conditions. Our political bodies as at present constituted cannot possibly administer such a delicate and intricate situation with success. Disaster can only be averted by improvement in the quality and character of our legislatures and executive instruments. You technical men must take a hand in politics or politics will take you in hand and you will soon have no business.

I think you will agree that ignorance, superstition and prejudice are the most dangerous enemies of social happiness and industrial progress. Europe was plunged into intellectual darkness for a thousand years because of the ascendency of the forces of superstition and ignorance. I believe that our future prosperity and happiness will be largely in proportion to the social diffusion of sound knowledge. Therefore, the greatest emphasis should be placed upon *education*, and I think, and I believe you all will agree, that the best kind of education for every citizen is what is known as a scientific education. I do not mean a narrow technical education but a broad education which includes all useful experience and knowledge, but with special emphasis placed upon scientific principles. I think that there was no time in the history of the world when a scientific education was more useful or more necessary to a correct point of view or to make possible that adjustment to one's environment which is necessary not only to survive but to progress. Educated men, therefore, have a duty—a selfish duty if you please—to take a lively and constant interest in all matters of education.

It is also vital that we should take an interest in those whom we select to represent us in our Government offices. We must not only have honest men, men possessed of so-called common honesty, but men possessed of that rare quality—intellectual honesty; men who scorn to be swayed from their duties by threats from any class of men; men who will not capitulate to capitalists or yield to unjust demands of so-called labor, or of farmer or of merchant, but who will have regard in all their actions for the interests of the people as a whole. It is a fatal fallacy to suppose that one group of our citizens can be exploited at the expense of another group without all of us suffering in consequence. If production is restricted, if success is penalized, if weak and incompetent men are placed in position to control the competent and efficient, industrial disaster will follow as surely as the night follows the day.

I repeat, therefore, that upon you educated men rests a great responsibility; not only must you be the architects of your own fortune, but even in a larger sense, to a greater extent than perhaps even you realize, will your country's future be as you make it. I have confidence that the future will be bright and satisfactory because I believe you will do your duty; but you must remember that the forces of ignorance are always with us, and that ignorance has greater valor and a louder voice, and sometimes greater oratorical power than the forces of intelligence; therefore, it is vital that every man possessed with a good education and intelligence should be active and vigilant and fight for the right as he sees it. It is as true now as it ever was, that eternal vigilance is the price of liberty.

INDUSTRIAL CONTROL

Part V

MAGNETIC CONTROL AS APPLIED TO THE AUTOMATIC ACCELERATION OF DIRECT-CURRENT AND ALTERNATING-CURRENT MOTORS

By A. E. Button

Industrial Control Department, General Electric Company

The present installment of the Industrial Control series first states the purpose and advantage of automatic acceleration, then enumerates some of the typical applications embodying remote control. Following this, it explains the systems of pump-back and dynamic braking, the method of obtaining maximum starting torque, the purpose of the field accelerating relay, and the method of calculating starting resistance values. The installment concludes with a detailed description of the time-limit, the current-limit, and the counter-electromotive-force methods of control.—Editor.

There are several methods of obtaining automatic acceleration; namely, time limit, current limit, c.e.m.f., and a combination of c.e.m.f. and current limit, all of which make use of contactors for short-circuiting the starting resistance. The particular field of application of each will be described later. It is obvious that the two last mentioned methods can be used only with direct-current motors.

With apparatus designed to accelerate the motor automatically and controlled by means of push buttons or master switch, the starting and stopping may be, and often is, done by persons without previous experience in operating electric motors; and this operation is equal to that obtained by an experienced operator with manually operated apparatus. Thus a purchaser of automatic-acceleration apparatus obtains a device which will safely and properly control the motor and will allow the operator to give his whole attention to the particular work he is doing.

When a customer purchases manually operated apparatus for starting an electric motor he obtains a device by means of which an experienced operator can bring the motor from rest to normal speed without causing excessive current peaks or undue shock to the apparatus which the motor is driving but which does *NOT* prevent possible damage to the starting apparatus or motor if improperly operated.

Automatic acceleration also finds a wide field of application where the starting and stopping of a motor can be done more advantageously at a remote point. The starting and stopping may be controlled by a hand-operated control switch, float switch, pressure governor, thermostat or similar device.

If low-voltage protection is desired to prevent the motor from starting up again after failure of voltage, one or more push-button stations, each provided with "start" and "stop" buttons, are used; for otherwise the contactors would drop out on failure of voltage and as soon as voltage returned would close again and restart the motor.

Float switches control the starting and stopping of motor-driven pumps, following the variation in fluid level. Several forms of these switches are made, differing in the manner of mounting the switch on the tank and of connecting the float to the switch lever. All forms require a minimum difference of ten or twelve inches between the high and low-level to cause the switch to operate. They are generally used on open tanks, as in Fig. 1, where there is no liability of the fluid freezing so as to prevent the float from moving up or down with the fluid level.

Pressure governors control the starting and stopping of motor-driven pumps or compressors, following the variation in pressure. They are made in two general forms known as the gauge type and the diaphragm type.

The gauge type consists of a modification of the operating mechanism used in the indicating pressure gauge, with the addition of adjustable contacts by means of which an electric circuit is made or broken. Because of the delicate operating parts the current which can be handled by the gauge is very small, necessitating the use of a relay for making and breaking the control circuit of the starting device.

To prevent fluctuations in the water pressure affecting the operations of the pressure governor, where a plunger type of pump is used on a pressure tank, a needle valve having a fine adjustment should be connected in the pipe line between the tank and the governor. The tank should be one-third full of air, to act as a cushion, and should have a water glass installed near the upper part to indicate the level of the water.

If it is impossible to install an independent pipe from the storage tank to the governor, there should be interposed between the outlet pipe and the governor a compression tank and a needle valve having a fine adjustment, as shown in Fig. 2, to prevent the governor being affected by fluctuations of pressure in the outlet pipe. The compression tank should have a capacity of 10 gallons and when installed should be about half full of water. The upper part of the tank should contain air to act as a cushion. To indicate the water level, a water glass should be installed. To prevent leakage of the air from the tank, the connection from the tank to the pressure gauge should be air-tight; otherwise, the air in the tank would gradually be forced out and become replaced by water which would transmit to the gauge any fluctuation in the discharge pipe.

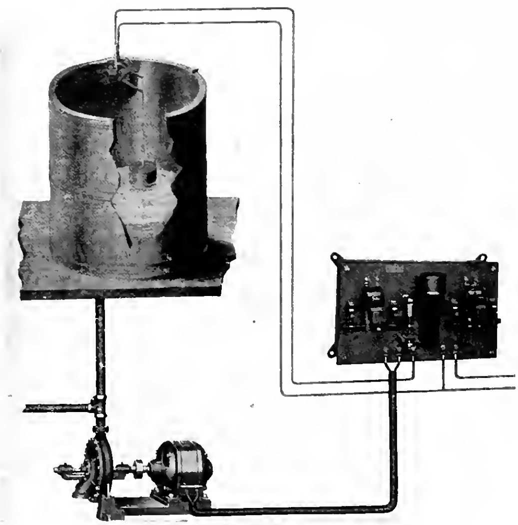


Fig. 1. Installation of a Single-phase Motor Controlled by Means of a Float Switch and a Control Panel

By means of gauges of different rating it is possible to use this type of governor for pressures from vacuum to 1200 pounds per square inch, with a minimum range between the cutting-in and cutting-out pressure of 3 pounds for the low-pressure gauges and 40 pounds for the high-pressure gauges.

The diaphragm types of governor employ a rubber or metal diaphragm with suitable operating mechanism so arranged that when the pressure on the inner surface of the diaphragm has increased to a predetermined value the governor will operate and open the motor circuit. The pressure range of this type of governor varies with different springs from vacuum to 200 pounds, with a range from 10 pounds on the low-pressure governors to 20 pounds on the high pressure governors.

Since one foot of water is equal to 0.433 pounds pressure, either type of governor requires a greater variation in water level than that required by a float switch.

Overload Protection

Overload protection is obtained by means of circuit breakers, fuses, overload relays, or oil switches.

Circuit breakers are used with both direct-current and alternating-current motors on circuits of 550 volts or less. They provide means for adjusting the trip-out point between wide limits of calibration and their maintenance cost is very low.

Fuses are used with both direct-current and alternating-current motors which drive a load that fluctuates from time to time with overload peaks of short duration. Under these conditions the inherent time element of the fuse prevents the fuse from rupturing the circuit but still provides protection against continued overload. Compared with circuit breakers, the use of fuses for overload protection has the disadvantages of high maintenance cost, the necessity of substituting fuses (sometimes of different dimensions) in order to change the value of current at which the circuit will be ruptured, and also the more or less dependence of the rupturing point upon local conditions.

Overload relays are also used with both direct-current and alternating-current motors in connection with a line contactor so connected that when the relay functions, due to overload, the control circuit of the line contactor is opened, thus disconnecting the motor from the line. Relays are made in several forms, to be reset by gravity, by hand, or electrically from a remote point by means of a resetting contact on the control switch or by a push button.

Relays, provided with an adjustable time element, are often used to provide protection against a continued overload. The time element prevents the relay from responding to normal accelerating current peaks which are of short duration, but does not prevent disconnecting the motor from the line in case of a continued overload either during accelerating or after the motor is running at normal speed. If the load requires high current peaks during acceleration, the relay is adjusted to give a longer time element while the adjustment of the trip-out value is made sufficiently low to provide overload protection for normal running conditions. Thus is secured the advantage furnished by the use of fuses, a low maintenance cost, and a means of adjusting the trip-out value.

Oil switches are used principally on alternating-current circuits, and find their general application in motor control equipments where the motor operates on a circuit of 550 volts or higher.

Pump-back and Dynamic Braking

If a rheostat in series with the shunt field of an adjustable-speed motor, running at or near maximum speed, is suddenly short-circuited, resulting in full-field excitation, the c.e.m.f. will increase to a value corresponding to the speed and may be several times the line potential. This fact makes it necessary to provide a dynamic braking circuit on control equipments where the auxiliary contact short-circuits the field rheostat each time the line contactor opens. If such a discharge circuit is not provided for the c.e.m.f., a severe strain on the motor insulation or a flash-over on the commutator would result.

The dynamic braking method of quickly stopping an electric motor, obtained by disconnecting the armature from the line and reconnecting it through a resistor of proper ohmic value while the motor field is excited with full-line voltage, is used with both constant and adjustable-speed motors. The load then drives the motor as a generator which transforms the kinetic energy into electrical energy which in turn is dissipated as heat from the dynamic brake resistor. As the value of the dynamic braking torque is proportional to the strength of the field flux, it is essential that the field rheostat be short-circuited during dynamic braking.

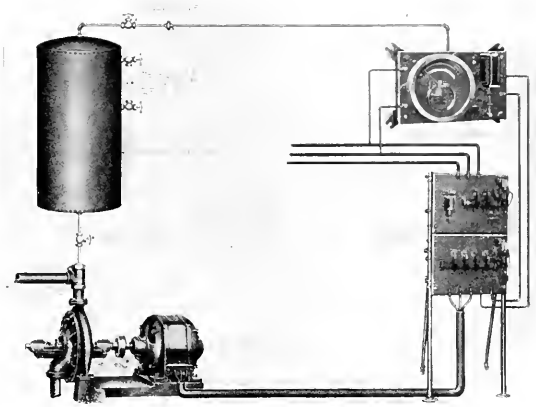


Fig. 2. Automatic Compensator and Pressure Governor Controlling Induction Motor Driven Pump on Pressure System

Dynamic braking is used with non-reversing equipments for controlling motors driving a load having considerable inertia, in order to stop the motor more quickly when the line contactor is opened: also, it is used with reversing equipments to prevent the closing of the reverse contactor until the motor has slowed down; otherwise, it would be possible to reverse the motor at maximum speed and the c.e.m.f. of the motor would be added to the line voltage until the motor armature could slow down and reverse.

Auxiliary Contact to Give Maximum Starting Torque

The torque of a direct-current motor is proportional to the product of the field flux and the armature current, so that if the field excitation is constant the torque will vary directly with the armature current. Where an adjustable speed motor must start a load requiring high torque, the field rheostat is short-circuited by a normally closed auxiliary contact on the last accelerating contactor so that the motor is always started with full-field excitation. When the last accelerating contactor closes, this auxiliary contact opens and inserts resistance in series with the shunt-field circuit to give a speed corresponding to the rheostat adjustment previously made by the operator. The auxiliary contact is also used to provide full field on the motor for dynamic braking.

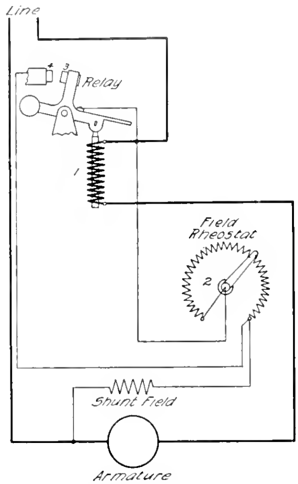


Fig. 3. Simple Diagram of Accelerating Field Relay as Used with Adjustable-speed Direct-current Motors

Field Accelerating Relay

In addition to the auxiliary contact described above, there is furnished an automatic field accelerating relay by means of which there is obtained either one of two results, or a combination of both, viz.:

1. In order to limit the armature current to a safe value after the auxiliary contact has opened and inserted the rheostat in series with the shunt field, when a motor having a wide range of speed control is liable to be started with the field rheostat adjusted to give maximum speed.
2. In order to obtain maximum torque per ampere during the period between the opening of the auxiliary contact and the acceleration of the motor armature to a speed corresponding to the adjustment of the field rheostat. Where the motor must accelerate a heavy load, as when driving a conveyor system, the relay is used even with motors where the speed variation is 2 to 1 or less.

Fig. 3 shows the field rheostat No. 2 connected in series with the shunt field. Relay No. 1 is arranged with contacts 3 and 4 which close at a predetermined flow of current through the armature, thereby short-circuiting the resistance which is inserted by the field rheostat, and open again on a reduction of current.

