Cyclopedia
of
Applied Electricity

A General Reference Work on

DIRECT-CURRENT GENERATORS AND MOTORS, STORAGE BATTERIES, ELECTRIC WIRING, ELECTRICAL MEASUREMENTS, ELECTRIC LIGHTING, ELECTRIC RAILWAYS, POWER STATIONS, POWER TRANSMISSION, ALTERNATING-CURRENT MACHINERY, TELEPHONY, TELEGRAPHY, ETC.

Prepared by a Corps of

ELECTRICAL EXPERTS, ENGINEERS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Two Thousand Engravings

SEVEN VOLUMES

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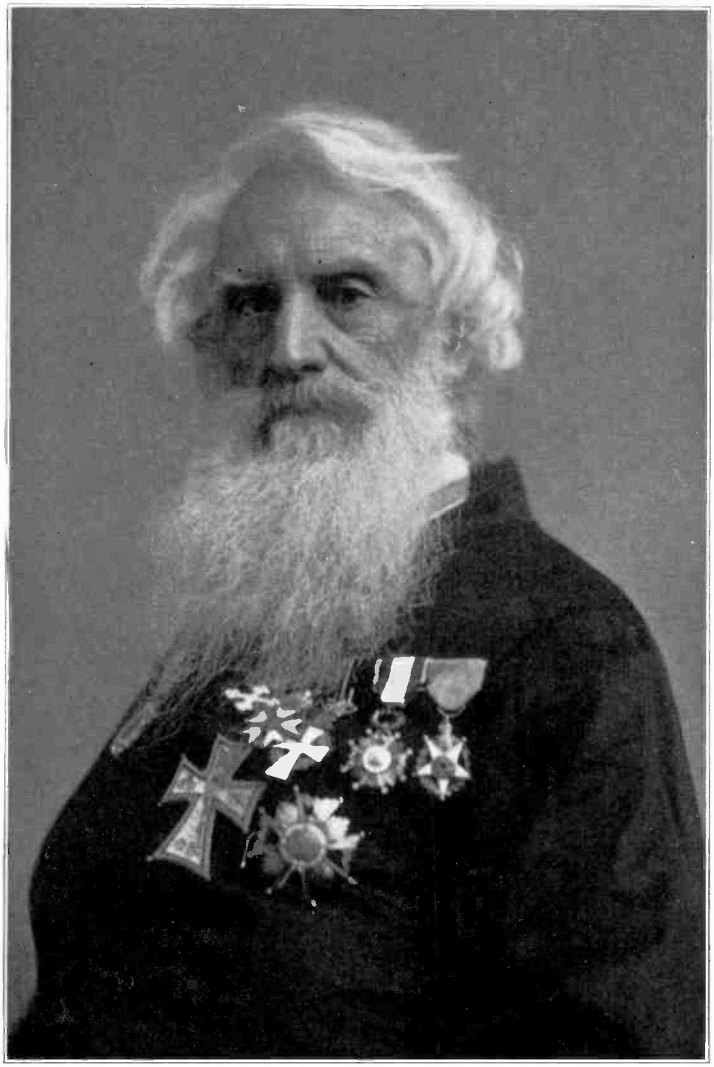

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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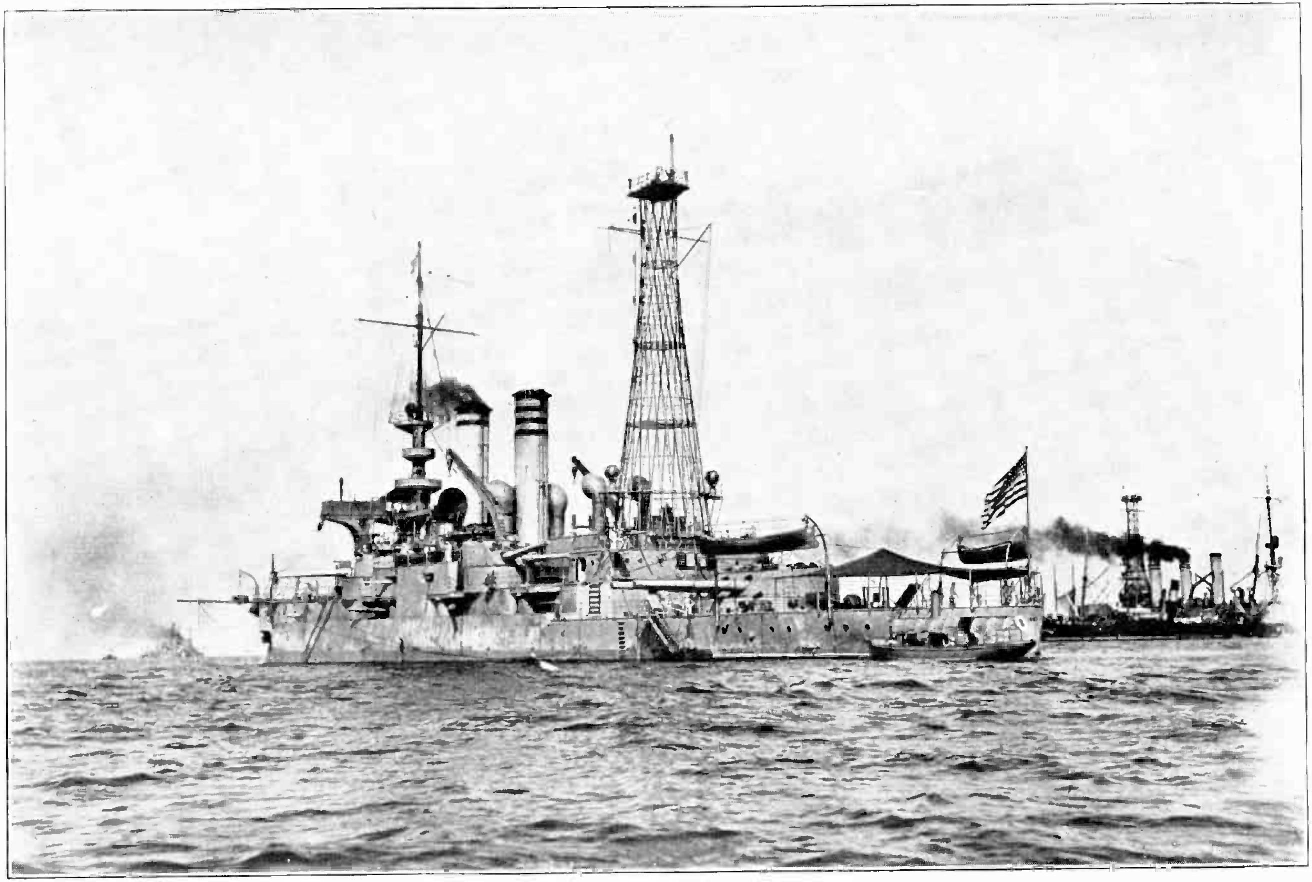

BATTLESHIP SUPPLIED WITH WIRELESS TELEGRAPH EQUIPMENT
The New- and Old-Style Masts or Aërials are shown in Contrast—the New at the Right, and the Old at the Left.

Foreword

ONE of the simplest acts in modern life is switching on the electric current that gives light or power, or that makes possible communication between distant points. A child can perform that act as effectively as a man, so thoroughly has electricity been broken to the harness of the world's work; but behind that simple act stand a hundred years of struggle and achievement, and the untiring labors of thousands of the century's greatest scientists. To compact the results of these labors into the compass of a practical reference work is the achievement that has been attempted—and it is believed accomplished—in this latest edition of the Cyclopedia of Applied Electricity.

¶ Books on electrical topics are almost as many as the subjects of which they treat and many of them are worthy of a place in the first rank. But many, also, worthy in themselves, are too scientific in their treatment to be available for the mass of electrical workers; and all of them, if gathered into a great common library, would contain so many duplicate pages that their use would entail an appalling waste of time upon the man who is trying to keep up with electrical progress. To overcome these difficulties the publishers of this Cyclopedia went direct to the original sources, and secured as writers of the various sections, men of wide practical experience and thorough technical training, each an acknowledged authority in his work; and these contributions have been correlated by our Board of Editors so as to make the work a unified whole, logical in arrangement and at the same time devoid of duplication.

¶ The Cyclopedia is, therefore, a complete and practical working treatise on the generation and application of electric power. It covers the known principles and laws of Electricity, its generation by dynamos operated by steam, gas, and water power; its transmission and storage; and its commercial application for purposes of power, light, transportation, and communication. It includes the construction as well as the operation of all plants and instruments involved in its use; and it is exhaustive in its treatment of operating "troubles" and their remedies.

¶ It accomplishes these things both by the simplicity of its text and the graphicness of its supplementary diagrams and illustrations. The Cyclopedia is as thoroughly scientific as any work could be; but its treatment is as free as possible from abstruse mathematics and unnecessary technical phrasing, while it gives particular attention to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are used without stint, where they can help to explain the subject under discussion; and they are kept simple, practical, and easy to understand.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Books of the American School of Correspondence, and the method adopted in its preparation is that which this School has developed and employed so successfully for many years. This method is not an experiment, but has stood the severest of all tests —that of practical use—which has demonstrated it to be the best devised for the education of the busy, practical man.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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CAZADRO HYDRO-ELECTRIC POWER PLANT OF THE PORTLAND (ORE.) RAILWAY, LIGHT & POWER CO.
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POWER STATIONS

INTRODUCTION

With the rapid increase of the use of electricity for power, lighting, traction, and electro-chemical processes, the power houses equipped for the generation of the electrical supply have increased in size from plants containing a few low-capacity dynamos, belted to their prime movers and lighting a limited district, to the modern central station, furnishing power to immense systems and over extended areas. Examples of the latter type of station are found at Niagara Falls, and such stations as the Metropolitan and Manhattan stations in New York City, and the plants of the Boston Edison Illuminating Company, etc.

The subject of the design, operation, and maintenance of central stations forms an extended and attractive branch of electrical engineering. The design of a successful station requires scientific training, extensive experience, and technical ability. Knowledge of electrical subjects alone will not suffice, as civil and mechanical engineering ability is called into play as well, while ultimate success depends largely on financial conditions. Thus, with unlimited capital, a station of high economy of operation may be designed and constructed, but the business may be such that the fixed charges for money invested will more than equal the difference between the receipts of the company and the cost of the generation of power alone. In such cases it is better to build a cheaper station and one not possessing such extremely high economy, but on which the fixed charges are so greatly reduced that it may be operated at a profit to the owners.

The designing engineer should be thoroughly familiar with the nature and extent of the demand for power and with the probable increase in this demand. Few systems can be completed for their ultimate capacity at first and, at the same time, be operated economically. Only such generating units, with suitable reserve capacity, as are necessary to supply the demand should be installed at first, but all apparatus should be arranged in such a manner that future extensions can readily be made.

Power stations, as here treated, will be considered under the following general topics:

Location of Station
Steam Plant
Hydraulic Plant
Gas Plant
Electric Plant
Buildings
Station Records

LOCATION OF STATION

The choice of a site for the generating station is very closely connected with the selection of the system to be used, which system, in turn, depends largely on the nature of the demand, so that it is a little difficult to treat these topics separately. Several possible sites are often available, and we may either consider the requirements of an ideal location, selecting the available one which is nearest to this in its characteristics, or we may select the best system for a given area and assume that the station may be located where it would be best adapted to this system. Wherever the site may be, it is possible to select an efficient system, though not always an ideal one.

The points that should be considered in the location of a station, no matter what the system used, are accessibility, water supply, stability of foundations, surroundings, facility for extension, and cost of real estate.

Accessibility. The station should be readily accessible on account of the delivery of fuel, of stores, and of machinery. It should be so located that ashes and cinders may easily be removed. If possible, the station should be located so as to be reached by both rail and water, though the former is generally more desirable. If the coal can be delivered to the bunkers directly from the cars, the very important item of the cost of handling fuel may be greatly reduced. Again, the station should be in such a location that it may readily be reached by the workmen.

Water Supply. Cheap and abundant water supply for both boilers and condensers is of utmost importance in locating a steam station. The quality of the water supply for the boiler is of more importance than the quantity. It should be as free as possible from impurities which are liable to corrode the boilers, and for this reason water from the town mains is often used, even when other water is available, as it is possible to economize in the use of water by the selection of proper condensers. The supply for condensing purposes should be abundant, otherwise it is necessary to install extensive cooling apparatus, which is costly and occupies much space.

Stability of Foundations. The machinery, as well as the buildings, must have stable foundations, and it is well to investigate the availability of such foundations when selecting the site.

Surroundings. In the operation of a power plant using coal or other fuels, certain nuisances arise, such as smoke, noise, vibration, etc. For this reason it is preferable to locate where there is little liability to complaint on account of these causes, as some of these nuisances are costly and difficult, or even impossible, to prevent.

Facility for Extension. A station should be located where there are ample facilities for extension and, while it may not always be advisable to purchase land sufficient for these extensions at first, if there is the slightest doubt in regard to being able to purchase it later, it should be bought at once, as the station should be as free as possible from risk of interruption of its plans. Often real estate is too high for purchasing a site in the best location, and then the next best point must be selected. A consideration of all the factors involved is necessary in determining whether or not this cost is too high. In densely populated districts it is necessary to economize greatly with the space available, but it is generally desirable that all the machinery be placed on the ground floor and that adequate provision be made for the storage of fuel, etc.

Cost of Real Estate. The location of substations is usually fixed by other conditions than those which determine the site of the main power house. Since, in the simple rotary-converter substation, neither fuel nor water is necessary, and there is little noise or vibration, it may be located wherever the cost of real estate will permit, provided suitable foundations may be constructed. The distance between substations depends entirely on the selection of the system and the nature of the service.

GENERAL FEATURES

Miscellaneous Considerations. Where low voltages are used, it is essential that the station be located as near the center of the system as possible. This center is located as follows:

Having determined the probable loads and their points of application for the proposed system, these loads are indicated on a drawing with the location of the same shown to scale. The center of gravity of this system, considering each load as a weight, is then found and its location is the ideal location, as regards amount of copper necessary for the distributing system.

Consider Fig. 1, which shows the location of five different

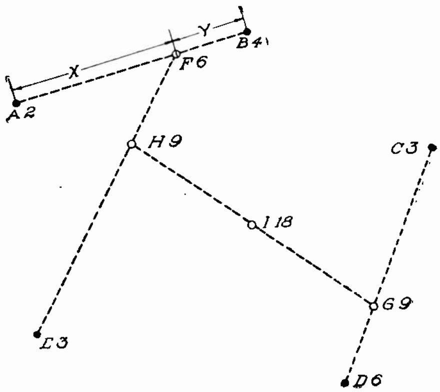


Fig. 1. Graphical Method of Locating Center of the System

loads, indicated in this case by the number of amperes. Combining loads A and B, we have

$$Ax = By \qquad\qquad x + y = a$$

Solving these equations, we find that A and B may be considered as a load of $A + B$ amperes at F. Similarly, C and D, E and F, and G and H may be combined giving us I, the center of the system. The amount of copper necessary for a given regulation runs up very rapidly as the distance of the station from this point increases. Where there are obstructions which will not permit the feeders to be run in an approximately straight line, the distance A B, etc., should be measured along the line the conductors must take.

Selection of System. General rules only can be stated for the selection of a system to be used in any given territory for a certain class of service.

For an area not over two miles square and a site reasonably near the center, direct-current, low-pressure, three-wire systems may be used for lighting and ordinary power purposes. Either 220 volts or 440 volts may be used as a maximum voltage, and motors should, preferably, be connected across the outside wires of the circuits. Five-wire systems with 440 volts maximum potential have been used, but they require very careful balancing of the load if the service is to be satisfactory. 220-volt lamps are giving good satisfaction; moderate-size, direct-current motors may readily be built for this pressure and constant-potential arc lamps may be operated on this voltage, though not so economically as on 110 volts, if single lamps are used. The new types of incandescent lamps in low candle-power units are not suitable for 220 volts. For direct-current railway work, the limit of the distance to which power may be economically delivered with an initial pressure of 600 volts is from five to seven miles, depending on the traffic.

If the area to be served is materially larger than the above, or distances for direct-current railways greater, either of the two following schemes may be adopted: (1) Several stations may be located in the territory and operated separately or in multiple on the various loads; or (2) one large power house may be erected and the energy transmitted from this station at a high voltage to various transformers or transformer substations which, in turn, transform the voltage to one suitable for the receivers. Local conditions usually determine which of these two shall be used. The alternating-current system with a moderate potential—about 2,300 volts for the primary lines—is now often installed for very small lighting systems.

The use of several low-tension stations operating in multiple is recommended only under certain conditions, namely, that the demand is very heavy and fairly uniformly distributed throughout the area, and suitable sites for the power house can readily be obtained. Such conditions rarely exist and it is a question whether or not the single station would not be just as suitable for such cases as where the load is not so congested.

One reason why a large central station is preferred to several smaller stations is that large stations can be operated more economically, owing to the fact that large units may be used and they can be run more nearly at full load. There is a gain in the cost of attendance, and labor-saving devices can be more profitably installed. The location of the power plant is not determined to such a large extent by the position of the load, but other conditions, such as water supply, cheap real estate, etc., will be the governing factors. In several cities, notably New York, Chicago, and Boston, large central stations are being installed to take the place of several separate stations, the old stations being changed from generating power houses to rotary-converter substations. Both direct-current low-tension machines—for supplying the neighboring districts—and high-tension alternating-current machines—for supplying the out, lying or residence districts—are often installed in the one station.

As examples of the central station located at some distance from the center of the load, we have nearly all of the large hydraulic power developments. Here it is the cheapness of the water power which determines the power-house location. The greatest distance over which power is transmitted electrically at present is in the neighborhood of 200 miles.

If a high-tension alternating-current system is to be installed, there remains the choice of a polyphase or single-phase machine as well as the selection of voltage for transmission purposes. As pointed out in "Power Transmission," polyphase generators are cheaper than single-phase generators and, if necessary, they can be loaded to about 80 per cent of their normal capacity, single-phase, while motors can more readily be operated from polyphase circuits. If synchronous motors or rotary converters are to be installed, a polyphase system is necessary. The voltage will be determined by the distance of transmission, care being taken to select a value considered as standard, if possible. Generators are wound giving a voltage at the terminals as high as 15,000 volts, but in many districts it is desirable to use step-up transformers for voltages above 6,600 on account of liability to troubles from lighting.

With the development of the single-phase railway motor, central stations generating single-phase current only, are occasionally built in larger sizes than previously, as their use heretofore has been limited to lighting stations.

Factors in Design. A few general notes in regard to the design of plants will be given here, the several points being taken up more in detail later.

Direct driving of apparatus is always superior to methods of gearing or belting as it is efficient, safe, and reliable, but it is not as flexible as shafting and belts, and on this account its adoption is not universal.

Speeds to be used will depend on the type and size of the generating unit. Small machines are always cheaper when run at high speeds, but the saving is less on large generators. For large engines slow speed is always preferable.

It is desirable that there be a demand for both power and lighting, and a station should be constructed which will serve both purposes. The use of power will create a day load for a lighting station, which does much to increase its ultimate efficiency and, as a rule, its earning capacity.

In addition to generator capacity necessary to supply the load, a certain amount of reserve, either in the way of additional units or overload capacity, must be installed. The probable load for, say three years, can be closely estimated, and this, together with the proper reserve, will determine the size of the station. The plant as a whole, including all future extensions, should be planned at the start as extensions will then be greatly facilitated. Usually it will not be desirable to begin extensions for at least three years after the first part of the plant has been erected.

Enough units must be installed so that one or more may be laid off for repairs, and there are several arguments in favor of making this reserve in the way of overload capacity, for the generators at least. Some of these arguments are:

Reserve is often required at short notice, notably in railway plants.

With overload capacity the rapid increase of load, such as occurs in lighting stations when darkness comes on suddenly, may more readily be taken care of.

There is always a factor of safety in machines not running to their fullest capacity.

Reserve capacity is cheaper in this form than if installed as separate machines.

As a disadvantage, we have a lower efficiency, due to machines not usually running at full load, but in the case of generators this is very slight.

TABLE I

Permissible Overload 33 Per Cent

	Machines added one at a time		Machines added two at a time		Machines added three at a time	
	No.	Size.	No.	Size.	No.	Size.
Initial installment	4	500	4	500	4	500
First extension	1	666	2	1000	3	2000
Second extension	1	888	2	2000	5	5000
Third extension	1	1183	2	4000	4	5000
Fourth extension	1	1577	4	4000		
Fifth extension	1	2103	8	4000		
Sixth extension	1	2804				

With an overload capacity of $33\frac{1}{3}$ per cent, four machines should be the initial installment, since one can be laid off for repairs, if necessary, the total load being readily carried by three machines. In planning extensions, the fact that at least one machine may require to be laid off at any time should not be lost sight of, while the units should be made as large as is conducive to the best operation.

Table I is worked out showing the initial installment for a 2,000-kw. plant with future extensions. It is seen from this table that adding two machines at a time gives more uniformity in the size of units—a very desirable feature.

The boilers should be of large units for stations of large capacity, while for small stations they must be selected so that at least one may be laid off for repairs.

STEAM PLANT

BOILERS

The majority of power stations have as their prime movers either steam or water power, though there are many using gas. If steam is the power selected, the subject of boilers is one of vital importance to the successful operation of central stations. The object of the boiler with its furnace is to abstract as much heat as possible from the fuel and impart it to the water. The various kinds of boilers used for accomplishing this more or less successfully are described in books on boilers, and we will consider here the merits of a few of the types only as regards central-station operation.

The considerations are: (1) Steam must be available throughout the twenty-four hours, the amount required at different parts of the day varying considerably. Thus, in a lighting station, the demand from midnight to 6 A. M. is very light, but toward evening, when the load on the station increases very rapidly, there is an abrupt increase in the rate at which steam must be given off. The maximum demand can readily be anticipated under normal weather conditions, but occasionally this maximum will be equaled or even exceeded at unexpected moments. For this reason a certain number of boilers must be kept under steam constantly, more or less of them running with banked fires during light loads. If the boilers have a small amount of radiating surface, the loss during idle hours will be decreased.

(2) The boilers must be economical over a large range of rates of firing and must be capable of being forced without detriment. Boilers should be provided which work economically for the hours just preceding and following the maximum load while they may be forced, though running at lower efficiency, during the peak.

(3) Coming to the commercial side of the question, we have first cost, cost of maintenance, and space occupied. The first cost, as does the cost of maintenance, varies with the type and the pressure of the boiler. The space occupied enters as a factor only when the situation of the station is such that space is limited, or when the amount of steam piping becomes excessive. In some city-plants, space may be the determining feature in the selection of boilers.

Classification. Boilers for central stations may be classified as fire-tube and water-tube types. Of the former may be mentioned the Cornish, Lancashire, Galloway, multitubular, marine, and economic boilers. The Babcock and Wilcox, Stirling, and Heine boilers are examples of the water-tube type.

Fire-Tube Boilers. The *Cornish and Lancashire* boilers have the fire tubes of such a diameter that the furnaces may be constructed inside of them. They differ only in the number of cylindrical tubes in which the furnaces are placed, as many as three tubes being placed in the largest sizes (seldom used) of the Lancashire boilers. They are made up to 200-pound steam pressure and possess the following features:

1. High efficiency at moderate rates of combustion
2. Low rate of depreciation
3. Large water space
4. Easily cleaned
5. Large floor space required
6. Cannot be readily forced

The *Galloway boiler* differs from the Lancashire boiler in that there are cross-tubes in the flues.

In the *multitubular boiler*, the number of tubes is greatly increased and their size is diminished. Their heating surface is large and they steam rapidly. They require a separate furnace and are used extensively for power-station work.

Marine boilers require no setting. Among their advantages and disadvantages may be mentioned:

1. Exceedingly small space necessary
2. Radiating surface reduced
3. Good economy
4. Heavy and difficult to repair
5. Unsuitable for bad water
6. Poor circulation of water

The economic boiler is a combination of the Lancashire and multitubular boilers, as is the marine boiler. It is set in brickwork and arranged so that the gases pass under the bottom and along the sides of the boiler as well as through the tubes. It way be compared with other boilers from the following points:

1. Small floor space
2. Less radiating surface than the Lancashire boiler
3. Not easily cleaned
4. Repairs rather expensive
5. Requires considerable draft

Water-Tube Boilers. The chief characteristics of the water-tube boilers, of which there are many types, are

1. Moderate floor space
2. Ability to steam rapidly
3. Good water circulation
4. Adapted to high pressure
5. Easily transported and erected
6. Easily repaired
7. Not easily cleaned
8. Rate of deterioration greater than for Lancashire boiler
9. Small water space, hence variation in pressure with varying demands for steam
10. Expensive setting

Initial Cost. As regards first cost, boilers installed for 150-pound pressure and the same rate of evaporation, will run in the following order: Galloway and Marine, highest first cost, Economic, Lancashire, and Babcock and Wilcox. The increase of cost, with increase of steam pressure, is greatest for the Economic and least for the water-tube type.

Deterioration. Deterioration is less with the Lancashire boiler than with the other types.

Floor Space. The floor space occupied by these various types built for 150 pounds pressure and 7,500 pounds of water, evaporated per hour, is given in Table II.

TABLE II

Boiler Floor Space

Kind of Boiler	Floor Space in sq. ft.
Lancashire	408
Galloway	371
Babcock and Wilcox	200
Marine wet-back	120
Economic	210

Efficiency. The percentage of the heat of the fuel utilized by the boiler is of great importance, but it is difficult to get reliable data in regard to this. Table III* will give some idea of the efficiencies of the different types. The efficiency is more a question of proper proportioning of grate and heating surface and condition of boiler than of the type of boiler. Economizers were not used in any of these tests, but they should always be used with the Lancashire type of boiler.

It is well to select a boiler from 20 to 50 pounds in excess of the pressure to be used, as its life may thus be considerably extended, while, when the boiler is new, the safety valve need not be set so near the normal pressure, and there is less steam wasted by the blowing off of this valve. Again, a few extra pounds of steam may be carried just previous to the time the peak of the load is expected. For pressures exceeding 200 or, possibly, 150 pounds, a water-tube boiler should be selected.

In large stations, it is preferable to make the boiler units of

*From Donkin's "Heat Efficiency of Steam Boilers."

TABLE III
Boiler Efficiencies

Kind of Boiler	No. of Experiments	Mean Efficiency of Two Best Experiments	Lowest Efficiency	Mean Efficiency of All Experiments
Lancashire hand-fired	107	79.5	42.1	62.3
Lancashire machine-fired	40	73.0	51.9	64.2
Cornish hand-fired	25	81.7	53.0	68.0
Babcock and Wilcox hand-fired	49	77.5	50.0	64.9
Marine wet-back hand-fired	6	69.6	62.0	66.0
Marine dry-back hand-fired	24	75.7	64.7	69.2

large capacity, to do away as much as possible with the extra piping and fittings necessary for each unit. Water-tube boilers are best

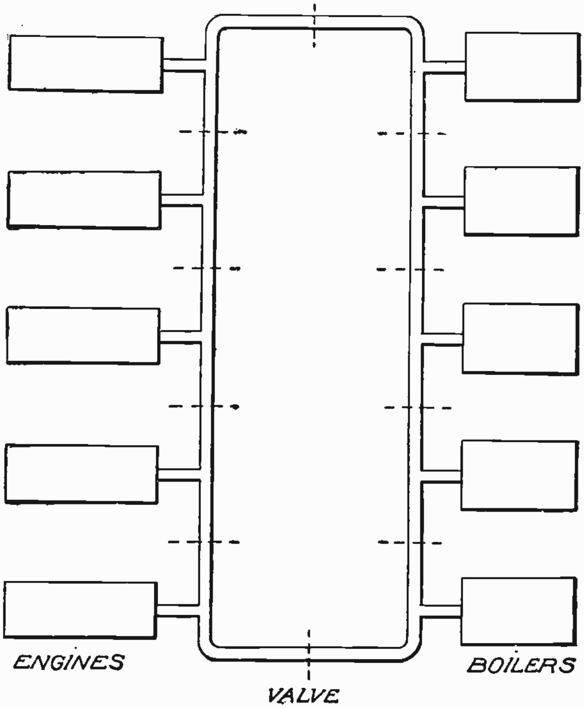


Fig. 2. Diagram of *Ring* System of Piping

adapted for large sizes. These may be constructed for 150-pound pressure, large enough to evaporate 20,000 pounds of water per hour, at an economical rate.

Boilers of the multitubular type or water-tube boilers are used in the majority of power stations in the United States. For stations of moderate size, with medium steam pressures and plenty of space, the return tubular boiler is often employed. For the larger stations and the higher steam pressures, the water-tube boilers are employed. Marine or other special types are used only occasionally where space is limited or where other local conditions govern.

Steam Piping. The piping from the boilers to the engines should be given very careful consideration. Steam should be avail-

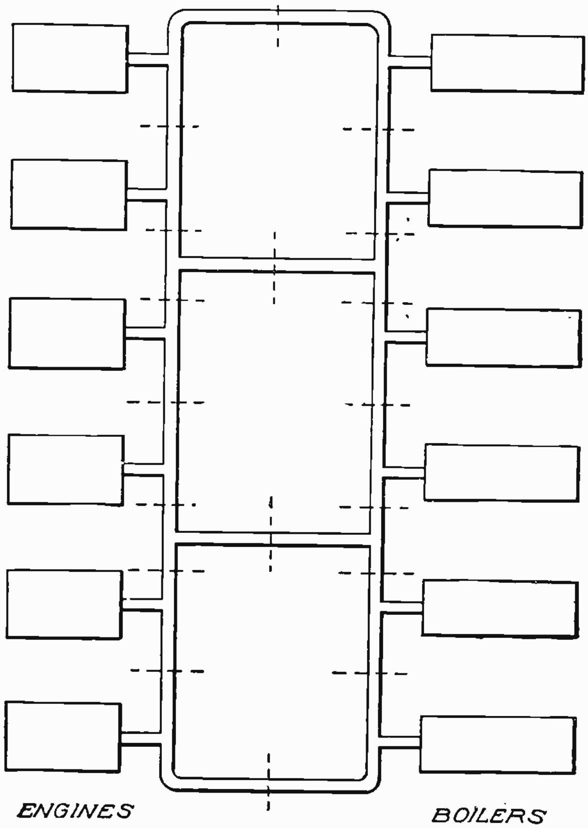


Fig. 3. Diagram of *Ring* System with Cross-Connections

able at all times and for all engines. Freedom from serious interruptions due to leaks or breaks in the piping is brought about by very careful design and the use of good material in construction.

Duplicate piping is used in many instances. Provision must always be made for variations in length of the pipe with variation of temperature. For plants using steam at 150-pound pressure, the variation in the length of steam pipe may be as high as 2.5 inches for 100 feet, and at least 2 inches for 100 feet should always be counted upon.

Arrangement. Fig. 2 shows a simple diagram of the *ring system* of piping. The steam passes from the boiler by two paths to the engine and any section of the piping may be cut out by the closing of two valves. Simple ring systems have the following characteristics:

1. The range, as the main pipe is called, must be of uniform size and large enough to carry all of the steam when generated at its maximum rate.
2. A damaged section may disable one boiler or one engine.
3. Several large valves are required.
4. Provision may readily be made to allow for expansion of pipes.

Cross-connecting the ring system, as shown in Fig. 3, changes these characteristics as follows:

1. Size of pipes and consequent radiating surface is reduced.
2. More valves are needed but they are of smaller size.
3. Less easy to arrange for expansion of the pipes.

If the system is to be duplicated, that is, two complete sets of main pipes and feeders installed, Fig. 4, two schemes are in use:

1. Each system is designed to operate the whole station at maximum load with normal velocity and loss of pressure in the pipes, and only one system is in use at a time. This has the disadvantage that the idle section is liable not to be in good operating condition when needed. Large pipes must be used for each set of mains.
2. The two systems may be made large enough to supply steam at normal loss of pressure when both are used at the same time, while either is made large enough to keep the station running should the other section need repairs. This has the advantages of less expense, and both sections of pipe are normally in use; but it has the disadvantages of more radiating surface to the pipes and consequent condensation for the same capacity for furnishing steam.

Complete interchangeability of units cannot be arranged for if the separate engine units exceed 400 to 500 horse-power. Since engine units can be made larger than boiler units, it becomes necessary to treat several boiler units as a single unit, or battery, these batteries being connected as the single boilers already shown. For still larger plants the steam piping, if arranged to supply any engines from any batteries of boilers, would be of enormous size. If the boilers do not occupy a greater length of floor space than the engines, Fig. 5 shows a good arrangement of units. Any engine can be fed from either of two batteries of boilers and the liability of serious interruptions of service due to steam pipes or boiler trouble is very remote.

In many plants but a single steam range is used, the station depending upon good material, careful construction, and thorough

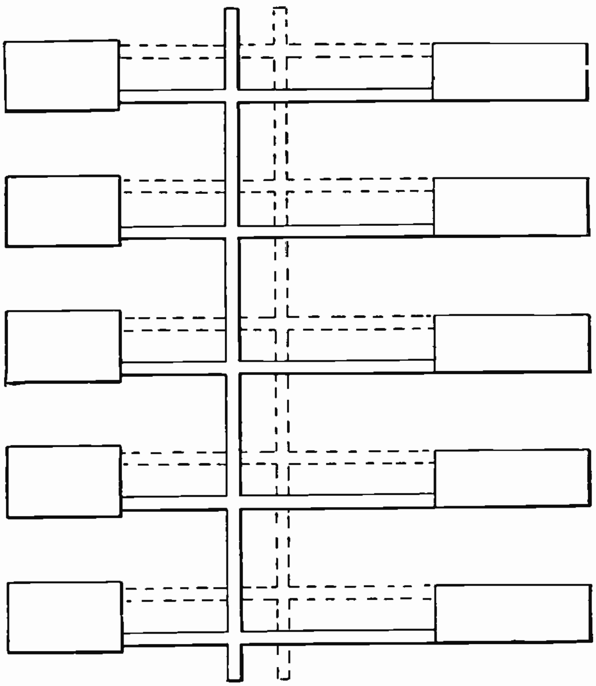


Fig. 4. Duplicate System of Piping

inspection for reliability of service. In the largest steam-turbine stations, the so-called unit system is employed as is explained later under "Station Arrangement."

Material. Steel pipe, lap welded and fastened together by means of flanges, is to be recommended for all steam piping. The flanges may be screwed on the ends of sections and calked so as to render this connection steam tight, though in large sizes it is better to have the flanges welded to the pipes. This latter construction costs no more for large pipes and is much more reliable. All valves and fittings are made in two grades or weights, one for low pressures, and the other for high pressures. The high-pressure fittings should always be used for electrical stations. Gate valves should always

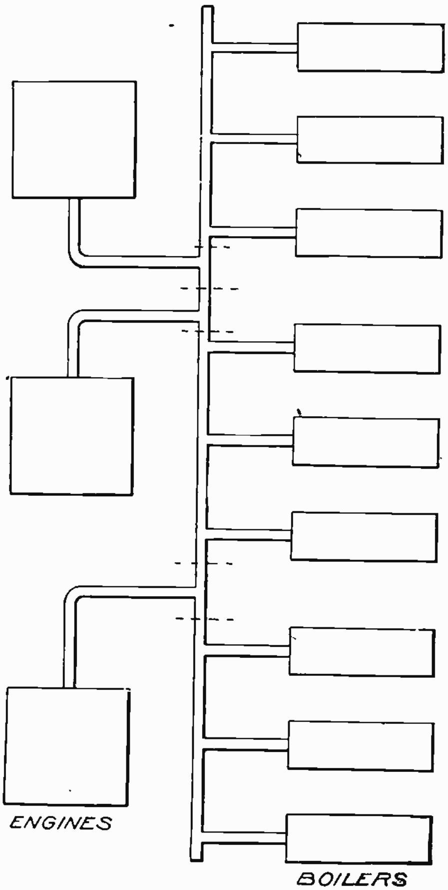
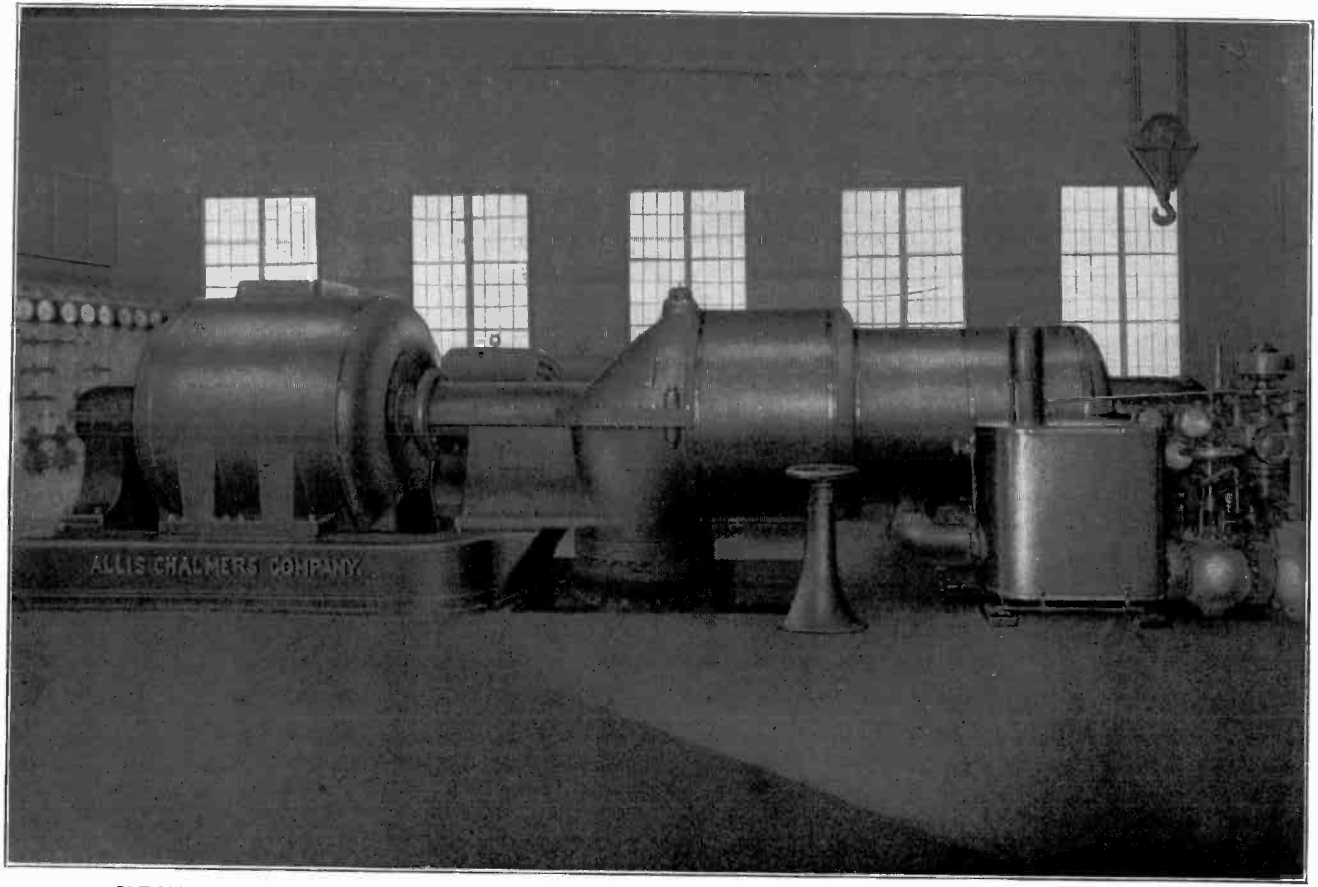


Fig. 5. Arrangement of Boilers and Engines in Very Large Plants

be selected, and, in large sizes, they should be provided with a by-pass.