Assume that the operator has adjusted the field rheostat used with a motor, having a speed variation of 3 to 1, to give maximum speed; then when the motor is started and the short-circuit is removed from the field rheostat, due to the opening of the auxiliary contact on the last accelerating contactor, the reduced field flux would cause the armature current to increase until the relay operated and short-circuited the field rheostat. This increases the current in the field circuit and likewise decreases the current in the armature circuit, causing the contacts of the relay to again open so as to insert this resistance. The contacts of the relay continue to vibrate, the speed of the motor increasing until it finally reaches a speed corresponding to the strength of the field determined by the setting of the field rheostat.

Method of Calculating Starting Resistance Values

Resistance, consisting of resistors in various forms depending on the value of the current to be carried, is the usual means employed to reduce the initial current when starting direct-current or alternating-current motors. The following formulæ taken from Mr. B. W. Jones's article in the General Electric Review of February, 1915, are used to determine the proper ohmic value of the starting resistor:

First, either the maximum or the minimum accelerating current peaks are assumed, together with the number of rheostat divisions and the internal motor resistance. If it is a series motor resistance, then the speed characteristic curve of the motor is necessary. It is assumed that during acceleration the successive divisions of resistor are short-circuited as fast as the current decreases to a fixed assumed value, and all the current peaks are of equal value.

It should be noted that if all values are in percentages it will cause less confusion. Therefore, all of the series motor formulæ will be expressed on that assumption.

Let

V = line volts.

I_1 = Minimum acceleration current $= \frac{V}{R_1}$

S_1 = (for series motors) speed corresponding to I_1.

I_2 = Maximum acceleration current $= \frac{V}{R_2}$

S_2 = (for series motors) speed corresponding to I_2.

S_3 = Speed corresponding to 1.5 I_1.*

R_1 = Total resistance to give minimum current $= \frac{V}{I_1}$

R_2 = Total resistance to give maximum current $= \frac{V}{I_2}$

r = Internal resistance of motor.

r_1; r_2; r_3; r_4; etc., = Resistance of the successive divisions of the rheostat.

n = Number of rheostat divisions.

$$X = \text{Ratio} \frac{\text{maximum acceleration current}}{\text{minimum acceleration current}}$$

$$= \frac{I_2}{I_1}.$$

$$Y = (S_1 - S_3)^*$$

$$A_1 = \frac{100\,V - I_1 r}{S_1\,I_1}.$$

$$A_2 = \frac{100\,V - I_2 r}{S_2\,I_2}.$$

$$Z = \frac{A_1}{A_2}.$$

For Shunt or Induction Motors

I. *Assume that the minimum accelerating current, the number of rheostat divisions, and the internal resistance of the motor are known.*

Log

$$X = \frac{1}{n+1} \log \frac{R_1}{r}.$$

$$r_1 = (X-1)r.$$

$$r_2 = X r_1.$$

$$r_3 = X r_2.$$

$$r_n = X r_{n-1}.$$

II. *Assume that the maximum accelerating current, the number of rheostat divisions, and the internal resistance of the motor are known.*

Log

$$X = \frac{1}{n} \log \frac{R_2}{r}.$$

$$r_2 = (X-1)r.$$

$$r_2 = X r_1.$$

$$r_3 = X r_2.$$

$$r_n = X r_{n-1}.$$

It is apparent that if any three values are known, the forth can be found.

For Series Motors

III. *Assume that the minimum accelerating current, the number of rheostat divisions, and the internal resistance of the motor are known.*

The following is an empirical formula:

Log

$$X = \frac{1}{n+1} \log \frac{R_1}{1.5\left(\frac{n+1}{n+2}\right) Y}.^*$$

Then, from the article "Determination of Resistance Steps for the Acceleration of Series Motors" by E. R. Carichoff and H. Pender in the GENERAL ELECTRIC REVIEW, July, 1910, we take

$$r_1 = A_1\,(S_1 - S_2).$$

$$r_2 = Z_1 r.$$

$$r_3 = Z_2 r.$$

$$r_n = Z r_{n-1}.$$

THEORY

I. From geometrical progressions:

$$\text{Sum} = r + rX^1 + rX^2 + rX^3 + \ldots rX^n + r + X^{n+1}.$$

(Where n equals two less than the number of terms which correspond to the number of rheostat divisions.)

Therefore the last term, R_1, which is the sum of all the previous terms is:

$$R_1 = rX^{n+1}.$$

$$X^{n+1} = \frac{R_1}{r}$$

Log

$$X = \frac{1}{n+1} \log \frac{R_2}{r}.$$

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*Note that the denominator $1.5\left(\frac{n+1}{n+2}\right) Y = 0.75\left(\frac{n+1}{n+2}\right)\left(\frac{S_1 - S}{I_3 - I_1}\right)$

It is sometimes convenient and slightly more accurate to make I_3 as near equal to I_2 as can be approximated instead of $I_3 = 1.5\,I_1$

II. If n represents three less than the number of terms, then the next to the last term is

$$R_2 = rX^n,$$

$$X^n = \frac{R_1}{r},$$

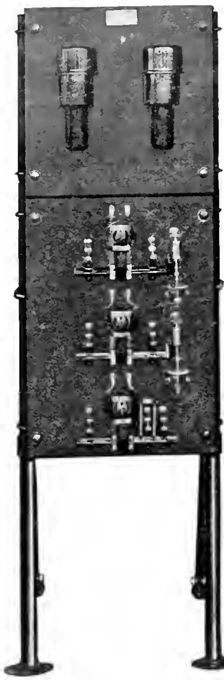


Fig. 4. Control Panel for Automatic Acceleration of Slip-ring Type Induction Motor

Log

$$X = \frac{1}{n}\log\frac{R_2}{r},$$

III. For series motors a modification of the above is necessary. Since there are already too many variables to solve the equation, it is necessary to resort to an empirical formula which is accurate enough for all practical purposes.

The motor field flux varies as a function of the current, and the current fluctuation is a function of the motor's internal resistance and the number of rheostat divisions. Therefore in place of

r there is placed $1.5\left(\frac{n+1}{n+2}\right)Y$.*

Log

$$X = \frac{1}{n+1}\log\frac{R_1}{1.5\left(\frac{n+1}{n+2}\right)Y}.$$

METHODS OF CONTROL

Time Limit

The time-limit method of control is used with motor applications requiring an inexpensive starting device for motors of small capacity which accelerate their load quickly, or installations requiring larger size motors where the load may increase when the motor is not running to such an extent that when the control circuit is closed the motor would be unable to accelerate, as sometimes happens if a pump becomes "frozen."

Under the above condition, with the time-limit method of control, the starting resistor would be cut out of circuit step by step until the current increased to the trip-out value of the overload device thereby causing it to disconnect the motor from the line. Figs. 4 and 4a show the wiring diagram and general appearance of a panel to provide auto-

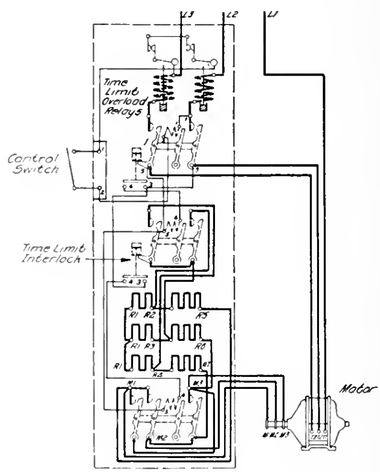


Fig. 4a. Diagram of Connections of Panel shown in Fig. 4

matic acceleration to slip-ring type induction motors.

The time element is obtained by the use of a dashpot relay, the core of which is connected to the contactor in such a way as to be lifted when the contactor closes and then allowed to fall slowly due to the retardation of the dashpot. When the core drops the circular disk bridges two stationary posts and thereby energizes the coil of the next contactor. The last contactor is energized by the operation of the relay connected to the second contactor.

Current Limit

The current-limit method of control accelerates the motor in the minimum time consistent with the load and is the method most generally used. Current-limit acceleration for alternating-current motors is obtained by the use of current-limit relays; for direct-current motors either by current-limit relays or series contactors.

The current-limit relay consists essentially of a coil which is in series with one of the line leads, a core or armature which responds to the magnetic pull produced by current flowing in the series coil, and some form of control switch which is closed when the core is in the down position. When the line contactor closes, and until the motor begins to accelerate, the inrush current is limited only by the ohmic value of the starting resistor and the motor winding. As the motor accelerates, the value of the current is reduced due to the induced c.e.m.f., the value of which is proportional to the speed of the motor; and the reduction in current causes a corresponding reduction in the magnetic pull on the relay core or armature until the force of gravity overcomes the magnetic pull allowing the core to drop and close the circuit of the next contactor. As each accelerating contactor closes, the current inrush, followed by a reduction in the value of the current, and the operation of a relay, is repeated until all the accelerating contactors have closed, short-circuiting the starting resistor and connecting the motor to full line potential.

The series contactor operates in the same manner as the current-limit relay except that the function of both the relay and accelerating contactor are combined in one unit, the contactor closing and short-circuiting a portion of the starting resistor when the current has fallen to a predetermined value. Both the current-limit relay and series contactor provide means for adjusting the value at which they will close.

The advantages of the series contactor compared with current-limit relays are the simplicity of wiring, the more rugged construction, and the lesser number of units on the control panel.

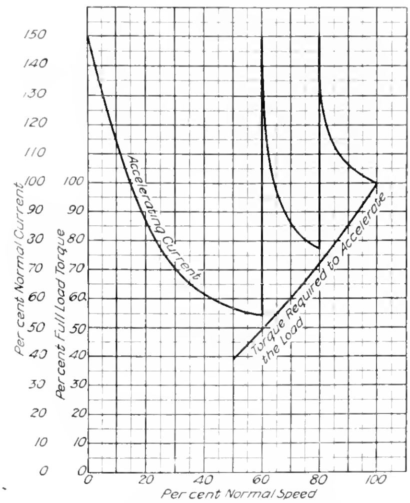


Fig. 5. Typical Current Curve of Motor Driving a Load which requires rising torque with increased speed

If the motor is starting a load requiring the same torque at all speeds, the several contactors should close when the current drops to the same value; but if the motor is driving a load which increases with the speed, as a fan or centrifugal pump, each succeeding contactor should close at a higher value than that of the preceding contactor, as shown in Fig. 5.

Figs. 6 and 6a show the wiring diagram and general appearance of an automatic compensator to provide current-limit acceleration, by means of a relay, to squirrel-cage type motors.

When the control switch is closed, the four-pole contactor is energized which applies full voltage to the open delta-connected compensator coils and connects two phases of the motor to compensator taps thereby obtaining a reduced voltage for starting. The closing of this contactor completes an electric interlock circuit which energizes the shunt coil of the current-limit relay and allows the core to drop when the current has fallen to a predetermined value. When the relay functions the four-pole contactor opens before the double-pole contactor is energized to connect the motor to full line potential.

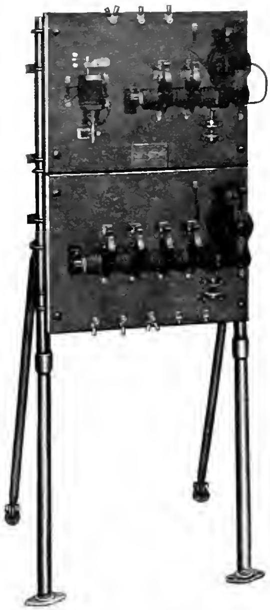


Fig. 6. Low-voltage Current-limit Automatic Compensator Panel

Several taps are brought out from each compensator coil to meet various requirements of service. Compensators for use with motors from 5 to 18 h.p. inclusive are provided with taps for 50, 65, and 80 per cent of the line voltage, with respective line currents equal to 25, 42, and 65 per cent of the current that would be taken by the motor if no compensators were used.

For larger motors, compensator taps are provided giving potentials equal to 40, 58, 70, and 85 per cent of the line voltage and respective line currents equal to 16, 34, 50, and 72 per cent of the current that would be taken by the motor if it were started direct from the line.

Standard squirrel-cage type motors manufactured by the General Electric Company if connected to full line potential would take the following inrush current from the line:

60-cycle motors: approximately 5½ times full-load current.

25-cycle motors: approximately 7 times full-load current.

Motors of other manufacture may take more or less than these values, depending on the value of several factors used in designing the motor.

An automatic compensator provides but one starting point, as any voltage which will start a low-resistance secondary squirrel-cage type motor will accelerate it to nearly synchronous speed.

The fact that a single starting point is used makes it necessary that the motor be connected to the tap which will best start the particular load which the motor is driving. Fig. 7 shows the result of starting a load by connecting the motor first to a tap giving 50

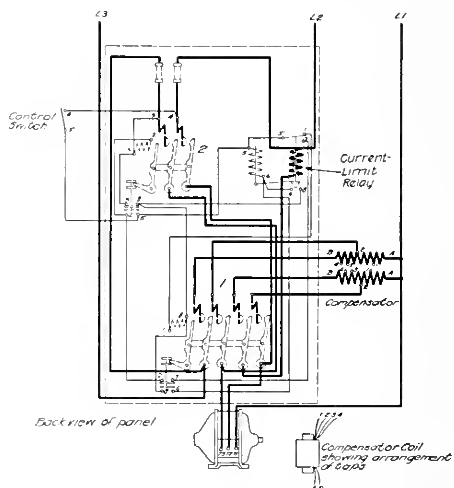


Fig. 6a. Connections of Low-voltage Current-limit Automatic Compensator shown in Fig. 6

per cent line voltage and later to a tap giving 70 per cent line voltage. It will be noted that the 70 per cent tap gives better results.

The time required for the current-limit relay to function depends upon the rate of acceleration which, in turn, depends upon the voltage tap used and the kind of load the motor is starting. When the motor is connected to the proper tap, the relay will function in from 2 to 8 seconds; and if a longer time is required it indicates that the next higher voltage tap should be used. Likewise, if the relay functions in less than 2 seconds, it would indicate that a lower voltage tap would be sufficient to start the motor.

Fig. 8 shows a characteristic starting curve for both a fan load and one requiring constant torque both connected to a compensator tap giving 50 per cent line voltage. The value of the initial current peak depends upon the voltage tap and the impedence of the motor with which the compensator is used.

Figs. 9 and 9a show the wiring diagram and general appearance of a panel to provide current-limit acceleration by means of two current-limit relays to slip-ring type motors.

When the control switch is closed the main line contactor is energized, throwing the motor on the line with the resistor in the secondary circuit. The sudden inrush of current holds the first current-limit relay open until the current, which gradually falls off as the motor increases in speed, has reached a predetermined value. This relay, on closing, energizes the first secondary contactor which cuts out the first step of resistor, and at the same time puts voltage on the second relay, through an interlock circuit. As the motor further speeds up, the process just described is repeated, the current-limit relays acting alternately, until the last secondary contactor is closed. On the closing of this contactor, the other secondary contactor opens and the motor runs with secondary short-circuited, only the line contactor and last secondary contactor remaining closed. In this way continuous exciting current is required for only two contactors.

The starting resistor is short-circuited by means of triple-pole contactors, the tips of which are connected delta, as by this means contactors can be used having a capacity approximately 60 per cent of what would be required if double-pole contactors, the tips of which are connected Y, were used.

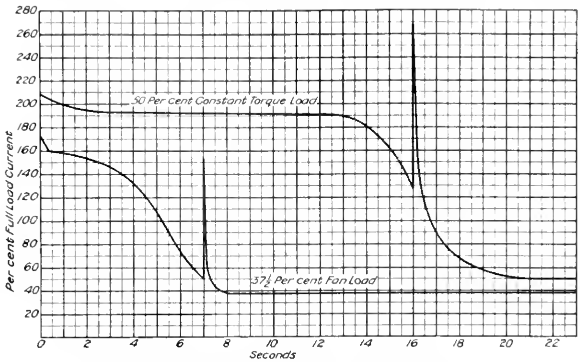


Fig. 7. Curve showing Results of Starting Motor by Connecting to a 50 per cent Tap or to a 70 per cent Tap, Current-limit Relay Drops at 125 per cent Current

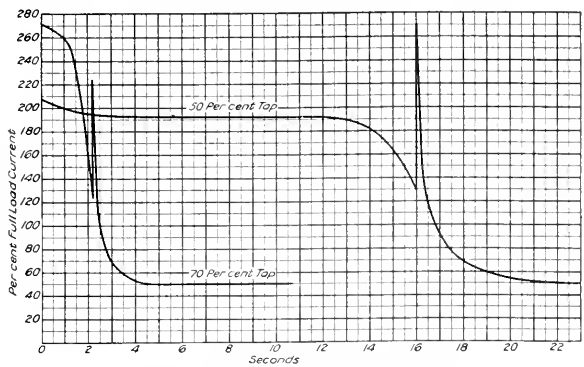


Fig. 8. Characteristic Curve of Motor on Constant Torque Load and Variable Torque Load and Connected to 50 per cent Tap

Figs. 10 and 10a show the wiring diagram and general appearance of a panel to provide automatic acceleration for direct-current motors using several current-limit relays. The arrangement between the contactor tail-piece and the relay core is such that when the contactor is open the relay core is held up mechanically, but when the contactor closes the core is influenced only by the magnetic pull produced by the flow of current in the series coil. This arrangement allows the core to drop as soon as the current has fallen, due to the acceleration of the motor armature to a predetermined value.

The coil of the relay, below the first contactor to close, is shunt wound and responds to the voltage drop across the starting resistor due to the reduction in value of the first inrush current.

When the line contactor is energized by the closing of the control switch, the motor is connected to the line with the resistor in series with the armature. Until the motor begins to accelerate, the inrush of current produces sufficient voltage across the resistor to hold up the core of the first relay but as the current value decreases the predetermined drop-out point of the relay is reached and the core drops and closes the circuit of No. 2 contactor. The coil of the No. 2 relay is in series with the armature circuit, so that when the second contactor closes the relay core is free to drop as soon as the value of the second current inrush has fallen to the drop-out value of the relay, which energizes the coil of No. 3 contactor. As each accelerating contactor closes, the current inrush followed by a reduction in the value of the current and the operation of a relay is repeated until all the accelerating contactors have closed, short-circuiting the resistor and connecting the motor to full line potential.

Figs. 11 and 11a show the wiring diagram and general appearance of a panel to provide current-limit acceleration to adjustable-speed direct-current motors for reversing service by means of series contactors. The operation of the contactors depends upon the inrush of current caused by the closing of the preceding contactor followed by a reduction in current value as the armature accelerates, the same as

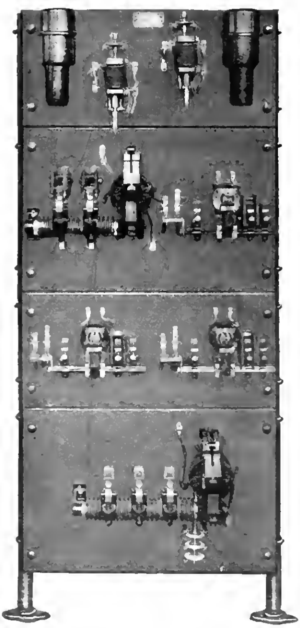


Fig. 9. Five-point Contactor Panel for Controlling Three-phase Slip-ring Induction Motor

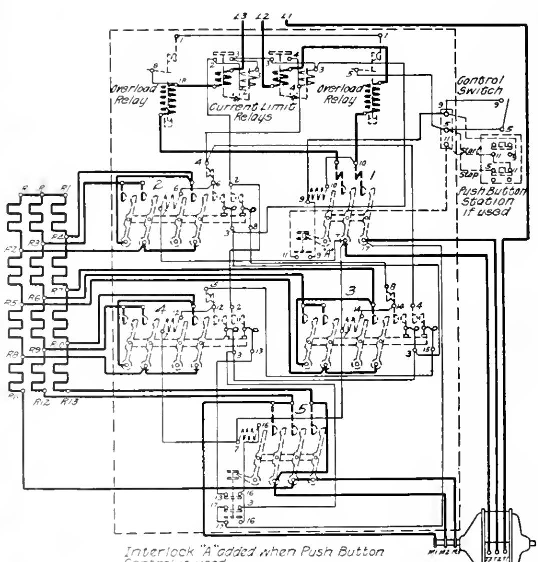


Fig. 9a. Diagram of Connections of Control Panel shown in Fig. 9

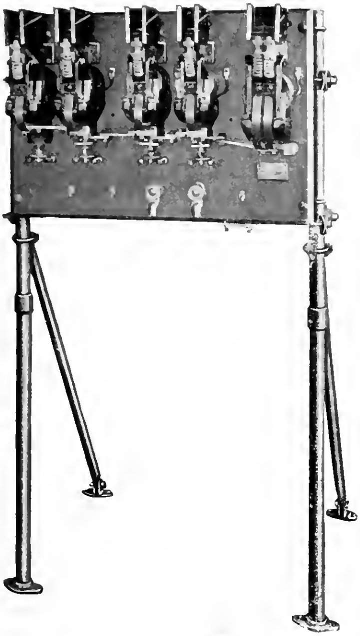


Fig. 10. Control Panel for D-C. Motor using Current-limit Relays

current-limit relays. The design of the contactor and its location in the circuit is such that after the line contactor closes the accelerating contactors close in proper sequence as soon as each succeeding current peak drops to a predetermined value.

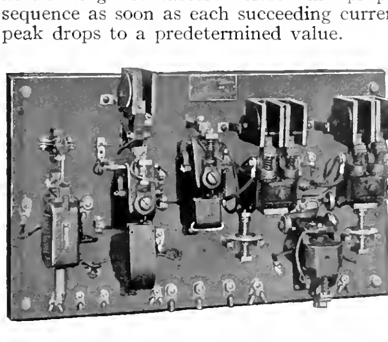


Fig. 11. Reversing Control Panel for Adjustable Speed Motor

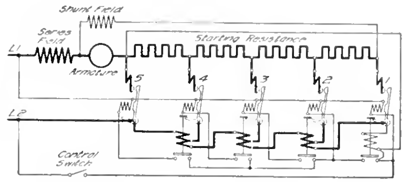


Fig. 10a. Wiring Diagram of Panel shown in Fig. 10

This control incorporates the features previously mentioned as required for control panels used with adjustable speed motors, such as dynamic braking, auxiliary contact to give maximum starting torque and field accelerating relay.

Counter E.M.F.

The counter-e.m.f. method of control is sometimes used with direct-current shunt motors by which the contactors used to short-circuit the starting resistor are actuated by the counter e.m.f. of the motor. As the value of the counter e.m.f. with a given field flux is proportional to the speed of the armature, which in turn is affected by any variation in line voltage, this method has the disadvantage that the closing of the contactors is affected by variation in line voltage. If a starting equipment using three or more counter e.m.f. contactors is used on a circuit where the voltage at times may be considerably less than normal,

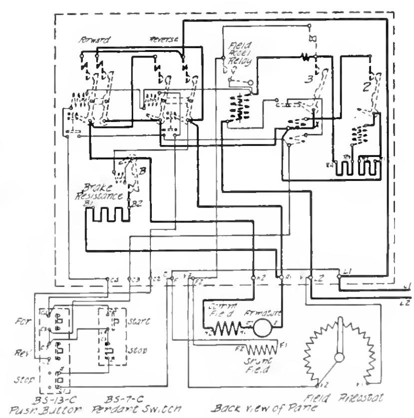


Fig. 11a. Wiring Diagram of Panel shown in Fig. 11

the speed of the motor will not be great enough to generate the necessary counter e.m.f. to close the last contactor, and the motor will run with part of the starting resistor in circuit until the latter burns out and opens the circuit.

Fig. 12. Counter-e.m.f. Self-starting Rheostat

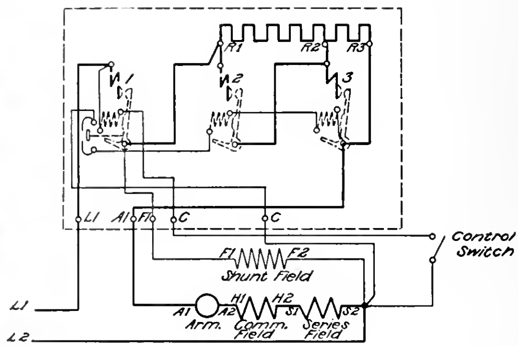


Fig. 12a. Wiring Diagram of Rheostat shown in Fig. 12

Where the counter-e.m.f. method of control is used with small horse-power motors which do not require more than one or two steps of resistance, the variation in line voltage does not seriously affect the operation of the starting apparatus as the last contactor can be adjusted to close at a value below the minimum value of the line voltage. A combination of current-limit and counter-e.m.f. control is sometimes used where several accelerating contactors are required. The counter e.m.f. actuated contactors short-circuit the first step or two of resistance and contactors actuated by current limit short-circuit the last step of resistance, which overcomes the liability of unsatisfactory operation due to variation in voltage.

Figs. 12 and 12a show the wiring diagram and general appearance of a panel to provide automatic acceleration to small direct-current motors by using the counter e.m.f. of the motor to actuate the accelerating contactors.

LOCOMOTIVE WEIGHING SCALES

By A. W. Thompson

General Electric Company, Erie, Pa.

This is a well illustrated account of some large locomotive weighing scales, the arrangement of which has been made so flexible that a great deal of valuable data concerning the distribution of weight on wheels, etc., can be readily obtained. The results of actual weighings are given in tabular form. The design of these scales incorporates several improvements on former weighing devices.—Editor.

In designing locomotives, especially where each pair of wheels has its own individual drive, it is essential for the designer to know the weight carried by each axle. Several different arrangements of scales to determine these weights have been in use, the one which until now has proved most satisfactory being that used by the American Locomotive Company, in which a number of scales, each mounted on its individual truck, operate on a common runway extending the entire length of the pit. After placing the scales so that each scale platform engages the flanges of a pair of wheels, the runways are raised by a system of hydraulic jacks operating simultaneously, thus giving the weight carried by each individual axle. The objection to this method is that there is no way of relieving the stiffness of frames and equalizing systems, so that a pair of axles which are absolutely equalized may show a difference of several hundred pounds or even a ton or more.

When the General Electric Company moved its Locomotive Department to its Erie Works, it was decided to equip the plant with scales, and the Company's engineers worked out an arrangement which, it is believed, eliminates many of the objectionable features of methods previously in use.

The objects to be attained were:

First. To provide for the raising or lowering of any axle independently, so as to relieve —or shift—the friction of frames and equalizers.

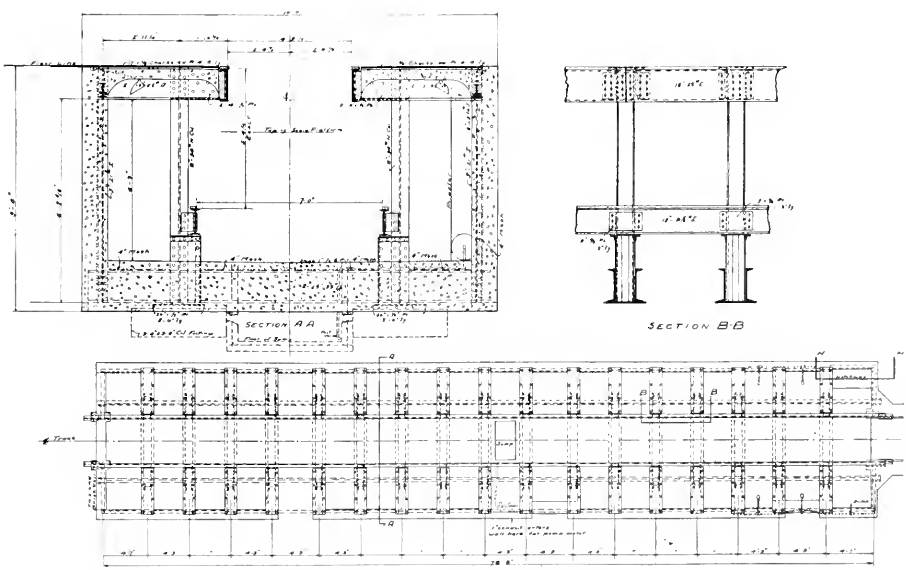


Fig. 1. Plan and Sectional Views of Locomotive Weighing Pit

Second. To compute the distance from the top of rail to the center of gravity of the locomotive by raising one side of a locomotive, say 6 inches, and weighing the low side, taking into account the known angle of tipping, the total weight of the locomotive, and the weight of one side when tipped.