Asbestos, either alone or with copper rings, vulcanized India rubber, asbestos and India rubber, etc., are used for packing between flanges to render them steam tight. Where there is much expansion, the material selected should be one that possesses considerable



STEAM TURBINE INSTALLATION IN A CENTRAL POWER AND LIGHTING STATION OF ONE OF THE PRINCIPAL COAL PRODUCING DISTRICTS
Allis-Chalmers Co., Milwaukee, Wis.

elasticity. Joints for high-pressure systems require much more care than those for low-pressure systems, and the number of joints should be reduced to a minimum by using long sections of pipe.

Fittings. A list of the various fittings required for steam piping, together with their descriptions, is given in books on boilers. One precaution to be taken is to see that such fittings do not become too numerous or complicated, and it is well not to depend too much on automatic fittings. Steam separators should be large enough to serve as a reservoir of steam for the engine and thus equalize, to a certain extent, the velocity of flow of steam in the pipes.

Expansion. In providing for the expansion of pipes due to change of temperature, U bends made of steel pipe and having a radius of curvature not less than six times, and preferably ten times the diameter of the pipe, are preferred. Copper pipes cannot be recommended for high pressures, while slip expansion joints are most undesirable on account of their liability to bind.

Size. The size of steam pipes is determined by the velocity of flow. Probably an average velocity of 60 feet per second would be better than 100 feet per second, though in some cases where space is limited a velocity as high as 150 feet per second has been used.

Loss in Pressure. The loss in pressure in steam pipes may be obtained from the formula

$$p_1 - p_2 = \frac{Q^2 wL}{c^2 d^5}$$

where $p_1 - p_2$ is the loss in pressure in pounds per square inch; Q is the quantity of steam in cubic feet per minute; d is the diameter of pipe in inches; L is the length in feet; w is the weight per cubic feet of steam at pressure p_1 and c is a constant, depending on size of pipe, values of which for the variation in the size of pipe are as follows:

Diameter of pipe	½″	1″	2″	3″	4″	5″	6″	7″	8″	9″	10″
Value of c	36.8	45.3	52.7	56.1	57.8	58.4	59.5	60.1	60.7	61.2	61.8

Diameter of pipe	12″	14″	16″	18″	20″	22″	24″
Value of c	62.1	62.3	62.6	62.7	62.9	63.2	63.2

Mounting. In mounting the steam pipe, it should be fastened rigidly at one point, preferably near the center of a long section, and allowed a slight motion longitudinally at all other supports. Such supports may be provided with rollers to allow for this motion, or the pipe may be suspended from wrought-iron rods which will give a flexible support.

Location. Practice differs in the location of the steam piping, some engineers recommending that it be placed underneath the engine-room floor and others that it be located high above the engine-room floor. In any case it should be made easily accessible, and the valves should be located so that nothing will interfere with their operation. Proper provision must be made for draining the pipes.

Lagging. All piping as well as joints should be carefully covered with a good quality of lagging as the amount of steam condensed in a bare pipe, especially if of any great length, is considerable. In selecting a lagging bear in mind that the covering for steam pipes should be incombustible, should present a smooth surface, should not be damaged easily by vibration or steam, and should have as large a resistance to the passage of heat as possible. It must not be too thick, otherwise the increased radiating surface will counterbalance the resistance to the passage of heat.

The loss of power in steam pipes due to radiation is

$$H = .262\, r\, L\, d$$

where H is loss of power in heat units; d is diameter of pipe in inches; L is the length of pipe in feet; and r is a constant depending on steam pressure and pipe covering, values of which for the variations of these two factors are as follows:

Steam pressure in pounds (absolute)	40	65	90	115
Values of r for uncovered pipe	437	555	620	684
Value of r for pipe covered with 2 inches of hair felt	48	58	66	73

Referring to tables in books on boilers, the relative values of different materials used for covering steam pipes may be found.

Superheated Steam. Superheated steam reduces condensation in the engines as well as in the piping, and increases the efficiency of the system. Its use was abandoned for several years, due to difficulties in lubricating and packing the engine cylinders, but by the use of mineral oils and metallic packing, these difficulties have been done away with to a large extent, while steam turbines are especially adapted to the use of superheated steam. The application of heat directly to steam, as is done in the superheater, increases the

TABLE IV

Boiler Efficiencies

Amount of Superheat	Water Evaporated per Pound of Coal	
	Without Superheat	With Superheat
40 degrees F.	7.82	9.99
42 degrees F.	6.42	7.06
55 degrees F.	6.00	7.00
56.5 degrees F.	6.78	8.66
55.2 degrees F.	7.15	8.65

efficiency of the boilers. Table IV shows the increase in boiler efficiency for a certain boiler test, the results being given in pounds of water changed to dry, saturated steam. Tests on various engines show a gain in efficiency as high as 9 per cent with a superheat of 80° to 100° F., while special tests in some cases show even a greater gain.

Superheaters are very simple, consisting of tubular boilers containing steam instead of water, and either located so as to utilize the heat of the gases, the same as economizers, or separately fired. They should be arranged so that they may be readily cut out of service, if necessary, and provision must be made for either flooding them or turning the hot gases into a by-pass, as the tubes would be injured by the heat if they contained neither water nor steam. Superheaters may be mounted in the furnace of the regular boiler setting or they may have furnaces of their own and be separately fired. For electrical stations using superheated steam the former type is usually employed and it has proved very satisfactory for moderate degrees of superheat.

Feed Water. All water available for the feeding of boilers contain some impurities, among the most important of which as regards boilers are soluble salts of calcium and magnesium. Bicarbonates of the alkaline earths cause precipitations on the interior of boilers, forming *scale*. Sulphate of lime is also deposited by concentration under pressure. Scale, when formed, not only decreases the efficiency of the boiler but also causes deterioration, for if sufficiently thick, the diminished conducting power of the boiler allows the tubes or plates to be overheated and to crack or burst. Again, the scale may keep the water from contact with sections of the heated plates for some time and then, giving way, large volumes of steam are generated very quickly, and an explosion may result.

Some processes to prevent the formation of scale are used, which affect the water after it enters the boilers, but they are not to be recommended, and any treatment the water receives should affect it previous to its being fed to the boilers. Carbonates and a small quantity of sulphate of lime may be removed by heating in a separate vessel. Large quantities of sulphate of lime must be precipitated chemically.

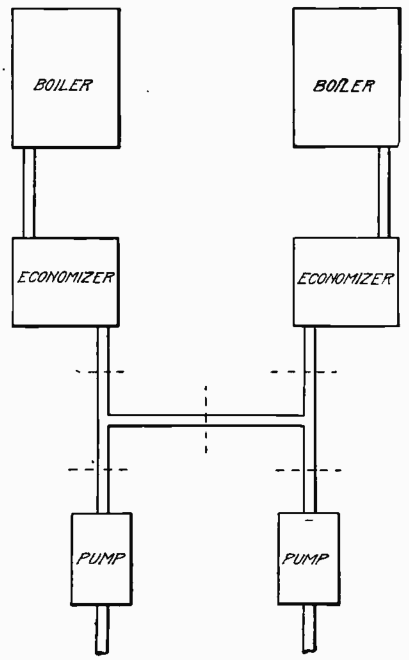


Fig. 6. Feeding System for Boilers and Pumps

Sediment must be removed by allowing the water to settle. Vegetable matters are sometimes present, which cause a film to be deposited. Certain gases, in solution—such as oxygen, nitrogen, etc.—cause pitting of the boiler. This effect is neutralized by the addition of chemicals. Oil from the engine cylinder is particularly destructive to boilers and when present in the condensed steam must be carefully removed.

Feeding Appliances. Both feed pumps and injectors are used for feeding the water to the boilers. *Feed pumps* may be either steam- or motor-driven. Steam-driven pumps are very inefficient, but they are simple and the speed is easily controlled. Motor-driven pumps are more efficient and neater, but more expensive and more difficult to regulate efficiently over a wide range of speed. Direct-acting pumps may have feed-water heaters attached to them, thus increasing the efficiency of the apparatus as a whole. The supply of electrical energy must be constant if motor-driven pumps are to be used.

TABLE V

Rate of Flow of Water, in Feet per Minute, Through Pipes of Various Sizes, for Varying Quantities of Flow

Gallons per Min.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	218	122½	78½	54½	30½	19½	13½	7⅔
10	436	245	157	109	61	38	27	15⅓
15	653	367½	235½	163½	91½	58½	40½	23
20	872	490	314	218	122	78	54	30⅔
25	1090	612½	392½	272½	152½	97½	67½	38⅓
30		735	451	327	183	117	81	46
35		857½	549½	381½	213½	136½	94½	53⅔
40		980	628	436	244	156	108	61⅓
45		1102½	706½	490½	274½	175½	121½	69
50			785	545	305	195	135	76⅔
75			1177½	817½	457½	292½	202½	115
100				1090	610	380	270	153⅓
125					762½	487½	337½	191⅔
160					915	585	405	230
175					1067½	682½	472½	268⅓
200					1220	780	540	306⅔

Feed pipes must be arranged so as to reduce the risk of failure to a minimum, and for this reason they are almost always duplicated. More than one water supply is also recommended if there is the slightest danger of interruption on this account. One common arrangement of feed-water apparatus is to install a few large pumps supplying either of two mains from which the boiler connections are taken. This is a complicated and costly system of piping. A scheme for feeding two boilers where each pump is capable of supplying both boilers is shown in Fig. 6. Pipes should be ample in cross-section, and, in long lengths, allowance must be made for expansion. Cast iron or cast steel is the material used for their construction; the joints being made by means of flanges fitted with rubber gaskets.

The rate of flow of water in feet per minute through pipes of various sizes is given in Table V. A flow of 10 gallons per minute for each 100 h. p. of boiler equipment should be allowed without causing an excessive velocity of flow in the pipes—400 to 600 feet per minute represents a fair velocity.

Boiler Setting. The economical use of coal depends, to a large extent, on the setting of the boiler and proper dimensions of the furnaces. Internally-fired boilers require support only, while the setting of externally-fired boilers requires provision for the furnaces. Common brick, together with fire brick for the lining of portions exposed to the hot gases, are used almost invariably for boiler settings. It is customary to set the boiler units up in batteries of two, using a 20-inch wall at the sides and a 12-inch wall between the two boilers. The instructions for settings furnished by the manufacturers should be carefully followed out as they are based on conditions which give the best results in the operation of their boilers.

Draft. The best ratio of heating to grate surface for boiler plants depends upon the kind of fuel used and the draft employed. Based on a draft of 0.5 inch of water, the following values are given for different grades of fuel:

Pocahontas, W. Va., 45; Youghiogheny, Pa., 48; Hocking Valley, O., 45; Big Muddy, Ill., 50; Lackawanna, Pa., No. 1 buckwheat, 32. The first of these coals is semi-bituminous, the Lackawanna coal is anthracite, and the other coals are bituminous.

Natural Draft. Natural draft is the most commonly used and is the most satisfactory under ordinary circumstances. In determining the size of the chimney necessary to furnish this draft, the following formula is given by Kent:

$$A = \frac{.06\,F}{\sqrt{h}} \qquad \text{or } h = \left(\frac{.06\,F}{A}\right)^2$$

where A = area of chimney in sq. ft.; h = height of chimney in ft.; and F = pounds of coal per hour.

The height of chimney should be assumed and the area calculated, remembering that it is better to have the chimney too large than too small.

The chimney may be either of brick or iron, the latter having a less first cost but requiring repairs at frequent intervals. General rules for the design of a brick chimney may be given as follows:

The external diameter of the base should not be less than $\frac{1}{10}$ of the height.
Foundations must be of the best.
Interiors should be of uniform section and lined with fire brick.
An air space must exist between the lining and the chimney proper.

The exterior should have a taper of from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot.
Flues should be arranged symmetrically.

Fig. 7 shows the construction of a brick chimney of good design, this chimney being used with boilers furnishing engines which develop 14,000 h. p.

Mechanical Draft. Mechanical draft is a term which may be used to embrace both forced and induced draft. The first cost of mechanical-draft systems is less than that of a chimney, but the operation and repair are much more expensive and there is always the risk of break-down. Artificial draft has the advantage that it can be varied within large limits and it can be increased to any desired extent, thus allowing the use of low grades of coal.

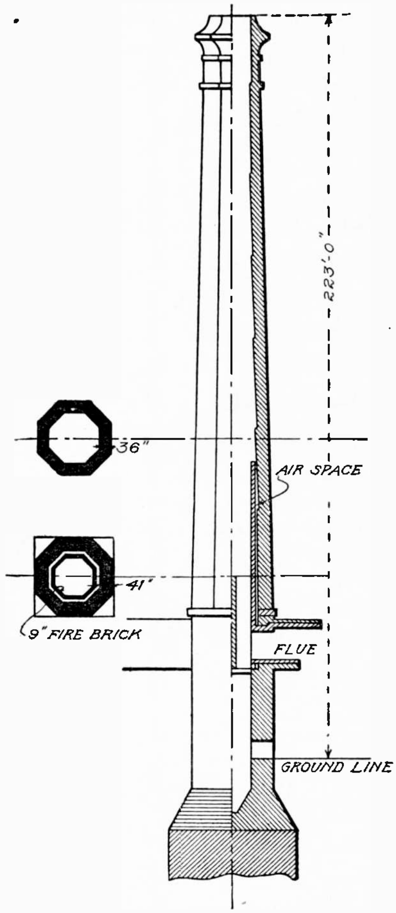


Fig. 7. Good Design of Brick Chimney

Firing of Boilers. Coal is used for fuel to a greater extent than any other material, though oil, gas, wood, etc., are used in some localities. Local conditions, such as availability, cost, etc., should determine the material to be used; no general rules can be given. From data regarding the relative heating values of different fuels we find: that 1 pound of petroleum, about $\frac{1}{7}$ of a gallon, is equivalent, when used with boilers, to 1.8 pounds of coal and there is less deterioration of the furnace with oil; that $7\frac{1}{2}$ to 12 cubic feet of natural gas are required as the equivalent of 1 pound of coal, depending on the quality of the gas; that $2\frac{1}{2}$ pounds of dry wood is assumed as the equivalent of 1 pound of coal.

Stoking. When coal is used, it requires stoking and this may be accomplished either by hand or by means of mechanical stokers, many forms of which are available. Mechanical stoking has the advantage over hand stoking in that the fuel may be fed to the furnace more uniformly, thus avoiding the subjection of the fires and boilers to sudden blasts of cold air as is the case when the fire doors are opened; in that a poorer grade of coal may be burned, if necessary; and in that the trouble due to smoke is much reduced. It may be said that mechanical stokers are used almost universally in the more important electrical plants. Economic use of fuel requires great care in firing, especially if it is done by hand.

Where gas is used, the firing may be made nearly automatic, and the same is true of oil firing, though the latter requires more complicated burners, as it is necessary that the oil be vaporized.

In large stations, operated continuously, it is desirable that, as far as possible, all coal and ashes be handled by machinery, though the difference in cost of operation should be carefully considered before installing extensive coal-handling machinery. Machinery for automatically handling the coal will cost from $7.50 to $10 per horse-power rating of boilers for installation, while the ash-handling machinery will cost from $1.50 to $3 per horse-power.

The coal-handling devices usually consist of chain-operated conveyors which hoist the coal from railway cars, barges, etc., to overhead bins from which it may be fed to the stokers. The ashes may be handled in a similar manner, by means of scraper conveyors, or small cars may be used. Either steam or electricity may be used for driving this auxiliary apparatus.

It is always desirable that there be generous provision for the storage of fuel sufficient to maintain operations of the plant over a temporary failure of supply.

STEAM ENGINES

The choice of steam prime movers is one which is governed by a number of conditions which can be treated but briefly here. The first of these conditions relates to the speed of the engine to be used. There is considerable difference of opinion in regard to this as both high- and low-speed plants are in operation and are giving good satisfaction. Slow-speed engines have a higher first cost and a higher economy. Probably in sizes up to 250 kw., the generator should be driven by high-speed engines; from 250 to 500 kw., the selection of either type will give satisfaction; above 500 indicated horse-power, the slow-speed type is to be recommended. Drop valves cannot be used with satisfaction for speeds above about 100 revolutions per minute, hence high-speed engines must use direct-driven valve gears, usually governed by shaft governors. Corliss valves are used on nearly all slow-speed engines.

The steam pressure used should be at least 125 pounds per square inch at the throttle and a pressure as high as 150 to 160 pounds is to be preferred.

Close regulation and uniform angular velocity are required for driving generators, especially alternators which are to operate in parallel. This means sensitive and active governors, carefully designed flywheels, and proper arrangement of cranks when more than one is used.

High-speed engines should not have a speed change greater than $1\frac{1}{2}$ per cent from no load to full load, but for prime movers used for driving large alternators operated in multiple, a speed change as great as 4 or 5 per cent may be desirable. The variation in angular velocity, where alternators are to be operated in parallel, should be within such limits that at no time will the rotating part be more than $\frac{1}{60}$ of the pitch angle of two poles from the position it would occupy if the angular velocity were uniform at its mean value.

For large engine-driven plants or plants of moderate size, compound condensing engines are almost universally installed. The advantage of these engines in increased economy are in part counterbalanced by higher first cost and increased complications, together with the pumps and added water supply necessary for the condensers. The approximate saving in amount of steam is shown in Table VI, which applies to a 500 horse-power unit.

Triple expansion engines are seldom used for driving electrical machinery, as their advantages under variable loads are doubtful. Compound engines may be tandem or cross-compound and either horizontal or vertical. The use of cross-compound engines tends to produce uniform angular velocity, but the cylinder should be so proportioned that the amount of work done by each is nearly equal.

TABLE VI

Engine	Pounds of Steam per H. P. Hour
Simple non-condensing	30
Simple condensing	22
Compound non-condensing	24
Compound condensing	16

A cylinder ratio of about $3\frac{1}{2}$ to 1 will approximate average conditions. Either vertical or horizontal engines may be installed, each having its own peculiar advantages. Vertical engines require less floor space, while horizontal engines have a better arrangement of parts. Either type should be constructed with heavy parts and erected on solid foundations.

Engines should preferably be direct-connected, but this is not always feasible, and gearing, belt, or rope drives must be resorted to. Countershafts, belt or rope driven, arranged with pulleys and belts for the different generators, and with suitable clutches, are largely used in small stations. They consume considerable power and the bearings require attention.

Careful attention must be given to the lubrication of all running parts, and extensive oil systems are necessary in large plants. In such systems a continuous circulation of oil over the bearings and through the engine cylinders is maintained by means of oil pumps. After passing through the bearings, the machine oil goes to a properly arranged oil filter where it is cleaned and then pumped to the bearings again. A similar process is used in cylinder lubrication, the oil being collected from the exhaust steam, and only enough new oil is added to make up for the slight amount lost. The latter system is not installed as frequently as the continuous system for bearings.

STEAM TURBINES

Advantages. The steam turbine is now very extensively used as a prime mover for generators in power stations on account of its many advantages, some of which may be stated as follows:

1. High steam economy at all loads.
2. High steam economy with rapidly fluctuating loads.

3. Small floor space per kw. capacity, reducing to a minimum the cost of real estate and buildings.
4. Uniform angular velocity, thus facilitating the parallel operation of alternators.
5. Simplicity in operation and low expense for attendance.
6. Freedom from vibration, hence low cost for foundations.
7. Steam economy is not appreciably impaired by wear or lack of adjustment in long service.
8. Adaptability to high steam pressures and high superheat without difficulty in operation and with consequent improvement in economy.
9. Condensed steam is kept entirely free from oil and can be returned to the boilers without passing through an oil separator.

Types. The detailed descriptions of the different types of steam turbines are given in books devoted to steam engines and turbines and only a small amount of space can be devoted to them here. The first classification of steam turbines is into the impulse type and the reaction type of turbine. In the impulse type the steam is expanded in passing through suitable nozzles and does useful work in moving the blades of the rotating part by virtue of its kinetic energy. In the reaction type the steam is only partially expanded before it comes into contact with the blades and much of the work on the moving blades is accomplished by the further expansion of the steam and the reaction of the steam as it leaves the blades. Of the impulse type the *DeLaval* and the *Curtis* turbines are well-known makes. The DeLaval turbine is built in small and moderate sizes only and is of the single-stage type. The Curtis turbine is built in all sizes up to the very largest and is of the multi-stage type. The Curtis turbine may be briefly described as follows:

The Curtis turbine is divided into sections or stages, each stage containing one or more sets of stationary vanes and revolving buckets. These vanes and buckets are supplied with steam which passes through suitable nozzles to give it the proper expansion and velocity as it issues from the nozzles. By dividing the work into stages, the nozzle velocity of the steam is kept down to a moderate value in each stage and the energy of the steam is effectively given up to the rotating part without excessively high speeds. Fig. 8

shows the arrangement of nozzles, buckets, and stationary blades or guiding vanes for two stages. A complete turbine of the vertical type and of 5,000 kw. capacity is shown in Fig. 9. Governing is accomplished by automatically opening or closing some of the nozzles,

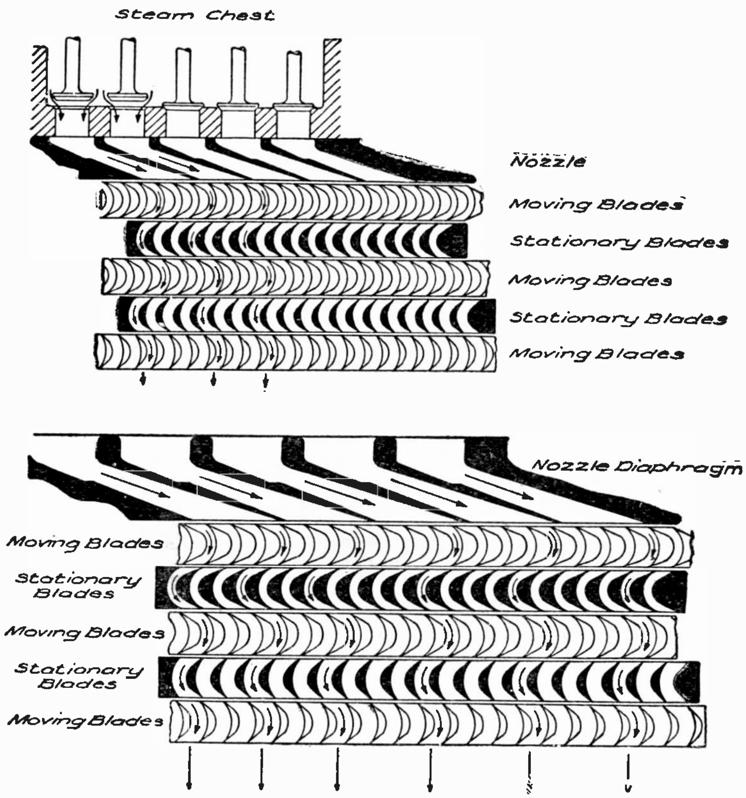


Fig. 8. Diagram of Nozzles and Buckets in Curtis Steam Turbine

and on overloads the steam may be automatically led directly into the second stage of the turbine. The step bearing which supports the weight of the rotating part may be lubricated by either oil or water under high pressure, this pressure being made great enough to support the weight of the moving element on a thin film of the lubricant. Only a vertical type of the Curtis turbine is shown here but it is also manufactured in the horizontal form.

Of the reaction turbines the *Parson's* type is the most prominent one. It is manufactured in the United States by the Westinghouse Machine Company and the Allis-Chalmers Company. An elementary drawing of the cross-section of the Allis-Chalmers turbine is shown in Fig. 10. Steam enters this turbine at *C* through the governing valve *D*, passes through the opening *E*, and thence expands in its passages through the series of revolving and stationary blades

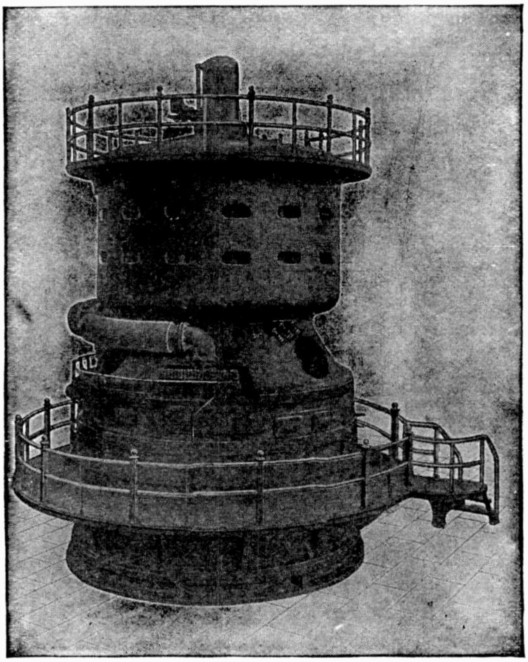


Fig. 9. Turbo-Alternator of 5,000 kw. Capacity

in the three stages *H*, *J*, and *K*. The steam pressure is balanced by means of a series of disks or balance pistons shown at *L*, *M*, and *N*. The valve shown at *V* is automatically opened on overload, thus admitting steam directly into stage *J*.

The steam economy of the turbine increases with increase in vacuum approximately as follows: For every increase in vacuum of one inch between 23 inches and 28 inches the increase in economy is 3 per cent for 100-kw. units, 4 per cent for 400-kw. units, and 5 per cent for 1,000-kw. units. This is a greater improvement than can be obtained with steam engines under corresponding conditions

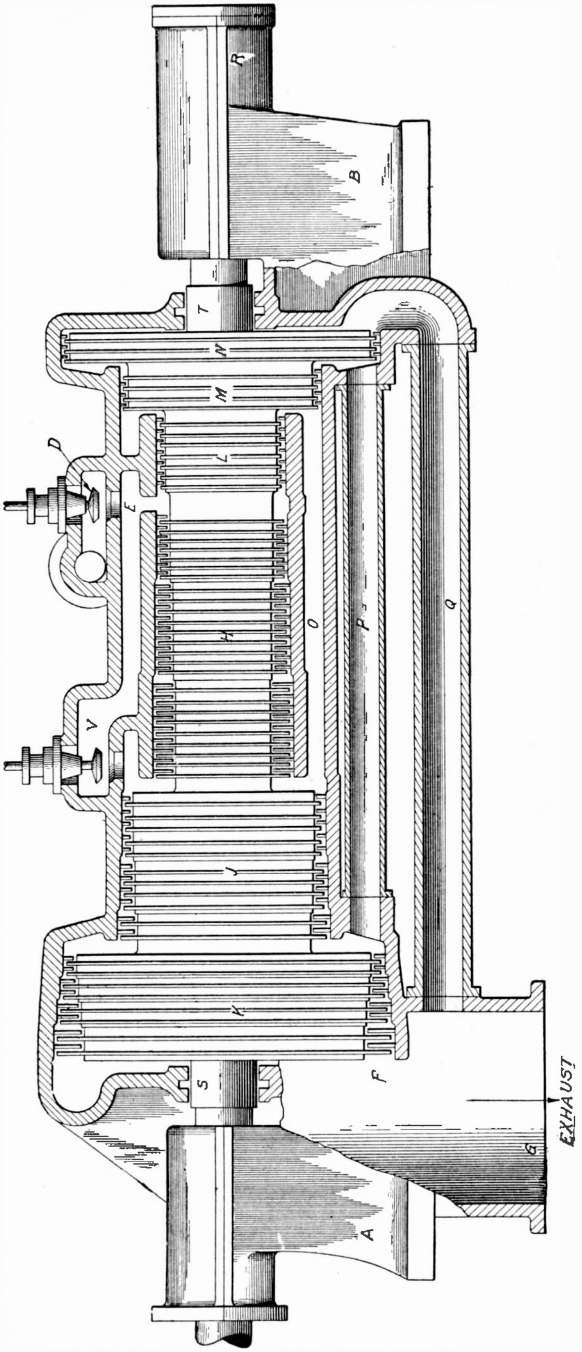


Fig. 10. Parson-Allis-Chalmers Turbine

and the exhaust-steam or low-pressure turbine is being introduced to work in conjunction with the reciprocating steam engine, the steam expanding down to about atmospheric pressure in the engine and continuing down to a high vacuum through the low-pressure turbine. A receiver may be introduced between the engine and the turbine. A higher steam economy is claimed for such a combination than could be secured by either engine or turbine alone.

HYDRAULIC PLANTS

Because of the relative ease with which electrical energy may be transmitted long distances, it has become quite common to locate large power stations where there is abundant water power, and to transmit the energy thus generated to localities where it is needed. This type of plant has been developed to the greatest extent in the western part of the United States, where in some cases the transmission lines are very extensive. The power houses now completed, or in the course of erection at Niagara Falls, are examples of the enormous size such stations may assume.

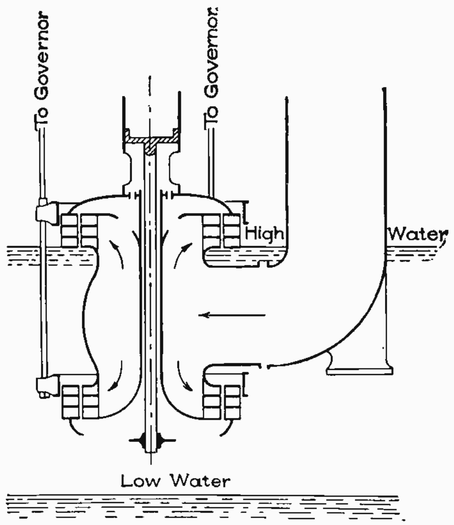


Fig. 11. Diagram of Reaction Turbines

Before deciding to utilize water power for driving the machinery in central stations, the following points should be noted:

1. The amount of water power available.
2. The possible demand for power.
3. Cost of developing this power as compared with cost of plants using other sources of power.
4. Cost of operation compared with other plants and extent of transmission lines.

Hydraulic plants are often much more expensive than steam plants, but the first cost is more than made up by the saving in operating expenses.

Methods for the development of water powers vary with the nature and the amount of the water supply, and they may be studied best by considering plants which are in successful operation, each one of which has been a special problem in itself. A full description of such plants would be too extensive to be incorporated here, but they can be found in the various technical journals.

Water Turbines. Water turbines used for driving generators are of two general classes, *reaction* turbines and *impulse* turbines.

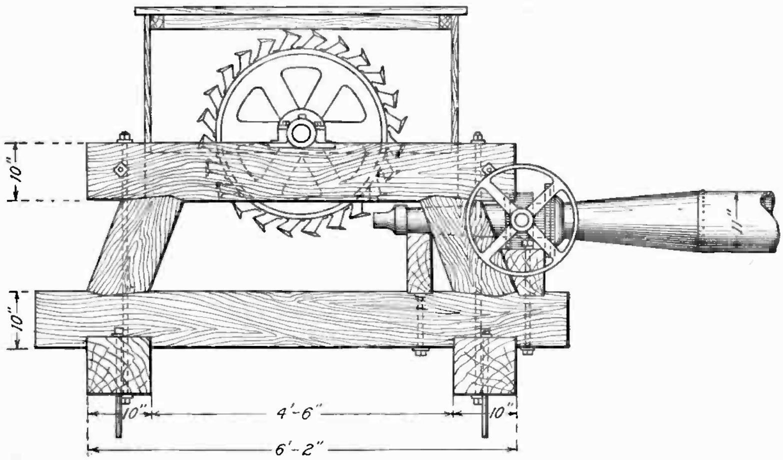
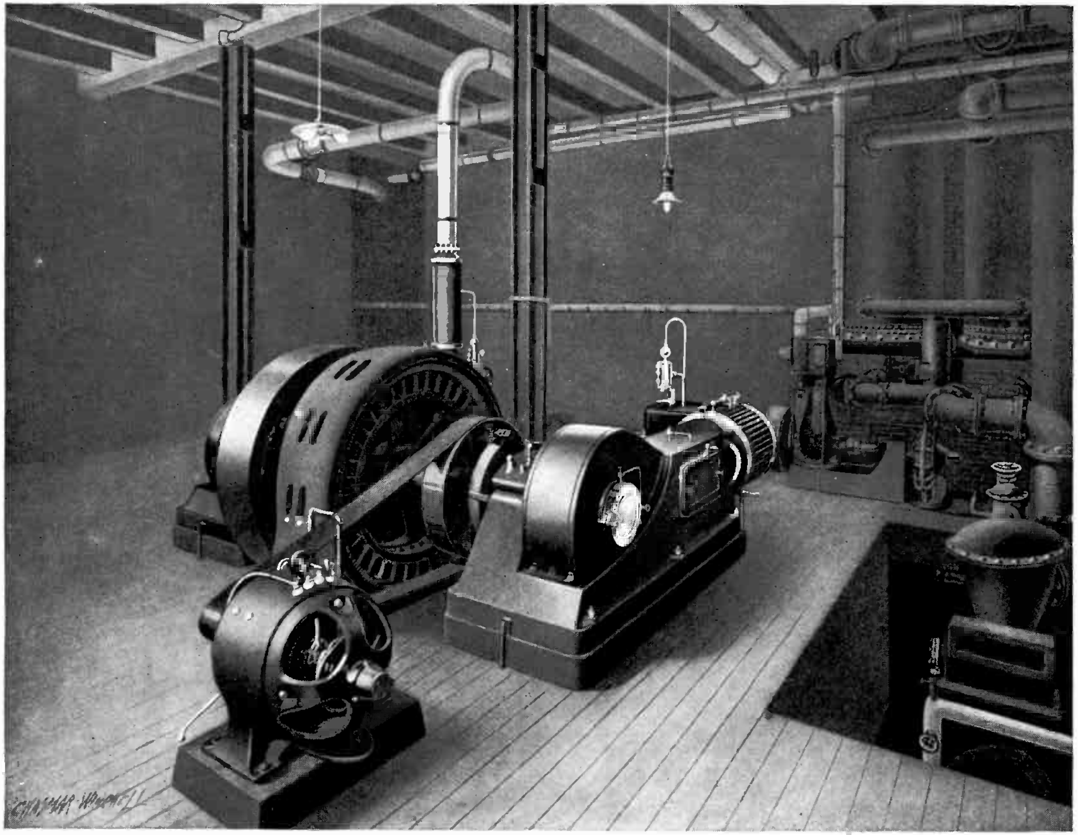


Fig. 12. Pelton Type of Impulse Turbine

Reaction turbines may be subdivided into *parallel-flow*, *outward-flow*, and *inward-flow* types. Parallel-flow turbines are suited for low falls, not exceeding 30 feet. Their efficiency is from 70 to 72 per cent. Outward-flow and inward-flow turbines give an efficiency from 79 to 88 per cent. Impulse turbines are suitable for very high falls and should be used from heads exceeding, say, 100 feet, though it is difficult to say at what head the reaction turbine would give place to the impulse wheel, as reaction turbines are giving good satisfaction on heads in the neighborhood of 200 feet, while impulse wheels are operated with falls of but 80 feet. A reaction wheel is shown in Fig. 11, and the Pelton wheel, one of the best known types



HORIZONTAL CROSS-COMPOUND SINGLE-VALVE ENGINE, DIRECT-CONNECTED TO GENERATOR

LOWER LOCK AND POWER HOUSE, ST. MARY'S FALLS CANAL, MICHIGAN

Overcoming rapids in the St. Mary's River between Lake Superior and Lake Huron, Upper Peninsula of Michigan.