The scale pit shown in Fig. 1 was built 78 ft. long with provision for extension whenever the increased wheel base of locomotives renders it necessary. Standard bridge specifications were used as the basis of the steel design, with the following allowable stresses: tension, net section, 16,000 lb. per sq. in.; direct compression, 16,000 lb. per sq. in.; bending on extreme fibers, 16,000 lb. per sq. in.; shear on shop rivets, 12,000 lb. per sq. in.; shear on bolts and field rivets, 10,000 lb. per sq. in.; shear—the average—on the webs of rolled beams, gross section, 10,000 lb. per sq. in.; bearing on shop rivets, 24,000 lb. per sq. in.; bearing on bolts and field rivets, 20,000 lb. per sq. in. The work was designed to carry 60,000 lb. axle loads on 5 ft. centers. A minimum impact allowance of 200 per cent was made to accommodate the severe shocks liable to occur in the raising and lowering of heavy locomotives. The cross bents are spaced 4 ft. 3 in. centers and support the channels carrying the running rails. Attached to the compression legs of these bents, and supported by the bottom members are the scale runways. The scales can be readily moved to accommodate the varying wheel spacing and can be placed on 3 ft. 0 in. centers if necessary.

Electric lights are placed in each bay on both sides of the pit. Air connections are placed so that a 3-ft. length of air hose will reach any scale.

The eight scales, one is shown in Fig. 2, were designed and built by the Buffalo Scale Company under the following specifications:

Overall height,	2 ft. 10 in.	Capacity 80,000 lb. to be placed anywhere on platform. Double beam each 4000 lb. by 20 lb.
Overall length,	3 ft. 0 in.	
Track gauge	7 ft. 0 in.	

Cast steel, tension 8000 lb. per sq. in.
Compression 8000 lb. per sq. in.
Cast iron, tension 2500 lb. per sq. in.
Compression 5000 lb. per sq. in.
Wrought iron, tension 8000 lb. per sq. in.
Compression 8000 lb. per sq. in.
On knife edges 5000 lb. per linear inch.

The truck frame, platform, and main lever are of one piece steel castings. The truck wheels are of cast iron with the treads chilled

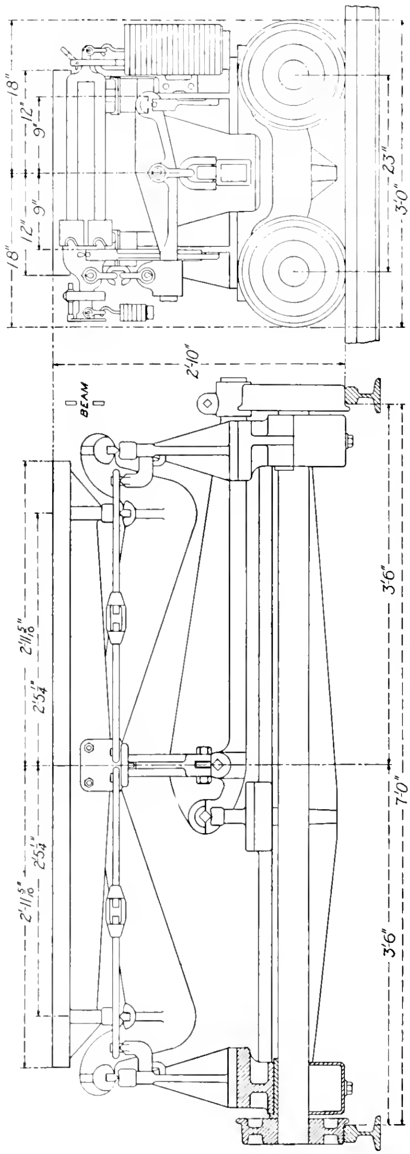


Fig. 2. Locomotive Scales

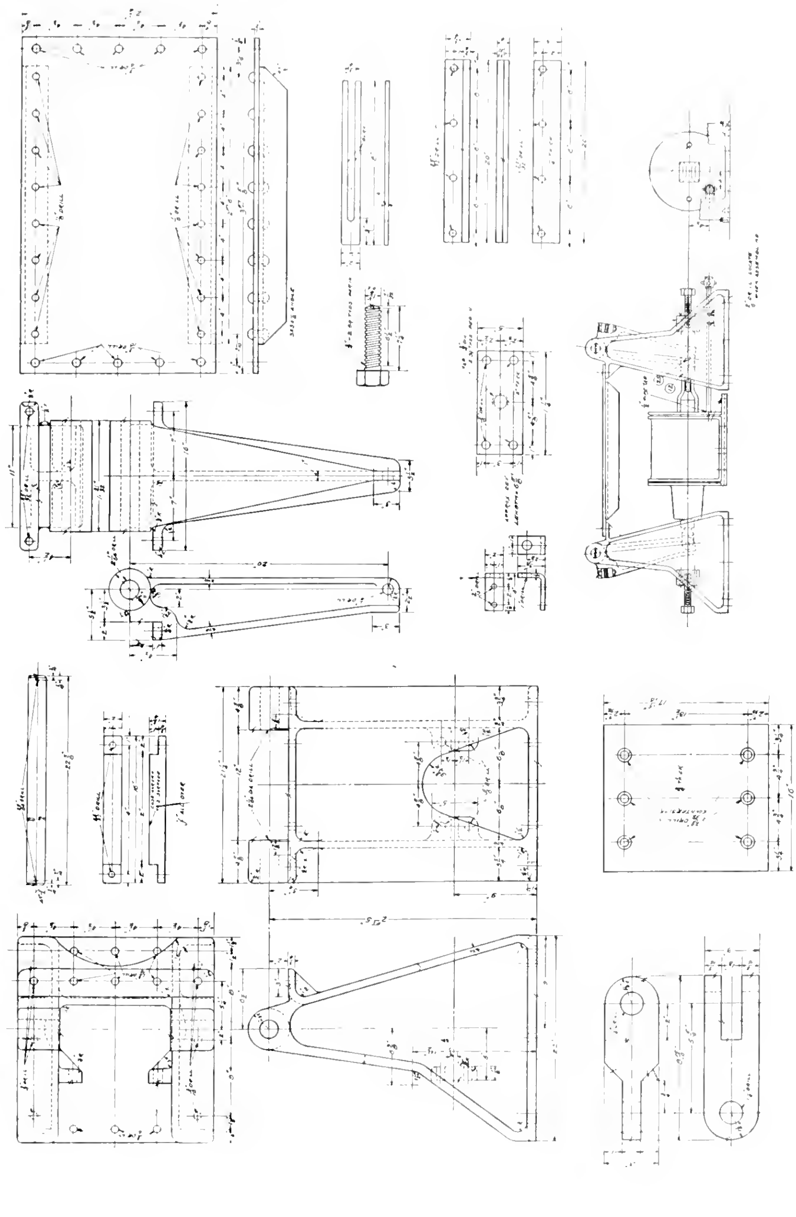


Fig. 3. Details of Lifting Mechanism

and ground. The bearings are of bronze with oil cellars for lubrication.

Eccentric washers are used on all stands, allowing 3/4 in. shift in any direction.

Compensating or self-aligning bearings are used throughout. The main lever is of the A type. The highest leverage ratio is 8. The weight of each scale without the lifting mechanism is 5000 lb. or the complete weight about 6300 lb.

The lifting mechanism, see Fig. 3, was designed and built by the General Electric Company and consists of two cast iron brackets, bolted to the scale platform, each supporting a cast steel lever which turns on a steel pin 2 inches in diameter. The short arm of these levers (extending horizontally to engage the wheel flanges of the locomotive) is made adjustable in height by the use of shims to accommodate varying flange heights. The long arms of the levers drop vertically and are connected to a standard 14 by 12 in. air brake cylinder floating between guides on top of the scale platform. The ratio of these levers is 4 to 1. The amount of lift can be varied from zero to 3/4 inches by set screws bearing against the long arm of the lifting levers.

Air at about 100 lb. pressure is supplied by a 1 1/4-inch pipe extending along the entire length of the pit, which is provided with a three-way valve so that the entire locomotive can be raised or lowered at once. One half inch connections are provided in each bay so that a 3 ft. length of hose will reach any scale, no matter where it is located, and the air connection to each air cylinder is provided with a three-way valve so that any axle can be raised or lowered separately when desired.

Tables I and II show the results obtained in weighing one of the units of a C., M. & St. P. locomotive of the freight type.

Table II gives the results of "juggling" with different axles of a C., M. & St. P. of the passenger type.

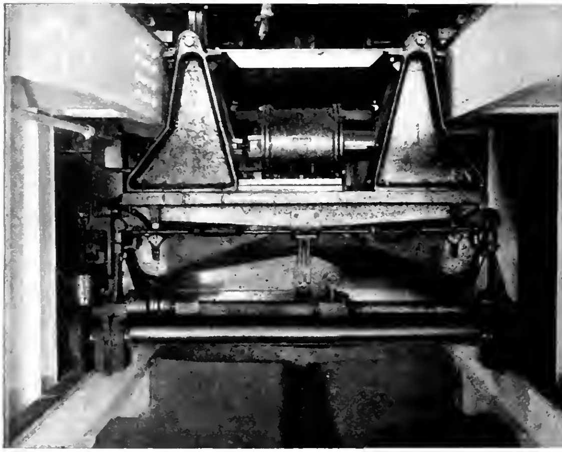


Fig. 4. End View showing Scale and Lifting Mechanism

Fig. 5. Showing Passageway on Weighing Side

TABLE I

RESULTS OF WEIGHING C., M. & ST. P. LOCMOTIVE No. 10220-B

Operation No.	Totals	Axle No. 6	Axle No. 5	Axle No. 4	Axle No. 3	Axle No. 2	Axle No. 1
1 All axles raised together	285,950	56,610	57,660	53,460	55,560	31,400	31,260
2 Lower No. 1	255,670	56,520	56,790	53,850	57,570	30,840	
3 Lower No. 2	225,520	56,390	56,500	54,210	58,420		
4 Lower No. 3	169,100	56,030	58,290	54,780			
5 Lower No. 4	114,470	56,280	58,190				
6 Lower No. 5		57,480					
7 Lower No. 6 and raise it		57,440					
8 Raise No. 5	114,440	56,040	58,400				
9 Raise No. 4	172,200	56,080	58,070	58,650			
10 Raise No. 3	224,890	56,420	56,710	54,230	57,530		
11 Raise No. 2	255,160	56,580	57,110	53,830	56,600	31,040	
12 Raise No. 1	285,910	56,790	57,470	53,470	55,380	31,440	31,360
13 Lower 6 and 5 together	172,690			54,940	56,710	30,820	30,720
14 Raise 6 and 5 together	285,920	56,660	57,590	53,570	55,330	31,420	31,360
15 Lower 6 and 5 together	173,070			55,100	56,390	30,930	30,650
16 Raise No. 6	231,120	57,750		55,070	56,360	31,080	30,860
17 Raise No. 5	285,920	56,200	58,260	53,540	55,140	31,500	31,280
18 Lower 4 and 3 together	178,650	56,190	58,480			32,210	31,770
19 Raise 4 and 3 together	285,890	56,610	57,660	53,370	55,680	31,290	31,280
20 Lower 4 and 3 together	178,570	56,380	58,260			32,200	31,730
21 Raise No. 3	233,630	56,720	57,670		57,450	30,920	30,870
22 Raise No. 4	285,890	56,690	57,540	53,630	55,260	31,300	31,470
23 Lower 4 and 3 together	178,610	56,450	58,210			32,230	31,720
24 Raise No. 4	233,070	56,590	57,690	54,790		31,980	32,020
25 Raise No. 3	285,870	56,820	57,430	53,250	55,740	31,320	31,310
26 Lower and raise all wheels	285,930	56,570	57,730	53,340	55,620	31,390	31,250
27 Raise all axles together	285,910	56,570	57,530	53,650	55,560	31,430	31,170
28 Lower No. 3 and No. 4	178,590	56,700	58,070			32,280	31,540
29 Raise No. 3 and No. 4	285,900	56,630	57,490	53,650	55,490	31,400	31,240

TABLE II

RESULTS OF WEIGHING C., M. & ST. P. FREIGHT LOCOMOTIVE No. 10220-B

After above weights were taken, about 1,365 pounds of sand, gear grease, etc., was placed on locomotive

Operation No.	Totals	Axle No. 6	Axle No. 5	Axle No. 4	Axle No. 3	Axle No. 2	Axle No. 1
30 Raise all axles together	287,270	56,460	57,840	57,820	55,980	31,700	31,470
31 Lower No. 1	256,650	56,300	57,280	54,030	57,720	31,320	
32 Raise No. 1	287,290	56,420	58,020	53,780	55,740	31,750	31,850
33 Lower No. 2	256,650	56,340	57,180	54,190	57,860		31,080
34 Raise No. 2	287,230	56,420	57,990	53,850	55,580	31,850	31,540
35 Lower No. 2 and No. 1	226,600	56,130	56,700	54,670	59,100		
36 Raise No. 2 and No. 1	287,230	56,470	57,980	54,000	55,210	31,750	31,820

TABLE III

RESULTS OF "JUGGLING" WITH DIFFERENT AXLES OF C., M. & ST. P. PASSENGER LOCOMOTIVE No. 10104-B

Operation No.	Totals	Axle No. 6	Axle No. 5	Axle No. 4	Axle No. 3	Axle No. 2	Axle No. 1
1 Raise all axles together	301,260	62,870	59,530	57,910	56,820	32,040	32,090
2 Lower and raise No. 5	301,260	62,870	59,680	57,630	56,940	32,050	32,090
3 Lower and riase No. 3	301,300	62,890	59,230	57,290	58,900	31,490	31,500
4 Lower and raise No. 4	301,280	62,730	59,620	57,290	58,310	31,640	31,690
5 Lower and raise No. 4	301,260	62,730	59,540	57,500	58,110	31,660	31,720
6 Lower and raise No. 5	301,280	62,880	59,440	57,310	58,210	31,690	31,750
7 Lower and raise No. 4	301,270	62,770	59,560	57,440	58,050	31,690	31,760
8 Average	301,273	Lower and raise No. 4. No change.					

Fig. 6. Side View of a C., M. & St. P. Locomotive on the Scales

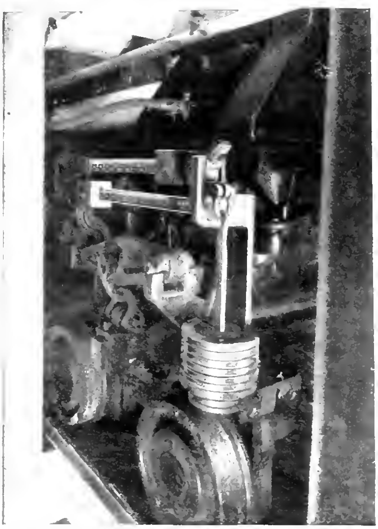


Fig. 7. Diagonal View showing Beam and Air Hose Connection

Fig. 8. End View Looking West with Front End of a C., M. & St. P. Locomotive

DETERMINATION OF THE CENTER OF GRAVITY

Fig. 9 shows the data used in the construction of Fig. 10 and the values of "A" read from diagram of Fig. 10 are correct for standard gauge locomotive only.

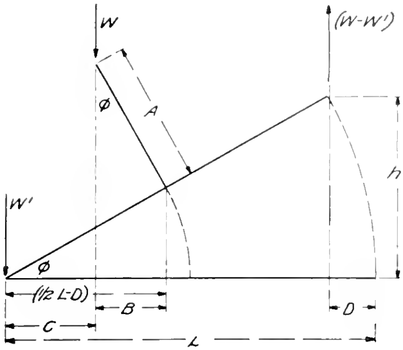


Fig. 9

Steel inclines are provided for each wheel on one side of the locomotive, designed so that when the locomotive is at the top of the inclines, the wheels are supported on their flanges. When raised by the scales, the flanges resting on the inclines are exactly 1/10 of their gauge higher than the flanges on the low side.

The sum of the weights on the low side (W^1) compared with the total weight (W) of the locomotive is the datum used in Fig. 10 for determining the height of the center of gravity.

Before the locomotive is run up the inclines, it is necessary to have the trucks carefully blocked on the wheels and the cab blocked on the trucks, to eliminate side motion.

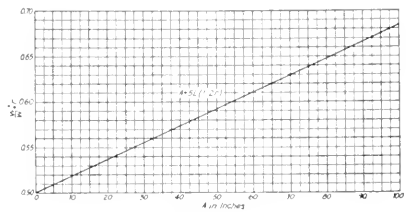


Fig. 10

By equating moments, the following general equation is derived.

$$A = \frac{L\ (W - 2\ W^1)}{2\ W\ \tan.\ \phi},\ A \text{ and } L \text{ are expressed in inches.} \qquad (1)$$

In this case $\phi = \text{arc tan. } 0.1$, and $L = 54\tfrac{5}{8}$ inches $= 54.625$ inches. From these values the special equation is obtained:

$$A = \frac{L\ (W - 2\ W^1)}{0.2\ W} = 5\ L\ (1 - 2\ r),\ \text{where}$$

$$r = \frac{W^1}{W}$$

$$W^1 = \frac{W}{2\ L}(L - 0.2\ A.)$$

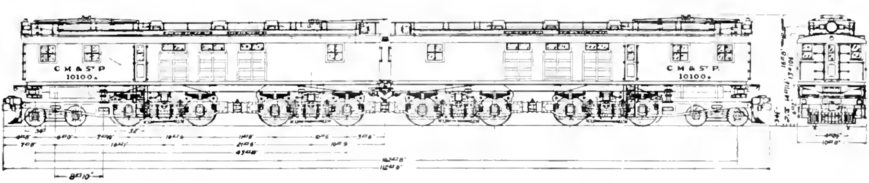


Fig. 11. Outline Drawing of a C., M. & St. P. Locomotive

THE PROTECTION OF TELEPHONE CIRCUITS USED IN ELECTRIC POWER DISTRIBUTION

By E. K. Shelton

Lightning Arrester Engineering Department, General Electric Company

The disturbances on telephone lines used in connection with electric transmission may be classified under two headings, viz: those that interfere with communication and those that introduce risk to human life. The protection of the line against these disturbances has assumed an important place in electric transmission engineering, and manufacturers have devoted a great deal of attention to the development of apparatus to fulfill the requirements of this service. This article discusses the nature of the disturbances and describes briefly the special protective devices that have been developed, and offers specific recommendations for the installation of protective apparatus on the several classes of telephone lines. We wish to call special attention to the fact that the protection described and recommended is intended only for the private telephone circuits of power companies and does not apply to the lines of commercial telephone companies which are for the use of the general public.—Editor.

DISTURBANCES AND THE REQUIREMENTS FOR PROTECTION

The protection of telephone lines used in power distribution is a subject which has recently received a considerable amount of attention, and the importance of which is quite evident. As power systems develop from the single transmission line to the large and ever increasing high-tension network with numerous generating stations feeding in at various points and with a large number of substations having various and irregular power requirements, the need of as nearly a perfect means of communication between these various stations becomes of the first importance. The best possible scheme of protection is warranted, as the expense is negligible when its value to the continuity of service and to the ready control of this service is considered. Even with the most perfect scheme of protection there will be occasional interruptions to the telephone service under certain abnormal conditions, but with the proper protective apparatus danger to the operator can be practically eliminated. In such emergencies continuity of service can be established over standard commercial telephone lines, but the needless exposure of employees to dangerous risks is in the meantime avoided.

The lack of system or standardization in the construction of telephone circuits used in power distribution makes the problem of protection a difficult one. For the most part such lines have been erected by the power companies, and consist of standard telephone instruments connected with various types of conductors, variously spaced and insulated, sometimes transposed and sometimes not. The result is that there are about as many different types of construction as there are power systems using them. The protection in many cases consists entirely or in part of home made devices designed by the operating engineers, which are more or less efficient, according to conditions. Many of these telephone circuits and the schemes of protection have been studied for the purpose of selecting and developing a scheme of protection that would be adaptable to all kinds of telephone systems used in power distribution. The purpose of this scheme of protection is the maintenance of telephone service and the prevention of danger to the operators.

The main sources of trouble to which such telephone circuits are exposed can be briefly stated as follows:

Electrostatic and electromagnetic induction from the power circuit.

Crosses with the power circuit.

Lightning disturbances.

Induction is likely to be the most troublesome on account of its being continuous, but lightning and crosses, although infrequent and of short duration, are likely to cause the most damage to the telephone apparatus, and in general to be dangerous to the operators.

Electromagnetic and Electrostatic Induction

The effect of electromagnetic and electrostatic induction is to cause noise in the telephone instruments and high voltage on the telephone lines and instruments, thus making communication difficult and dangerous. Transient currents and voltages caused by the operation of switches, lightning discharges to, or in the neighborhood of the transmission line, short circuits on the transmission line, arcing grounds, and in fact all phenomena which occur on the transmission line, have a more or less serious effect on the telephone line, due to the sensitiveness of the telephone instruments and the cumulative effect of the long paralleling.

Induction between lines produces a voltage between the wires of the telephone circuit and raises the potential of the telephone line above earth.

Voltage between the telephone wires results in a circulating current through the line, which produces noise in the instruments. This is an electromagnetic action caused by the fact that the wires of the transmission line cannot be spaced symmetrically with respect to both wires of the telephone line. The effect is that of a residual loop in the transmission line, which may be exaggerated by abnormal conditions. The remedy is careful transposition of the telephone line so that such induced voltages are broken into opposed sections and neutralized. Transposition of the transmission line also tends to reduce this effect.

Voltage between the telephone line and earth causes danger to operators and produces leaks to earth which may drain the static charge on the telephone line to earth through the instruments, resulting in noise. Further, if unequal voltages are induced on the two sides of the telephone line, a circulating current will result similar to that discussed above. This kind of disturbance may be caused by an electrostatic induction due to the position of the telephone line with reference to the transmission wires and earth, this position and the transmission line voltage determining the value of the induced voltage. It may also be caused by any circuit composed of the transmission line and earth return, such as a ground of one wire, triple or three multiple harmonic charging currents in grounded star systems, single-phase grounded return systems, etc. Transposition of the telephone line or the transmission line, or both, will not eliminate this trouble, but transposition of the transmission line tends to reduce it, as this prevents any one wire from having a predominant effect throughout the line. While the usual effect of such induction is to raise both telephone wires equally above earth potential, transposition of the telephone line would prevent any difference of potential between the wires.

In general, the effect of higher harmonics in the transmission line is greater than that of the fundamental frequency, since both the telephone instruments and the ear are more sensitive to these higher frequencies than to the fundamental frequencies, although the magnitude of the harmonics is less. It should be remembered, however, that harmonics which may be of inconsiderable value in the generator wave may be augmented to a very great extent by resonance conditions in the line, and may therefore be quite serious.

It is evident, therefore, that with both lines carefully transposed so that induction will produce very little noise in the telephone instruments, there may still be a dangerous and troublesome induced potential on the telephone line. Tests made on a telephone line on the towers of a double circuit 110,000-volt transmission line showed a steady induced potential to earth of 5600 volts.

One method of relieving this strain is to run a grounded shielding wire parallel and as close to the telephone line as possible. This wire should be grounded at every tower. Due to field distortion, however, this method is not always satisfactory, and the method which has given best results in practice consists in the use of so-called "drainage" or "bleeding" coils, connected between the telephone lines with the neutral point grounded. These coils present a path of low impedance to currents which pass equally from each of the two telephone lines to earth, such as charging current produced by the relation of the telephone line to the transmission line, and which, passing from the two ends of the coil in opposite directions to the center, neutralize each other's magnetic effect. On the other hand such coils present a relatively high impedance to the high frequency alternating telephone currents. There are several precautions which must be taken to insure satisfactory service.

In the first place, the number of these coils must be kept as low as possible, since, as they are inductances across the line, they take a comparatively high exciting current from the low frequency ringing generator, and under certain conditions may also affect telephone transmission. The installation of one drainage coil at each end of the line should usually be sufficient to obtain good results. If necessary a third may be installed at the center of the line. The characteristics of the two halves of the coil should be exactly the same, and the current capacity great enough to carry the line charging current without overheating. The currents which flow in a coil connecting the telephone line to earth may be calculated if all conditions are known, but the process is laborious and probably the best method is to experiment with lighting transformers, as stated before. If for any special conditions special drainage coils are required, the General Electric Company is prepared to build such coils in any capacity desired.

General Scheme of Protection

For lightning disturbances only, uncomplicated by any of the other kinds of disturbances, a vacuum gap (the vacuum tube arrester) gives the best and most reliable discharge path to ground. Where there are induced potentials on the telephone line either between lines or from lines to ground, due to either electromagnetic or electrostatic induction, an air gap, using knurled cylinders for the electrodes, is used between lines and ground. The air gap is preferred to the vacuum gap in order to avoid the continual grounding of the telephone lines which would occur through the low breakdown path of the vacuum arrester as a result of the induced potential to ground, which may be quite high. The vacuum gap is put across the telephone lines where the induced potentials can be controlled by careful transposition. Here the vacuum gap holds the voltage across the telephone apparatus to a value below its breakdown.

Where there is any possibility of induction troubles (and these may occur up to one-fourth or one-half mile away from the power circuit under abnormal conditions) the telephone line insulating transformer is of prime importance. This provides an insulation barrier of 25,000 volts test between the telephone instruments and the lines.

The next step in the case of circuits subject to induced potentials is the reduction of these permanent excess voltages to a safe low value so that protective devices of comparatively low breakdown can be installed on the circuit and not form a source of trouble themselves due to continuous discharging. This reduction can be accomplished by transposition of the telephone wires and also of the power wires and by the use of the drainage coil or "bleeding coil." Transposition will take care of induced potentials between the two sides of the telephone circuit, caused by the unequal position of these wires with respect to the magnetic field surrounding the power line conductors. The drainage coil when properly installed will relieve the telephone circuit from the induced potentials against ground caused by the position of the telephone circuit in the electrostatic field of the power circuit. These coils should be few in number, usually two, as too many will seriously affect the operation of the telephones. They present a high impedance path across the telephone line, thus shunting the high frequency talking currents, but at the same time provide a low impedance path across the telephone line for the flow of equal currents from both line to ground at the center of the coil.

On the line side of the insulating transformer, but back of the drainage coil where used, is installed a combined multigap and vacuum gap unit which holds the voltages to ground and between lines to moderate values. In series with this in the telephone lines are fused switches for cutting off the apparatus in case of heavy continued discharges through the gaps. These discharges may be caused by induced potentials or crosses. The fused switches can also be operated manually to cut off the station in an emergency.

The possibility of crosses with the power line requires the additional feature to the above scheme of the double pole horn gap, which serves as an auxiliary protection to the telephone line insulation until the telephone or power lines burn off. Where there is a cross but no paralleling, it is necessary to use only the fused switch on either side of the cross to isolate this section in case of a break.

Basis of Design of Protective Apparatus

At first sight the most obvious basis for rating and designing these various types of protective apparatus would be the transmission line voltage. On second consideration it will be seen that the only case in which this applies directly is a cross, which with modern line construction is comparatively rare. The induction troubles depend upon the circuit and load conditions on the power circuit and the distance of the telephone wires from the power circuit. The insulation of the telephone circuit has, therefore, been taken as a basis for designing, rating, and applying this apparatus. Thus the insulation on the line side of the fused switch and on the horn gaps will be just above the insulation of the telephone line, so that if arcing over the insulators occurs, it will take place on the line insulators. Furthermore, the insulation will be consistent with that on the telephone line, whereas by using the power voltage as a base it would bear no relation to the telephone line insulation.

DESCRIPTION OF PROTECTIVE APPARATUS

Vacuum Tube Lightning Arresters

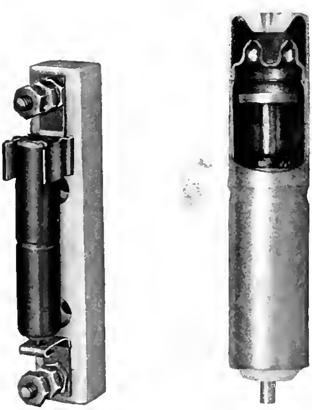
The purpose of this arrester is to protect the telephone apparatus against lightning. Two are required at each telephone station for protection.