TABLE VII

Pressure of Water

Feet Head	Pressure Pounds per Sq. In.	Feet Head	Pressure Pounds per Sq. In.	Feet Head	Pressure Pounds per Sq. In.	Feet Head	Pressure Pounds per Sq. In.
10	4.33	105	45.48	200	86.63	295	127.78
15	6.49	110	47.64	205	88.80	300	129.95
20	8.66	115	49.81	210	90.96	310	134.28
25	10.82	120	51.98	215	93.13	320	138.62
30	12.99	125	54.15	220	95.30	330	142.95
35	15.16	130	56.31	225	97.46	340	147.28
40	17.32	135	58.48	230	99.63	350	151.61
45	19.49	140	60.64	235	101.79	360	155.94
50	21.65	145	62.81	240	103.90	370	160.27
55	23.82	150	64.97	245	106.13	380	164.61
60	25.99	155	67.14	250	108.29	390	168.94
65	28.15	160	69.31	255	110.46	400	173.27
70	30.32	165	71.47	260	112.62	500	216.58
75	32.48	170	73.64	265	114.79	600	259.90
80	34.65	175	75.80	270	116.96	700	303.22
85	36.82	180	77.97	275	119.12	800	346.54
90	38.98	185	80.14	280	121.29	900	389.86
95	41.15	190	82.30	285	123.45	1000	433.18
100	43.31	195	84.47	290	125.62		

of impulse wheels, is shown in Fig. 12. An efficiency as high as 86 per cent is claimed for the impulse wheel under favorable conditions. The fore bay leading to the flume should be made of such size that the velocity of water does not exceed 1½ feet per second; and it should be free from abrupt turns. The same applies to the tailrace. The velocity of water in wooden flumes should not exceed 7 to 8 feet per second. Riveted steel pipe is used for the penstocks and for carrying water from considerable distances under high heads. In some locations it is buried, in others it is simply placed on the ground. Wooden-stave pipe is used to a large extent when the heads do not much exceed 200 feet. In Table VII is given the pressure of water in pounds per square inch at different heads, while in Table VIII is given considerable data relating to riveted-steel hydraulic pipe. Governors of the usual types are required to keep the speed of the turbine constant under change of load and change of head.

TABLE VIII

Riveted Hydraulic Pipe

Diam. of Pipe in Inches	Area of Pipe in Square Inches	Thickness of Iron by Wire Gauge	Head in Feet the Pipe will Safely Stand	Cu. Ft. Water Pipe will Convey per Min. at Vel. 3 Ft. per Sec.	Weight per Lineal Foot in Pounds
3	7	18	400	9	2
4	12	18	350	16	2¼
4	12	16	525	16	3
5	20	18	325	25	3½
5	20	16	500	25	4¼
5	20	14	675	25	5
6	28	18	296	36	4¼
6	28	16	487	36	5¾
6	28	14	743	36	7½
7	38	18	254	50	5¼
7	38	16	419	50	6¾
7	38	14	640	50	8½
8	50	16	367	63	7½
8	50	14	560	63	9½
8	50	12	854	63	13
9	63	16	327	80	8½
9	63	14	499	80	10¾
9	63	12	761	80	14¼
10	78	16	295	100	9¼
10	78	14	450	100	11¾
10	78	12	687	100	15¾
10	78	11	754	100	17½
10	78	10	900	100	19½
11	95	16	269	120	9¾
11	95	14	412	120	13
11	95	12	626	120	17¼
11	95	11	687	120	18¾
11	95	10	820	120	21
12	113	16	246	142	11¼
12	113	14	377	142	14
12	113	12	574	142	18½
12	113	11	630	142	19¾
12	113	10	753	142	22¾
13	132	16	228	170	12
13	132	14	348	170	15
13	132	12	530	170	20
13	132	11	583	170	22
13	132	10	696	170	24½
14	153	16	211	200	13
14	153	14	324	200	16
14	153	12	494	200	21½
14	153	11	543	200	23½
14	153	10	648	200	26
15	176	16	197	225	13¾
15	176	14	302	225	17
15	176	12	460	225	23
15	176	11	507	225	24½
15	176	10	606	225	28
16	201	16	185	255	14½
16	201	14	283	255	17¼
16	201	12	432	255	24¼
16	201	11	474	255	26½
16	201	10	567	255	29½

Riveted Hydraulic Pipe
(Continued)

Diam. of Pipe in Inches	Area of Pipe in Square Inches	Thickness of Iron by Wire Gauge	Head in Feet the Pipe will Safely Stand	Cu. Ft. Water Pipe will Convey per Min. at Vel. 3 Ft. per Sec.	Weight per Lineal Foot in Pounds
18	254	16	165	320	16½
18	254	14	252	320	20½
18	254	12	385	320	27¼
18	254	11	424	320	30
18	254	10	505	320	34
20	314	16	148	400	18
20	314	14	227	400	22½
20	314	12	346	400	30
20	314	11	380	400	32½
20	314	10	456	400	36½
22	380	16	135	480	20
22	380	14	206	480	24¾
22	380	12	316	480	32¾
22	380	11	347	480	35¾
22	380	10	415	480	40
24	452	14	188	570	27¼
24	452	12	290	570	35½
24	452	11	318	570	39
24	452	10	379	570	43½
24	452	8	466	570	53
26	530	14	175	670	29¼
26	530	12	267	670	38½
26	530	11	294	670	42
26	530	10	352	670	37
26	530	8	432	670	57¼
28	615	14	102	775	31¼
28	615	12	247	775	41¼
28	615	11	273	775	45
28	615	10	327	775	50¼
28	615	8	400	775	61¼
30	706	12	231	890	44
30	706	11	254	890	48
30	706	10	304	890	54
30	706	8	375	890	65
30	706	7	425	890	74
36	1017	11	141	1300	58
36	1017	10	155	1300	67
36	1017	8	192	1300	78
36	1017	7	210	1300	88
40	1256	10	141	1600	71
40	1256	8	174	1600	86
40	1256	7	189	1600	97
40	1256	6	213	1600	108
40	1256	4	250	1600	126
42	1385	10	135	1760	74½
42	1385	8	165	1760	91
42	1385	7	180	1760	102
42	1385	6	210	1760	114
42	1385	4	240	1760	133
42	1385	¼	270	1760	137
42	1385	3	300	1760	145
42	1385	5/16	321	1760	177
42	1385	⅜	363	1760	216

TABLE IX

Horse-Power per Cubic Foot of Water per Minute for Different Heads

Heads in Feet	Horse-Power	Heads in Feet	Horse-Power	Heads in Feet	Horse-Power	Heads in Feet	Horse-Power
1	.0016098	170	.273666	330	.531234	490	.788802
20	.032196	180	.289764	340	.547332	500	.804900
30	.048294	190	.305862	350	.563430	520	.837096
40	.064392	200	.321960	360	.579528	540	.869292
50	.080490	210	.338058	370	.595626	560	.901488
60	.096588	220	.354156	380	.611724	580	.933684
70	.112686	230	.370254	390	.627822	600	.965880
80	.128784	240	.386352	400	.643920	650	1.046370
90	.144892	250	.402450	410	.660018	700	1.126860
100	.160980	260	.418548	420	.676116	750	1.207350
110	.177078	270	.434646	430	.692214	800	1.287840
120	.193176	280	.450744	440	.708312	900	1.448820
130	.209274	290	.466842	450	.724410	1000	1.609800
140	.225372	300	.482940	460	.740508	1100	1.770780
150	.241470	310	.499038	470	.756606		
160	.257568	320	.515136	480	.772704		

GAS PLANT

The gas engine using natural gas, producer gas, blast furnace gas, or even illuminating gas in some instances, is being used to a considerable extent as a prime mover for electric generators. The advantages claimed for the gas engine are:

1. Minimum fuel and heat consumption.
2. Low cost of operation and maintenance.
3. Simplification of equipment and small number of auxiliaries.
4. No heat lost due to radiation when engines are idle.
5. Quick starting.
6. Extensions may be easily made.
7. High pressures are limited to the engine cylinders.

As disadvantages of the gas engine may be mentioned the large floor space required; small overload capacity; and the heavy and expensive foundations necessary.

Fig. 13 shows the efficiency and amount of gas consumed by a 500-h. p. engine, Pittsburg natural gas being used.

The only auxiliaries needed where natural gas is employed are the igniter generators and the air compressors—with a pump for the jacket water in some cases—which may be driven by either a motor or a separate gas engine. The jacket water may be utilized for heating purposes in many plants. Cooling towers may be installed where water is scarce.

Parallel operation of alternators when direct-driven by gas engines has been successful, a spring coupling being used between

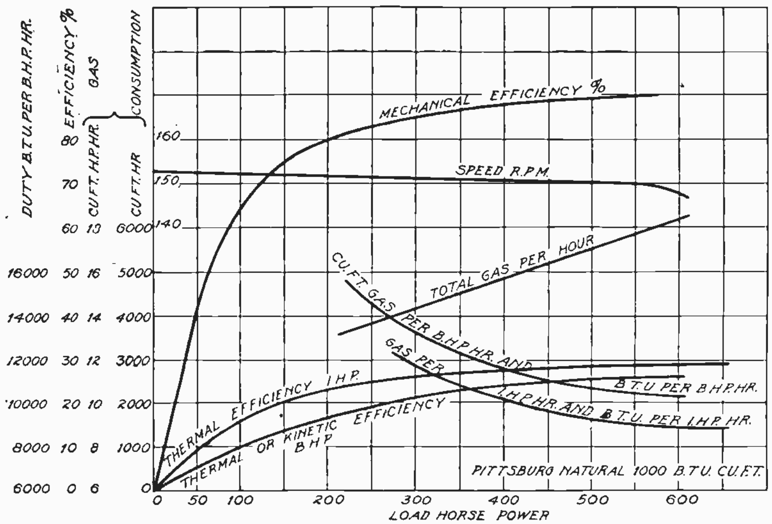


Fig. 13. Efficiency Curves of a 500-H. P. Gas Engine

the engines and the generators in some cases to absorb the variation in angular velocity.

The overload capacity of gas engines depends upon the manner of rating. The ultimate capacity is reached when the engine is using a full charge of the best mixture of gas and air at each power stroke. Many manufacturers rate their engines at 10 per cent below the maximum capacity, thus allowing for a limited amount of overload. The gas consumption of gas engines is relatively high at loads less than 50 per cent of normal; hence, it is desirable that the load be fairly constant and at some value between 50 and 100 per cent of the rating of the machine. H. G. Stott has proposed that the gas engine be combined with the steam turbine in some electrical plants, since the turbine can carry heavy overloads and is fairly economical on all loads. In such a plant the steam turbine would carry the fluctuations, and arrangements would be made so that the gas engine would carry a nearly constant load.

Gas-producers for gas engines are of two types: the *suction producer*, used for small plants and employing high-grade fuels; and the *pressure producer*, used for the larger units and manufactured for all grades of fuel.

The fact that no losses occur, due to heat radiation when the machines are not running, and the lack of losses in piping, add greatly to the plant efficiency. If producer gas or blast-furnace gas is used, a larger engine must be installed to give the same power than when natural or ordinary coal gas is used. Electric stations are often combined with gas works, and gas engines can be installed in such stations to particular advantage in many cases.

In addition to the gas engine, other forms of internal combustion engines, such as oil engines and gasoline engines, are being used to a limited extent in small stations.

ELECTRIC PLANT

GENERATORS

The first thing to be considered in the electric plant is the generators, after which the auxiliary apparatus in the way of exciters, controlling switches, safety devices, etc., will be taken up. A general rule which, by the way, applies to almost all machinery for power stations, is to select apparatus which is considered as "standard" by the manufacturing companies. This rule should be followed for two reasons: *First*, reliable companies employ men who may be considered as experts in the design of their machines, and their best designs are the ones which are standardized. *Second*, standard apparatus is from 15 to 25 per cent cheaper than semi-standard or special work, owing to larger production, and it can be furnished on much shorter notice. Again, repair parts are more cheaply and readily obtained.

Specifications should call for performance, and details should be left, to a very large extent, to the manufacturers. Following are some of the matters which may be incorporated in the specifications for generators:

1. Type and general characteristics.
2. Capacity and overload with heating limits.
3. Commercial efficiency at various loads.
4. Excitation.
5. Speed and regulation.
6. Mechanical features.

Types. The type of machine will be determined by the system selected. Generators may be direct-current or alternating-current—single or polyphase—or as in some plants now in operation, they may be double-current. The voltage, compounding, frequency, etc., should be stated. Direct-current machines are seldom wound for a voltage above 600, but alternating-current generators may be purchased which will give as high as 15,000 volts at the terminals. As a rule it is well not to use an extremely high voltage for the generators themselves, but to use step-up transformers in case a very high line voltage is necessary. Up to about 7,000 volts, generators may be safely used directly on the line. Above this, local conditions will decide whether to connect the machine directly to the line or to step up the voltage. Machines wound for high potential are more expensive for the same capacity and efficiency, but the cost of step-up transformers and the losses in the same are saved by using such machines, so that there is a slight gain in efficiency which may be utilized in better regulation of the system, or in lighter construction of the line. On the other hand, lightning troubles are liable to be aggravated when transformers are not used, as the transformers act as additional protection to the machines, and if the transformers are injured they may be more readily repaired or replaced.

The following voltages are considered standard: Direct-current generators 125, 250, 550-600. Alternating-current systems, high pressure, 2,200, 6,600, 11,000, 22,000, 33,000, 44,000, 66,000, 88,000, and 110,000. The generators, when used with transformers, should be capable of giving a no-load voltage 10 per cent in excess of these figures. Twenty-five and 60 cycles are considered as standard frequencies, the former being more desirable for railway work and the latter for lighting purposes.

Capacity. The size of machines to be chosen has been briefly considered. Alternators are rated for non-inductive load or a power

TABLE X

Average Maximum Efficiencies

Kw.	Per Cent	Kw.	Per Cent
5	85	150	93
10	88	200	94
25	90	500	95
50	92	1000	96

factor of unity unless a different power factor is distinctly stated. Aside from the overload capacity to be counted upon as reserve, the Standardization Report of the American Institute of Electrical Engineers recommends the following for the heating limits and overload capacity of generators:

Maximum Values of Temperature Elevation

Field and armature, by resistance,	50° C.
Commutator and collector rings and brushes, by thermometer,	55° C.
Bearings and other parts of machine, by thermometer,	40° C.

Overload capacity should be 25 per cent for two hours, with a temperature ise not to exceed 15 degrees above full load values, the machine to be at constant temperature reached under normal load, before the overload is applied. A momentary overload of 50 per cent should be permissible without excessive sparking or injury. Some companies recommend an overload capacity of 50 per cent for two hours when the machines are to be used for railway purposes. The above temperature increases are based upon a room-temperature of 25° C.

Efficiency. As a rule, generators should have a high efficiency over a considerable range of load, although much depends upon the nature of the load. It is always desirable that maximum efficiency be as high as is compatible with economic investment.

Table X gives reasonable efficiencies which may be expected for generating apparatus. In order to arrive at what may be considered the best maximum efficiency to be chosen, the cost of power generation must be known, or estimated, and the fixed charges on capital invested must also be a known quantity. From the cost of power, the saving on each per cent increase in efficiency can be determined, and this should be compared with the charges on the

TABLE XI

Exciters for Single-Phase Alternating-Current Generators

60 Cycles

Alternator Classificaton			Exciter Classification		
Poles	Kw.	Speed	Poles	Kw.	Speed
8	60	900	2	1.5	1,900
8	90	900	2	1.5	1,900
8	120	900	2	1.5	1 900
12	180	600	2	2.5	1,900
16	300	450	2	4.5	1,800

additional investment necessary to secure this increased efficiency. A certain point will be found where the sum of the two will be a minimum.

If a generator is to be run for a considerable time at light loads, one with low "no-load" losses should be chosen. These losses are not rigidly fixed but they vary slightly with change of load. It is the same question of "all-day efficiency" which is treated, in the case of transformers, in "Power Transmission." Under no-load losses may be considered, in shunt-wound generators, friction losses, core losses, and shunt-field losses. I^2R losses in the series field, in the armature, and in the brushes, vary as the square of the load.

Excitation. Dynamos, if for direct current, may be self-excited, shunt-wound, compound-wound, or separately excited. Separate excitation is not recommended for these machines. Alternators require separate excitation, though they may be compounded by using a portion of the armature current when rectified by a commutator. Automatic regulation of voltage is always desirable, hence, the general use of compound-wound machines for direct currents. Many alternators using rectified currents in series fields for keeping the voltage nearly constant are in service in small plants, as well as several of the so-called "compensated" alternators, arranged with special devices which maintain the same compounding with different power factors. The latter machine gives good satisfaction if properly cared for, but an automatic regulator, governed by the generator voltage and current, which acts directly on the exciter field, is taking its place. This regulator, known as the Tirrill regulator, is described under "Power Transmission." The capacity of the exciters must be such that they will furnish sufficient excitation to maintain normal voltage at the terminals of the generators when running at 50 per cent overload. Table XI gives the proper capacity of exciters for the generators listed. On account of the fact that the speed at which the unit runs is an important factor in the excitation required, no general figure can be given.

Exciters may be either direct-connected or belted to the shaft of the machine which they excite, or they may be separately driven. They are usually compound-wound and furnish current at 125 or 250 volts. Separately-driven exciters are preferred for most plants as they furnish a more flexible system, and any drop in the speed of the generator does not affect the exciter voltage. Ample reserve capacity of exciters should be installed, and in some cases storage batteries, used in conjunction with exciters, are recommended in order to insure reliability of service.

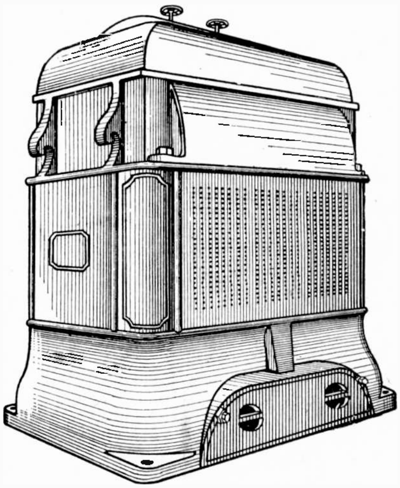


Fig. 14. Air-Cooled Transformer

Speed and Regulation. If direct-connected, the speeds of the generators will be determined by the prime mover selected. If belt-driven, small machines may be run at a high speed, as high-speed machines are cheaper than slow- or moderate-speed generators. In large sizes, this saving is not so great.

When shunt-wound dynamos are used, the inherent regulation should not exceed 2 to 3 per cent for large machines. For alternators, this is much greater and depends on the power factor of the load. A fair value for the regulation of alternators on non-inductive load is 10 per cent.

Mechanical Features. Motor-generator sets, boosters, frequency changers, and other rotating devices come under the head of special apparatus and are governed by the same general rules as generators.

Transformers. Transformers for stepping the voltage from that generated by the machine up to the desired line voltage, or *vice versâ*, at the substation, may be of three general types, according to the method of cooling. Large transformers require artificial means of cooling, if they are not to be too bulky and expensive. They may be air-cooled, oil-cooled, or water-cooled.

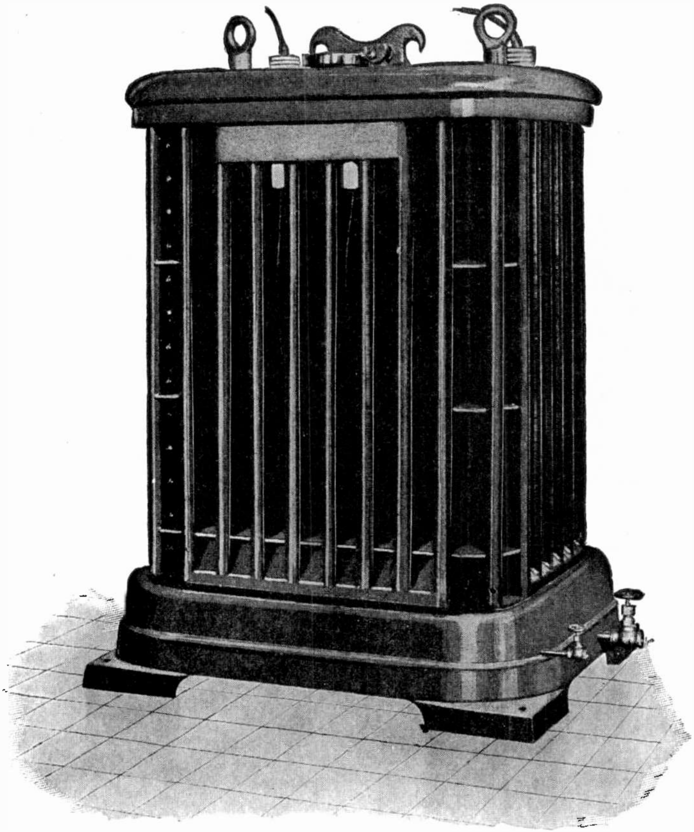


Fig. 15. Oil-Cooled Transformer

Air-cooled transformers, Fig. 14, are usually mounted over an air-tight pit fitted with one or more motor-driven blowers which feed into the pit. The transformer coils are subdivided so that no part of the winding is at a great distance from air and the iron is provided with ducts. Separate dampers control the amount of air which passes between the coils or through the iron. Such transformers give good satisfaction for voltages up to 20,000 or higher, and can be built for any capacity. Care must be taken to see that there is no liability of the air supply failing, as the capacity of the transformers is greatly reduced when not supplied with air.

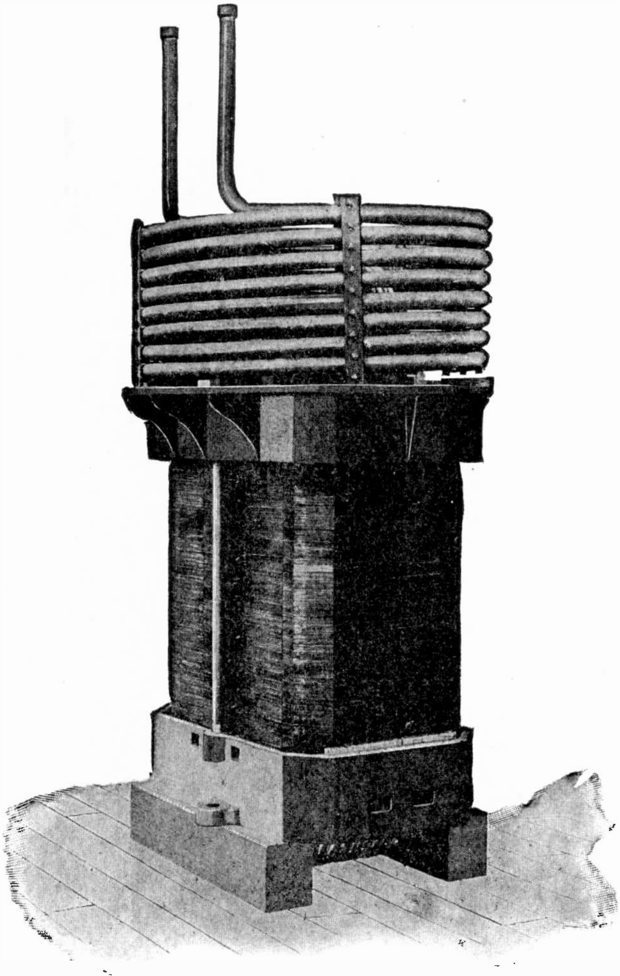


Fig. 16. Water-Cooled Transformer

Oil-cooled transformers, Fig. 15, have their cores and windings placed in a large tank filled with oil. The oil serves to conduct the heat to the case, and the case is usually made either of corrugated sheet metal or of cast iron containing deep grooves, so as to increase the radiating surface. These transformers do not require such heavy insulation on the outside of the coils as air-blast machines because the oil serves this purpose. Simple oil-cooled transformers are seldom built for capacities exceeding 250 kw. as they become too bulky, but they are employed for the highest voltages now in use.

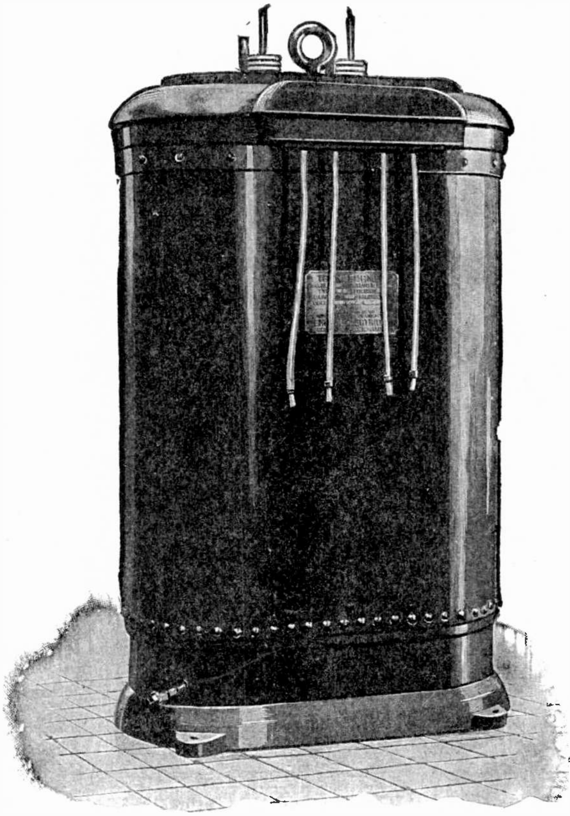


Fig. 17. 400-Kw. Water-Cooled Oil Transformer

Water-cooled transformers, Figs. 16 and 17, are used when high voltages are required. This type is like an oil-cooled transformer, but with water tubes arranged in coils in the top. Cold water passes through these tubes and aids in removing heat from the oil. Some types have the low-tension windings made up of tubes through which the water circulates. Water-cooled transformers must not have the supply of cooling water shut off for any length of time when under normal load or they will overheat.

One or more spare transformers should always be on hand and they should be arranged so that they can be put into service on very short notice.

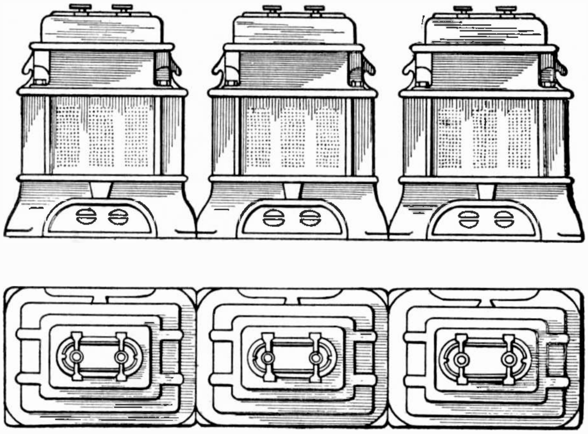


Fig. 18. Three-Phase Air-Blast Transformers. Total Capacity, 3,000 Kw.

Three-phase transformers allow a considerable saving in floor space, as shown by a comparison of the machines in Figs. 18 and

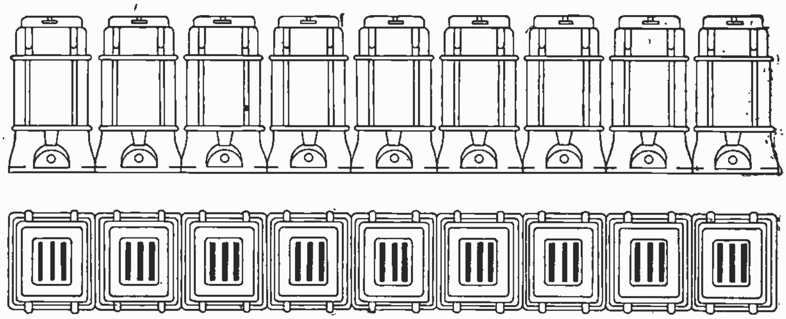


Fig. 19. Single-Phase Air-Blast Transformers. Total Capacity, 3,000 Kw.

19. They are cheaper than three separate transformers which make up the same capacity, but they are not as flexible as a single-phase transformer and one complete unit must be held for a reserve or "spare" transformer.

Storage Batteries. The use of storage batteries for central stations and substations is clearly outlined in "Storage Batteries."

The chief points of advantage are:

1. Reduction in fuel consumption due to the generating machinery being run at its greatest economy.
2. Better voltage regulation.
3. Increased reserve capacity and less liability to interruption of service.

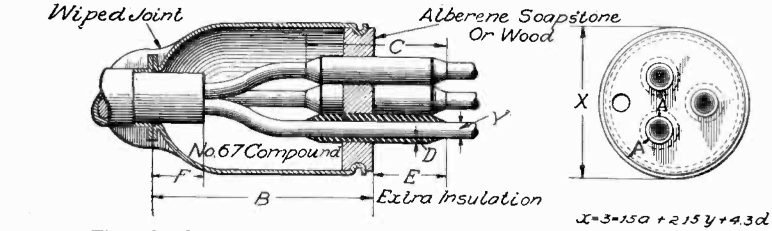
The main disadvantage is the high first cost and depreciation.

SWITCHBOARDS

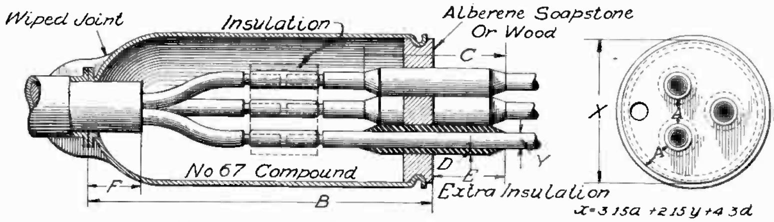
The switchboard is the most vital part of the whole system of supply, and should receive consideration as such. Its objects are: to collect the energy as supplied by the generators and to direct it to the desired feeders, either overhead or underground; to furnish a support for the various measuring instruments connected in service, as well as the safety devices for the protection of the generating apparatus; and to control the pressure of the supply. Some of the essential features of all switchboards are:

1. The apparatus and supports must be fire-proof.
2. The conducting parts must not overheat.
3. Parts must be easily accessible.
4. Live parts except for low potentials must not be placed on the front of the operating panels.
5. The arrangement of circuits must be symmetrical and as simple as it is convenient to make them.
6. Apparatus must be arranged so that it is impossible to make a wrong connection that would lead to serious results.
7. It should be arranged so that extensions may be readily made.

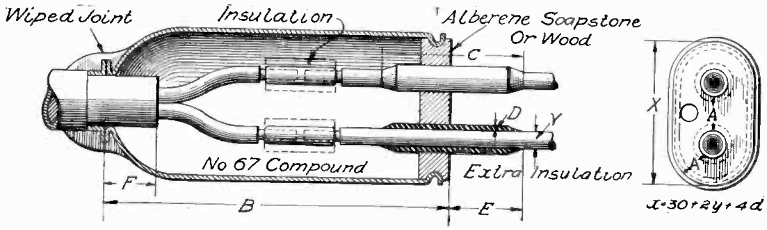
There are two general types—in the first, all of the switching and indicating apparatus is mounted directly on panels; and in the second, the current-carrying parts are at some distance from the panels, the switches being controlled by long connecting rods, or else operated electrically or by means of compressed air. The first may again be divided into direct-current and alternating-current switchboards. It is from the first class of apparatus that the switchboard gets its name and the term is still applied, even when the board proper forms the smallest part of the equipment. The term "switchgear" is now being introduced to cover all of the apparatus connected with the switching operations and the term "switchboard" is being reserved for the panels and their apparatus only. Switchboards have been standardized to the extent that standard generator, exciter, feeder, and motor panels may be purchased for certain classes



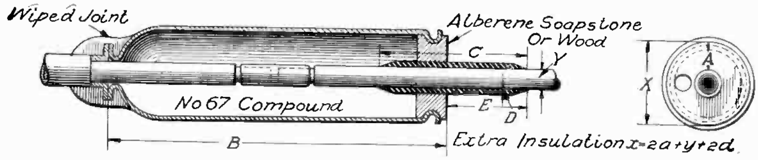
Three-Conductor Cable Without Joints



Three-Conductor Cable With Joints



Two-Conductor Cable With Joints



Single-Conductor Cable With Joints

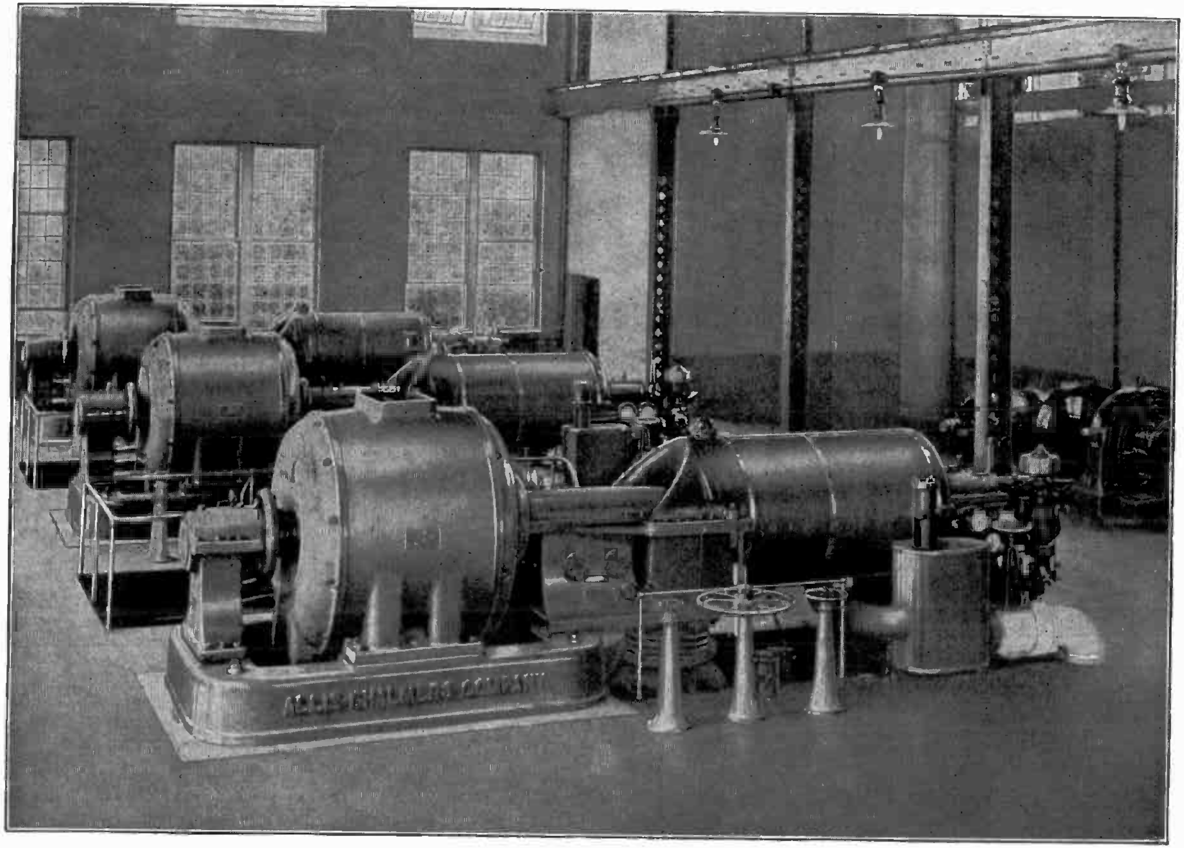
VOLTS	A	B	C	D	E	F
6,600	1	12	5	$\frac{1}{8}$	$2\frac{1}{2}$	1
13,200	$1\frac{1}{2}$	15	8	$\frac{1}{4}$	4	2
26,400	2	19	14	$\frac{1}{2}$	7	4

$\frac{1}{8}$-inch Lead or $\frac{1}{16}$-inch Brass Bells

Fig. 20. Part Section—Showing Cable Bells in Place

HEADWORKS OF THE ONTARIO POWER COMPANY, NIAGARA FALLS, ONTARIO

View showing outer and inner forebays, with screen house between. Gate house at further end of inner forebay.



THREE ALLIS-CHALMERS STEAM TURBINES AND GENERATORS
3,250 Kilowatt Installation. Allis-Chalmers Co., Milwaukee, Wis.

of work, but the vast majority of them are made up as semi-standard or special.

The leads which carry the current from the machines to the switches should be put in with very careful consideration. Their size should be such that they will not heat excessively when carrying the rated overload of the machine, and they should preferably be placed in fire-proof ducts, although low-potential leads do not always require this construction. Curves showing sizes for lead-covered cables for different currents are given in "Power Transmission." Table XII gives standard sizes of wires and cables together with the thickness of insulation necessary for different voltages. Cables should be kept separate as far as possible so that if a fault does occur on one cable, neighboring conductors will not be injured. For lamp and instrument wiring, such as leads to potential and current transformers, the following sizes of wire are recommended:

No. 16 or No. 14, wiring to lamp sockets.

No. 12 wire, $\frac{3}{64}''$ rubber insulation, all other small wiring under 600 volts potential.

No. 12, $\frac{3}{32}''$ rubber insulation for primaries of potential transformers from 600 to 3,500 volts.

No. 8, $\frac{5}{32}''$ rubber insulation for primaries of potential transformers up to 6,600 volts.

No. 8, $\frac{7}{32}''$ rubber insulation for primaries of potential transformers up to 10,000 volts.

No. 4, $\frac{21}{64}''$ rubber insulation for primaries of potential transformers up to 15,000 volts.

No. 4, $\frac{14}{32}''$ rubber insulation for primaries of potential transformers up to 20,000 volts.

No. 4, $\frac{17}{32}''$ rubber insulation for primaries of potential transformers up to 25,000 volts.

Where high-tension cables leave their metallic shields they are liable to puncture, so that the sheath should be flared out at this point and the insulation increased by the addition of compound. Fig. 20 shows such cable bells, as they are called, as are recommended by the General Electric Company. Other types of cable outlets are introduced from time to time. A very excellent type makes use of porcelain sleeve for each conductor at the point when it leaves the lead sheath.

Panels. Central-station switchboards are usually constructed of panels about 90 inches high, from 16 inches to 36 inches wide, and $1\frac{1}{2}$ inches to 2 inches thick. Such panels are made of blue Vermont,

TABLE XII

Standard Wire

(Solid)

Area	Diameter Inches	Terminal Drilling	Amperes	Thickness of Rubber Insulation Volts							Gauge
Circular Mils	Bare	Drill Number	Constant Current Capacity	600	3,500	6,600	10,000	15,000	20,000	25,000	B. & S.
2,582	.051	30	4								16
4,106	.064	30	6	[illegible]/64							14
6,530	.081	30	10	$\frac{3}{64}$	$\frac{3}{32}$						12
16,510	.128	18	25	$\frac{3}{64}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$				8
26,251	.162	5	40	$\frac{1}{16}$							6
41,743	.204	$\frac{1}{4}$	60	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{14}{32}$	$\frac{17}{32}$	4
66,373	.257	$\frac{5}{16}$	90	$\frac{1}{16}$							2
83,695	.289	$\frac{11}{32}$	110	$\frac{5}{64}$							1
105,593	.325	$\frac{3}{8}$	130	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{14}{32}$	$\frac{17}{32}$	0
133,079	.365	$\frac{7}{16}$	170	$\frac{5}{64}$							00
167,805	.410	$\frac{15}{32}$	205	$\frac{5}{64}$							000
211,600	.460	$\frac{17}{32}$	250	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{14}{32}$	$\frac{17}{32}$	0000

Standard Cable

(Stranded)

Circular Mils	Diameter, Inches Bare	Terminal Drilling Inches	Con. Cur. Capacity Amperes	Thickness of Rubber Insulation (For 6000 V. only)
250,000	.568	$\frac{5}{8}$	290	$\frac{3}{32}$
300,000	.637	$\frac{23}{32}$	240	$\frac{3}{32}$
350,000	.680	$\frac{3}{4}$	380	$\frac{3}{32}$
400,000	.735	$\frac{13}{16}$	420	$\frac{3}{32}$
500,000	.820	$\frac{29}{32}$	500	$\frac{3}{32}$
600,000	.900	1	575	$\frac{7}{64}$
800,000	1.037	$1\frac{1}{8}$	710	$\frac{7}{64}$
1,000,000	1.157	$1\frac{1}{4}$	830	$\frac{7}{64}$
1,500,000	1.412	$1\frac{1}{2}$	1100	$\frac{1}{8}$
2,000,000	1.65	$1\frac{3}{4}$	1350	$\frac{1}{8}$

pink Tennessee, or white Italian marble, or of black enameled or oiled slate. Slate is not recommended for voltages exceeding 1,100. The panels are made in two or three parts. When made in two parts, the sub-base is from 24 to 28 inches high. They are polished on the front and the edges are beveled. Angle and tee bars or pipe work, together with foot irons and tie rods, form the supports for such panels, and on these panels are mounted the instruments, main switches, or controlling apparatus for the main switches, as the case may be, together with relays and hand wheels for rheostats and regulators.

The usual arrangement of the panels is to have a separate panel for each generator, exciter, and feeder, together with what is known as a station or total-output panel. In order to facilitate extensions and simplify connections, the feeder panels are located at one end of the board, the generator panels are placed at the other end, and the total-output panel occupies a position between the two. The main bus bars extend throughout the length of the generator and feeder panels, and the desired connections are readily made. The instruments required are very numerous. Lists of meters required for standard practice and regular panels are given later.

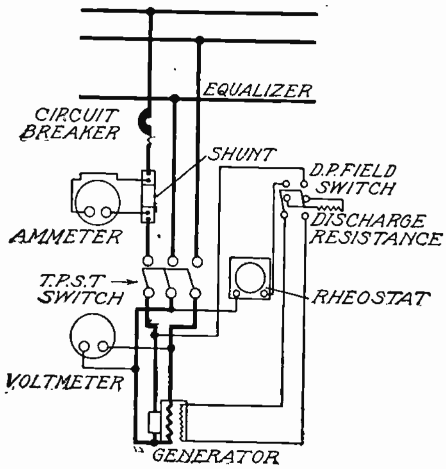


Fig. 21. Wiring Diagram of D. C. Generator Panel

For *direct-current generator panels* or for the *direct-current side of synchronous converters, two-wire system,* there are usually required:

1 Main switch
1 Field switch
1 Ammeter
1 Voltmeter
1 Field rheostat with controlling mechanism
1 Circuit breaker
1 4-point starting switch (for use when machine is to be started as a direct-current motor).
Bus bars and various connections.

These may be arranged in any suitable order, the circuit breaker being preferably located at the top so that any arcing which may occur will not injure other instruments. Fig. 21 gives a wiring diagram of such a panel.

The main switch may be a single- or a double-throw, depending on whether one or two sets of bus bars are used. It may be a triple-pole, as shown in Fig. 21, in which the middle bar serves as the equalizing switch, or the equalizing switch may be mounted on a pedestal near the machine, in which case the generator switch would be double-pole.

The field switch for large machines should be double-pole fitted with carbon breaks and arranged with a discharge resistance consisting of a resistance which is thrown across the terminals of the

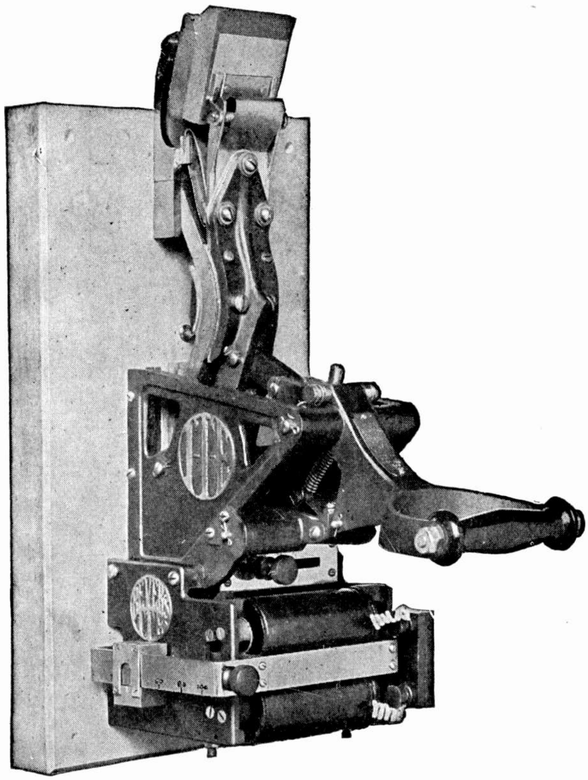


Fig. 22. Carbon Break Circuit Breaker

field just before the main circuit is opened. One voltmeter located on a swinging bracket at the end of the panel, and arranged so that it can be thrown across any machine or across the bus bars by means of a dial switch, is sometimes used, but it is preferable to have a separate meter for each generator.

Small rheostats are mounted on the back of the panel, but large ones are chain-operated and preferably located below the floor, the controlling hand wheel being mounted on the panel.

The circuit breaker may be of the carbon break or the magnetic blow-out type. Figs. 22 and 23 show circuit breakers of these types. Lighting panels for low potentials are often fitted with fuses instead of circuit breakers, in which case they may be open fuses on the back

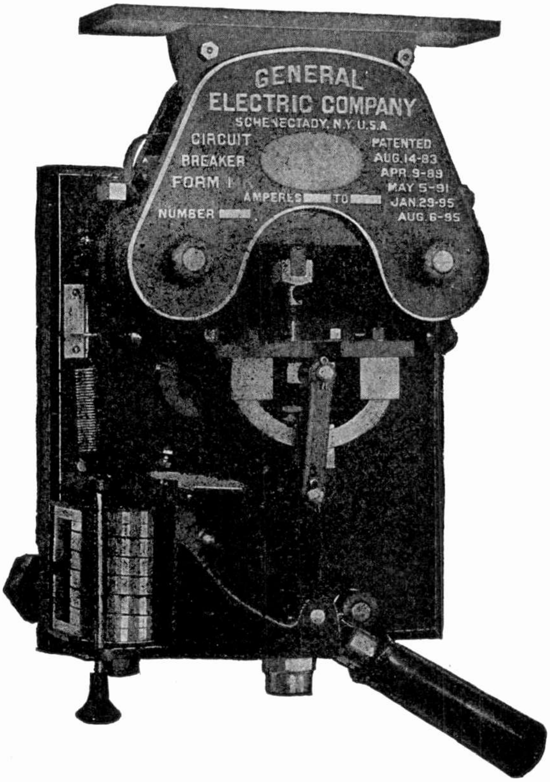


Fig. 23. Magnetic Blow-Out Circuit Breaker

of the panel or enclosed fuses on either the front or back of the panel.

A panel for a *direct-current generator or a synchronous converter for a 3-wire system* should contain:

2 Ammeters.
2 Circuit breakers. Fuses used on small generators.

3 Single-pole switches, double-throw if there are two sets of bus bars. For a three-wire generator or a synchronous converter two single-pole or one double-pole switch may be used, in which case the neutral wire is not brought to the switchboard.
2 Hand-wheels for the field rheostats. But one required if a three-wire generator is used but the two are necessary if the three-wire system is obtained by the use of two generators or a balancer set.
2 Field switches. But one is required for a three-wire generator or synchronous converter.
1 Four-point starting switch. Required only when the machine is to be started as a direct-current motor at times.
2 Potential receptacles, four-point, used in connection with a voltmeter, usually mounted on a swinging bracket. Only one is required for the three-wire generator or the synchronous converter.

An alternating-current generator or a synchronous motor panel for a *three-phase, three-wire system* will require:

3 Ammeters. Only one required for a single-phase panel or for a synchronous motor.
1 Three-phase indicating wattmeter.
1 Voltmeter.
1 8-point potential receptacle used to connect the above voltmeter across any phase. Not necessary for the synchronous motor.
1 Field ammeter. Convenient but not always necessary.
1 Double-pole field switch with discharge clips.
1 Hand-wheel for field rheostat.
1 Synchronizing receptacle.
1 Triple-pole oil switch, usually non-automatic for generators but automatic for motors. This may be single- or double-throw, depending upon the bus bar arrangements.
1 Synchronizer. A single instrument may serve for several machines.
2 Current transformers.
2 Potential transformers. Only one necessary for motor.
1 Power Factor indicator. Not always necessary.
1 Governor control switch. Not always necessary.

Where the switches are of the remote control type, the control switches or the operating handles are mounted on the panel.

A three-phase induction-motor panel should contain:

1 Ammeter.
1 Automatic oil switch, preferably operated by means of an inverse time-limit relay.
The starting compensator used with induction motors is usually mounted independently of the switchboard panel.

The instruments used on a *synchronous converter panel, alternating-current control,* are:

1 Ammeter.
1 Synchronizing receptacle.
1 Oil-switch, automatic.
1 Potential transformer.
2 Current transformers.
1 Switch for control of regulator where a regulator is used and operated by means of a small motor.

A three-phase feeder panel requires:

3 Ammeters. In some cases only one is necessary.
1 Automatic oil switch.
2 Current transformers.
1 Potential Transformer. Not always needed.
1 Voltmeter. Not always needed.
1 Hand-wheel for control of regulator where a regulator is used.

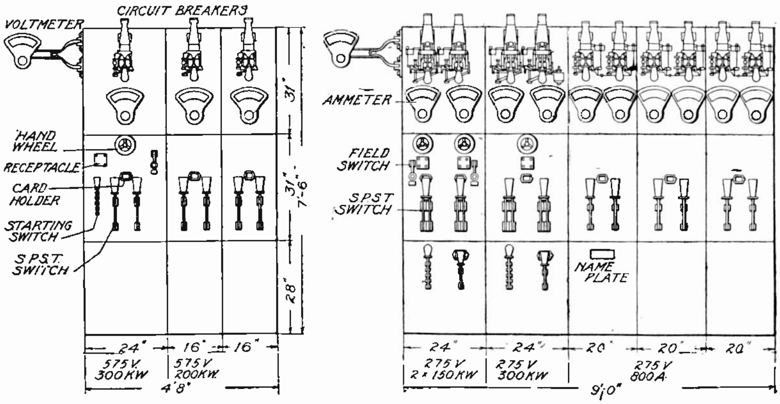


Fig. 24. Standard Switchboard Panel

Direct-Current feeder panels contain:

1 Ammeter. Two are required for a 3-wire feeder.
1 Circuit breaker, single-pole. Two are required for a 3-wire feeder.
1 or more main switches, single-pole or double-pole, and single- or double-throw, depending upon the number of bus bars.
1 Recording wattmeter, not always used.
1 Potential receptacle.
Apparatus for controlling regulators when such are used.

One voltmeter usually serves for several feeder panels, such a meter being mounted above the panels or on a swinging bracket at the end. Switches should preferably be of the quick-break type. Figs. 24 and 25 show some standard switchboard panels as manufactured by the General Electric Company.

Exciter panels are nothing more than generator panels on a small scale. The necessary instruments for a panel controlling one exciter are:

1 Ammeter.
1 Field rheostat.
1 Voltmeter.
1 3-pole switch with fuses.
1 4-point potential receptacle.
1 Equalizing rheostat. This is necessary only where a Tirrill regulator is used and more than one exciter is operated on the same set of excitation buses.

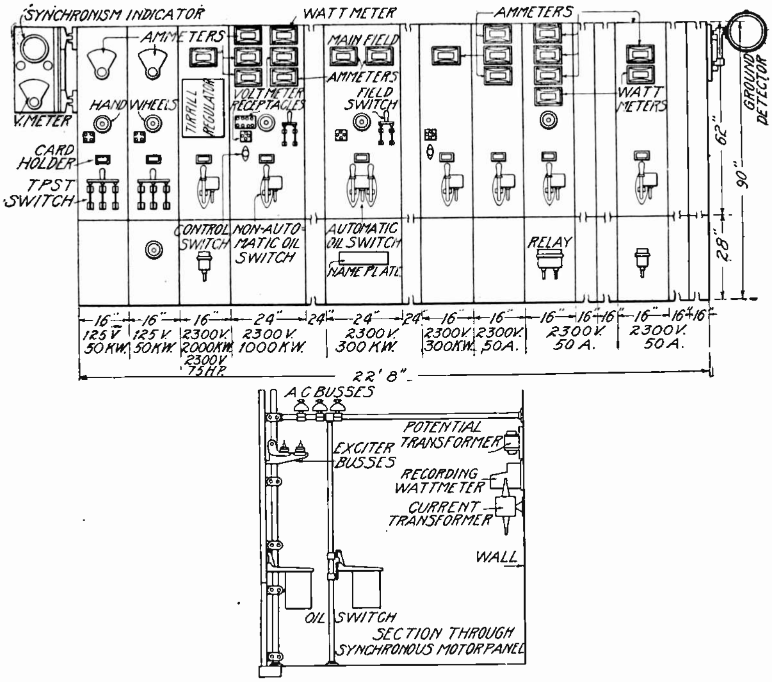


Fig. 25. Standard Switchboard Panel

Total Output Panels contain instruments recording the total power delivered by the plant to the switchboard. The paralleling of alternators is treated in "Management of Dynamo Electric Machinery."

For the higher voltages on alternating-current boards, the measuring instruments are no longer connected directly in the circuit, and the main switch is not mounted directly on the panel. Current and potential transformers, as called for in the lists given in connection with the different panels, are used for connecting to the indicating voltmeters and the ammeters and the recording wattmeters, and potential transformers are used for the synchronizing device.

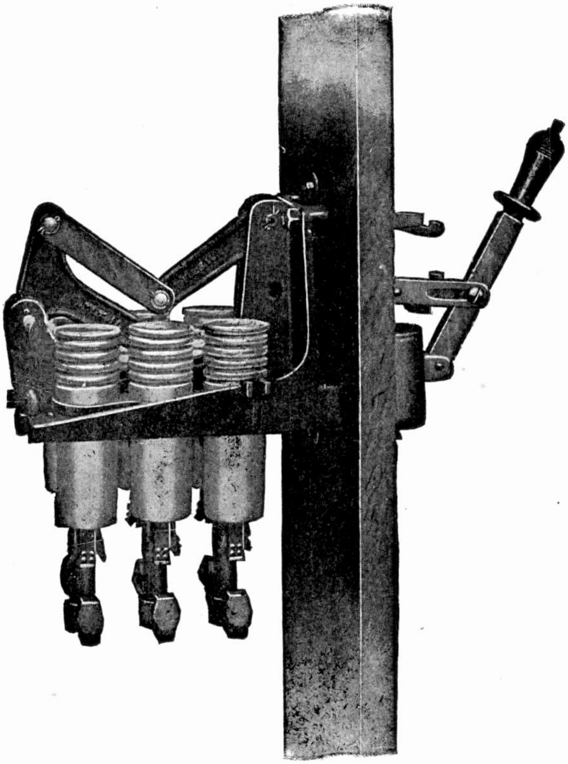


Fig. 26. Three-Phase Oil Switch with Oil Container Removed

These transformers are mounted at some distance from the panel, while the switches may be located near the panel and operated by a system of levers, or they may be located at a considerable distance and operated by electricity or by compressed air.

Oil Switches. Oil switches are recommended for all high potential work for the following reasons:

By their use it is possible to open circuits of higher potential and carrying greater currents than with any other type of switch.

They may be made quite compact.

They may readily be made automatic and thus serve as circuit breakers for the protection of machines and circuits when overloaded.

There are several types of oil switches on the market. A switch constructed for three-phase work, to be closed by hand and to be

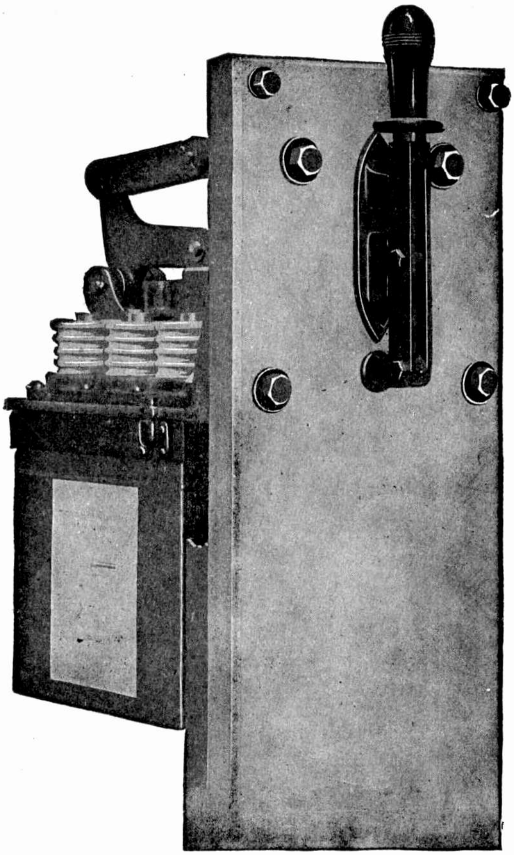


Fig. 27. Three-Phase Oil Switch with Oil Container in Place

electrically tripped or opened by hand, is shown in Fig. 26. This shows the switch without the can containing the oil. Fig. 27 shows a similar switch hand-operated, with the can in place. Both of these switches are arranged to be mounted on the panel. Fig. 28 shows how the same switches are mounted when placed at some distance from the panel. For high voltages, they are placed in brick

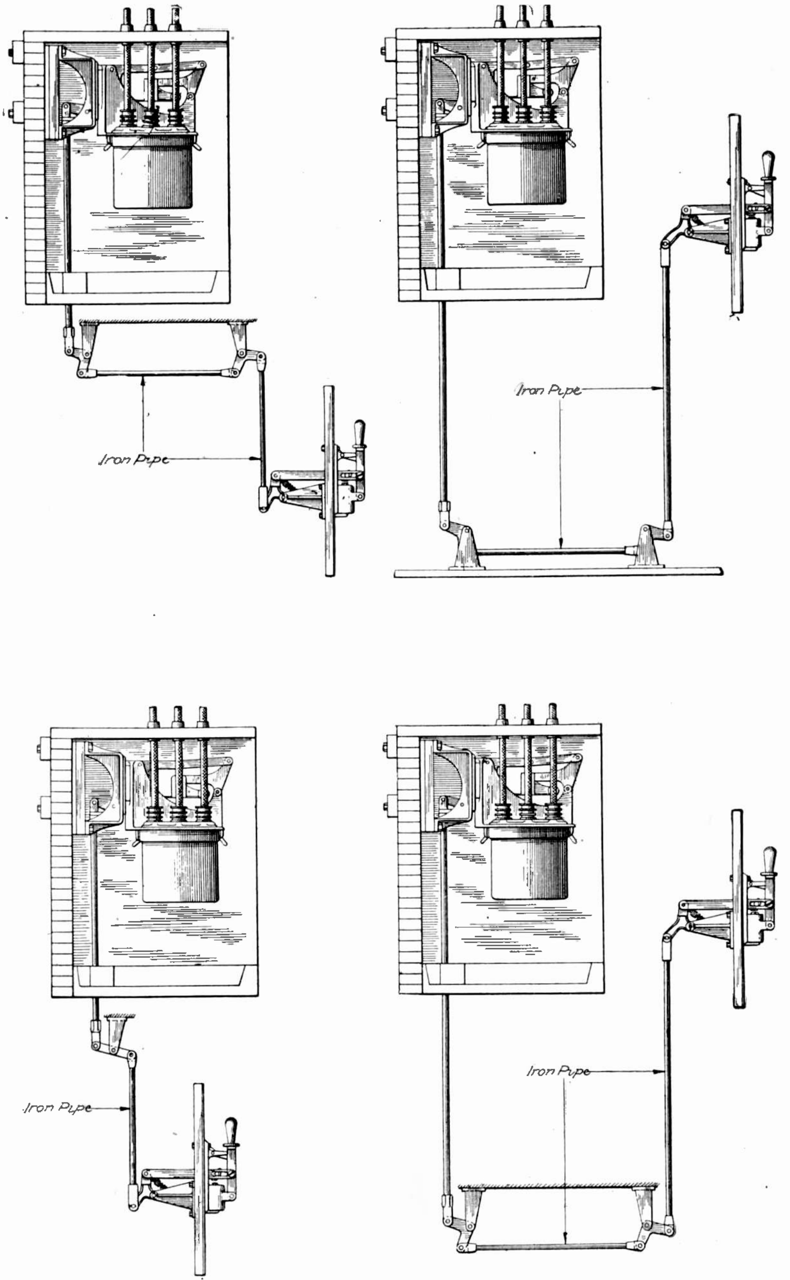


Fig. 28. Four Arrangements of Oil Switch when Mounted at Some Distance from the Panel

cells and often three separate single-pole switches are used, each placed in a separate cell so that injury to the contacts in one leg will in no way affect the other parts of the switch. A form of oil switch used for the higher potentials and currents met with in practice, is shown in Fig. 29. This particular switch is operated by means of an electric motor, though it may as readily be arranged to operate by means of a solenoid or by compressed air. General

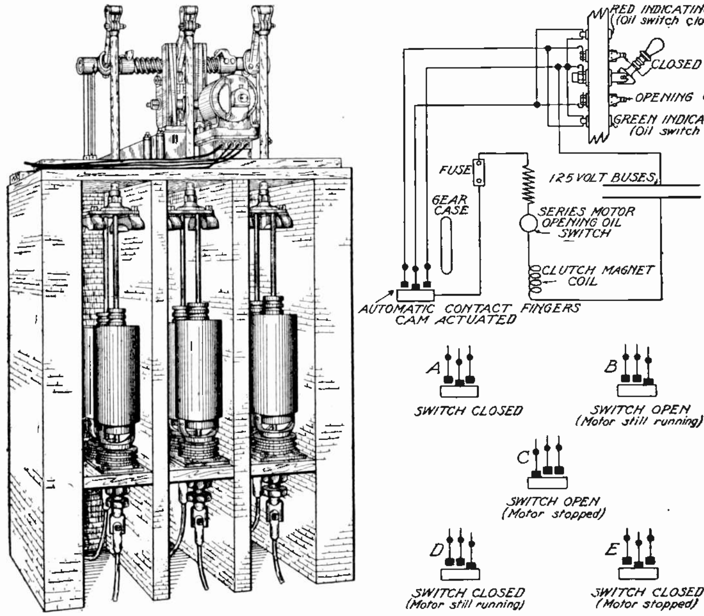


Fig. 29. Form of Oil Switch for High Potentials

practice is to place all high-tension bus bars and circuits in separate compartments formed by brick or cement, and duplicate bus bars are quite common.

Oil switches are made automatic by means of *tripping magnets,* which are connected in the secondary circuits of current transformers, or they may be operated by means of relays fed from the secondaries of current transformers in the main leads. Such relays are made very compact and can be mounted on the front or back of the switchboard panels. The wiring of such tripping devices is shown in Fig. 30.

With remote control of switches, the switchboard becomes in many instances more properly a switch house, a separate building being devoted to the bus bars, switches and connections. In other cases a framework of angle bars or gas pipe is made for the support of the switches, bus bars, current and potential transformers, etc. The supports for the controlling switches are sometimes mounted in a nearly horizontal position, forming the bench type of control board.

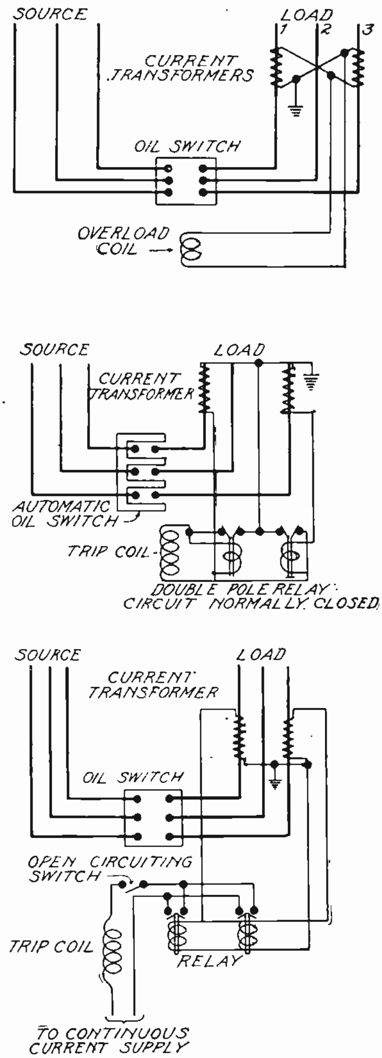


Fig. 30. Wiring Diagram for Tripping Devices

Additional types of panels which may be mentioned are transformer panels, usually containing switching apparatus only, and arc-board panels. The latter are arranged to operate with plug switches. A single panel used in the operation of series transformers on arc-lighting circuits is shown in Fig. 31.

Safety Devices. In addition to the ordinary overload tripping devices which have already been considered, there are various safety devices necessary in connection with the operation of central stations. One of the most important of these is the *lightning arrester*. For direct-current work, the lightning arrester often takes the form of a single gap connected in series with a high resistance and fitted with some device for destroying the arc formed by discharge to the ground. One of these is connected between either side of the circuit and the ground, as shown diagrammatically in

Fig. 32. A "kicking" coil is connected in circuit between the arresters and the machine to be protected, to aid in forcing the lightning discharge across the gap. In railway feeder panels such kicking coils are mounted on the backs of the panels.

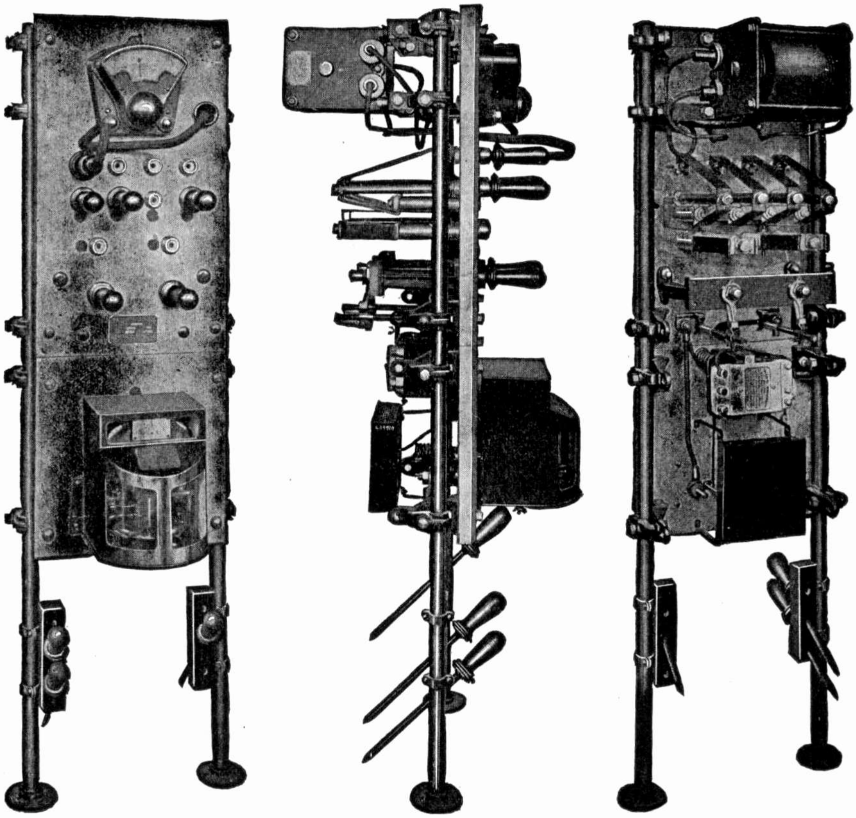


Fig. 31. Single Panel for Series Transformers in Arc-Lighting Circuits

For alternating-current work, several gaps may be arranged in series, these gaps being formed between cylinders of "non-arcing" metal. High resistances and reactance coils are used with these, as in direct-current arresters. Fig. 33 shows connections for a 10,000-volt lightning arrester. The resistance used in connection with lightning arresters are of special design and non-inductive. In recent types these resistances are connected in shunt to the gaps as shown in Fig. 34. Lightning arresters should always be provided with knife blade switches so that they can be disconnected from the circuit for inspection and repairs. A typical installation of lightning arresters is shown in Fig. 35.

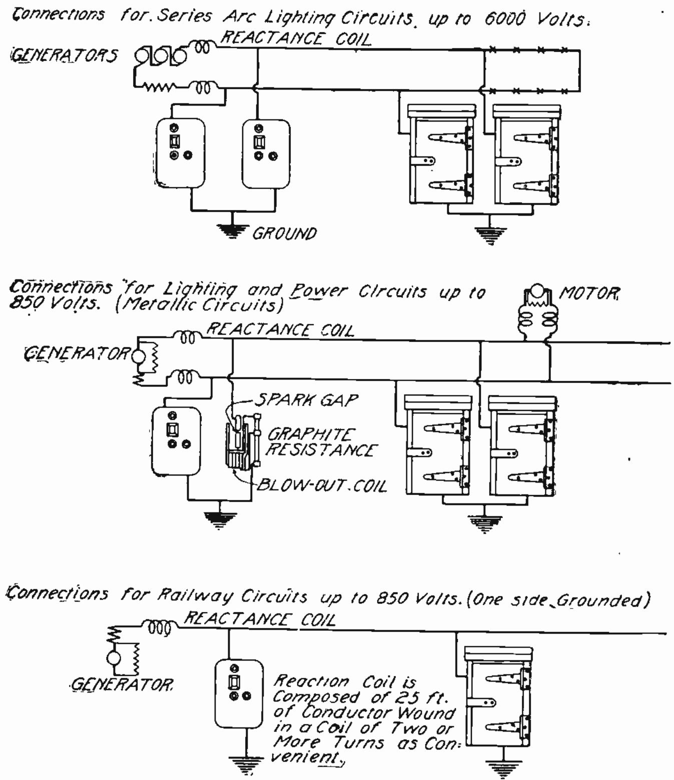


Fig. 32. Lightning-Arrester Diagrams of D. C. Work

In place of a series of gaps a single gap with terminals made in the form of horns is employed in some cases for lightning protection. Such an arrester is known as a *horn gap*, or *horn arrester*. The gap is connected between the line and the ground and when the potential strain becomes great enough the gap is broken down. The arc formed by the machine current after the gap is broken down

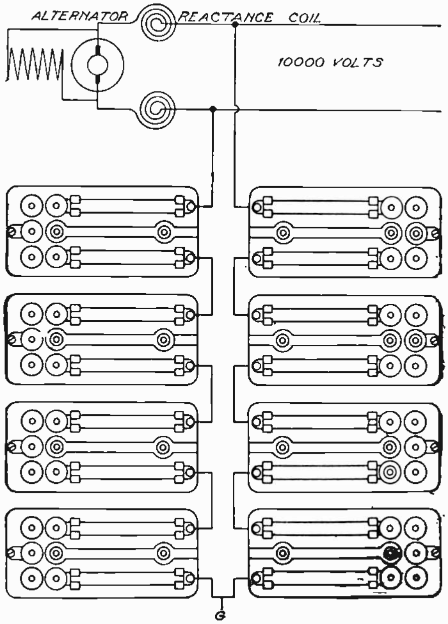


Fig. 33. Connections for 10,000-Volt Lightning Arrester

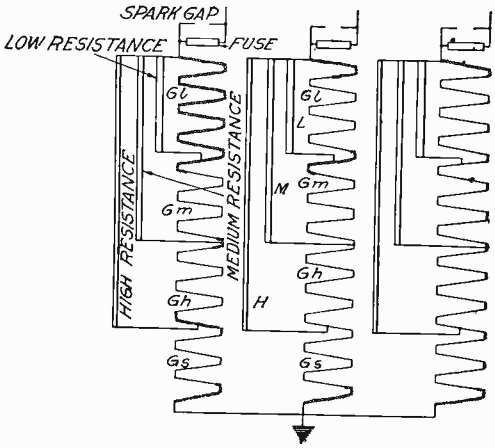
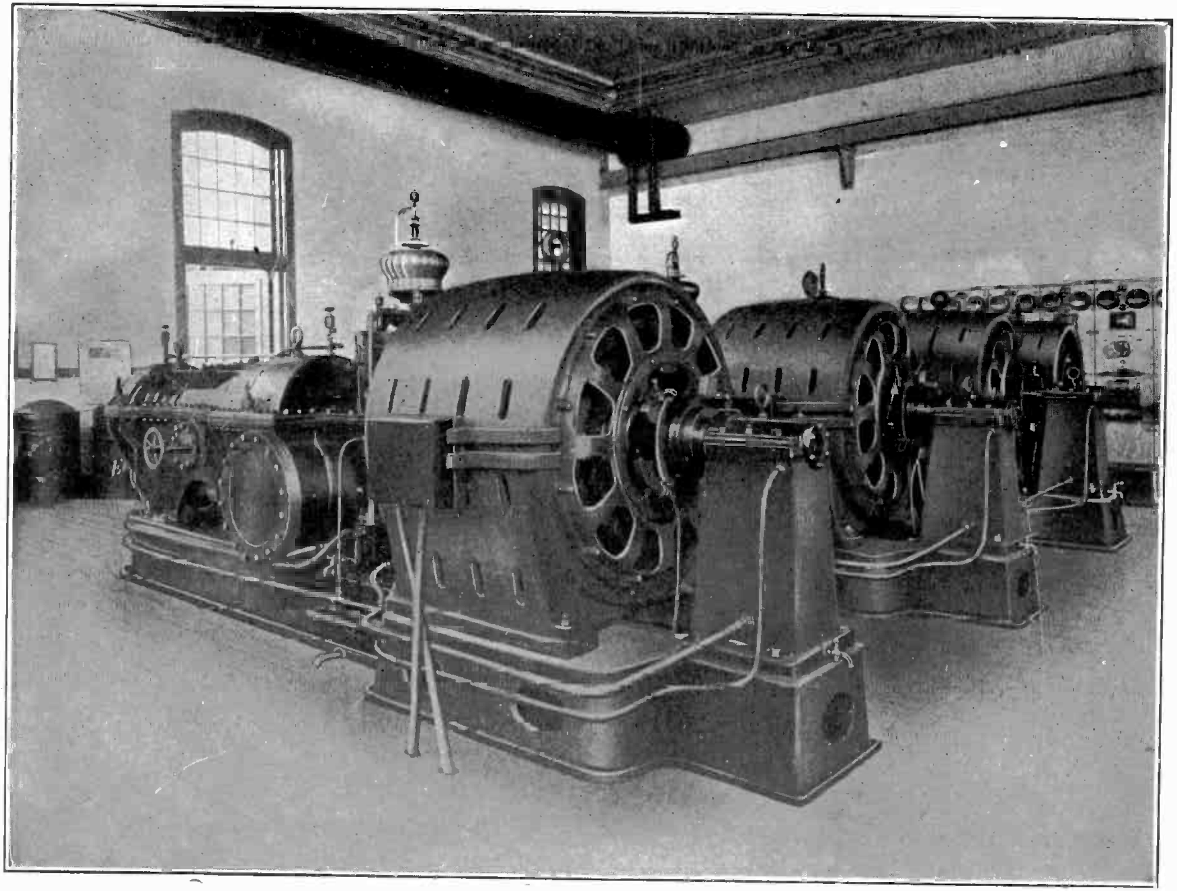


Fig. 34. Non-Inductive Resistances in Shunt with Lightning Arrester



FOUR 400 K.W. TURBINE GENERATING UNITS.
Westinghouse Electric and Manufacturing Co.

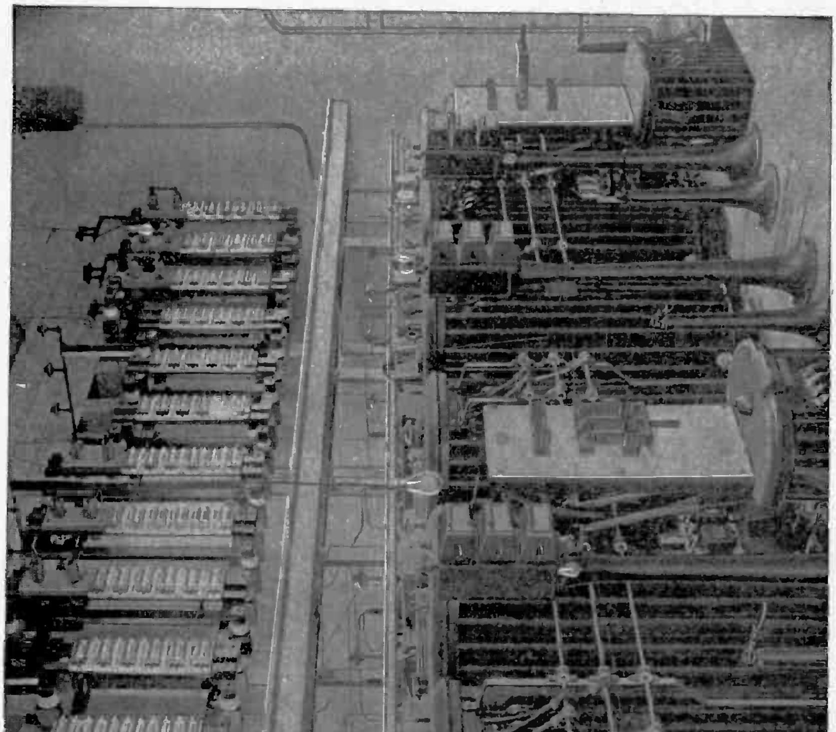


Fig. 35. Typical Installation of Lightning Arresters

rises and lengthens until it can no longer be maintained by the generator or generators in service. The horn arrester as applied to series lighting circuits is shown in Fig. 36. A series resistance, shown in the lower part of the figure, is used with this particular arrester.