In order to afford adequate protection to telephone circuits an arrester must have a low spark potential to ground. At the same time, leakage over the gap under normal conditions must be prevented. The first of these requirements demands a small gap; the second a large gap. By putting a comparatively large gap in a vacuum both requirements are met. The spark potential of the gap in the vacuum is far below what it would be in air and is sufficiently low to afford protection. An elaborate sealing scheme is used to prevent loss of vacuum. Large metallic current carrying parts ensure a high discharge rate.

The external appearance of the arrester is shown in Fig. 1, and the internal construction of the tube in Figs. 2 and 3.

Combined Vacuum and Air Gap Arresters

The purpose of this arrester is to protect against lightning and to equalize a difference in potential between lines. The former is provided by the adjustable air gaps between lines and ground. Protection against lightning is provided by the vacuum gap, which as will be noticed from Fig. 5, is connected between lines. An adjustable air gap is in shunt with the vacuum gap to provide an additional discharge path between lines and to be available in case the vacuum tube should be removed from service. The vacuum tube is the same as that used in the vacuum tube lightning arrester, Fig. 1. The general appearance of the arrester is shown in Fig. 4. The insulation to ground is designed with reference to the maximum gap between the knurled cylinders from line to ground. The air gaps are adjustable from 0 to $\frac{3}{16}$ inch. The voltage of the telephone lines on which this device is used must not exceed 250 volts between wires. If, on account of induction, the voltage is higher, drainage coils should be used to reduce it.



Figs. 1 and 2. Vacuum Tube Lightning Arrester

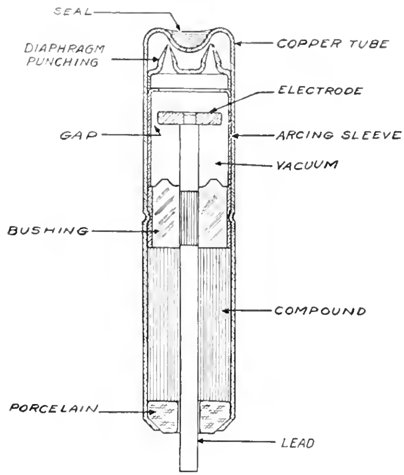


Fig. 3. Sectional Drawing of Vacuum Tube Lightning Arrester

Combined Double-pole Fused Switch and Lightning Arrester

The purpose of this device is to provide means for manually disconnecting the telephone circuit so that the telephone apparatus can be handled without danger. It provides means for automatically opening the telephone circuit (series fuse) in case the induced line current should reach such a magnitude as to endanger the telephone apparatus. The vacuum tube of the arrester is connected between lines and hence tends to equalize potentials between lines. The adjustable air gaps of the arrester are connected between lines and ground for discharging lightning disturbances, thus protecting the telephone equipment against lightning.

The general appearance of this device is shown in Fig. 6. It consists essentially of a double-pole fused switch and a vacuum tube arrester as described above. As this device is connected to the telephone line it is necessary that the insulation, especially on the line side, shall correspond to the insulation on the telephone line. The insulation on the telephone side is made lower, corresponding to the maximum gap setting of the arrester.

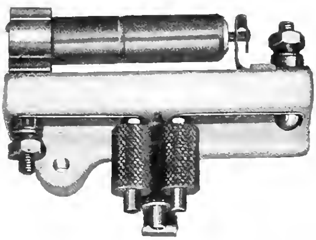


Fig. 4. Combined Vacuum and Air Gap Arrester

Double-pole Horn Gap

The purpose of this device is to protect the telephone apparatus, telephone line insulators, and lightning protective equipment against the power line voltage in the case of a cross between the power lines and the telephone line. The other telephone protective equipment is designed to protect the telephone apparatus against lightning and similar transitory disturbances. They will not withstand the transmission line voltage. In case of a cross the fuses on the combined switch and lightning arrester will at once blow, but the insulator on the line side of the fuses will still be subject to the strain of the line voltage. The double-pole horn gap connected outside of the other apparatus provides a means for relieving this strain.

The general appearance of this device is shown in Fig. 7.

Telephone Line Insulating Transformers

The purpose of the telephone line insulating transformer is as follows:

1st. To safeguard the users of telephones from the dangers of high voltages, due either to induction or accidental contact between telephones and power lines, where these lines are on the same pole, or upon a parallel adjacent line of poles.

2nd. To improve the telephone service by making it safe to adjust or inspect the arrester usually connected between line and ground on the telephone side and by increasing the insulation of the telephone line as a whole through the insulating barrier between the interior wiring, instruments, batteries, etc., and the lines.

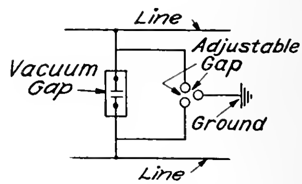


Fig. 5. Wiring Diagram of Combined Vacuum and Air Gap Arrester

The necessity for an insulating barrier between a telephone line which is subjected to influence from a power line, and the instruments, is supplied by means of the telephone line insulating transformer shown in Fig. 8. As a transformer strong enough to alone withstand all of the strains met in this service would be very expensive, insulation to permanently stand 25,000 volts from coils to ground is used, and this has been found sufficient for use on telephone circuits paralleling the highest voltage transmission lines, if the proper protective apparatus, consisting of drainage coils, fuses and arresters, is used.

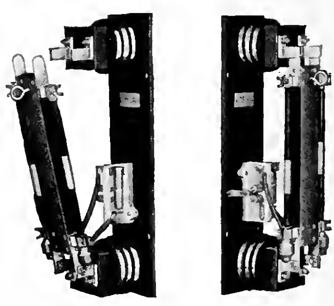


Fig. 6. Combined Double-pole Fused Switch and Lightning Arrester

Two forms of transformers are built: The Form B2, which is used in the majority of cases, and the Form A3, which is used when it is necessary to obtain a neutral point for composite or phantom systems. Both have

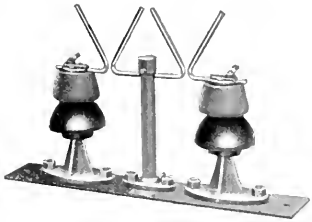


Fig. 7. Double-pole Horn Gap

a simple 1:1 ratio with small loss, and small magnetizing current. These transformers are given a very durable waterproof finish so that they may be installed out of doors.

The Form B2 transformer is the one recommended for general use. It has a single wind-

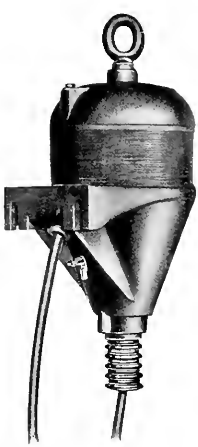


Fig. 8. Telephone Line Insulating Transformer

ing in both primary and secondary, has more iron, and is of lower resistance than the Form A3. As many as ten or twelve stations equipped with the transformer can be connected to the same line if the resistance of the line is not too great and the best commercial 5-bar magneto generators are used.

The Form A3 transformer has a double winding in both primary and secondary, making available a neutral tap in both primary and secondary. This neutral tap serves in special cases for any of the various combination circuit arrangements, such as simultaneous telegraphing or signalling over the same wires without disturbing the telephonic instruments.

The neutral tap also permits grounding the neutral, if this is found desirable, although this is not always recommended, for unless the telephone line is perfectly balanced (which is seldom the case), grounding the neutral tends to make the line noisy, due to earth currents, both direct and alternating, shunted into the telephonic line. When so connected they act as drainage coils and may be burned out due to insufficient capacity.

The Form B2 is generally recommended and is supplied unless conditions are special and Form A3 is specifically called for.

Drainage Coils

The purpose of the drainage coil, which should be used on telephone circuits paralleling transmission lines, is to drain the tele-

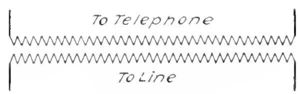
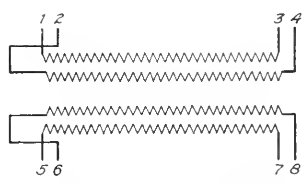


Fig. 9. Connections of Form B2 Telephone Line Insulating Transformer



	Line		Instrument	
Series	5&8	6&7 together and ground if desired	1&4	2&3 together and ground
Parallel	5&6,7&8		1&2,3&4	

Fig. 10. Connections of Form A3 Telephone Line Insulating Transformer

phone circuits of the potentials caused by electromagnetic and electrostatic induction.

Standard 2200-volt distributing transformers selected as outlined below may be used as drainage coils. The number of these coils should be kept as low as possible; in general two should be sufficient, one at each end of the circuit. On large systems, or those of considerable length, a third at the center of the circuits may be found advisable. In connecting these coils across the telephone lines standard fuse cutouts based on maximum rated current capacity of the winding should be used. The transformers should be connected with the high tension windings in series (2200-volt) with the middle point grounded and with the secondaries open.

The mistake must not be made of using too small a transformer, as this may render the telephone line inoperative at just the time when it is most needed, that is, under abnormal or unbalanced conditions on the power circuit. The size of the transformer to be used as a drainage coil depends upon the following factors:

1. Voltage of power circuit.
2. Distance of telephone lines from power circuit.
3. Number of transformers used.
4. Increase of induced potential due to accidental conditions on the power circuit such as arcing grounds, open circuiting of one line, short circuits, etc.

The higher the power voltage and the nearer to the power circuit the telephone lines are located, the larger the transformer that will be required. The number of transformers used has been generally settled by experience at two or three for the average system. The fourth factor is problematical, as it depends upon operating and local conditions. The size of transformer selected should allow a factor of safety of at least five times the normal conditions, so as to insure continuity of service over the telephone circuits and safety to the operators at times of abnormal condition.

The test under normal conditions should be made as follows: Connect the transformers into the circuit at the locations selected, preferably the terminals of the line where but two are to be used, using the same number as will eventually be installed, or otherwise the test is of no value. With the high tension coils in series across the telephone lines, middle point grounded and secondaries open, read the current in the ground connection. As both lines are discharging to ground, this current value is double that in the winding. Using the value of current in the winding with a factor of safety of at least five as a multiplier, the necessary transformer rating can be easily determined.

The series cutouts in the drainage coil connections will protect the coils against a long continued flow of excessive current as might exist under arcing ground conditions on the power circuit. Too frequent blowing of these fuses indicates that too small a transformer is being used.

CLASSIFICATION OF TELEPHONE LINES AND RECOMMENDATIONS FOR PROTECTION

Classification of Telephone Circuits from the Standpoint of Protection

As the position of the telephone circuit with respect to the transmission circuit determines the likelihood of troubles due to crosses or induction, the telephone circuits have been classified with this point in view.

Class 1. *Telephone circuits which do not cross or parallel power lines.*

Class 2. *Telephone circuits which cross but do not parallel power lines.*

Class 3. *Telephone circuits which parallel power lines but are not on the same towers or poles and do not cross power lines.*

Class 4. *Telephone circuits which are on the towers or poles with the power lines.*

This classification covers every possible case, from a telephone line far removed from the power circuit to one mounted on the transmission towers themselves. Classes 3 and 4 are the most common. The sources of trouble vary from lightning only in Class 1, to lightning, crosses, and induction in Class 4.

Specific Recommendations for Protection

Specific recommendations for the protection of the telephone circuit according to the classification of the circuit into which it falls are as follows:

Class 1. *Telephone circuits which do not parallel or cross power lines.*

Disturbances: Lightning.
Recommendations: Vacuum tube lightning arresters (Fig. 1) from each line to ground at all telephone stations.

Class 2. *Telephone circuits which cross but do not parallel power lines.*

Disturbances: These circuits are subject to lightning disturbances and to contact with the high voltage power lines through broken wires, etc. They are not subject, to any extent, to electromagnetic or electrostatic induction.

Recommendations:

1. Combined double-pole fused switch and lightning arrester (Fig. 6) in series with the main telephone line on both sides of crossing at nearest telephone stations.
2. Lightning arresters (Fig. 4) at all other stations.

this class of telephone circuits is shown in Fig. 11. The double-pole horn gap shown on the diagram is not used on this class of circuit but on circuits coming under Class 4.

Class 4. *Telephone circuits which are carried on the towers or poles with the power lines.*

Disturbances: These circuits are subject to lightning disturbances, electrostatic and electromagnetic induction, and to crosses with the power lines.

Recommendations:

1. Insulating transformers at all telephone stations. (Fig. 8).

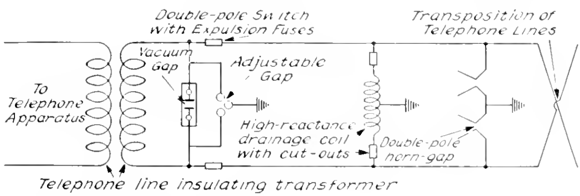


Fig. 11. Diagram of Connections for Protective Apparatus Recommended for Telephone Lines, Classes 3 and 4

Class 3. *Telephone circuits which parallel power lines, but are not on the same towers or poles and do not cross power lines.*

Disturbances: These circuits are subject to lightning disturbances, and electromagnetic and electrostatic induction They are not subject to contact with the power lines.

Recommendations:

1. Insulating transformers at all telephone stations. (Fig. 8.)
2. Combined double-pole fused switch and lightning arrester (Fig. 6) at all telephone stations on the line side of the insulating transformer.
3. Drainage coils, preferably one at each end of line.

Diagram of connections: A diagram of connections for the apparatus used on

2. Combined double-pole fused switch and lightning arrester (Fig. 6) at all telephone stations on the line side of the insulating transformer.
3. Double-pole horn gap (Fig. 7), across line at each station on line side of all other apparatus for the protection of insulators on telephone circuit in case of crosses with the power lines after series fuses are blown.
4. Drainage coils installed with fuses at each end of line; possibly an additional coil at the middle if the voltage to ground is not held to a safe value by two coils.

Diagram of connections: A diagram of the connections for the apparatus used on this class of telephone circuits is shown in Fig. 11.

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, N. Y.

ARCS: TALKING AND OSCILLATORY

(189) Please explain how the talking arc is produced and how it differs from the usual oscillatory arc which was discussed by Dr. C. P. Steinmetz in the GENERAL ELECTRIC REVIEW, February, 1916, Page 160.