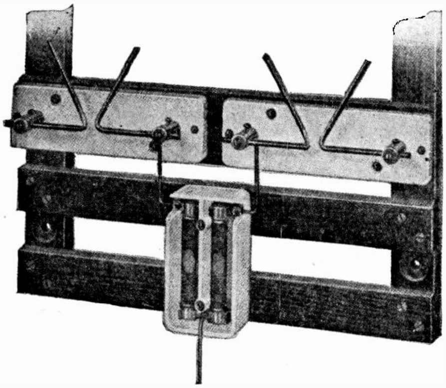


Fig. 36. "Horn" Lightning Arrester

The most recent development in the way of lightning protection is the introduction of the aluminum cell arrester. The elementary cell consists of two aluminum plates, on which a film of aluminum hydroxide is formed, and which are immersed in a suitable electrolyte. The peculiar property of such a cell which makes it useful as a lightning arrester is that it has a high resistance up to a certain potential impressed upon it but when a critical value of voltage is reached, the resistance becomes very low. The critical voltage for a single unit for alternating current is between 335 and 360 volts, and such a cell may be connected to a 300-volt circuit with only a very small current flow. For higher voltages, a number of cells are connected in series and a horn gap is inserted between the arrester and the line wire. The gap prevents any flow of current unless the arrester is brought into action by the discharge of excess line potential, in which case the aluminum cells offer a path of low resistance for the discharge of potential so long as the voltage is in excess of the critical voltage, but the machine or line potential, which is below the critical voltage of the arrester, cannot force enough current through the arrester circuit to maintain the arc at the gap. There is some dissolution of the film of hydroxide if the cell is left standing and not connected to the circuit, but it is readily formed again when the circuit is made. Arresters using a gap should have the gap closed for a short interval daily in order to insure a proper film on the aluminum plates. Views of the aluminum arrester are shown in Figs. 37 and 38.

Reverse-current relays are installed when machines or lines are operated in parallel. If two or more alternators are running and connected to the same set of bus bars, and one of these should fail to generate voltage by the opening of the field circuit, or some other cause, the other machine would feed into this generator and might cause considerable damage before the current flowing would be sufficient to operate the circuit breaker by means of the overload trip coils. To avoid this, reverse-current relays are used. They are so

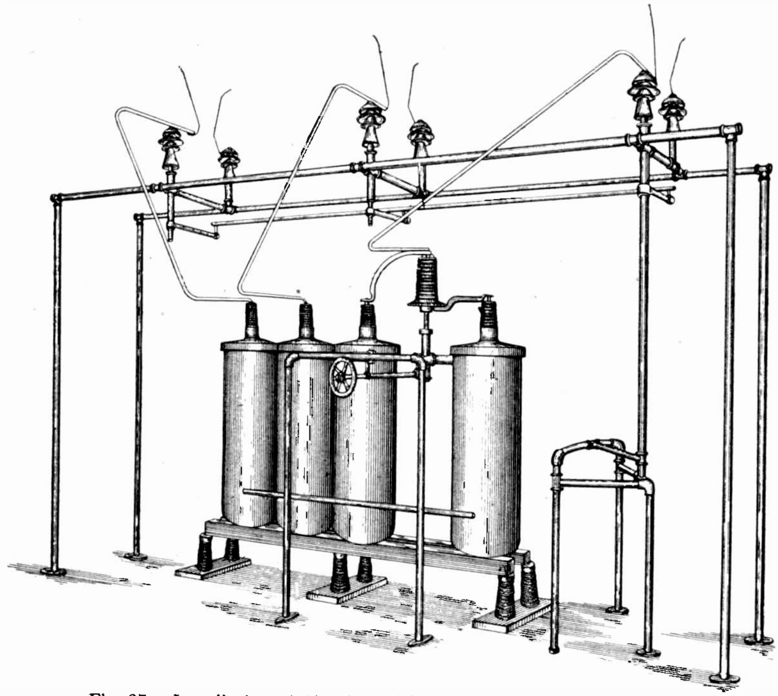


Fig. 37. Installation of Aluminum Lightning Arrester for 35,000 Volts

arranged as to operate at, say $\frac{1}{4}$ the normal current of the machine or line, but to operate only when the power is being delivered in the wrong direction.

Speed-limit devices are used on both engines and rotary converters to prevent racing in the one case and running away in the second. Such devices act on the steam supply of engines and on the direct-current circuit breakers of rotary converters, respectively.

Complete wiring diagrams for standard switchboards are shown in Figs. 39 and 40.

SUBSTATIONS

Substations are for the purpose of transforming the high potentials down to such potentials as can be used on motors or lamps, and in many cases to convert alternating current into direct current. Step-down transformers do not differ in any respect from step-up transformers. Either motor-generator sets or rotary converters may be used to change from alternating to direct current. The former consist of synchronous or induction motors, direct connected to direct-current generators, mounted on the same bedplate. The generator may be shunt or compound wound, as desired. Rotary or synchronous converters are direct-current generators, though specially designed; and they are fitted with collector rings attached to the winding at definite points. The alternating current is fed into these rings and the machine runs as a synchronous motor, while direct current is delivered at the commutator end. There is a fixed relation between the voltage applied to the alternating-current side and the direct-current voltage, which depends on the shape of the wave form, losses in the armature, pole pitch of the machine, method of connection, etc. The generally accepted values are given in Table XIII.

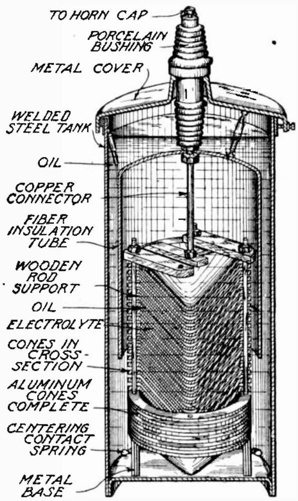


Fig. 38. Cross-Section of Aluminum Arrester

The increase of capacity of six-phase machines over other machines of the same size is given in Table XIV.

This increase is due to the fact that, with a greater number of phases, less of the winding is traversed by the current which passes through the converter. The saving by increasing the number of phases beyond six is but slight and the system becomes too complex. Rotary converters may be over-compounded by the addition of series fields, provided the reactance in the alternating circuits be of a proper value. It is customary to insert reactance coils in the leads from the low-tension side of the step-down transformers to the collector rings to bring the total reactance to a value which will insure

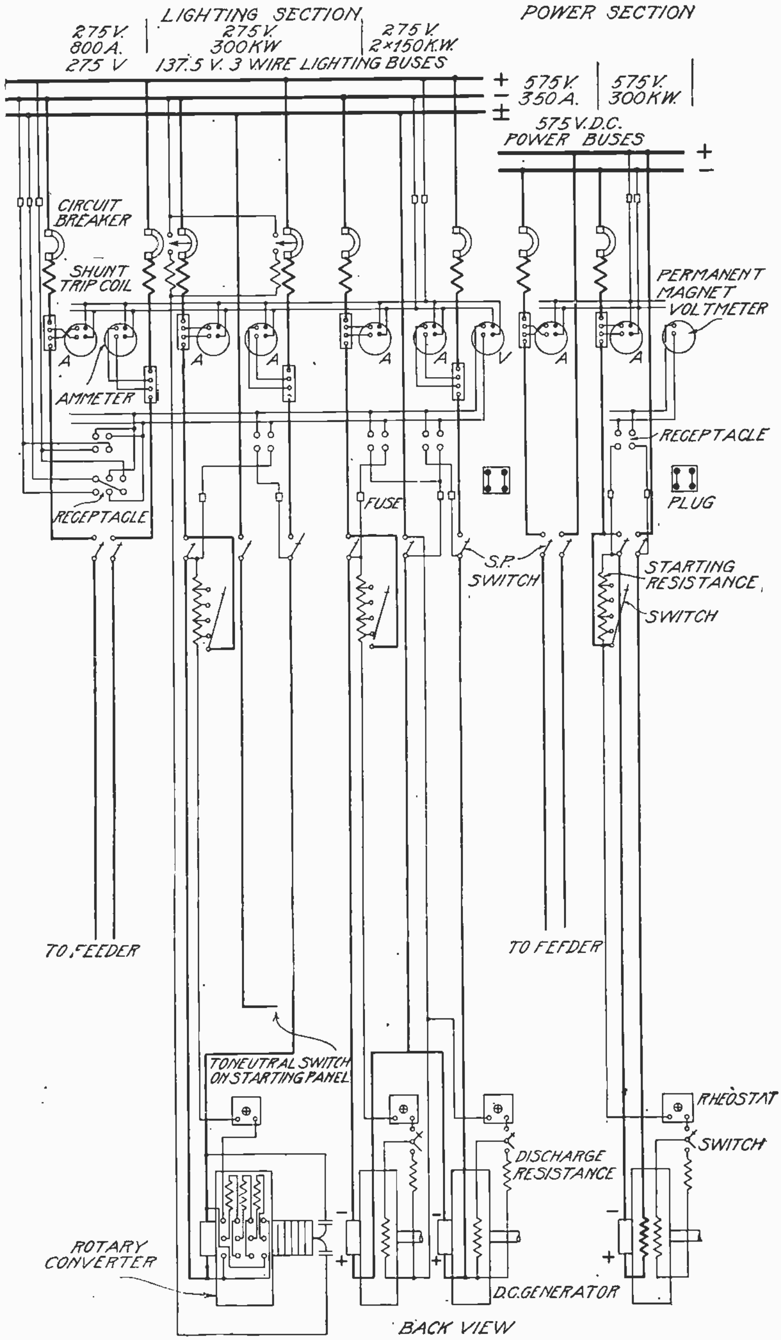


Fig. 39. Wiring Diagram for Standard Switchboard

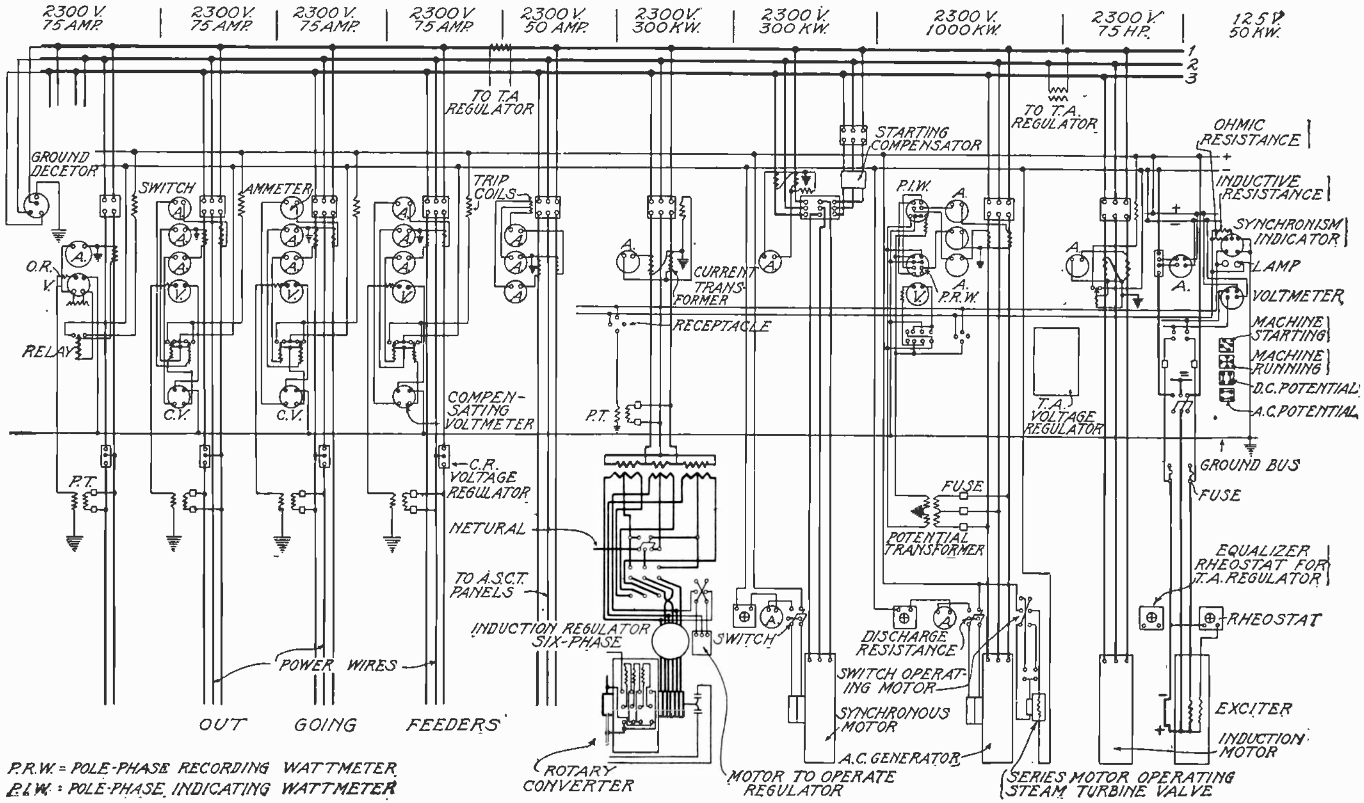


Fig. 40. Wiring Diagram for Standard Switchboard

TABLE XIII

Full Load Ratios

Current		Potential Per Cent
Continuous		100
Two-phase and Six-phase (diametrical)	550 volts	72.5
	250 volts	73
	125 volts	73.5
Three-phase and Six-phase (Y or delta)	550 volts	62
	250 volts	62
	125 volts	63

the desired compounding. Again, the voltage may be controlled by means of induction regulators placed in the alternating-current leads.

Two other methods of potential regulation for synchronous converters are in use. In the first of these methods a series generator is used, this generator consisting of a polyphase armature attached to the rotary converter shaft and revolving in a separate field. The phases of this armature are connected between the collector rings of the machine and the taps to the converter armature, and the voltage impressed upon the converter taps amounts to the line voltage plus or minus the potential developed in the regulating armature. By means of a suitable field rheostat for the regulating field, any ordinary range of direct current at the brushes of the converter can be obtained with a constant voltage of alternating-current supply. Fig. 41 shows a converter equipped with this regulating device.

In the regulating-pole converter each pole of the machine is made up of two parts, the main pole and the regulating pole. By

TABLE XIV

Capacity Ratios

Continuous-current generator	100
Single-phase converter	85
Two-phase converter	164
Three-phase converter	134
Six-phase converter	196

varying the excitation of the regulating pole the ratio of conversion between the alternating-current voltage and the direct-current voltage can be changed through a considerable range—a sufficient range to cover the requirements ordinarily required in practice. Fig. 42 shows a view of a regulating pole converter. Motor-generators are more costly and occupy more space than rotary converters but the regulation of the voltage is much better and they are to be preferred for lighting purposes.

BUILDINGS

The power station usually has a building devoted entirely to this work, while the substations, if small, are often made a part of

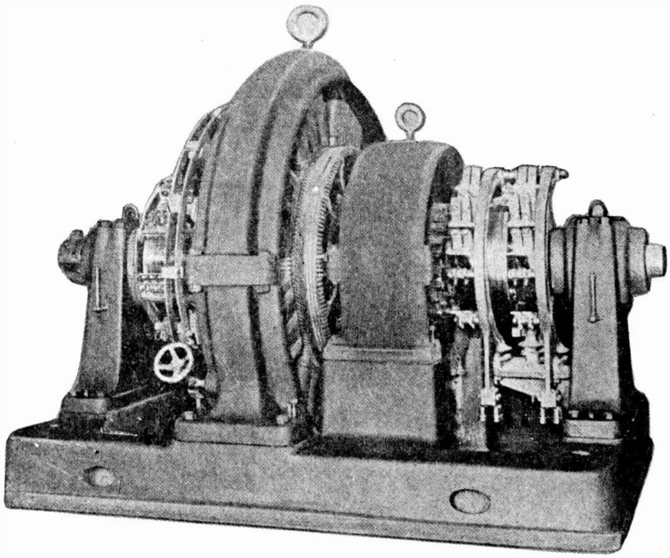


Fig. 41. Rotary Converter Equipped with Regulating Generator

other buildings. While the detail of design and construction of the buildings for power plants belongs primarily to the architect, it is the duty of the electrical engineer to arrange the machinery to the best advantage, and he should always be consulted in regard to the general plans, at least, as this may save much time and expense in the way of necessary modifications. The general arrangement of the machinery will be taken up later, but a few points in connection with the construction of the buildings and foundations will be considered here.

Space must be provided for the boilers—this may be a separate building—engine and dynamo room, general and private offices, store rooms and repair shops. Very careful consideration should be given to each of these departments. The boiler room should be parallel with the engine room, so as to reduce the necessary amount of steam piping to a minimum, and if both rooms are in the same building a brick wall should separate the two, no openings which would allow dirt to come from the boiler room to the engine room being allowed. The height of both boiler and engine rooms should

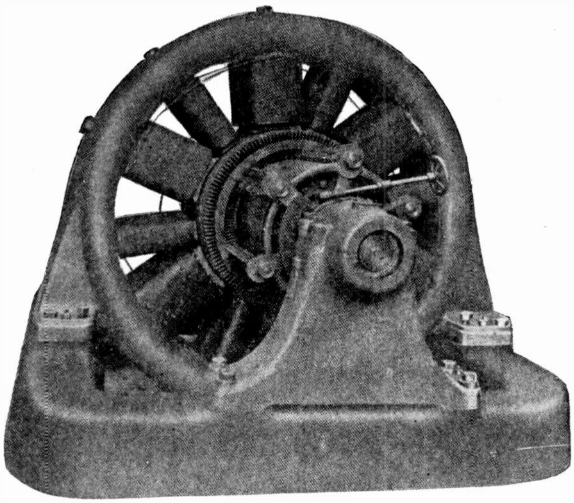


Fig. 42. Regulating-Pole Rotary Converter

be such as to allow ample headway for lifting machinery and space for placing and repairing boilers, while provision should be made for extending these rooms in at least one direction. Both engine and boiler rooms should be fitted with proper traveling cranes to facilitate the handling of the units. In some cases the engines and dynamos occupy separate rooms, but this is not general practice. Ample light is necessary, especially in the engine rooms. The size of the offices, store rooms, etc., will depend entirely on local conditions.

TABLE XV

Thickness of Walls for Power Plants

Width of Building clear between Walls	Height of Wall	First Section		Second Section		Third Section	
		Height	Thickness	Height	Thickness	Height	Thickness
25 feet	40 feet	40 feet	12 inches				
25 feet	40-60 feet	40 feet	16 inches	To top	12 inches		
25 feet	60-75 feet	25 feet	20 inches	To top	16 inches		
25 feet	75-85 feet	20 feet	24 inches	20-60 ft.	20 inches	To top	16 inches
25 feet	85-100 ft.	25 feet	28 inches	25-50 ft.	24 inches	50-75 feet	20 inches

NOTE. With clear space exceeding 25 feet the walls should be made 4 inches thicker for each 10 feet or fraction thereof in excess of 25 feet. For buildings greater than 100 feet in height, each additional 25 feet or fraction thereof next above the curb shall be increased 4 inches in thickness.

Foundations. The foundations for both the walls and the machinery must be of the very best. It is well to excavate the entire space under the engine room to a depth of eight to ten feet so as to form a basement, while in most cases the excavations must be made to a greater depth for the walls. Foundation trenches are sometimes filled with concrete to a depth sufficient to form a good underfooting. The area of the foundation footing should be great enough to keep the pressure within a safe limit for the quality of the soil. The walls themselves may be of wood, brick, stone, or concrete. Wood is used for very small stations only, while brick may be used alone or in conjunction with steel framing, the latter construction being used to a considerable extent. If brick alone is used, the walls should never be less than twelve inches thick, and eighteen to twenty inches is better for large buildings. They must be amply reinforced with pilasters. Stone is used only for the most expensive stations.

Table XV, which is taken from the New York Building Laws, may serve as a guide to the thickness of walls for power plants. The interior of the walls is formed of glazed brick, when the expense of such construction is warranted. In fireproof construction, which is always desirable for power stations, the roofs are supported by steel trusses and take a great variety of forms. Fig. 43 shows what has been recommended as standard construction for lighting stations, showing both brick and wood construction. The floors of the engine room should be made of some material which will not form grit or dust. Hard tile, unglazed, set in cement or wood floors, is desirable. Storage battery rooms should be separate from all others and should have their interior lined with some material which will not be affected by the acid fumes. The best of ventilation is desirable for all parts of the station, but is of particular importance in the dynamo room if the machines are being heavily loaded. Substation construction does not differ from that of central stations when a separate building is erected. They should be fireproof if possible.

The foundations for machinery should be entirely separate from those of the building. Not only must the foundations be

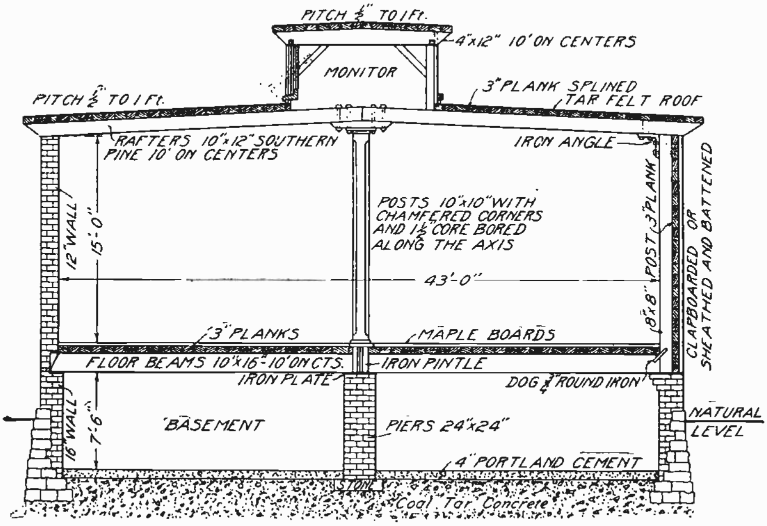


Fig. 43. Standard Construction for Lighting Station. Brick and Wood Construction

stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair, felt, mineral wool, and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from 2 to 3 feet deeper and 2 to 3 feet wider on all sides than the foundation, and the sand, or whatever material is used, occupies this extra space.

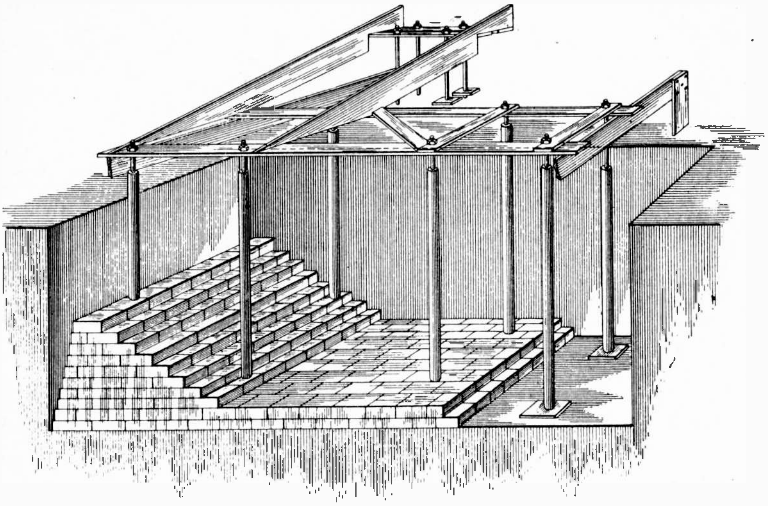


Fig. 44. Foundation for Machines Showing Use of Template and Iron Pipe for Holding Bolts

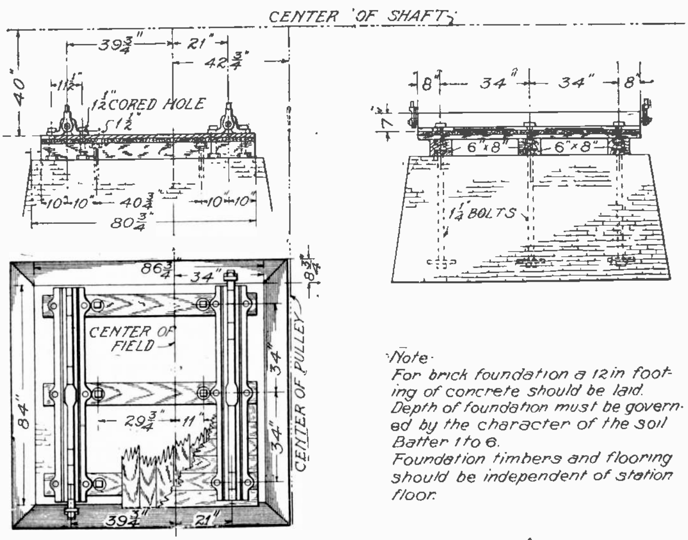


Fig. 45. Foundation for 150-Kw. Generator

Brick, stone, or concrete is used for building up the greater part of machinery foundations, the machines being held in place by means of bolts fastened in masonry. A template, giving the

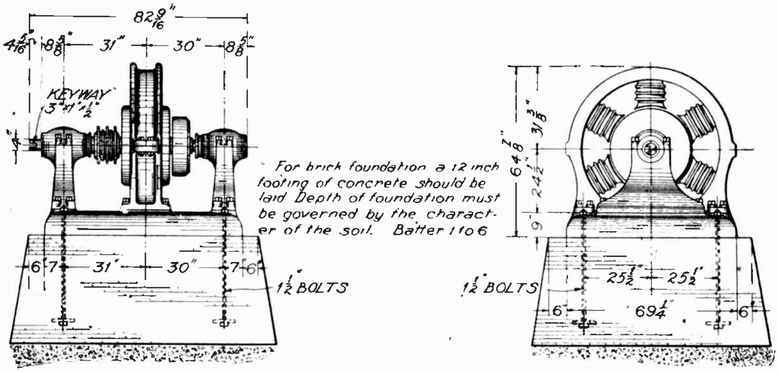


Fig. 46. Foundation for Rotary Converter

location of all bolts to be used in holding the machine in place, should be furnished, and the bolts may be run inside of iron pipes with an internal diameter a little greater than the diameter of the

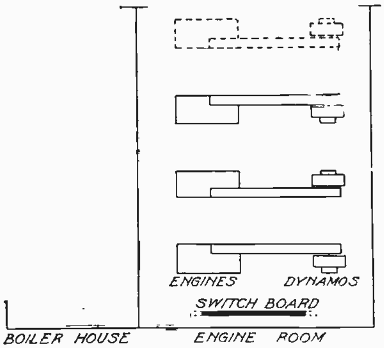


Fig. 47. Diagram of Simple Arrangement of Belted Machines

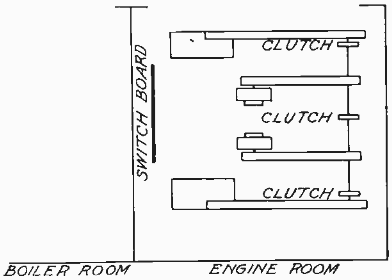


Fig. 48. Diagram of Arrangement of Machines Using Jack Shaft

bolt. This allows some play to the bolt and is convenient for the final alignment of the machine. Fig. 44 gives an idea of this construction. The brickwork should consist of hard-burned brick of the best quality, and should be laid in cement mortar. It is well to fit brick or concrete foundations with a stone cap, forming a level surface on which to set the machinery, though this is not necessary. Generators are sometimes mounted on wood bases to furnish insulation for the frame. Fig. 45 shows the foundation for a 150-kw. generator, while Fig. 46 shows the foundation for a rotary converter.

Station Arrangement. A few points have already been noted in regard to station arrangement, but the importance of the subject demands a little further consideration. Station arrangement depends chiefly upon two facts—the location and the machinery to be installed. Undoubtedly the best arrangement is with all of the machinery on one floor with, perhaps, the operating switchboard mounted on a gallery so that the attendants may have a clear view of all the machines. Fig. 47 shows the simplest arrangement of a plant using belted machines. Fig. 48 shows an arrangement of units where a jack shaft is used. Direct-current machines should be placed so that the brushes and commutators are easily accessible and the switchboard should be placed so as not to be liable to accidents, such as the breaking of a belt or a flywheel.

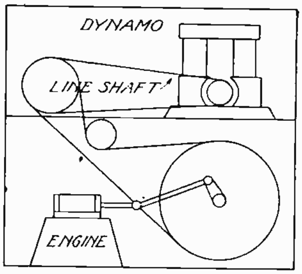


Fig. 49. Diagram of Double-Deck Arrangement of Machines

When the cost of real estate prohibits the placing of all of the machinery on one floor, the engines may be placed on the first floor and belted to generators on the second floor, Fig. 49. It is always desirable to have the engines on the main floor, as they cause considerable vibration when not mounted on the best of foundations. The boilers, while heavy, do not cause such vibration and they may be placed on the second or third floor. Belts should not be run vertically, as they must be stretched too tightly to prevent slipping.

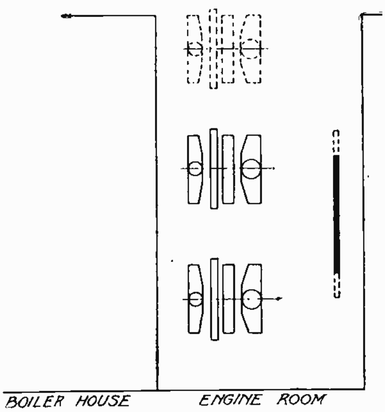


Fig. 50. Diagram of Station Using Direct-Connected Units

Fig. 50 shows a large station using direct-connected units, while Figs. 51 and 52 show the arrangement of the turbine plant of the Boston Edison Electric Illuminating Company. This station will contain twelve large turbine units when completed. Note the arrangement of boilers when several units are required for a single prime mover.

The use of the steam turbine has led to the introduction of a type of station known as a *double-deck power plant* and used in some instances where it is desirable to save space. In this type of station the boilers are placed on the ground floor and the turbines, which are of the horizontal type, are placed on a second floor directly above the boilers. Since there is but little vibration to the turbines and only light foundations are necessary, this construction may be readily carried out. Fig. 53 shows the general arrangement of such a plant. The use of a separate room or building for the cables, switches, and operating boards is becoming quite common for high-tension generating plants. The remarkable saving in floor space brought about by the turbine is readily seen from Fig. 54. The total floor space occupied by the 5,000 kw. units of the Boston station is 2.64 square feet per kw. This includes boilers—of which there are eight, each 512 h. p. for each unit—turbines, generators, switches, and all auxiliary apparatus. For the 10,000 and 15,000 kw. turbine sets now coming into use, this figure is still further reduced.

When transformers are used for raising the voltage, they may be placed in a separate building, as is the case at Niagara Falls, or the transformers may be located in some part of the dynamo room, preferably in a line parallel to the generators.

Fig. 55 shows the arrangement of units in a hydraulic plant. Fig. 56 is a good example of the practice in substation arrangement. The switchboard is at one end of the room, while the rotary converters and transformers are along either side.

Large cable vaults are installed at the stations operating on underground systems, the separate ducts being spread out, and sheet-iron partitions erected to prevent damage being done to cables which were not originally defective, by a short circuit in any one feeder.

Station Records. In order to accurately determine the cost of generating power and to check up on uneconomical or improper methods of operation and lead to their improvement, accurately-kept station records are of the utmost importance. Such records

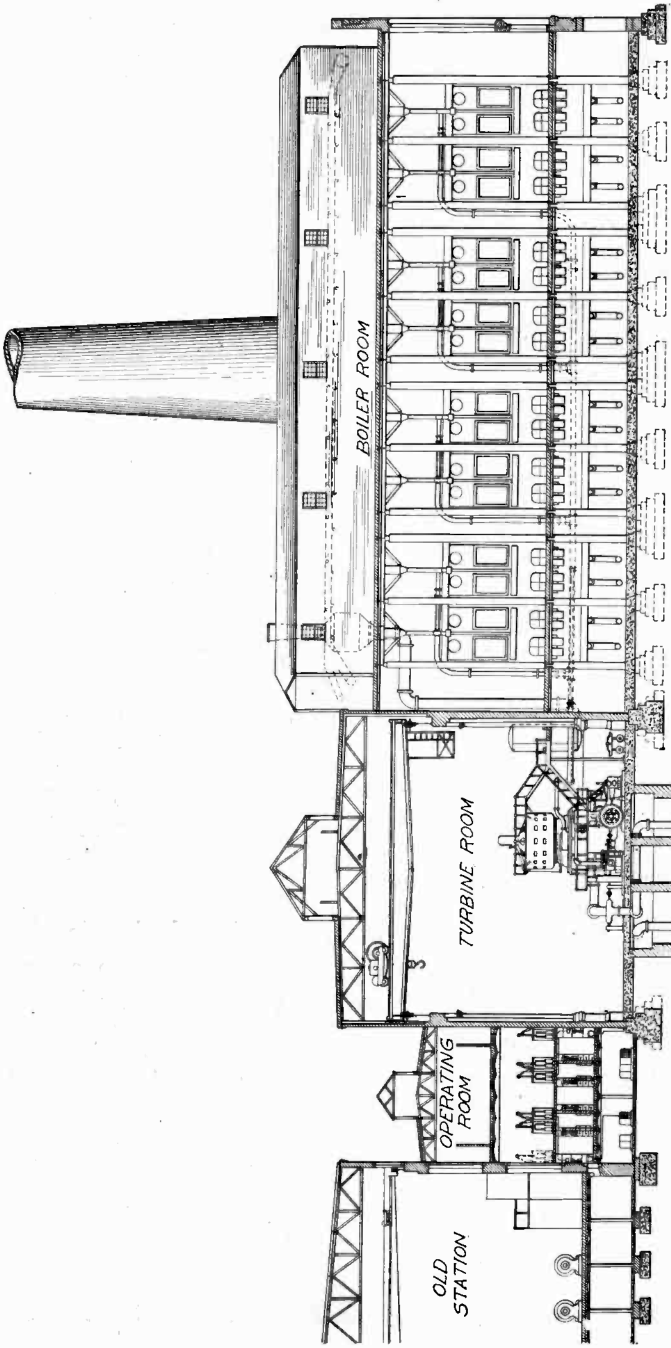
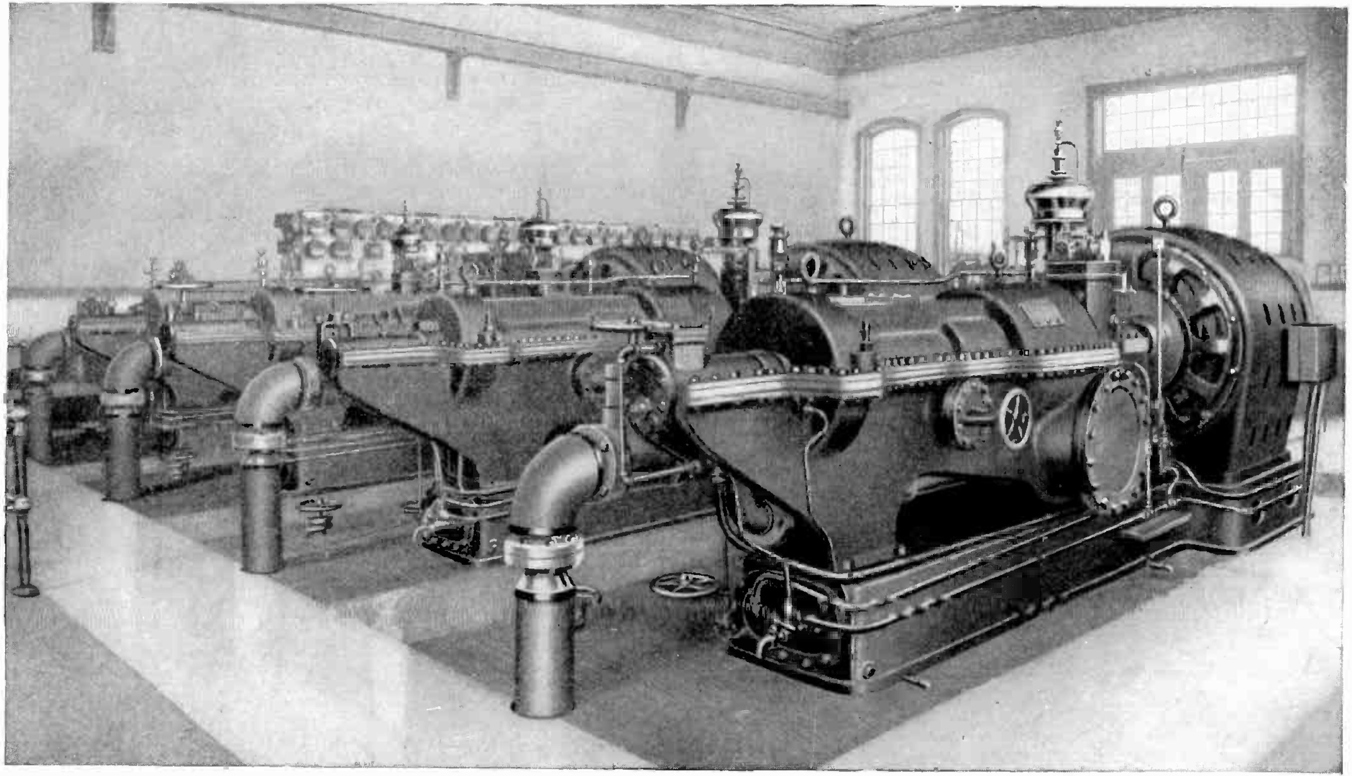


Fig. 51. Part Section of Turbine Plant. Boston Edison Luminating Company



THE FIRST TURBINE POWER PLANT IN AMERICA

An Installation of Four 400-Kilowatt Turbine Units at Wilmerding, Penna. This Plant Has Been in Continuous Operation Since August, 1899.
Westinghouse Electric & Manufacturing Co., Pittsburg, Penna.

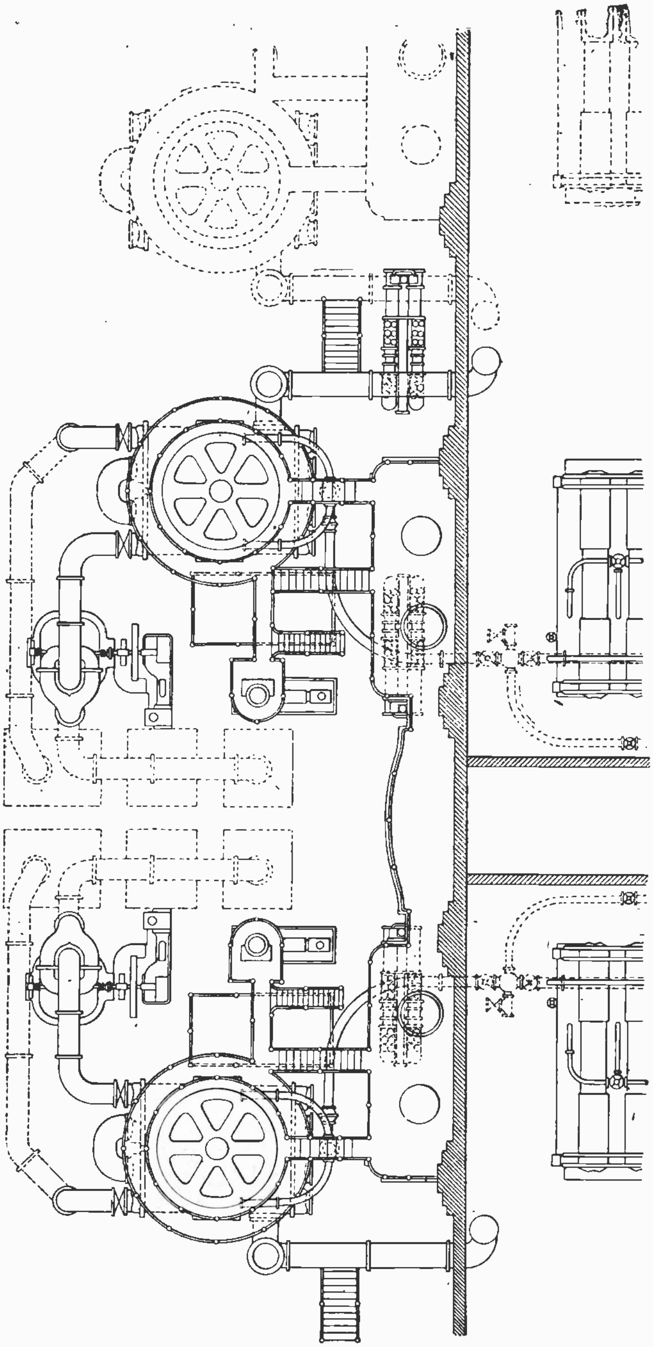


Fig. 52. Plan of Turbines of Fig. 51

should consist of switchboard records, engine-room records, boiler-room records, and distributing-system records. Such records accurately kept and properly plotted in the form of curves, serve admirably for the comparison of station operations from day to day and for the same periods for different years. It pays to keep these records even when additional clerical force must be employed.

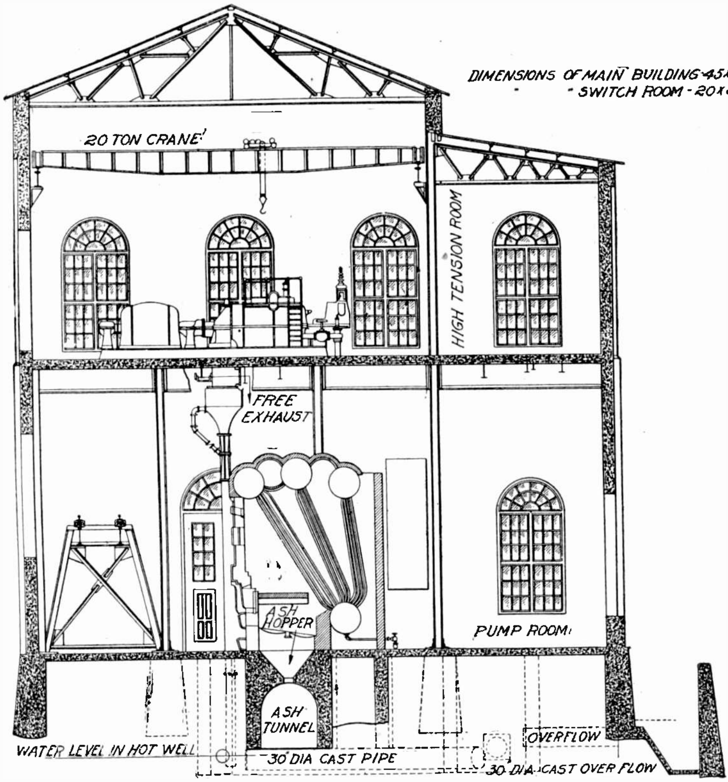


Fig. 53. Double-Deck Turbine Plant

In some states stations furnishing light or power to the public are required to make annual reports and the system of records, accounting, and form of report are all prescribed by the state.

Switchboard records consist, in alternating stations, of daily readings of feeder, recording wattmeters, and total recording wattmeter, together with voltmeter and ammeter readings at intervals of about 15 minutes, in some cases, to check upon the average power factor and determine the general form of the load curve. For direct-current lighting systems, volt and ampere readings serve to give the true output of the stations, and curves are readily plotted from these readings. The voltage should be recorded for the bus bars as well as for the centers of distribution.

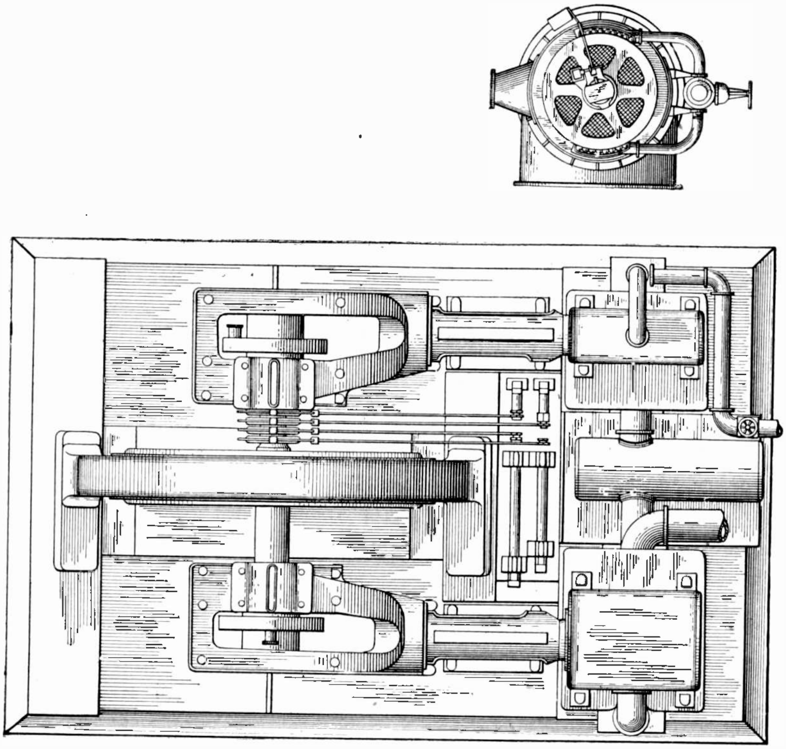


Fig. 54. Space Occupied by Turbo-Alternator Compared with that of Generator and Reciprocating Engine of Same Capacity

Indicator diagrams should be taken from the engines at frequent intervals for the purpose of determining the operation of the valves. Engine-room records include labor; use of waste, oil, and supplies; as well as all repairs made on engines, dynamos and auxiliaries.

Boiler-room records include labor and repairs, amount of coal used, which amount may be kept in detail if desirable, amount of water used, together with steam-gauge record and periodical analysis of flue gases as a check on the methods of firing.

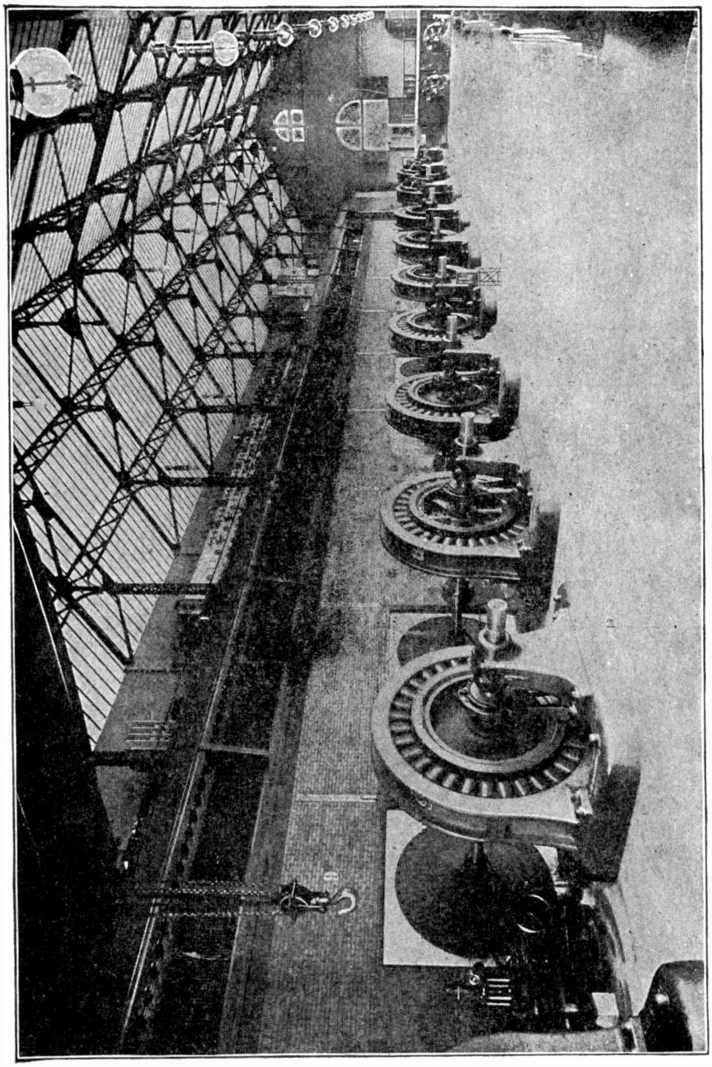


Fig. 55. Arrangement of Units in a Hydraulic Plant

Records for the distributing system include labor and material used for the lines and substations. For multiple-wire systems, frequent readings of the current in the different feeders will serve as a check on the balance of the load.

The cost of generating power varies greatly with the rate at which it is produced as well as upon local conditions. Station-operating expenses include cost of fuel, water, waste, oil, etc., cost of repairs, labor, and superintendence. Fixed charges include insurance, taxes, interest on investment, depreciation, and general office expenses. Total expenses divided by total kilowatt-hours gives

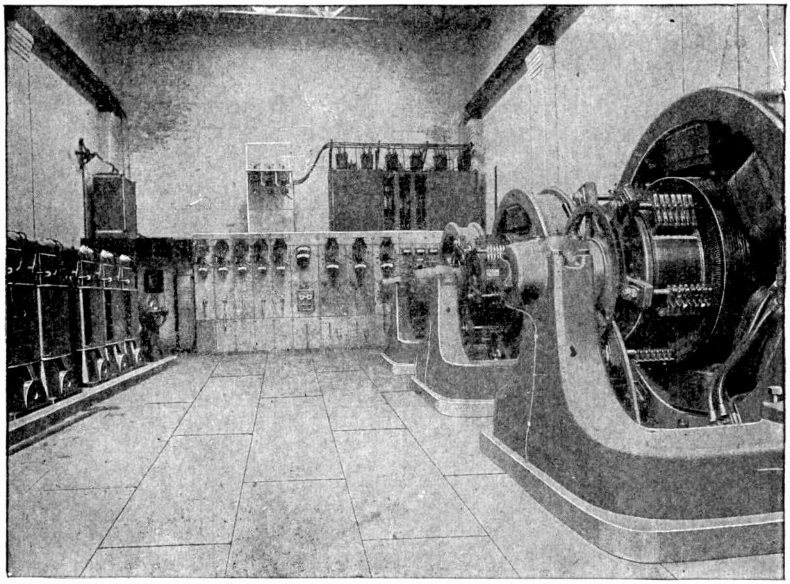


Fig. 56. A Good Arrangement of Apparatus for Substation

the cost of generation of a kilowatt-hour. The cost of distributing a kilowatt hour may be determined in a similar manner. The rate of depreciation of apparatus differs greatly with different machines, but the following figures may be taken as average values, these figures representing percentage of first cost to be charged up each year:

Fireproof buildings from 2 to 3 per cent.
Frame buildings from 5 to 8 per cent.
Dynamos from 2 to 4 per cent.
Prime movers from $2\frac{1}{2}$ to 5 per cent.
Boilers from 4 to 5 per cent.
Overhead lines, best constructed, 5 to 10 per cent.
More poorly constructed lines 20 to 30 per cent.
Badly constructed lines 40 to 60 per cent.
Underground conduits 2 per cent.
Lead covered cables 2 per cent.

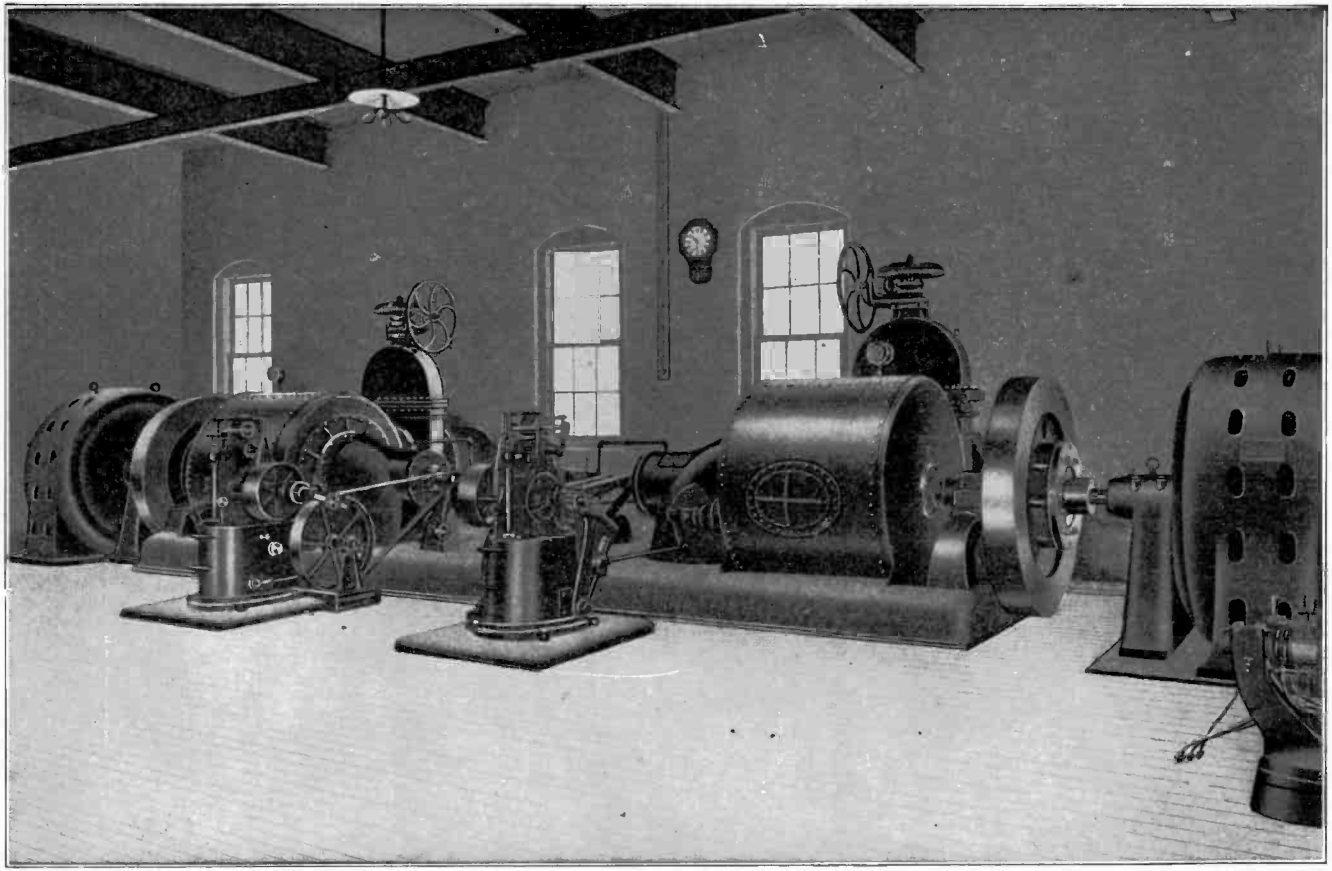
Methods of Charging for Power. There are four methods used for charging consumers for electrical energy, namely, *the flat-rate, or contract, system, the meter system, the two-rate meter system,* and *a system by which each customer pays a fixed amount depending on the maximum demand and in addition pays at a reasonable rate for the power actually used.*

In the flat-rate system, each customer pays a certain amount a year for service, this amount being based on the estimated amount of power to be used. These rates vary, depending on the hours of the day during which the power is to be used, being greatest if the energy is to be used during peak hours. It is an unsatisfactory method for lighting service, as many customers are liable to take advantage of the company, burning more lights than contracted for and at different hours, while the honest customer must pay a higher rate than is reasonable in order to make the station operation profitable. This method serves much better when the power is used for driving motors, and is used largely for this class of service.

The simple meter method of charging serves the purpose better for lighting, but the rate here is the same no matter what hour of the day the current is used. Obviously, since machinery is installed to carry the peak of the load, any power used at this time tends to increase the capital outlay from the plant, and users should be required to pay more for the power at such times. The meter system is often employed with a sliding scale or rate, the rate charged per kw.-hour depending upon the amount of electrical energy used.

The two-rate meter accomplishes this purpose to a certain extent. The meters are arranged so that they record at two rates, the higher rate being used during the hours of heavy load.

There are several methods of carrying out the fourth scheme. In the Brighton System a fixed charge is made each month, depending on the maximum demand for power during the previous month, a regular schedule of such charges being made out, based on the cost of the plant. An integrating wattmeter is used to record the energy consumed, while a so-called "demand meter" records the maximum rate of demand.



INTERIOR VIEW OF POWER PLANT OF THE DALTON POWER COMPANY, DALTON, MASSACHUSETTS
Two units of 21-inch "New American" turbines, operating under 152 feet head.

A QUARTER CENTURY OF AMERICAN CENTRAL STATION ENGINEERING.

Perhaps few of the younger generation engaged in the various branches of electrical work realize that the central-station industry, so large and permanent an institution of our present civic life, is barely a quarter of a century old. Marvelous, indeed, has been the progress of this industry, and its wheels of invention and development are stilling whirling rapidly on. No engineer who values his reputation would venture to prophesy what the next quarter-century will bring us.

Twenty-five years ago the commercial electric lamp was unknown. To-day there are in service in the United States alone nearly twenty million incandescent lamps, to say nothing of the tens of thousands of arc lamps and the few hundred thousand horse-power in electric motors. To-day nearly every city of any importance in America has an electric plant furnishing light and power to its citizens. Magnificent stations have sprung up in our large cities, representing millions of dollars in investment; and electricity is being distributed to nearly every corner of those cities. It may be of interest, then, to look back over the history of this industry, and see some of the steps by which it reached its present splendid growth.

In all the world's history of industrial progress, perhaps no chapter is more full of scientific and heroic romance than that dealing with the birth of the electric-light industry. To the youth of to-day no story could give greater inspiration than that of the men who were the leading figures—the great minds and the energetic workers—during the early days of central-station development. These men contributed as much toward the nation's growth as did our warriors and our statesmen. Most of them are still with us, and are still active in solving engineering problems. It was the good fortune of the readers of the *Electrical World and Engineer* to see, in its recent thirtieth anniversary issue, some interesting reminiscences of these early workers, and thus have brought home to them the youthful age of the industry. It is not the purpose of this paper, however, to relate biography, but rather to treat of the more prosaic subject of the growth of the central station from its small beginnings to the magnificent proportions of to-day.

BRUSH ARC SYSTEM.

In 1879, there was erected in Cleveland, Ohio, a series-arc system designed by Charles F. Brush. The dynamo furnishing current for these lamps had been built by Brush during the preceding year. The electric arc itself had been discovered by Sir Humphry Davy in London about the year 1802, the source of current for his lamp being a battery of several thousand cells. As the dynamo had not at that time come into existence, the commercial importance of the discovery was not then apparent.

From this first system of Brush's, dates the history of commercial electric lighting in America. As stated, the lamps of this system were all connected in series, so that the same current passed through all of them. With many lamps on the circuit this required a fairly high voltage. The efforts of many investigators were then directed toward developing an incandescent lamp for these circuits so that the lights could be used indoors where the arc lamps would be too brilliant. In order to obtain a lamp requiring only a low voltage, which is a desirable feature in series connection, a lamp of low resistance is necessary.

EDISON CONSTANT-POTENTIAL SYSTEM.

The master mind of Thomas Edison soon saw that a series system with high voltage on each line would never become commercially successful for general house lighting; therefore he set about to design a system which should properly meet the required conditions. On February 5, 1880, he patented a constant-potential system consisting of feeders and mains, with the load connected in parallel, or multiple arc, between the two wires forming the positive and the negative conductors, as shown in Fig. 1. How well this succeeded is evidenced by the present almost universal use of this system of connection. Obviously, a low-resistance lamp would not do on a constant-potential circuit; Edison, therefore, first developed a high-resistance lamp. His success in this is well known. His patent for the lamp is dated November 4, 1879. In December of that year he had a number of these lamps on exhibition at his laboratory in Menlo Park, and the following year he equipped his house and grounds with the lamps. The newspapers of the time were filled with accounts of what the "Wizard of Menlo Park" had accomplished, and visitors flocked to the town in great numbers to see the lights.

The first Edison plant for the public supply of current was located at Appleton, Wisconsin, where in 1881, was installed one of the first of the lanky bipolar dynamos, connected by a belt to a water wheel in a little wooden shed. The first central station for

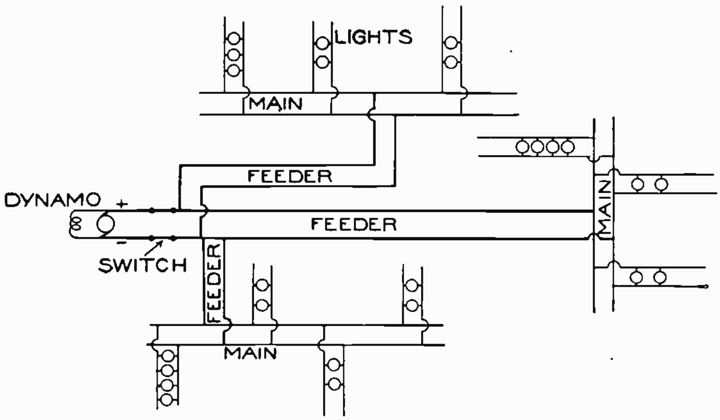


Fig. 1.

general distribution of current to incandescent lamps was started January 12, 1882, at Holborn Viaduct in London, England. The second and the third Jumbo dynamos (so named because of their bulk), built by Edison in America, furnished the current for this system. They weighed twenty-three tons each, and had a combined capacity of 3,000 lights. The first of these machines built by Edison was sent to the Paris Exposition of 1881. By October, 1882, the Edison Manufacturing Company had installed in all 123 plants, with a total of about 22,000 lamps.

The Edison Tube. During this time Edison's attention had been directed toward laying out a system for the city of New York. In such a city it was desirable to have the system underground. Accordingly, the Edison tube was designed. This consisted of two half-round copper bars laid in iron pipe in lengths of about twenty feet, and insulated by means of a tar compound While there are still many miles of these tubes giving good service, all new underground work has for some years been done with lead-covered cables drawn into ducts laid in the streets, the connections

Fig. 2.

being made in manholes. Fig. 2 shows a duct system made of cement-lined iron pipe laid in a bed of concrete.

Three-Wire Direct-Current System. Late in 1882, Edison made a series of experiments with a view toward a more economical distribution system, and he then devised the well-known three-wire system, in which two generators are connected in series, and a conductor is connected to their junction, and run out into the system as the neutral wire. This is illustrated in Fig. 3. By connecting the lights so that the load on the two sides of the system is nearly balanced, a saving of about sixty per cent was effected in the amount of copper necessary to transmit the same energy. This is due to the fact that, in the three-wire system, the current is transmitted at 220 volts instead of at 110, thus requiring for the same number of watts only half as many amperes; and therefore a smaller wire can be used. If the load on the two sides of the system is not balanced, the difference between the current in the positive conductor and that in the negative will come back to the dynamos over the neutral wire. Dr. John Hopkinson, in England, and Werner von Siemens, in Germany, devised similar systems at about the same time.

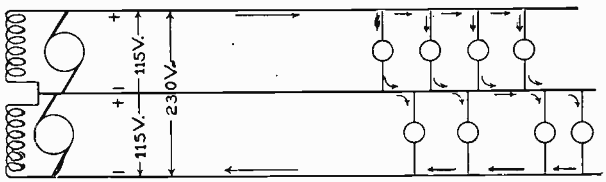


Fig. 3.

It was not until 1884 that electric motors were first used in New York; and the arc lamp designed for parallel connection on the constant-potential circuit was not introduced until 1889. The success of the constant-potential arc lamps made it possible for central stations to do all classes of business with one system of distribution—which was an important step in the march of progress. In 1890 the Duane Street Station was built in the heart of the Edison system, with a total engine capacity of 11,800 H.P. in direct-connected units.

In Boston, the Edison Electric Illuminating Company was organized in December, 1885, and the first station was started in February of the next year, using the Edison three-wire system of distribution. In 1887, a second station was built to take care of the load in another section of the city. Here, for the first time, was adopted the method of using 220-volt motors on the Edison system, connecting them to the two outer mains instead of between one outer and the neutral (110 volts), as had heretofore been done.

The Edison Companies. The good financial showing made by this company led to the formation of Edison Companies in many other cities, among the largest of which were Chicago and Philadelphia; and to the building of two up-town stations in New York. The original plant of the Western Edison Electric Light Company (now the Chicago Edison Company), a view of the dynamo room of which is shown in Fig. 4, was built at 139 Adams Street in 1887, and contained at first eight 100-K.W. Edison bipolar dynamos belted to four 250-H.P. engines located on the floor below. In 1891, additional dynamos and engines were added, until the total capacity reached 3,400 K.W.

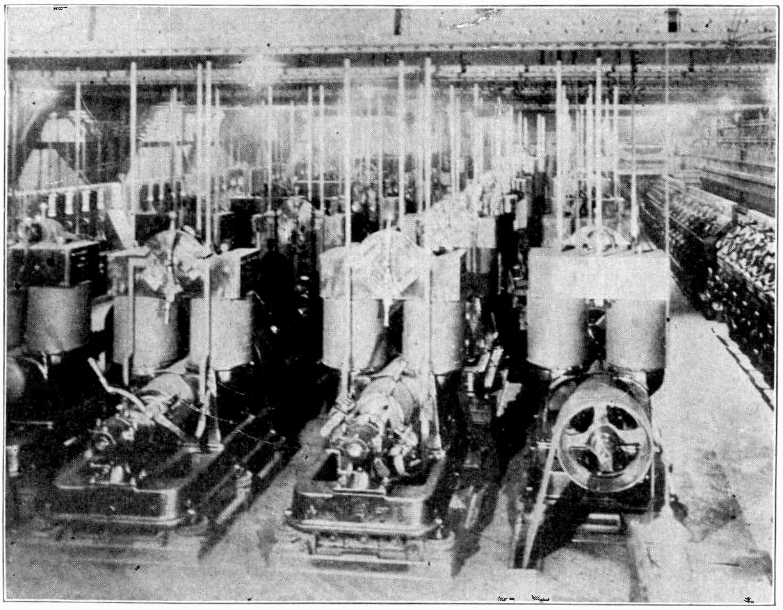


Fig. 4. Dynamo Room, Old Adams St. Station, Chicago Edison Co.

In the summer of 1892, the big station at Harrison Street, representing the most modern central-station engineering of the time, was started; and the next year the Adams Street Station was dismantled. The center of distribution, however, was kept at Adams Street, the current generated at the new station, about 3,000 feet away, being sent to this center over a trunk line consisting of twenty-eight Edison tubes and cables with a total sectional area of 66,000,000 circular mils. Of this, 9,000,000 c.m. of section was used for the neutral conductors, leaving 28,500,000 c.m. for each of the outsides, that is, for the positive and the negative.

In its onward march the Chicago Edison Company absorbed a number of plants, chief of which was that of the Chicago Arc Light & Power Company, located at Washington Street and the river. The systems operated from this station at that time consisted of series arcs, 500-volt direct current for power, and some 133-cycle 1,000-volt alternating-current lines. In 1894, there were added the Wabash Avenue Station near 27th Street on the South Side, with an Edison three-wire system and some series-arc

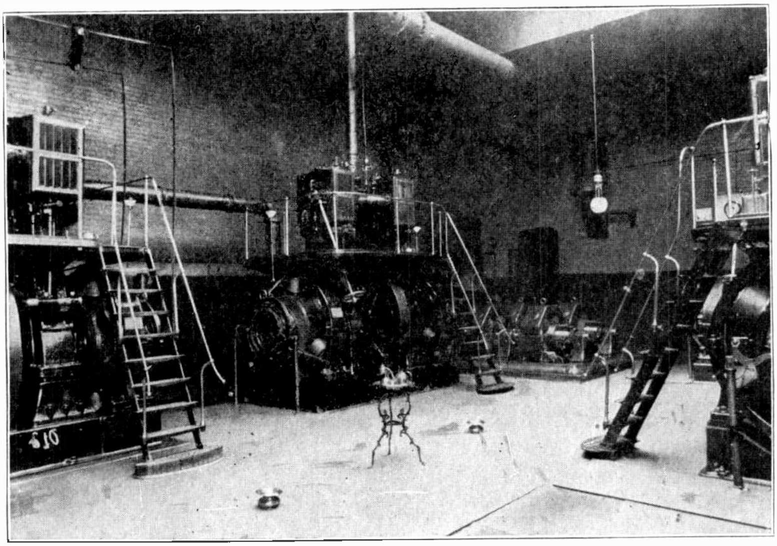


Fig 5. North Side Station, Chicago Edison Co.

lines; and the North Side Station at Clark and Oak Streets, which consisted solely of Edison generators connected to the usual three-wire system (Fig. 5). Fig. 6 is a view of the switchboard at Harrison Street Station. Fig. 6*a* is a back view of the generator gallery of this board, and shows the heavy copper bus bars. Fig. 7 is a cross-section of the engine and boiler rooms at Harrison Street Station, and Fig. 8 shows one of the 1,200-H.P. Southwark engines direct-connected to two 115-volt 400-K.W. generators. One of these dynamos connects with the positive, and the other with the negative, of the three-wire system.

Conservative Brooklyn waited to see what success was met by electric-light companies in other cities before its capitalists em-

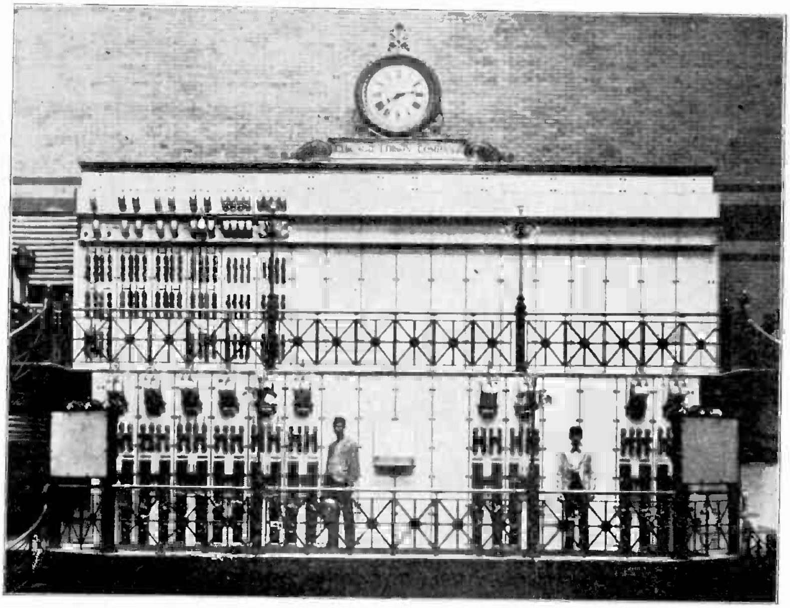


Fig. 6. Switchboard at Harrison Street Station.

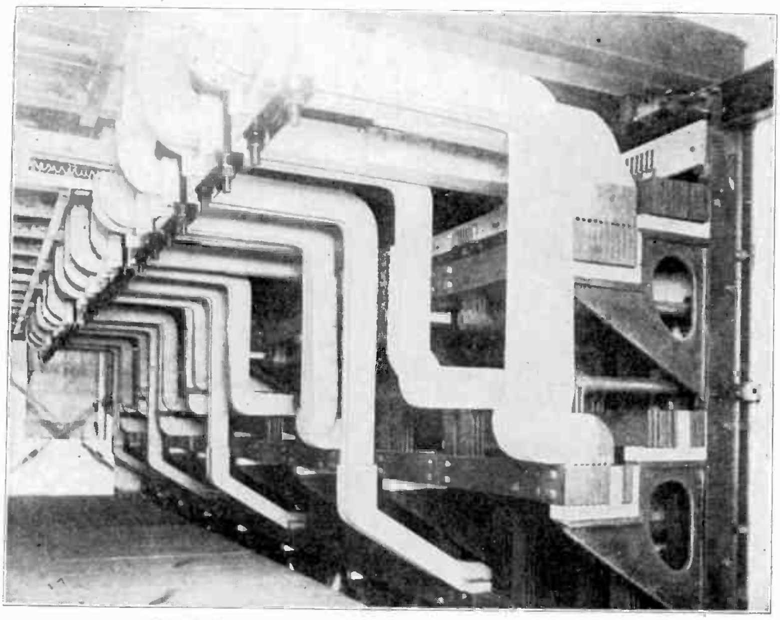
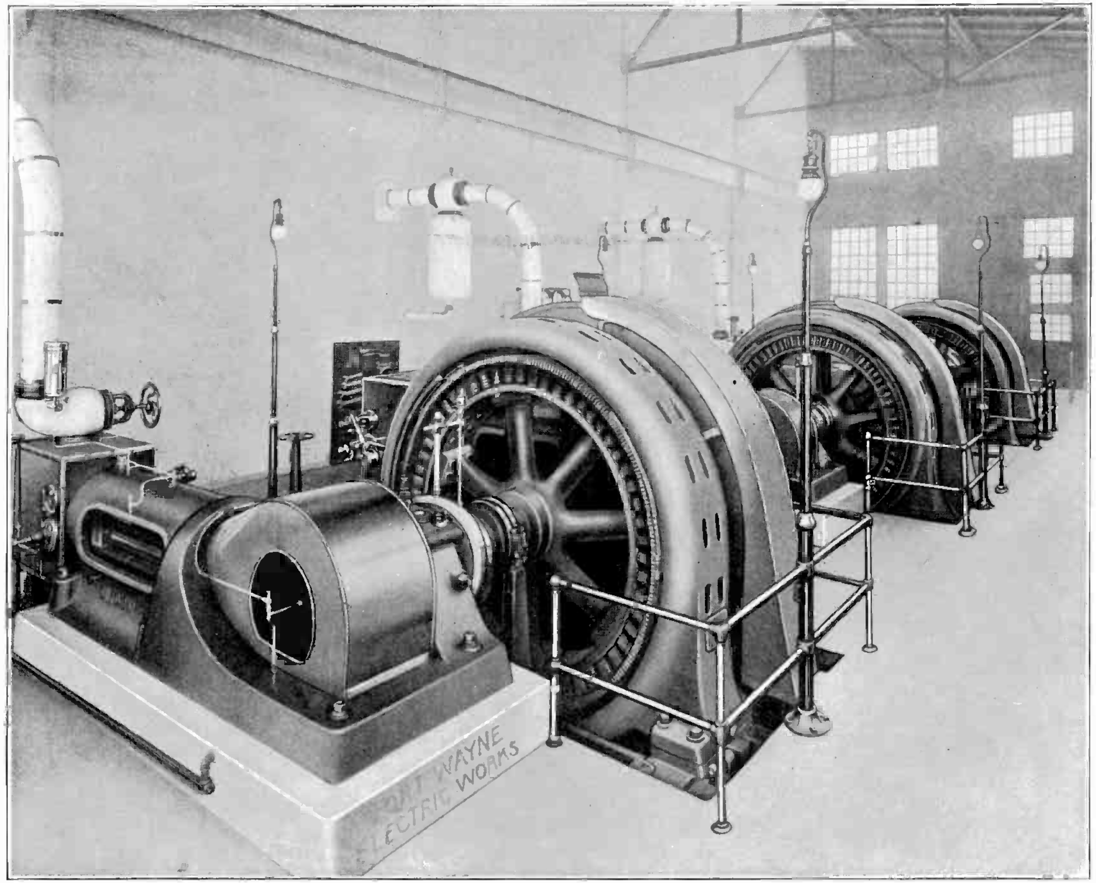


Fig. 6a. Back of Generator Gallery, Harrison Street Station.