The conditions required for the production of the talking arc are quite different from those in which the arc is used for the production of high-frequency oscillations. The circuit conditions for producing Elihu Thomson's oscillator (U. S. Patent No. 500,630, July 18, 1892) are illustrated in Fig. 1. The resistances and inductances, R_1, L_1, are used to isolate the supply source from the oscillating circuit proper which is composed of L, C and the arc. The direct-current supply voltage should be 500 volts or more.

In 1900, Duddell read an extremely interesting paper before the Institute of Electrical Engineers of London, (Vol. XXX, 1900-1901, p. 232) on "Rapid Variations in the Current through the Direct-Current Arc," in which various types of arc oscillations are fully described. He substituted for the metal spark-gap, previously used by Elihu Thomson, carbon electrodes and thereby showed a great variety of interesting phenomena. Fig. 2. illustrates the circuit connections. In this paper Duddell gave the following specifications for producing an oscillating arc using carbon electrodes:

Both carbons solid about 9 m.m. diameter.
Arc length about 1.5 m.m.
Arc current about 3.5 amperes.
Resistance in series with arc 42 ohms.
Inductance of shunt across carbons 5.3 millihenrys and 0.44 ohms resistance.
Capacity of condenser 1.1 to 5.4 m.f.
Effective value of current through condenser circuit 3 amperes.
Direct-current supply voltage about 50 volts.

The frequency of oscillation is given approximately by the usual formula for the oscillating discharge of a condenser through an inductance; viz.,

$$f=\frac{1}{2\pi\sqrt{LC}} \text{ cycles per second.}$$

Thus, if we take the values given by Duddell, when

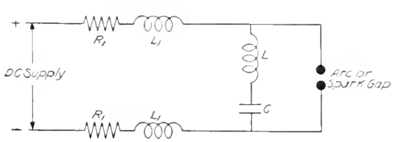
$L=5.3\times10^{-3}$ henrys.
$C=1.1\times10^{-6}$ farads.

$$f=\frac{1}{2\pi\sqrt{5.3\times1.1\times10^{-9}}}=2080 \text{ cycles per sec.}$$

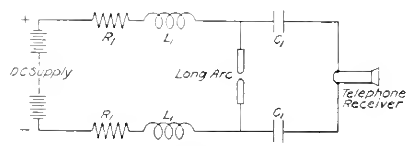
and when

$L=5.3\times10^{-3}$ henrys.
$C=5.4\times10^{-6}$ farads.
$f=945$ cycles per sec.

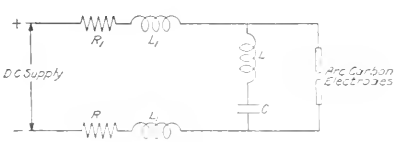
The first calculation gives 2080 cycles per second, which is barely audible. By increasing the capacity the frequency is lowered to 945 cycles per second, which is readily perceived as a musical note. Thus,



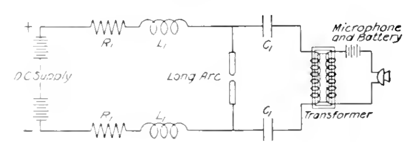
(189) Fig. 1



(189) Fig. 3



(189) Fig. 2



(189) Fig. 4

the so-called musical arc results when the inductance and capacity are such that the resulting frequency of oscillation lies within the audible range of frequencies. The fact that a musical note is heard, which corresponds approximately to the frequency of the current flowing through the arc, indicates that the rapid changes in the arc current produce proportionate changes in the volume of the vapor stream and, in this manner, impress waves of compression and rarefaction upon the surrounding air, or, in other words, sound waves.

H. Th. Simon of Göttingen, in 1898, applied this phenomenon to the production of articulate speech. For this purpose a long steady silent arc is desirable; it may be used either as a receiver or as a transmitter. For example, with a circuit connected as shown in Fig. 3, use can be made of the sensitivity of the arc current to those small changes in arc volume which are produced by the rarefactions and compressions of sound waves. Here the arc stream serves as a telephone transmitter and any sounds made near it can be distinctly heard in the telephone receiver. To employ the arc as a receiver the process is reversed; the current variations in a microphone circuit are super-imposed upon the arc stream, thereby altering the volume of the arc proportionately to the articulate speech. A diagram of connections for this latter case is given in Fig. 4. The circuits of the talking arc are not oscillatory. The function of the resistance and inductance, R_1, L_1, is to steady the arc, and, at the same time, to prevent the alternating current of speech from passing into the supply circuit. The condensers, C_1, are employed merely to prevent the direct current from going into the receiving or microphone circuits. The transformer is used to isolate the microphone circuit.

Since for the production of a talking arc a long silent arc is desirable, cored carbons and an arc current of from 10 to 12 amperes are usually employed. The source of supply should preferably be a battery of about 50 volts or more, for considerable noise will come into the system from commutator segments if a direct-current machine is used.

C.W.R.

CALCULATIONS: INDUCTANCE, CAPACITY, AND RESISTANCE IN SERIES AND IN PARALLEL

(190) What is the total impendance of the circuit illustrated in Fig. 1? Explain the method of calculation.

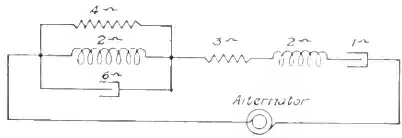
This problem can be solved by either of two methods. One is based on graphics; this is by far the simpler mode. The other employs only mathematics; this method furnishes a more exact answer than does the former. Both will be described.

Since there are two distinct combinations of the resistance, magnetic reactance, and capacity reactance in the circuit, the problem will be divided first into two parts, viz., (a) the impedance of the parallel group and (b) the impedance of the series group. The combination of these two impedances will then be the total impedance of the circuit.

The impedance of a parallel circuit is equal to the reciprocal of the vector sum of the reciprocals of the ohmic values of the sub-circuits. The impedance of a series circuit is equal to the vector sum of the ohmic values of all the parts of the circuit.

I Graphical Method:

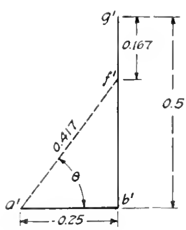
(Assume the vector direction for resistance to be horizontally to the right, for magnetic reactance to be vertically upward, and for capacity reactance to be vertically downward).



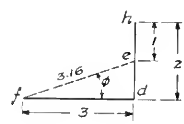
(190) Fig. 1

(*a*) For the parallel group lay out the vectors, as shown in Fig. 2, equal to the reciprocal of the ohmic values of the conductors, i.e., for resistance draw *a'b'* $\frac{1}{4}$ or 0.25 of a unit to the right, for magnetic reactance *b'g'* $\frac{1}{2}$ or 0.5 upward, and for capacity reactance *g'f'* $\frac{1}{6}$ or 0.167 downward. The vector, *a'f'*, that joins this last point to the first will be at some angle θ to the horizontal and will scale 0.417 in length. The impedance of the parallel group will therefore be $\frac{1}{0.417}$ or 2.4 ohms.

(*b*) For the series group lay out the vectors, as shown in Fig. 3, directly equal to the ohmic values of the conductors, i.e., for resistance draw *fd* 3 units to the right, for magnetic reactance *dh* 2 upward, and for capacity reactance *he* 1 downward. The resultant vector, *fe*, will be at some angle ϕ to the horizontal and will scale 3.16 ohms, which will be the impedance of the series group of the circuit.



(190) Fig. 2



(190) Fig. 3

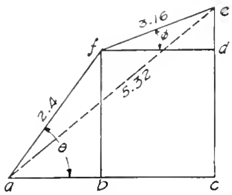
Combination of the two groups:

Lay out a vector, *af*, 2.4 units in length at the angle θ to the horizontal, see Fig. 4. From the end of this line lay out a vector, *fe*, 3.16 units in length at the angle ϕ to the horizontal. The line bridging these two vectors from end to end, *ae*, will represent the total impedance of the circuit, the value of which will be found to be 5.32 ohms by scaling the length.

II Mathematical Method

This method employes the general formula

"Impedance equals the square root of the sum of the resistance squared and the arithmetical difference between the magnetic and capacity reactances squared."



(190) Fig. 4

(*a*) For the parallel group the reciprocal of the ohmic values of the sub-circuits are used, the reciprocal of the resultant giving the impedance. This coincides mathematically with the graphical method described in Method I (*a*).

$$\text{Impedance} = \frac{1}{\sqrt{(\frac{1}{4})^2 + (\frac{1}{2} - \frac{1}{6})^2}}$$
$$= 2.4 \text{ ohms.}$$

(*b*) For the series group the general formula is applied directly

$$\text{Impedance} = \sqrt{3^2 + (2-1)^2}$$
$$= 3.16 \text{ ohms}$$

Combination of the two groups:

Since the influence of the parallel group on the power-factor is not the same as that of the series group, the respective resultant ohmic values of the two groups must be added in accordance with the difference in phase angle, in order to obtain the total impedance.

This is best accomplished by squaring the arithmetical sum of the two resistance components of the two groups, adding to this the square of the arithmetical sum of the resultant magnetic or capacity reactance of the two groups, and determining the square root of the whole. In the symbols of Fig. 4 this is

$$ae = \sqrt{(ab+bc)^2 + (cd+de)^2}$$

$$ab = 2.4 \times \frac{a'b'}{a'f'} \text{(from Fig. 2)} = 2.4 \times \frac{0.25}{0.417} = 1.44$$

$$bc = fd \text{ (from Fig. 3)} = 3$$

$$cd = bf = 2.4 \times \frac{b'f'}{a'f'} \text{ (from Fig. 2)} =$$

$$2.4 \times \frac{(0.5 - 0.167)}{0.417} = 1.92$$

$$de = 2 - 1 \text{ (from Fig. 3)} = 1$$

Impedance, therefore, equals

$$\sqrt{(ab+bc)^2 + (cd+de)^2}$$
$$= \sqrt{(1.44+3)^2 + (1.92+1)^2}$$
$$= 5.32 \text{ ohms}$$

E.C.S.

SYNCHRONOUS CONDENSER: LOSS AND POWER-FACTOR

(191) Consider a synchronous condenser operating at unity power-factor. If, now, a leading power-factor is produced by over-excitation of the condenser field, or a lagging power-factor by under-excitation of the field, will the increased energy drawn from the line be equal to the additional I^2R loss that is caused by the increase of current?

The increase of energy intake will be ***greater*** than the additional I^2R loss. The increment by which it is greater than the I^2R loss is a combination of core loss and copper loss and is due directly to the distortion of the field flux which occurs when the field is over-excited or under-excited. Under these conditions of distorted flux, higher than normal flux densities exist in some parts of the magnetic circuit and lower than normal densities exist in others. The increase of core loss caused by the higher densities more than offsets the decrease by the lower densities. The increase of copper loss occurs as an eddy current loss in the armature conductors and is caused by the deeper than normal flux penetration of the slots by the higher density flux.

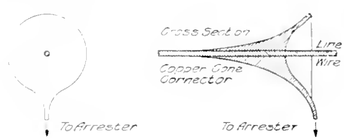
W. J. F.

CONE: PROTECTIVE VALUE

(192) If a metallic cone, such as shown in Fig. 1, is used at the point where a lightning arrester is tapped to a line, will not the skin effect of the cone considerably assist in deflecting a high-frequency disturbance into the arrester?

Although it is true that the skin effect of the metallic cone does tend to remove high-frequency current from the line wire, the added degree of protection secured by the use of such a cone is ordinarily quite inappreciable. This fact can be demonstrated as follows:

(The effect which the shape of a conductor has upon its skin effect, when carrying high-frequency current, should be studied in terms of the inductance of the conductor. The inductance of a conductor decreases inversely as its diameter and increases directly as its length.)



(192) Fig. 1

In the proposed arrangement, the inductance of the cone is less than that of an equal length of wire, because of the greater diameter of the cone. However, laboratory tests of various shaped conductors carrying high-frequency current show that only a slightly lessened inductance is secured by the substitution of such a cone for an equal length of wire. In the arrangement described, the decreased amount of inductance obtained by the use of a cone would be diminutive when compared to the total inductance of the arrester discharge circuit, which of necessity includes some 20 to 40 feet of ground wire down the pole.

In combination with the lightning arrester, a choke coil of a few turns placed next to the transformer would furnish a far greater degree of protection than would the cone at the same cost.

E.E.F.C.

STORAGE BATTERY: EFFECT WHEN IN SERIES WITH A CONSTANT-CURRENT GENERATOR

(193) Fig. 1 illustrates a constant-current circuit in which *G* is a direct-current generator.

***L's* are series arc lamps.**

***B* is a storage battery.**

What will be the effect of the storage battery, *B*, on the current, voltage, and watts in the circuit?

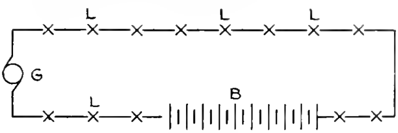
For the discussion of this problem the values of the current and certain voltages and resistances must be known. Assume these to be as follows:

Constant current in circuit $= C$

Operating voltage of a single lamp $= L_v$

Inherent internal voltage of the battery at the particular stage of charge or discharge considered $= B_v$

Internal resistance of battery $= B_r$ ohms.



(193) Fig. 1

The absence or presence of the battery will have no effect upon the current flowing in the circuit. The current will be C without the battery, or with the battery whether connected in to assist or to oppose the generator voltage.

The voltage and watt conditions in the circuit will, however, be influenced by the absence or presence of the battery and by the polarity of the battery (relative to that of the generator).

Without Battery

Consider for a moment that the battery has been omitted from the circuit illustrated in Fig. 1. To force the current C around the circuit of 13 lamps, the generator will deliver $13L_v$ volts and $13L_vC$ watts.

With Assisting Battery

Now, consider the effect of inserting the storage battery connected so as to *assist* the flow of current in the circuit. Since the lamp load remains constant and the current constant, the total voltage applied to the lamps will be the same as before. Therefore, the generator and the storage battery, assisting one another, together furnish 13 L_v volts. The battery's contribution to this is its terminal voltage, which is equal to its inherent internal voltage *minus* its voltage drop, equal to $B_v - B_rC$ volts.

Consequently, the generator voltage is now 13 $L_v - (B_v - B_rC)$ volts.