THREE MULTIPHASE ENGINE-DRIVEN FORT WAYNE ALTERNATORS
Two-Phase, Revolving Field, 240 Volts, 360 K. W.

barked on such enterprises, but in 1889 that city was added to the list of those having a central station for the production of electricity. In that year the Edison Electric Illuminating Company of Brooklyn built its first station on Pearl Street, and started operations with a load of 6,600 incandescent lamps connected to the system. The dynamos used were four of the Edison bipolar type of 100-K.W. capacity, each two of which were belted to a

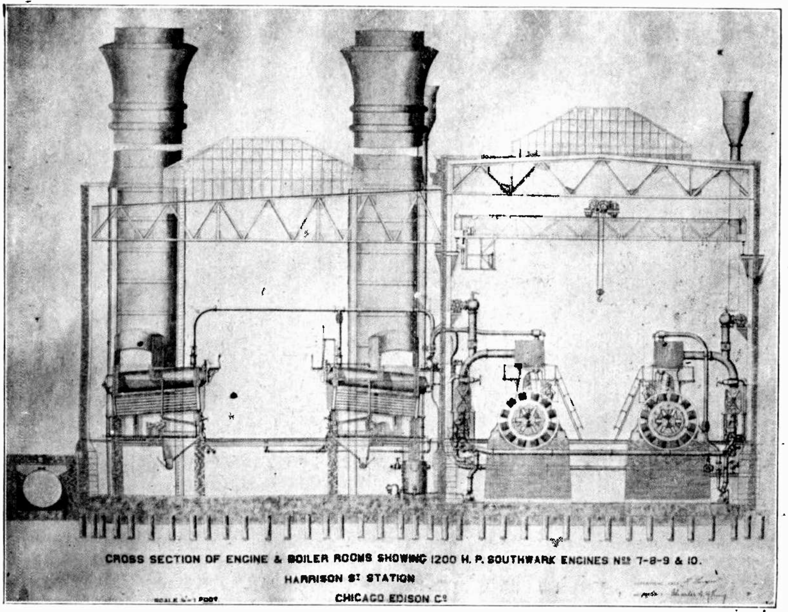


Fig. 7. Cross-Section of Engine and Boiler Rooms, Harrison Street Station.

250-H.P. cross-compound engine and were connected to an underground three-wire distribution system. In 1893, the station was remodeled, and larger dynamos were introduced direct-connected to vertical cross-compound condensing engines.

ALTERNATING-CURRENT SYSTEMS.

The development of the alternating-current system in America is due largely to Mr. George Westinghouse, who, in 1885, had built at Pittsburg, Pa., an experimental plant to work out the system devised by Gaulard and Gibbs in England. The first commercial result of the Westinghouse investigations, carried on

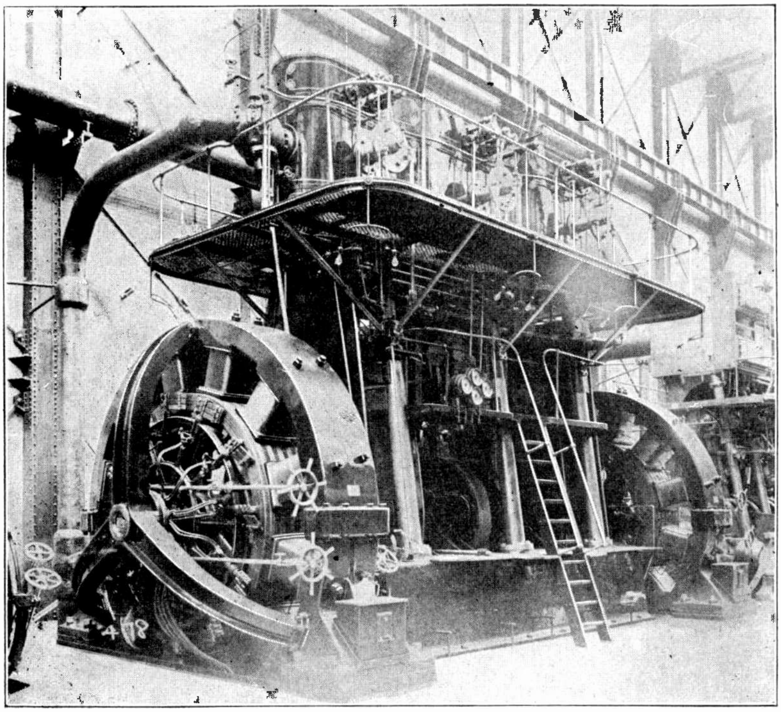


Fig. 8. 1200 H.P. Southwark Engine and 400 K.W. Generator.

by Shallenberger, Stanley, and others, appeared in the plant installed at Buffalo, N. Y., in November, 1886. The following year, 65 plants, with a total capacity of 125,000 lights, were built, and the increase thereafter was rapid.

With a direct-current three-wire system using 230 volts between outside conductors, it is uneconomical to transmit current much farther than one and a half miles, because of the prohibitively large amount of copper necessary to keep down the loss in the feeders. The resistance of a conductor varies with the length; and as it requires the expenditure of energy to send a current over a resistance, obviously a high resistance means a large amount of energy lost in the transmission. By increasing the cross-section of the feeder, this resistance can be kept low; but the cost of the feeder would then be prohibitive. By means of the alternating-current system with static transformers, connected as shown in Fig. 9, energy can be transmitted at a much higher voltage from the station. The higher the voltage of transmission, the smaller will be the current (amperes) for a given energy (watts); therefore with the high-voltage system, a given energy can be transmitted over a much smaller wire than would be required for that same energy at a low voltage. In the transformers placed at or near the point where the current is to be used, the pressure is "stepped down" to the voltage of the lamps on the circuit.

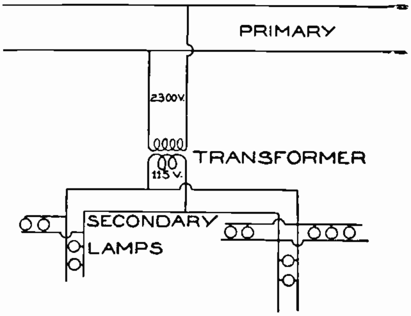


Fig. 9.

The regulation—that is, the steadiness and constancy—of the voltage of these alternating-current lines, was very much poorer than that of the direct-current system. This was largely due to the effects of self-induction, which is ever present with alternating currents. The early incandescent lamp used on the direct-current 110-volt systems was rather delicate, and had only a short life when burned on a circuit in which the pressure fluctuated very much. Consequently, it could not be used economically on the existing alternating-current lines. A 50-volt lamp could be made far more stable, and, largely because of this, the secondaries of the early transformers were wound for 50 volts. The primaries were wound for use on 1,000-volt circuits—which was then considered as high as desirable, because of the difficulties of insulating the line, the transformers, and other apparatus on which this voltage was applied. Rapid advance, however, was made in the art of insulating, and soon this primary pressure was doubled. Most of the city A. C. distributing systems now have a primary pressure of about 2,300 volts. It is interesting to note that the insulators used on the early European high-tension lines were constructed with a trough along the edge on the inner side, which was filled with oil in order to prevent current leaking over the surface of the insulator to the pin and thus to ground, by way of the cross-arm and pole, on wet days.

One of the larger of the early stations for the generation and distribution of alternating current was built in St. Louis, Mo., in 1889. The system adopted was single-phase, 1,200 volts, 60 cycles*, with a three-wire Edison system for the secondaries. These secondaries were tied together at street crossings, forming a complete network similar to that described for the direct-current system, and shown in Fig. 10. In this case the feeders of the D. C. system were replaced by the high-tension A. C. feeders and transformers,

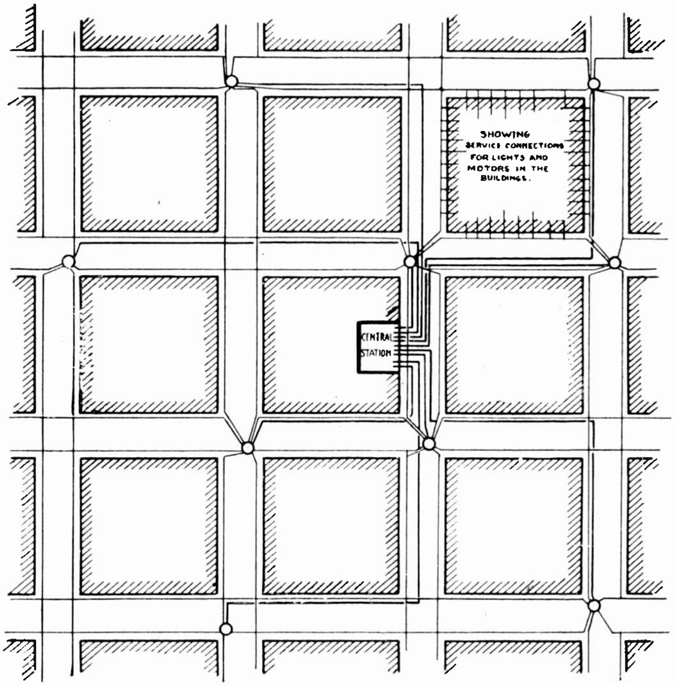


Fig. 10.

the latter being treated as part of the feeders. Pressure wires were connected to the secondaries of the transformers, and were run back to the station voltmeters to be used by the switchboard operator in regulating.

An interesting alternating-current line was built between San Bernardino and Pomona, California, in 1891. Here a transmission pressure of 10,000 volts was used, obtained by means of connecting the 500-volt primaries of twenty transformers in series. Thus each transformer had to have insulation for a working pressure of only 500 volts, which was comparatively easy to produce.

*Note. A current which alternates 120 times per second has 60 double alternations or "cycles" per second.

In 1891, the celebrated three-phase transmission line from Lauffen to Frankfort, in Germany, was operated. Originally this was intended for transmitting energy generated by water power at Lauffen, to the city of Heilbron, six miles away; but it was first used in the now famous transmission to Frankfort, a distance of 110 miles, at the time of the Frankfort Exhibition. The dynamo, built at the Oerlikon Works in Switzerland, was star-connected, and generated a star pressure of about 50 volts.

In a three-phase star-connected generator, the armature windings consist of three branches which are connected at one end to a common point. These branches are so placed on the armature core that the wave of the alternating pressure is set up in one coil a little later than is the wave of pressure set up in the coil immediately ahead of it, and a little sooner than the wave in the coil immediately back of it. These three pressures then follow each other in regular succession, the phase difference (the time between similar values of the different waves) being equal to one-third period.* The wires leading to the other ends of the three armature coils are called the "phase" wires, while the one connecting to their junction is the "neutral" wire. The pressure between a phase wire and the neutral is called the "star" pressure, while that between any two phase wires is called the "delta" pressure. This latter is 1.732 times as great as the star pressure. For greater safety in operation—principally to prevent abnormal rises in pressure between a phase wire and earth—the neutral wire is thoroughly "grounded" by being connected to a plate embedded in the moist earth.

The 50 volts pressure generated at Lauffen was "stepped up" by transformers of 8,000 volts, delta, at which pressure the current was transmitted.

DEVELOPMENT OF WATER POWERS.

After the success of polyphase transmission had been thus established, a great impetus was given to the development of water powers, and the following years found this system adopted by many companies. One of the first of these in America was built

*NOTE. A period is the fraction of a second for one complete cycle of the alternating wave.

at Telluride, Colorado, in 1892. The original pressure used here was 3,000 volts, three-phase, straight from the generator. As a result of an extended series of experiments made on this line in 1896, much valuable data was obtained regarding high-tension transmission; and to-day there are many such systems, some operated at a pressure as high as 40,000 volts, which is the pressure now used at Telluride, while a few others are going still higher. The limit to-day seems to be about 60,000 volts, but even this may be increased as the art advances.

The Sacramento-Folson line, in California, built in 1895, originally transmitted 1,000 H.P. at 11,000 volts, three-phase. The generators were wound to give a pressure of 800 volts, and this was raised in transformers to 11,000 volts.

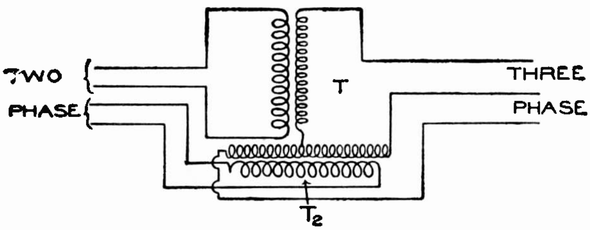


Fig. 11.

The Mechanicsville, N. Y., and the Snoqualmie Falls, Wash., plants are the most important three-phase transmission systems built in 1898. In the former, a transmission pressure of 12,000 volts, 38 cycles, was adopted; while in the latter, the generated pressure of 1,000 volts, 50 cycles, were stepped up to 25,000 volts.

Many of the polyphase stations built in the early nineties were equipped with two-phase generators. The two-phase currents were then stepped up and transformed to three-phase currents by means of a scheme of connections devised by Mr. Charles F. Scott. This connection is shown in Fig. 11. In this diagram, T and T_2 are two transformers, the primaries of which have the same number of turns and are connected to the two phases of the two-phase circuit. The secondary of T has only .866 times the turns of the secondary of T_2. By connecting one end of the secondary of T to the middle of the secondary of T_2, as shown, three-phase currents of equal pressures on each phase are obtained from these secondaries.

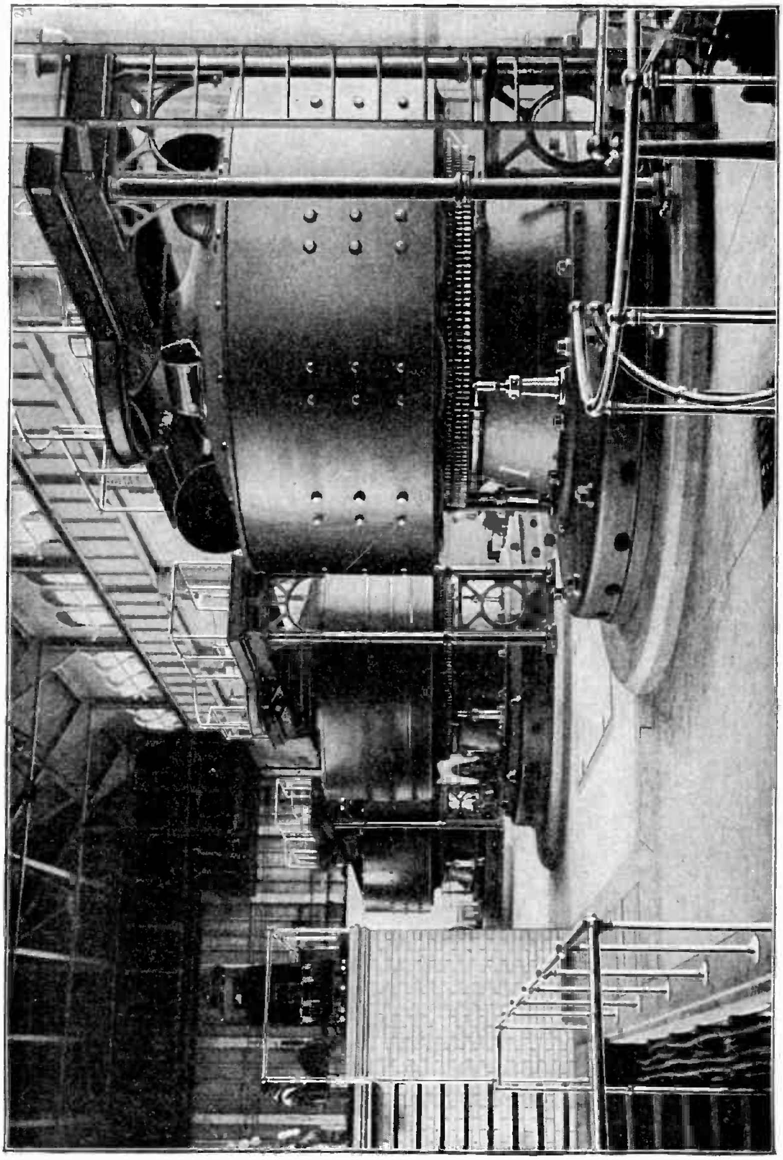


Fig. 12. Interior of Power House No. 1, at Niagara.

The best known example of this is the system at Niagara Falls, N. Y., where 25-cycle two-phase currents, generated at 2,200 volts, are transformed to three-phase currents at 22,000 volts, at which pressure the energy is transmitted to Tonawanda and to Buffalo, the latter being about twenty miles from the station. When this station was first operated, in 1896, the transmission pressure was 11,000 volts. Since that day many high-tension transmissions have sprung into existence; and the increase in voltage is keeping step with the improvement in insulators, as already noted. An interior view of Power House No. 1 at Niagara Falls is shown in Fig. 12.

FUNCTION OF THE STORAGE BATTERY.

While these important developments in cross-country transmission were under way, the engineers of the urban stations also had a few problems to solve. The convenience and other desirable features of the use of electric light and power were now being widely appreciated, especially when the cost of the lamps was reduced; and electric motors also were being used more liberally, in sizes from one-fourth horse-power to 300 H.P. and larger. This meant a big increase in the load on the station, as well as in the size of the district to be served. How to meet this increase economically, required an intelligent study of the problems of current distribution. As already noted, the distance over which it is economical to transmit current at a low voltage is limited; and, when the area to be served exceeds this limit, recourse must be had to more stations or to a higher distribution pressure. A study of the load curve of an average central station in a large city (Fig. 13) shows that the feeders are carrying their heavy current for but a short time each day. During all the remainder of the day, then,

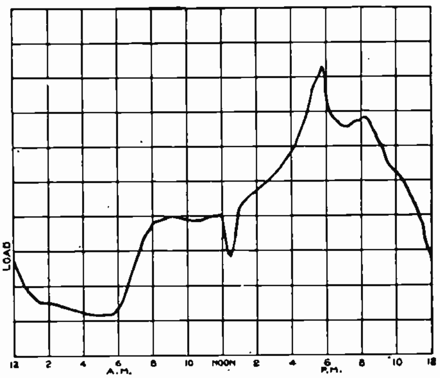


Fig. 13.

the current in these feeders is comparatively small; also, much of the generating capacity of the station is idle, representing just so much investment inactive and earning no returns. If now, during the period of light load, a current, additional to the regular load, can be sent over these feeders, and if this current can be stored in some way in a location within but near to the economical limit, so that it can be used at the period of heavy load, this storage substation will in turn become a point of distribution from which current can be sent out as far again as the economical limit. Here is where the storage battery filled the want. In 1894 we find storage-battery substations installed in Boston and New York, and soon after companies in other cities adopted them. In Boston, a number of battery substations were installed in the nearer outlying districts, all of them being connected with one another and with the steam station. The batteries are charged during the hours of light load by means of boosters, which form part of the substation equipment. Their usefulness, however, is not by any means limited to outlying districts. As an auxiliary to a generating station, it is considered good practice from the standpoint of economy to install a storage battery if the peak of the load does not exceed two and one-half hours. As a safeguard against interruption of service, and as a help in maintaining a uniform pressure on the system, they have been found almost invaluable.

CONSOLIDATION OF PLANTS.

The next step in the development was one of consolidation. Many cities had been liberal in granting franchises to lighting companies, and as a result there were built within the same city many systems of various excellence and stability. To the engineers of the consolidated company was then presented the problem of unifying the systems; but the changes to the new system had to be made without sacrificing the value of the investment represented by the generating apparatus and lines of the existing stations. Such a change, naturally, was made step by step, and thus required several years. In addition to providing for the existing load, the new system had to be designed for the future, and the probable development in the line of various classes of electrical apparatus had to be considered.

In our larger American cities, the load conditions can be divided into two general classes—one, in which a large load is concentrated over a comparatively limited area, which is the downtown or business district; and the other, the residence district, where the load is widely scattered over a large area. In the downtown district, nearly 30 per cent of the load goes to power users;

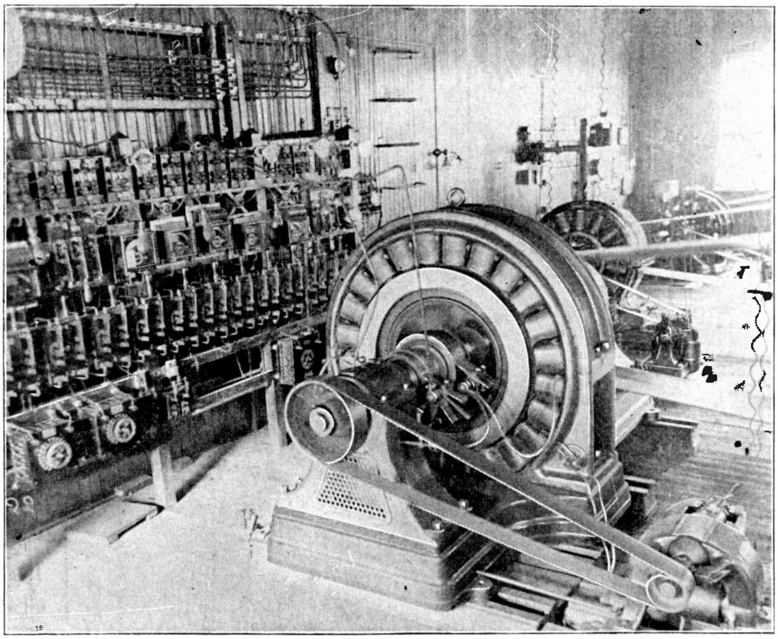


Fig. 14. Early Alternating-Current Station.

therefore the system had to be adapted to all classes of motor service, as well as for lighting. For this service in such a district, the Edison direct-current three-wire system is certainly the most satisfactory, and this system has been pretty generally adopted. It permits the use of storage batteries; requires less copper than does the alternating-current system, because in it there is no loss due to inductance; gives better regulation; and is far better for general all-around power service.

To consolidate several systems of this class was a simple matter. It required merely that the separate networks of mains be tied together, and a uniform pressure kept on the system by each station feeding into it. In the outlying districts, however, the problem was more complicated. Because of the scattered load, most of the systems feeding these districts used alternating current. But there was a wide divergence in regard to frequency and voltage. Some of the lines were 1,000-volt; others, 2,000-volt. Some used a frequency of 125 cycles; others, 133 or even 144 cycles. The secondary pressure ranged from 104 to 125 volts, while some of the earlier systems still maintained a secondary pressure of 50 volts. A few of the later stations had 2,000-volt lines, with a frequency of 60 cycles; and there were also polyphase (generally two-phase) lines for serving a motor load. A view of an early alternating-current station is given in Fig. 14.

High-Voltage Polyphase Systems. This conglomerate mass, then, had to be unified. A careful study of various systems showed

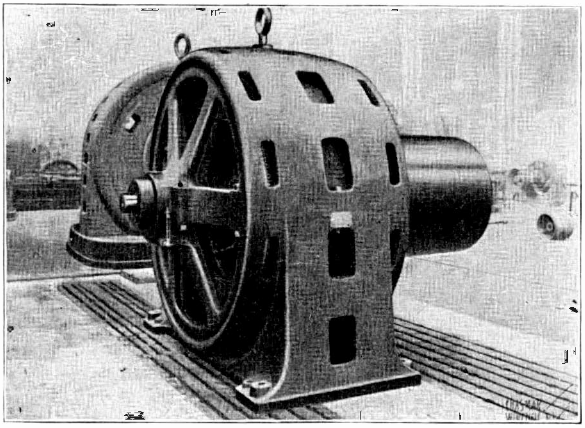


Fig. 15. Polyphase Induction Motor.

the four-wire three-phase system, with a frequency of 50 to 60 cycles, to be the best suited to the distribution of such a load; and this system is being freely adopted. Good examples of it are found in Chicago, Milwaukee, St. Paul, and Cincinnati. The generator for this system is star-wound, with the neutral grounded, as already explained. The voltage at which this system is generally operated is 4,000 between phase wires. This gives a pressure of approximately 2,300 volts between any phase wire and the neutral; and the single-phase lighting feeders are switched on to this 2,300-volt

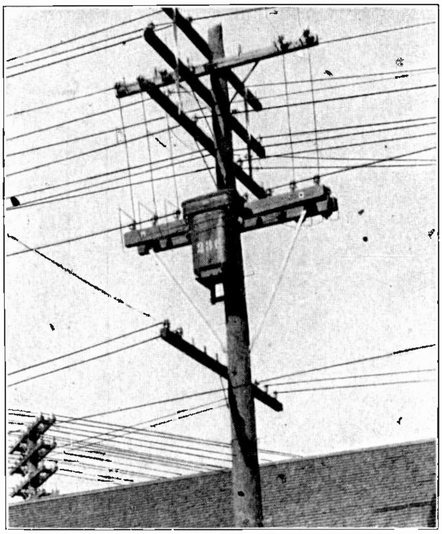


Fig. 16.

connection. The various feeders are connected each to one of the phases and the neutral, so that the three phases are approximately balanced. For a power load, then, connection is made to all three phases, and the motor is usually of the polyphase induction type, of which one is shown in Fig. 15. Where the capacity of the motor is very small—under 3 H.P.—the single-phase type of induction motor, equipped with some special starting device, is often used. Step-down of the voltage to the service pressure is, of course, accomplished by means of the ordinary 2,300-volt static transformers.

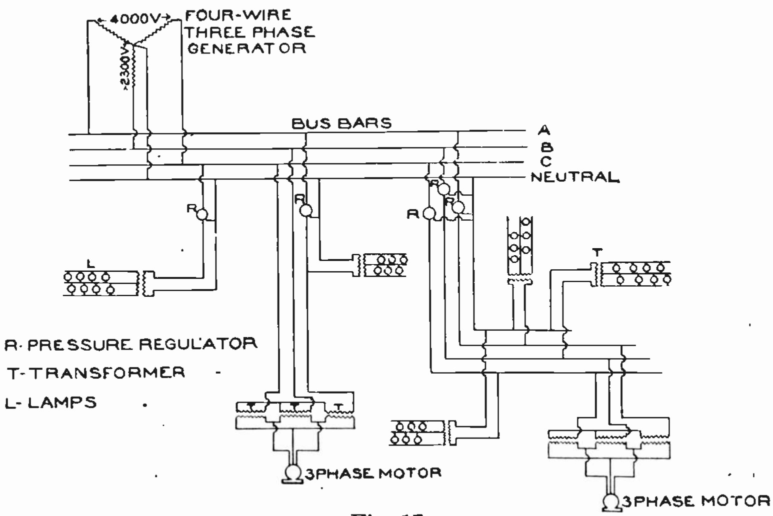


Fig. 17.

In Fig. 16 is seen a 150-light (7.5-K.W.) transformer on a pole. The two wires coming down at the right are the 2,300-volt primaries; while the three-wire secondaries, of 115 volts per side, are brought up at the left. A diagram of a four-wire three-phase distribution is shown in Fig. 17; and in Fig. 18 is seen a switchboard installed for such a system.

When the transmission distance is great, this three-phase pressure can be raised to any desired amount, and then stepped down again at the substation, the local distribution again being done on 2,300-volt single-phase feeders with a pressure of 4,000 volts between phase wires. In some cities, a two-phase system

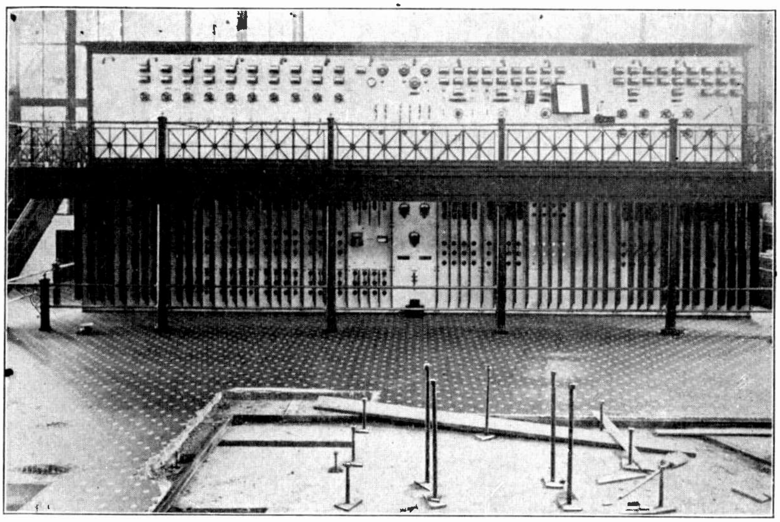


Fig. 18. Switchboard of 4-Wire 3-Phase Distribution System.

was adopted; while others, again, used the three-wire three-phase system (in which a neutral conductor is not used and all load is connected between phase wires). Brooklyn has a two-phase 2,300-volt 60-cycle system in the residence section; Philadelphia also, though in the latter city the current is generated at 5,500 volts and stepped down to 2,300 volts alternating-current distribution.

A 500-volt two-phase generator is shown in Fig. 19. For higher voltages the revolving-field type is used, thus avoiding collector rings and brushes for the high-voltage current. At the South Boston station of the Boston Electric Light Company (now part of the Boston Edison Illuminating Company), the generators are wound for 2,300-volt three-phase 60-cycle currents.

In the direct-current districts, the load often increased very heavily in sections somewhat remote from the generating or the distributing center; and then it became a question of more stations, more copper, or some other additional means of transmission. To provide enough copper for satisfactory transmission and regulation, would bankrupt a company. To build and operate a new generating station in each section of heavy load, would be equally ruinous. Consequently recourse is had to other means of transmission. The success and the comparative copper economy of polyphase transmission lines, already mentioned, showed that system to be the proper one to adopt; and the three-phase system was chosen as the means to transmit current to substations located at or near the electrical center of the load. Such a transmission system, from a large alternating-current station in preference to several direct-current generating stations, is considered good engineering whenever the total energy generated is large as compared with that used at any one locality. The voltage determined upon depended to some extent on the local conditions, but more largely on the efficacy of the insulation of underground cables, since in the cities all lines must be below the surface. In the early days of underground cables, 5,000 volts was thought very high pressure; to-day 25,000 volts is not considered excessive; and a recent article in the *Electrical Age* stated that an underground cable system will soon be installed, to be operated at 30,000 volts. The insulating material used in these high-tension cables consists of paper treated with a resinous compound, the thickness in the 30,000-volt cable

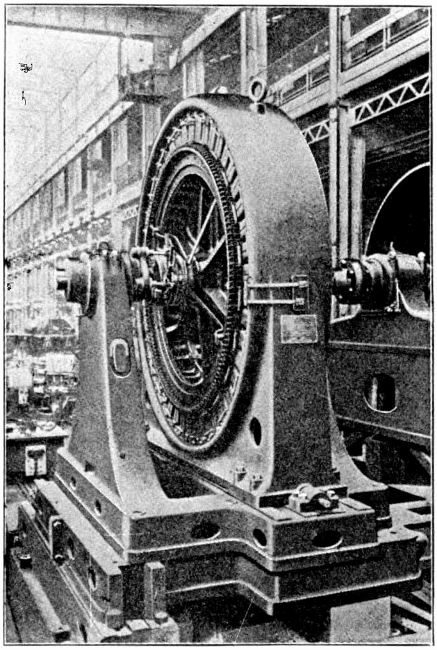


Fig. 19. 500-Volt 2-Phase Generator.

being about one-half inch. Over this is a lead sheath about $\frac{1}{8}$-inch thick, to protect the cable against moisture and mechanical injury. These cables are drawn into ducts laid below the surface in the streets, as shown in Fig. 2.

One of the earliest instances of the use of a three-phase transmission to a substation, for conversion to direct current of an Edison system, was in Chicago, where, in 1897, a 250-K.W. inverse rotary converter, which converted direct current of 250 volts to three-phase 25-cycle currents was installed at the Harrison Street station. By means of step-up transformers, this pressure was raised to 2,250 volts, the pressure of the transmission. In the substation on Wabash Avenue, near Twenty-seventh Street, this voltage was stepped down again; and, after passing through the rotary converters, the current was fed into the direct-current system at 115 volts, one rotary being connected to each side of the Edison system. Such was the humble beginning of the very extensive system of high-tension transmission lines and substations, which, at quadruple the initial voltage, is now in operation in Chicago.

In the same year there was installed in Brooklyn, N. Y., a similar transmission system with a rotary converter substation. Here the current was generated at 6,600 volts, 25 cycles, three-phase, at the Union station, a similar system to that operated by the New York Edison Company. In the magnificent Waterside station of this latter company, there are at present eleven 5,500-H.P. vertical engines, each driving a 4,500-K.W. three-phase 25-cycle 6,600-volt alternator. A 5,000-K.W. Curtis turbo-generator is being installed, and there is room for four more. This will make a total rated capacity of 75,000 K.W., all power being generated as alternating current for transmission to rotary converter substations, from which it will feed into the Edison three-wire direct-current system. In the splendid new Fisk Street station in Chicago, 9,000-volt 25-cycle three-phase current only is generated, all by Curtis turbo-generators. Fig. 20 shows a Westinghouse-Parsons unit of 5,000 K.W. capacity.

In Philadelphia, the 5,500-volt two-phase 60-cycle system, already referred to, is used for transmission to rotary converter substations, as well as for the alternating-current distribution, Fig. 21 shows a row of rotary converters of a substation located in

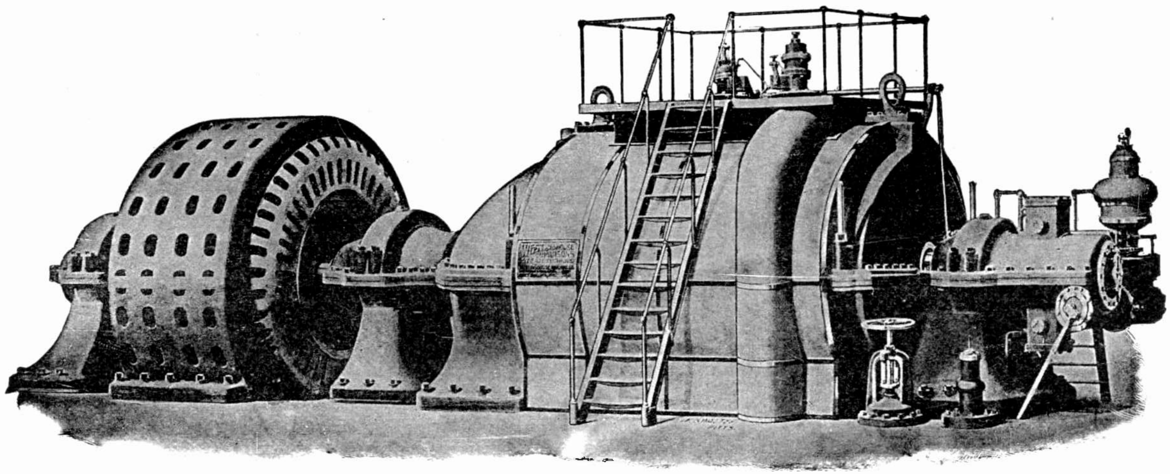


Fig. 20. WESTINGHOUSE-PARSONS 5,000 K. W. TURBINE GENERATOR.
For the Pennsylvania Railroad Tunnel, New York.

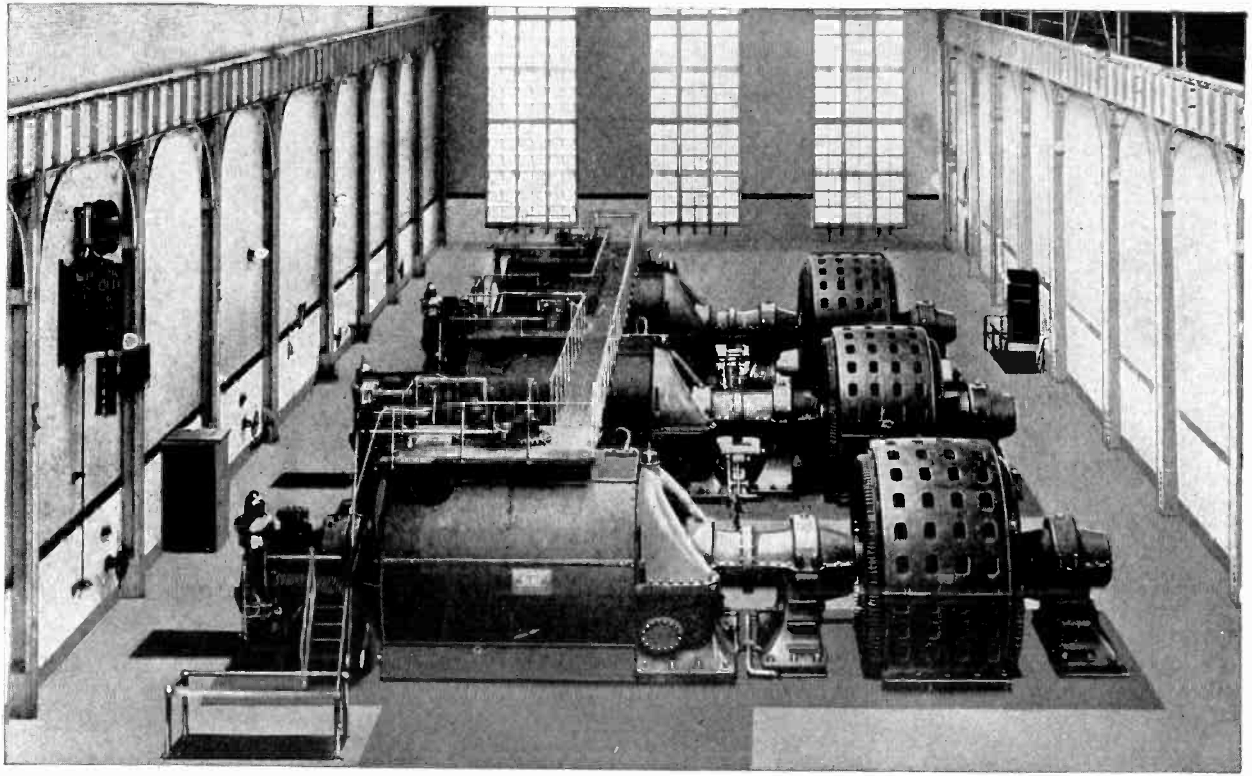


Fig. 89. Three Westinghouse-Parsons Steam Turbines Showing Divided Casing

the basement of a sky-scraper in the heart of the business district of Chicago.