Under these conditions the battery discharges, and in discharging, assumes a part of the lamp load, the total lamp load having previously been carried by the generator. The battery's output is its inherent capacity *minus* its loss; i.e., $B_vC - B_rC^2$ watts. Therefore, the generator's output is now 13 $L_vC - (B_vC - B_rC^2)$.

With Opposing Battery

Now, consider the effect of inserting the storage battery connected so as to *oppose* the flow of current in the circuit. Since the lamp load still remains constant and the current constant, the total voltage applied to the lamps will be the same as before. Therefore, the generator and the storage battery, opposing one another, together furnish 13 L_v volts. However, with this connection the 13 L_v volts is the *difference* between the generator and the battery voltages; while in the preceding case it was the *sum*. The battery terminal voltage in this case is equal to its inherent internal voltage *plus* its voltage drop, equal to $B_v + B_rC$. Therefore, the generator voltage is 13 $L_v + (B_v + B_r C)$.

Under these conditions of opposition, the battery is charged by the generator, thereby increasing the load on the machine which must also carry the entire lamp load. The battery's input, charge *plus* loss, is $B_vC + B_rC^2$. Therefore, the generator's output is now 13 $L_vC + (B_vC + B_rC^2)$.

E.C.S.

TRANSFORMERS: DELTA CONNECTION

(194) What is the maximum allowable difference between the impedances of three single-phase transformers that are to be operated in delta?

The heating due to load current plus circulating current is the factor determining the allowable difference in impedance. In the following cases a limit of 110 per cent is considered the maximum safe current for a transformer.

CASE I

Two transformers with equal impedance, the third with impedance different from the other two; also similar capacities, ratios, and impedance angles $\left(\text{ratio } \frac{\text{per cent } IX}{\text{per cent } IR}\right)$.

The impedance of the third transformer may be from 73 per cent minimum to 163 per cent maximum of one of the equal impedances, which condition results in a maximum overload current of 10 per cent in any transformer in the delta bank.

CASE II

All impedances different; ratios and impedance angles similar.

A general statement cannot be made to cover this case. However, bearing in mind the limit of 110 per cent current in any transformer winding, the following equations can be applied.*

$$i_1 = I_L \frac{\sqrt{Z_2^2 + Z_3^2 + Z_2Z_3}}{Z}$$

$$i_2 = I_L \frac{\sqrt{Z_1^2 + Z_3^2 + Z_1Z_3}}{Z}$$

$$i_3 = I_L \frac{\sqrt{Z_1^2 + Z_2^2 + Z_1Z_2}}{Z}$$

Where I_L = balanced line current

i_1, i_2, and i_3 = current in winding of transformers No. 1, 2, and 3.

Z_1, Z_2, and Z_3 = ohmic impedance of transformers No. 1, 2 and 3,

and

$Z = Z_1 + Z_2 + Z_3$.

H. C. S.

*From "Delta-Delta Transformer Banks in Multiple" by W. W. Lewis, GENERAL ELECTRIC REVIEW, Jan. 1912, p. 47.

DEFINITIONS: DEGREE OF ENCLOSURE FOR ROTATING MACHINES

(195) Is there a general agreement throughout the electrical industry with regard to the terms employed to describe rotating electrical machines with respect to the degree of enclosure or protection?

The American usage of such terms is set forth in Sections 160 to 172 (inclusive) of the October, 1916, edition of the A.I.E.E. Standardization Rules. British practice as set forth in the British Standardization Rules for Electrical Machinery, published in October, 1915, differs slightly. For convenience, the two sets of definitions are given below in parallel columns. H.M.H.

Classification of Rotating Machines Relative to Degree of Enclosure or Protection

(Numerals in italics are Section References)

AMERICAN	BRITISH
(161) An **open** machine is of either the pedestal-bearing or end-bracket type where there is no restriction to ventilation, other than that necessitated by good mechanical construction.	*(18)* An **open** machine is one in which there is no restriction to ventilation other than that necessitated by good mechanical construction.
(162) A **protected** machine is one in which the armature, field coils, and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.	*(19)* A **protected** machine is one having end shield bearings, and in which there is free access to the interior without opening doors or removing covers.
(163) A **semi-enclosed** machine is one in which the ventilating openings in the frame are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures not exceeding $\frac{1}{2}$ of a square inch (3.2 sq. cm.) in area.	*(20)* A **semi-enclosed** machine is one in which the ventilating openings in the frame are covered with: (a) Grids, expanded metal or wire gauze, with openings of not less than $\frac{1}{4}$ in., so as not to obstruct free ventilation. (b) Wire gauze, in which the openings are less than $\frac{1}{4}$ in. but not less than $\frac{3}{32}$ in. or with perforated metal having holes not less than $\frac{3}{16}$ in. (diameter or width). (c) Screens with smaller openings than the above. Machines in Class (c) shall comply with these rules when the openings are closed, as such openings frequently become clogged in actual service.
(164) An **enclosed** machine is so completely enclosed by integral or auxiliary covers as to prevent a circulation of air between the inside and outside of its case but not sufficiently to be termed air-tight.	
	(21) A **totally-enclosed** machine is one in which the enclosing case and bearings are dust-proof, and which does not allow a circulation of air between the inside and outside of the case.
(165) A **separately ventilated** machine has its ventilating air supplied by an independent fan or blower external to the machine.	*(23)* A **forced-draught** machine is an enclosed machine in which the ventilating air supply is maintained by an independent fan external to the machine itself.
(166) A **water-cooled** machine is one which mainly depends on water circulation for the removal of its heat.	
(167) A **self-ventilated** machine differs from a separately ventilated machine only in having its ventilating air circulated by a fan, blower or centrifugal device integral with the machine. If the heated air expelled from the machine is conveyed away through a pipe attached to the machine, this should be so stated.	*(22)* A **pipe-ventilated** machine is an enclosed machine in which the frame is so arranged that the ventilating air may be conveyed to it through a pipe attached to the frame, the ventilation being maintained by the fanning action produced by the machine itself. If the heated air expelled from the machine is conveyed away through a second pipe attached to the machine, this should be specially stated.

Classification of Rotating Machines Relative to Degree of Enclosure or Protection

(Continued)

AMERICAN	BRITISH
(*168*) A **drip-proof** machine is one so protected as to exclude falling moisture or dirt. A drip-proof machine may be either open or semi-enclosed, if it is provided with suitable protection integral with the machine, or so enclosed as to exclude effectively falling solid or liquid material.	(*24*) A **drip-proof** machine is one having a frame provided with openings for ventilation so protected as to exclude falling moisture or dirt.
(*169*) A **moisture-resisting** machine is one in which all parts are treated with moisture-resisting material. Such a machine shall be capable of operating continuously or intermittently in a very humid atmosphere, such as in mines, evaporating rooms, etc.	
(*170*) A **submersible** machine is a machine capable of withstanding complete submersion, in fresh water or sea water, as may be specified, for four hours without injury.	
(*171*) An **explosion-proof** machine is a machine in which the enclosing case can withstand, without injury, any explosion of gas that may occur within it, and will not transmit the flame to any inflammable gas outside it. (*172*) An induction motor in which the slip rings and brushes alone are included within an explosion-proof case should not be described as an explosion-proof machine, but as a machine "with explosion-proof slip-ring enclosure."	(*25*) A **flame-proof** machine is one in which the enclosing case can withstand, without injury, any explosion of gas that may occur within it, and will not transmit the explosion to any inflammable gas outside it. A machine in which the slip rings and brushes alone are enclosed in a flame-proof case is not called a flame-proof machine. Such a machine should be referred to as one with a "flame-proof slip-ring enclosure."

A-C. GENERATOR: DRYING OUT

(196) Describe the method recommended for drying out an alternating-current generator.

A generator may be dried out simply by driving the rotor at normal speed for several days by the prime mover.

However, if excitation is applied in addition the process will be accelerated. In this case, a generator of less than 6600 terminal volts should be run at normal speed with the armature windings short circuited and with a field excitation sufficient to give approximately 110 per cent normal current in the armature windings. For a generator of 6600 terminal volts or more, it is recommended that the drying-out process be conducted by alternate runs with the armature windings short circuited (and excited as previously described) and the windings open circuited (and excited to give approximately 110 per cent normal voltage). The former dries the insulation from the inside outward, and the latter the reverse. This alternation should be kept up until the insulation resistance, as measured by a megger, becomes fairly constant. An empirical rule which has proved very satisfactory is that the insulation resistance of the armature windings should be approximately equal to three times the terminal voltage divided by the kilovolt-ampere rating; e.g., assume a 10,000-kv-a., 6600-volt generator:

The insulation resistance should be approximately

$$\frac{3 \times 6600}{10,000} = 1.98 \text{ megohms.}$$

While this applies to the armature windings only, it may be used as an indication of the completion of the drying-out process, for stator and rotor windings are dried at the same time. T.S.E.

SYNCHRONOUS MOTOR: DRYING OUT

(197) Describe the method recommended for drying out a synchronous motor.

In general the methods described for alternating-current generators in Q. & A. No. 196 cannot be applied to synchronous motors and frequency changers. If a source of direct current is available, the field and armature windings may be connected in series or parallel depending on the machine and current passed through until a temperature of approximately 65 deg. C. by thermometer is reached. This should be continued until the insulation resistance by megger attains the value designated in Q. & A. No. 196, or until it becomes constant.

Another method is to dry out the machine by an application of external heat. For the source of heat an oven may be used, or a number of coils of steam pipe, which with the motor are to be enclosed in a box. Openings in the top and bottom of the box should be provided to give circulation, the moisture being carried off by the hot air. T.S.E.

RAILWAY MOTOR: SPEED CONTROL

(198) Describe the tapped-field method of railway motor speed control.

The tapped-field method of speed control consists simply of cutting out a portion of the field turns of a railway motor, when it is desired to increase the speed above that obtained with full-field excitation. Ordinarily this is done in one step; although in some cases a second section of the field is cut out thus giving two speeds higher than that corresponding to full field. In practice, the fields may be tapped for both series and multiple connections of the motors, but in most instances the multiple position only is used.

G.L.S.

TRANSFORMER : COOLING COIL

(199) Describe a means for removing the scale that accumulates, under certain conditions, in the cooling coils of water-cooled transformers.

The only method recommended for removing the scale, deposited by the cooling water, consists of dissolving it out with dilute acid. Both ends of the cooling coil are disconnected from the water system piping at a point some feet away from the transformer to prevent acid, dirt, or water from entering the transformer. All the water should be blown or syphoned from the coil and then the coil should be filled with a solution of hydrochloric acid having a specific gravity of 1.1 (this is made up by using equal parts of concentrated hydrochloric acid and commercially pure water). After the solution has stood in the coils for about an hour, the coils should be flushed out thoroughly. The number of times it will be necessary to repeat this performance will depend upon the amount of the scale. Ordinarily one or two fillings will be sufficient.

Since the chemical action which takes place is very noticeable and even forces acid, sediment, etc., from both ends of the coils, it is well to leave both ends open to prevent abnormal pressure.

F.R.F.

ELECTROSTATIC SYNCHRONISM INDICATOR: CONSTRUCTION, OPERATION AND APPLICATION

(200) Describe the electrostatic synchronism indicator and its operation. Under what conditions is it to be preferred to the ordinary (or magnetic) synchronism indicator?

The electrostatic instrument essentially consists of three special glower lamps which are operated by the charging current of suspension insulators used as condensers; one set of insulators being required for each phase of the incoming and operating lines. The lamps are mounted in a case and project through holes in the cover to permit observation from the side as well as the front. The instrument is mounted on a panel with the two three-pole switches which connect it to the incoming and operating lines. The suspension insulators have an insulation strength equal to that used on the line. The glower lamps when not excited have the appearance of ordinary spherical frosted incandescent lamp bulbs. When the proper difference of potential is applied across the terminals of the lamps, they glow with a reddish hue due to the special gas which they contain.

One of the glowers is connected to the lines of the incoming and running machines, so that the glower will be short circuited by one pole of the switch when the lines are connected together. The other two glowers have their connections to the line through the insulators reversed, so that at synchronism they are connected across the two remaining phases of the lines with one connection on each glower on the opposite side of the synchronizing oil circuit-breaker.

When the lines are not in synchronism, the glowers will indicate in an order similar to that of the ordinary synchronizing lamps the apparent direction of rotation, denoting whether the incoming machine is running fast or slow. When synchronism is reached, there will be no rotating effect and the one glower which is connected to corresponding lines will be dark while the other two glowers will indicate at about one-half brilliancy, which is the condition for throwing the machines together.

The instrument will give satisfactory indications on circuits of as low a pressure as 13,200 volts and it can be applied to lines of any higher voltage by simply connecting in the proper number of insulator condensers.

The electrostatic instrument is suitable primarily for indicating synchronism between high-tension circuits in stations where the voltage and current is measured on the low-voltage side. Under such conditions, the comparative cost of an electrostatic equipment is low because it is not necessary to install the expensive high-tension potential transformers that would be required by the magnetic instrument.

R.M.S.

CONDENSERS: TWO IN SERIES ON D-C.

(201) If two condensers of similar microfarad capacity are connected in series across a source of direct-current potential will the potential strain on the dielectric of one be equal to that on the other?

When two electrostatic condensers are connected in series across a source of direct-current potential having a perfectly uniform voltage curve, that is, without pulsations, the condensers will divide the voltage in proportion to their respective insulation resistances. Since the insulation resistance is a factor which varies over a wide range, there may be a very material inequality in their respective voltage drops. In such cases, therefore, it is customary to shunt the two condensers with a non-inductive high resistance having its middle point connected to the junction between the two condensers. Such a resistance, though it may take only a few hundredths of an ampere, is low in comparison with the insulation resistance of the condenser; and, hence, the current passing through it is able to control the distribution of voltage across the condensers.

If, on the other hand, the source of direct current is a pulsating voltage curve of such magnitude that the capacity current taken by the condensers is large in proportion to the leakage through their insulation, it is not necessary to use an auxiliary balancing resistance since the distribution of voltage across the units will now be determined by their respective capacities, which are equal.

S.T.

ERRATUM: In the thirteenth line from the bottom of the righ -hand column, page 1043, November GENERAL ELECTRIC REVIEW, the reference to Fig. 3 is a typographical error. Fig. 2 is the correct illustration.