Where the load connected to transmission lines consists solely of substation converting apparatus, a low frequency is desirable because of the accompanying low inductive and capacity reactance of the lines, and also because of the slower speed of the synchronous motors and rotary converters which is had for a given number of field poles with a lower frequency. The higher the frequency, the greater the number of poles required, or the greater the speed. Because of the necessary number of commutator bars required be-

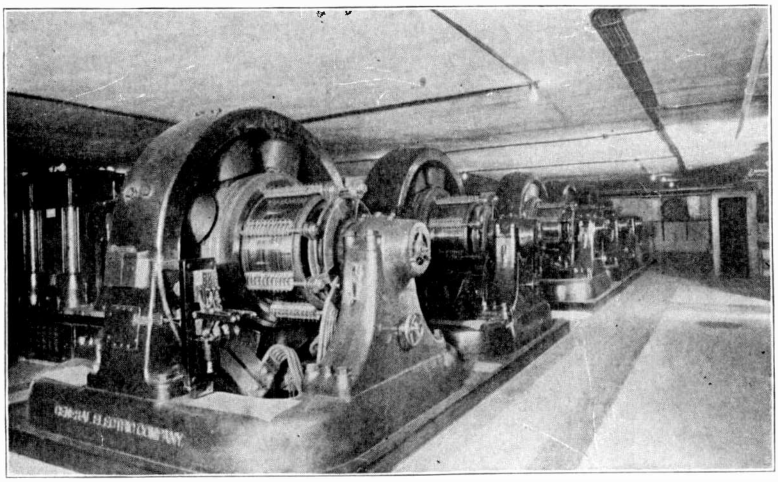


Fig. 21. Rotary Converters in Basement of Office Building.

tween the brushes of a D. C. machine, and therefore also on a rotary converter, the distance between the centers of the pole pieces (that is, the pole "pitch") cannot be less than a certain fixed limit; and, therefore, for a given speed, the lower frequency allows a far simpler and cheaper construction. The higher-frequency machines are also more liable to "hunt" especially when the load varies considerably. Furthermore, double-current generators having a commutator connected to the armature windings for direct current, and also having connections to collector rings from which alternating current is taken off, are not practicable for frequencies much above 25 cycles. These double current generators, producing both direct and alternating current at the same time, form a very valu-

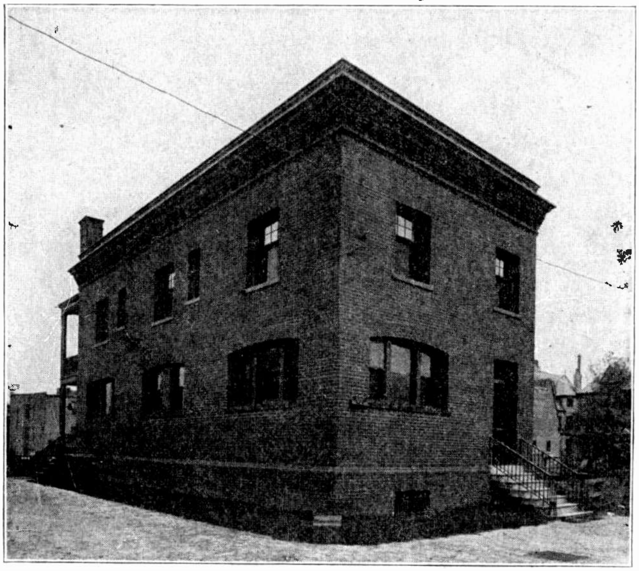


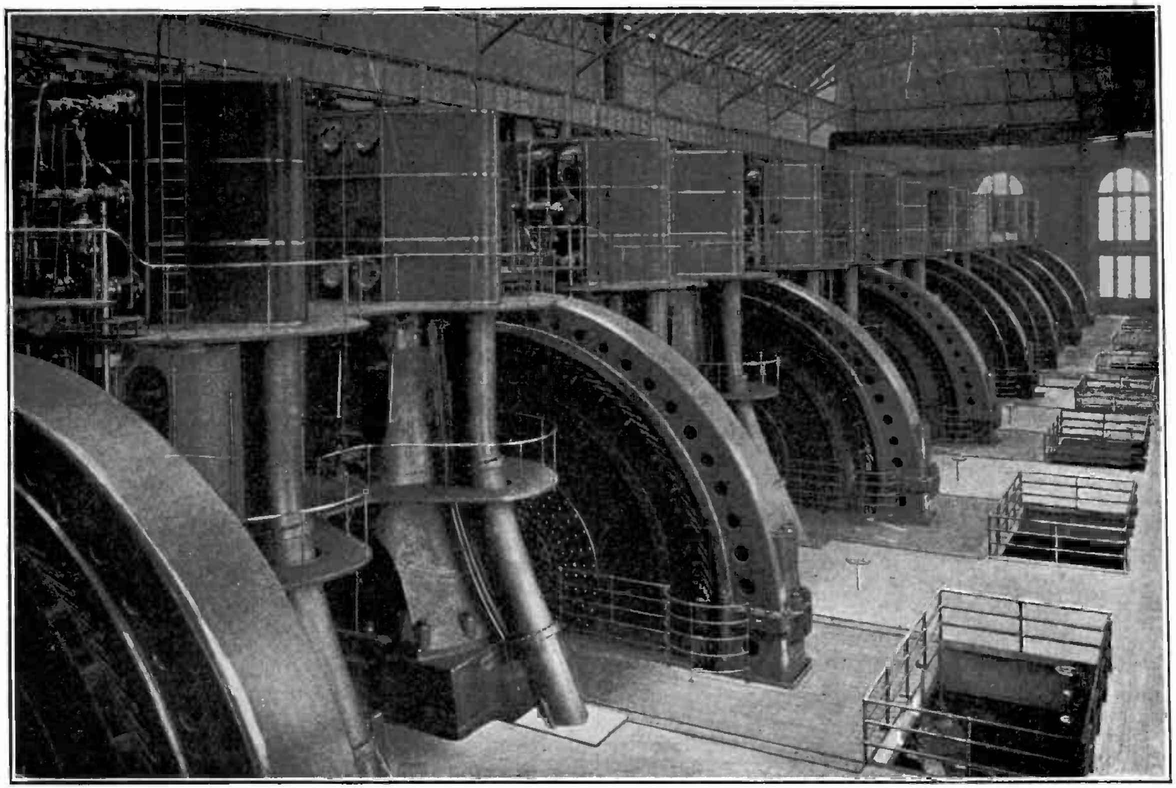
Fig. 22. Modern Light and Power Substation.

able element in a large station in which both these currents are generated, the direct current for general distribution, and the alternating current for transmission to substations. A frequency of 25 cycles is therefore generally accepted as the most desirable for straight transmission; but the alternations are noticeable on incandescent lamps at even 30 cycles, while arc lamps will not burn at all satisfactorily on frequencies of less than 40 cycles. Because of these facts, the alternating distribution, as distinguished from transmission to substations, is effected by 60-cycle current. The 25-cycle transmission current is then converted to current of 60 cycles per second by means of motor generators or straight frequency-changer sets.

In Europe, a compromise frequency of 42 and sometimes 50 cycles is common; and current is transmitted and distributed at this frequency, thus requiring only voltage transformers and no frequency changers. A few 25-cycle systems have been installed in Germany. For converting to direct current, motor generators are used more freely than are rotary converters. European transmission lines of 10,000 volts three-phase are not uncommon.

With the advent of polyphase transmission in connection with lighting and power systems, the old 500-volt power lines are gradually being abandoned, the power load being connected to the 230-volt circuit of the Edison three-wire system, or, if in the outlying districts, to the polyphase 60-cycle lines. Series arcs have already been largely displaced by constant-potential arc lamps. What this new system meant to the neighborhood in which the old stations were located, will be appreciated when one remembers the noise and dirt and smoke of these old stations, and then views Fig. 22, a substation set in the rear of a lot in a fine residence section.

We have seen, then, how the high-voltage polyphase system has been evolved out of, and has unified, the mixed systems which were brought under one head during the era of consolidation. A study of some of the newest installations leads to the thought that perfection of system has almost been reached, and that further progress will be rather along the line of higher efficiency of apparatus at both ends of the system. When the true electrical era has arrived, when houses no longer have need of chimneys and all operations are performed electrically, then new problems will arise. How they will be met, none can now say; but they will be met successfully. Another Edison—many of them, perhaps—will arise; and then our splendid systems of to-day may ultimately be supplanted by one of which the most imaginative dreamer as yet has seen no vision.



EIGHT 5,000-K. W. GENERATORS, INSTALLED AT THE MANHATTAN STATION, NEW YORK CITY
Westinghouse Electric & Mfg. Co.

A MODERN CENTRAL STATION DESIGN.*

The design of most of the central stations in this country can hardly be said to be ideal; first on account of the handicaps and limitations imposed by the location and environment of the selected site; secondly, because usually the cost of the land to be built upon renders it imperative that the area covered be made as small as possible.

In selecting the site for a large power station, three main problems confront the engineer—first, a satisfactory location with a low valuation must be found which is reasonably near to the bulk of the business; secondly, the location must be so situated that the fuel can be brought to it with the least expense for freight and handling; that is, it should be somewhere on a main ship-channel below all drawbridges with ample depth of water and docking facilities for coal-carrying vessels up to seven or eight thousand tons burden. Also there should be ample ground adjacent to both the dock and the proposed station site to permit the storing of at least six months' supply of fuel, and so situated that the minimum amount of coal-handling and conveying machinery is required. Thirdly, an unlimited supply of suitable cooling water must be provided for the condensers; this should be such that the temperature will not be excessive during the summer time. The water should be free from sewage, seaweed, and other debris; and the proposed location for the station should be such that the distance the water has to be lifted from the level of the supply to the top of the condensers is as small as possible; and the length of pipes or tunnels employed to take the water from the supply to the farthest condenser is as short as possible.

The location of the L Street station of the Boston Edison Company fulfills these conditions admirably. The ground consists of two city lots of about 25 acres, two-thirds of which is solid ground, and is situated at the corner of L and East First streets, South Boston.

* Prepared by I. E. Moultrop and presented at the 193d meeting of the American Institute of Electrical Engineers, New York, January 27, 1905. Reprinted by permission.

Measured by an air-line it is about two miles from the center of the business section of Boston. It has a water front of 815 feet on the so-called "Reserved Channel," is one-half mile from the main ship-channel of Boston Harbor, and is so located that no bridges will ever be built between it and the main ship-channel.

The solid ground consists principally of gravel with a bed of clay underneath so that the heaviest construction called for in the building of the station can be carried on ordinary footings without the use of piles. The area of the solid ground is more than double that required for the ultimate size of the station under consideration, consequently there is ample room for the storage of fuel close to the boiler-house.

Before taking up in detail the design of the station, a brief description of the company's territory will be given. The Boston Edison Company's system supplies electricity to a heavily-loaded business section of the city, which covers a comparatively small area located within a mile of the water-front. This business is supplied by a direct-current station on the water front having 10,500 K.W. of machinery, with room to increase the capacity to 14,500 K.W. Surrounding this business section is a city residential district where the load is considerable, although much lighter, than in the business part. Here the customer receives direct current from sub-stations supplied, through motor-generator sets, from the existing alternating-current station of 9,000 K.W. capacity, located on the L Street property. The output of these sub-stations being direct current, they are, with one exception, equipped with storage batteries.

Many of the business people of Boston live in the surrounding cities and towns. Up to a few years ago most of these suburban places had their own local electric-light companies, usually operating small uneconomical steam-generating stations equipped with more or less obsolete forms of machinery.

Within the last two years the Boston Edison Company have purchased the property of many of these local companies, and in most instances are changing the stations to modern alternating-current sub-stations, making a suburban business which extends in various directions from 12 to 30 miles outside of the city.

This large increase in suburban territory together with the rapidly-growing city business called for an immediate enlargement to the alternating-current station which was already loaded to its full capacity. A new station was therefore planned with an ultimate capacity of 60,000 K.W. to be built on the L Street property alongside the existing station. The first installation of 10,000 K.W. is just being completed. The position of the existing station on the property was fortunately such that it was no handicap in the location and arrangement of the new station. As a matter of fact, the old station naturally merges into and becomes a part of the new station, and had it not existed it is doubtful if any change would have been made in the design of the latter.

The value of the real estate is very small and will doubtless so continue for many years to come. Therefore the station buildings could spread out over the land as much as desired, and no attempt was made to build additional stories for the sake of saving ground area. Under these conditions, it is cheaper to spread out the buildings on the ground than to carry them up in the air to an equivalent area, and liberal room for and around the apparatus facilitates the operating, cheapens the cost of making repairs, and renders it easy to keep the stations clean.

The shape of the property was such as to make it desirable to erect the buildings with the ends toward the water front, which naturally brought the building of that end of the station first.

The turbine-room will be 650 feet long, 68 feet wide, 56.5 feet high, and without a basement. It has no side windows. A liberal monitor with glass sides and roof gives a better distribution of daylight than do side windows and in connection with windows in the end walls provides good ventilation.

The boiler-house will be 640 feet long, 149.5 feet wide and of the same height as the turbine-room. The arrangement of the boilers practically divides this building into seven fire-rooms. The lighting and ventilating is done from the roof similarly to the turbine-room.

The switch-house will be 605 feet long, 30 feet wide, and several stories high. The buildings for the installation of 60,000 kilowatts of machinery cover about 160,000 square feet, which is equivalent to about 2.67 square feet per K.W.

The ends of the buildings facing the water have been made the front of the station; with an entrance through offices located in the front end of the switch-house. The buildings are set back 136 feet from the sea-wall, the intervening space covered with a fine lawn and planted with shrubbery. Through the center of this lawn a paved driveway leads from the ornamental entrance gates on L Street to the office entrance, making a well finished and attractive environment in keeping with the interior.

In designing this station the grouping of the apparatus has been given special attention and care has been taken so to arrange them that they naturally come under the charge of the class of operators best fitted to care for them.

The turbine-room has received all of the machinery in the station; even the boiler feed-pumps usually considered an adjunct of the boiler-house are treated as part of the turbine auxiliaries, and are placed in charge of the turbine operators. The boiler-house contains only the boilers with the necessary piping, etc., so that the work in this room is to burn coal properly and maintain the steam pressure.

All of the electrical apparatus has been grouped together and installed in a separate building adjoining the turbine-room, isolated from the noise and dirt of the latter and free from liability of damage by accidents to any of the turbine-room machinery.

The electrical operating, a matter of brain work, is done under as favorable conditions as is found in any office building, with no duplication of apparatus, and the operators cannot be disturbed by anything going on in the turbine-room. Escaping steam can neither damage the apparatus nor interfere with the work of the operators, while they can oversee any of the generating rooms by stepping through doors in the side walls on to observation galleries.

To add to the architectural appearance of the interior of the turbine-room, and also to facilitate the work of keeping the room neat and clean, it is finished with tile and enameled brick. The floor is tiled in dark red with black borders arranged in the form of a simple design to relieve the monotony of one color. The walls have a wainscot of two-colored green tile about ten feet high, and above they are paneled with a light-colored tile and enameled brick. The crane track is concealed by the wall finish. This room is divided into three parts by permanent division-walls in which are large doors at the floor level, and large windows above, all equipped for quick closing. Ordinarily these will be opened, giving practically one long room, but in case of a serious accident in any room the openings can be quickly closed, isolating the trouble and leaving the other rooms free to operate without any interruption. The boiler-room has walls finished in tile similar to the turbine-room, but the floor is not tiled. The result is that these rooms are ornamental in character and are easily kept clean, while at the same time the cost of the decoration is quite moderate. Before the finish was determined upon, cost estimates were made on the various possible methods of satisfactorily finishing the rooms, including the up-keep for an extended period of years, and the finish employed was found to be the cheapest that could be adopted, being even less expensive than painting.

The exterior of the station buildings is simple and massive in character. Cut granite underpinning is used and the prominent walls are faced with a dark paving brick trimmed with terra-cotta.

The apparatus is installed on the unit system. In the turbine-room all the auxiliaries required for a generating unit are grouped around that unit and are generally of sufficient capacity to serve that unit alone. The boilers necessary to supply the generating unit are in one row directly behind the turbine. In this way each generating unit is a small central station in itself. Practically no cross-connections are installed between the various units except that between each pair of units. The steam mains are joined by a small-sized tie so that a generating unit can be run temporarily from the boilers of its mate, should an emergency require. In this way a very simple piping system is sufficient, reducing the cost of installation and maintenance, and simplifying the manipulation of the station under emergencies when the engineer has to think quickly, and when he must be sure that the manipulations are made rapidly and correctly. The duplication of auxiliaries is eliminated, and should a generating unit be put out of commission by the failure of any one of its essential parts, it is intended that the entire unit will be shut down and another one started in its place.

Before determining upon the apparatus to be installed in the station, careful consideration was given to the respective merits of turbines and reciprocating engines as prime movers. The advantages of the turbine over the engine in first cost, the lesser amount of help required to operate, the ability to use condensed steam with safety for feed in the boilers, together with the fact that the apparatus takes very much less room, decided the question in favor of the turbine. These considerations were held to justify the decision without regard to the water consumption, and the decision will be considered wise even though the water consumption proves to be no better than that of a good engine, although it is expected to be better. Another important feature is the ability to start an idle unit quickly. The earlier turbines were open to improvement in this respect, but the later machines have been safely started and brought up to full load with remarkable speed.

The turbines used in the first installation are of the Curtis type with a rated capacity of 5,000 kilowatts on a conservative temperature rise in the generator. They are four-stage machines with surface condensers built in their bases and are equipped with mechanical brakes for bringing the machine to rest for an emergency stop. In these features they are the first machines of their kind to be installed. The base condenser was adopted because it will give a somewhat better vacuum in the turbine, which is an important consideration in turbine work. It also considerably reduces the floor space required for the installation, somewhat simplifies the piping, and makes possible a more symmetrical and pleasing grouping of the machinery. Its disadvantage is that it increases the height of the turbine a few feet, which is, however, of little moment. Its first cost is somewhat more than an independent condenser, which may be partly balanced by the saving in piping; and it requires special arrangement for filling the condenser tubes with water when the turbine is to be non-condensing.

The brake is very useful for emergency shut-downs, because the turbine will run for some hours with no load and no field, while with the brake it is possible to bring the machine to rest in about five minutes. It also facilitates the overhauling of the step bearing by sustaining the weight of the rotating parts.

The generator is a three-phase alternator, Y-connected, 60-cycle machine, generating at 6,900 volts. This number of cycles was determined upon because the bulk of the alternating-current business is lighting, and also for the reason that the existing alternating-current apparatus has the same number of cycles.

The auxiliaries for each turbine consist of a circulating-pump, a wet and a dry vacuum-pump, a step-pump, a hydraulic-accumulator, and the boiler feed-pump for the group of boilers connected to the turbine. All these machines are steam driven with the exception of the wet vacuum-pump which is motor driven because its speed is too high to be conveniently handled by an engine. Careful consideration was given to the subject of steam- versus electrically-driven auxiliaries, and steam was determined upon because it gives better station economy. All the exhaust steam from the auxiliaries is carried to the feed-water heater and is condensed in heating the boiler-feed. The condensation is then discharged to the sewer as it contains too much cylinder oil to warrant trying to purify it. As all the exhaust from the auxiliaries can be condensed in heating the feed-water, the greatest possible use is made of the heat originally put into this water in the boilers, for practically all that is not taken up in the form of work in the engine cylinder is returned to the boiler in the feed. Moreover the first cost of steam-driven auxiliaries is less than the electric drives, and speed regulation over wide ranges is much more easily accomplished.

The circulating water-pump consists of a centrifugal-pump driven by a simple high-speed engine with a throttle governor. The quantity of water to be handled is very great, and the head very low, so that a centrifugal-pump is well adapted for this duty. It also makes a very much smaller machine than a piston-pump, is much less expensive, and at the same time it is very simple and requires almost no attention.

The distinctive feature of the dry vacuum-pump is that the air-cylinder is placed at a right angle to the steam-cylinder, thus giving a better turning moment on the crank, and it takes less room. The air end is built single stage, and will maintain a vacuum on a closed tank within one-half inch of absolute. The steam end is throttle governed to permit of speed variations while running. The wet vacuum-pump consists of a two-stage centrifugal-pump, motor driven. This pump will maintain a vacuum in the condenser equal to that of the dry vacuum-pump without the use of either suction- or discharge-valves; thus requiring a minimum amount of repairs and almost no operating attention. The boiler feed-pump is an ordinary duplex, center-packed plunger-pump, selected because it is easier and quicker to repack, and a casual inspection will show if there be leakage from the plungers.

The step on the turbine is lubricated by water instead of oil, because the water is as good a lubricant for this purpose, is cheaper, and the lubricating system simpler. The water is forced into the step under a pressure of about 1,000 lbs. by a steam pump of similar design to the boiler feed-pump. As even a momentary stoppage of the water supply to the step would result in damage to the bearings, a motor-driven triplex-pump, which can be started much quicker than a steam-pump, is installed as a relay to the main step-pump. To obviate fluctuations in the pressure due to the pump's reversing its stroke, a weighted hydraulic accumulator is used. This is made of sufficient capacity to keep the step supplied with water for ten minutes, thus giving time either to shut down the turbine by means of the brake or to put the relay-pump in service, should the steam-pump fail.

The condensing apparatus is designed to condense 153,000 lbs. of steam per hour and maintain a 28-inch vacuum in the condenser, with the cooling water at summer temperature of 70 degrees Fahrenheit. The same apparatus under winter conditions and when the heaviest loads occur on the station, will give a vacuum within about three-quarters of an inch of the barometer.

The cooling water is conveyed to the pumps by brick tunnels running under the center of the turbine-room, at such grade that they are always flooded, and constructed within the building so that the machinery can be installed above them. For additional insurance, two tunnels are provided for the incoming water, each supplying one-half the station. The notable feature of this system is the intake construction at the sea wall. Racks and screens, provided to keep out all floating material, are so installed that they require very little cleaning, and the screens are arranged to be easily removed and cleaned without permitting debris to pass into the tunnels. Where the tunnels join the screen chamber, heavy timber gates are provided so that the tunnels may be pumped dry for inspection of repairs. The water-front construction is of concrete with a wing-dam so designed that, while the warm discharge-water empties into the harbor alongside of the incoming tunnels, thus simplifying the construction, at the same time the latter tunnels get the coldest water available, without danger of taking any of the warm discharge-water.

The rows of boilers are placed in pairs alternately face to face and back to back, with a chimney for each pair midway of the row and between them. Thus six chimneys in all are required, each being 230 feet high above the level of the grates, or sufficient to dispense with forced draft. Building the chimneys between the rows of boilers, considerably increases the ground area of the boiler-house, but the additional space is very useful for work-room, toilet-rooms, etc. The boilers are elevated from the ground to provide liberal space beneath for the ash handling. Large brick chambers immediately below the boiler furnaces collect the ashes, and discharge through valves in their bottoms into carts or cars on the ground floor. Other distinctive features of the boiler-room are the provisions for bringing air to the furnaces, the location of the piping mains, and the small capacity of the coal-bunkers.

The ash-room has a free circulation of air at all times through openings in the exterior walls which are without doors and are provided with grills. In the front wall of each ash-chamber, close to the fire-room floor, are openings equipped with dampers admitting air directly to the ash-pits and maintaining an adequate supply to the furnaces, while permitting the windows and doors to be closed, during extreme weather conditions.

A portion of the basement under each two rows of boilers is separated from the ash-room by partitions forming the pipe-room. Immediately under each row of boilers in this pipe-room are installed all the various pipe-mains which connect with them, and only branch pipes to each battery of boilers are taken into the fire-room. This puts the most of the boiler-room piping into a warm, clean room by itself where it is accessible, free from cold drafts which would tend to start leaks, and where it can be carried upon substantial supports.

The grouping of boilers and turbines which has been adopted, gives a smaller amount of piping than would be the case were the boilers placed in the usual manner in two rows, parallel to the turbine-room, and makes a very short smoke-flue with a minimum amount of reduction in the draft.

Supplying each row of boilers is a line of coal-bunkers built in monitors above the roof. As there is practically no piping on top of the boilers, little space is needed above them, and building the coal-bunkers in monitors enables the boiler-house to be made quite low, saving considerable expense in the cost of the structure, and also in heating only a small waste space above the boilers. As there is always a large amount of coal stored alongside the station, the capacity of the bunkers is made small, being sufficient to last during the time of making routine repairs in the coal-conveying system. This reduces the cost of the building very materially. The boilers are equipped with the attached type of superheaters and automatic stokers. They are higher by two rows of tubes than is the usual practice, which provides for additional storage of hot water, and in such form that it will also serve as additional heating surface.

The amount of superheating, 150° Fahrenheit, was made conservative to be sure that the temperature would not cause trouble with flanged joints and in the steam-cylinders of the auxiliaries. The attached type were selected because they took no additional room and are self-regulating. Use of superheaters at the direct-current station shows a gain of about 9 per cent per 100° Fahrenheit of superheating in the engine economy, and while with the attached type it is impossible to make comparative tests with and without superheaters upon the same apparatus, the station economy indicates a substantial net gain by moderate superheating.

Stokers were selected that seemed to give the best results with the high-grade fuel used in New England, and with a minimum amount of repairs; the labor required to operate them is small, and very little combustible fuel is wasted in the ash pits.

Beneath the coal-bunkers small non-automatic weighing hoppers are installed. Direct-reading beam-scales are used because they are reasonably accurate, cheap in first cost, and are easily tested.

No economizers have been installed because of their doubtful value under the operating conditions of this station and of their effect on the chimney draft, which is liable to cause a reduction in the capacity of the boiler plant at the time when the maximum is needed, or else make it necessary to cut the economizers out of commission at a time when they would be most useful.

The storage of coal is a very essential feature of a large central station, and is seldom adequately taken care of. Alongside of this station and adjacent to the water front an open-air storage of from 60,000 to 70,000 tons of coal is provided where the coal is stored without any shelter and immediately on the ground. The winter's supply of coal can therefore be purchased while the freight rates are low during the summer time, which, notwithstanding the loss from weathering coal, reduces the cost of fuel delivered in the fire room.

The coal-wharf is equipped with an electric tower, operating a one-ton clam-shell bucket and one electro-hydraulic tower operating a similar bucket of 1.5 tons capacity. The electro-hydraulic tower is a new design in which hydraulic-elevator cylinders furnish the power for operating the bucket. The water pressure is obtained by a three-stage centrifugal pump driven by an induction motor. This pump is automatic in its action, and when the water pressure reaches the maximum point the pump continues running and maintains that pressure without delivering any water, until the pressure drops. The tower is operated by one man with a minimum amount of physical exertion.

The coal is conveyed from the wharf to the storage-yard by a system of conveying belts, the conveyors from the wharf to the yard having a maximum capacity of 700 tons of coal per hour. This conveying system was adopted because it was possible to obtain a very large capacity when desired, with a minimum amount of attendance and repairs.

The storage-yard is equipped with an electric reclaiming-bridge which operates a clam-shell bucket of the usual type and of two tons capacity. This bridge is so installed that it will cover the entire storage-yard, and besides taking coal from the field and putting it on to the conveyor running into the station, it is very useful to turn over the coal quickly should it show signs of heating.

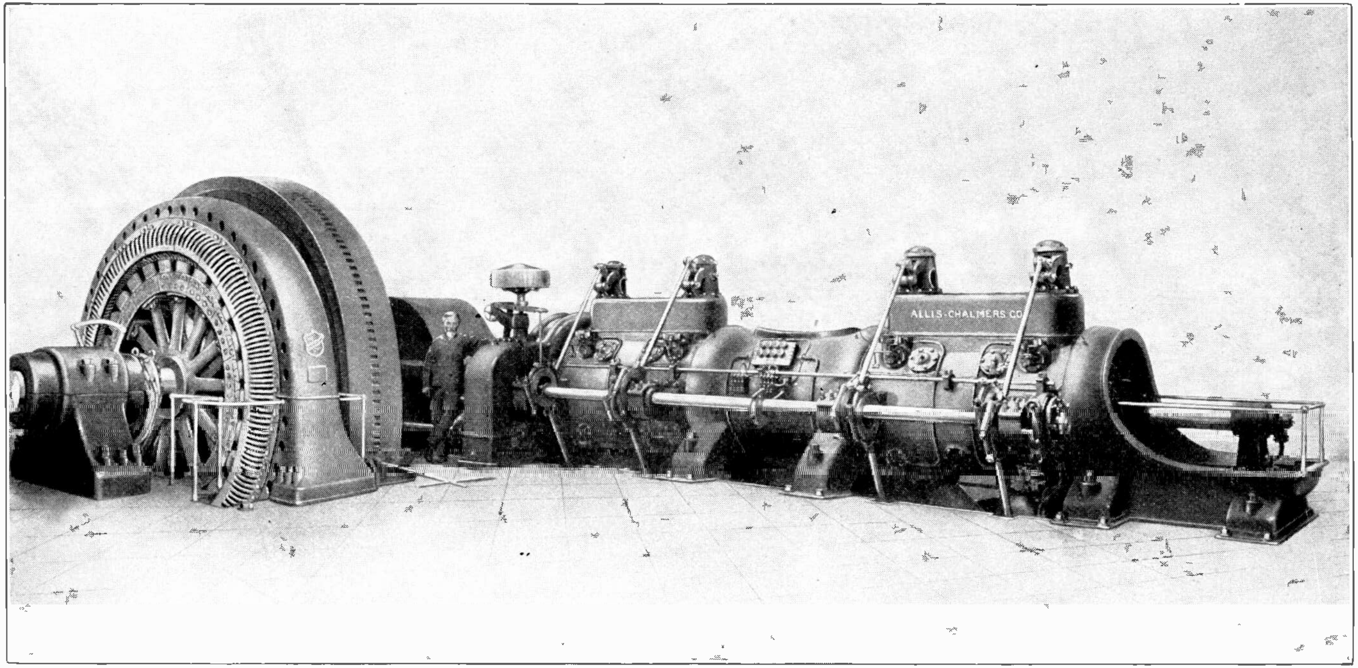
The distinctive feature of this reclaiming-bridge is the fact that all the machinery for operating the bucket is installed on a trolley car running on the deck of the bridge. The operator riding on this trolley is always immediately over his work, and can control the motions of the bridge at the same time he is operating the bucket.

The water-supply for the boilers is of equal importance to that of the fuel. Water-service pipes of ample capacity for the total station are brought into it from large mains in the two adjacent streets. These will shortly be fed from separate trunk mains. For a further safeguard to the water-supply, a system of storage-tanks, with a combined capacity of 50,000 cubic feet of water or sufficient to run one turbine on the condenser for about ten days, is installed on the ground alongside the station building and at an elevation considerably above that of the feed-pumps.

As to the general arrangement of the switching, there are of necessity three bus-bar pressures, the excitation, and the possibility of a fourth pressure being required later. The engine-driven alternators generate at 2,300 volts, and the turbine-driven alternators at 6,900 volts. This latter was fixed upon after careful consideration of the location of the present business with reference to the station and of its probable growth. There is also a certain amount of 4,600-volt business which crept into the system some time previous because a considerable amount of business developed at a distance too far away for the economical use of 2,300 volts, and the standard cables on the system would safely carry only 5,000 volts. Therefore, the simplest expedient at that time was to install two-to-one transformers and supply them from the old station bus-bar. This business which started in a small way long before a turbine station was considered, had grown to a considerable size at the time the turbine was installed, and the loss in the underground cables and other apparatus—which would have no commercial value in case this pressure was changed—prohibits making any change at the present time. The turbine pressure of 6,900 volts promises to be ample for the present needs of the company, but it can be easily foreseen should the lines be extended beyond their present limits or should the business at the end of some of the transmission lines materially increase, that this pressure might be too low. If this happens, it is planned to double the pressure on the transmission lines in question and transmit in these instances at 13,800 volts. All transformers installed on these lines are built with 13,800-volt taps.

The bus-bars in each system are installed in duplicate, and so arranged that they can be cut into short sections of no more than 10,000 K.W. each by tie-switches, and any transmission line or generator can be isolated if it is desired to do so. Transmission lines are grouped with the generators on a section of bus-bar so that this bus-bar does not have to carry much current any distance lengthwise. The generator is connected to the bus-bars through one main-switch and two selector-switches. These switches are designed to open under the full station capacity, should emergency ever demand it. The transmission lines have selector-switches but no main-switches at present, space being reserved for the installation of selector-switches should they prove desirable later.

The switches are all installed on the third floor of the switch-house. The selector-switches are in two rows. Each row consists of two switches (placed back to back) running through the center of the building and immediately over the bus-bars they connect to. The main-switches are installed in two single rows, one on each side of the



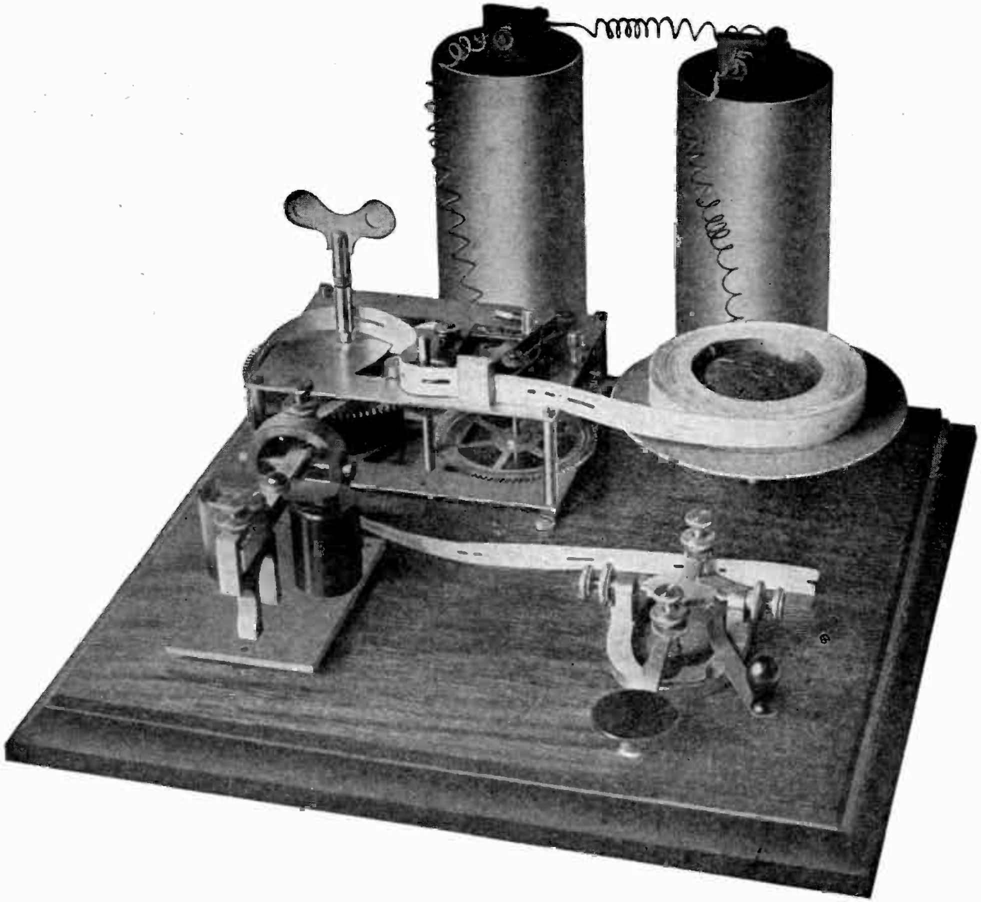
ALLIS-CHALMERS GAS ENGINE DIRECT-CONNECTED TO ALLIS-CHALMERS ALTERNATING-CURRENT GENERATOR switch-house and against the side walls. On the floor below, the bus-bar compartments are arranged similarly to the selector-switches, two rows of two through the center of the room. In two single rows on each side wall immediately under the main-switches are grouped the instrument transformers in special compartments.

The oil-switch cells, the bus-bar chambers, and the instrument transformer chambers are all built of a light-yellow brick with a fine cement joint, the brick being selected for its low absorption properties. The barriers in the bus-bar compartments and also in the instrument compartments are of reinforced concrete with a fine, close-grained finish. These are all made in moulds and set in place similarly to slabs of alberene; they have as good insulating qualities as alberene with less absorption, are much cheaper, and furthermore are less liable to break. The bus-bar chambers are fully enclosed, small doors being left in the wall for access to the connections only. The instrument transformer cells are left open. The front of each switch-cell is enclosed with a wooden frame filled with a pane of glass which permits an inspection of the pot, while at the upper part of the frame there are a few slats for ventilation, and for vents in case of an explosion.

The transmission lines and also the turbine-leads and transformer-leads enter the basement of the switch-house in duct-lines which terminate in this room and at a point nearly underneath the selector-switches they connect with the upper floor. The lead-sheathed cables terminate in end-bells as close to the end of the ducts as possible, from which points cable with flame-proof braiding is carried on glass insulators and through porcelain tubes to the switches overhead. From the end of the ducts, the cables are taken in air-runs and they are so grouped throughout the basement that there is ample air-space between all cables. Provision has been made for the installation of static-discharge apparatus in this basement, but at present none has been installed.

The electrical operating-room is on the top floor of the switch-house about in the center of the building and contains nothing but the operating apparatus. Convenient stairways leading down from this room through the switch-house bring the operator in close touch with all the switching apparatus. A signal system similar to that used on board ship enables him quickly to communicate his orders to any of the generating rooms, doing this with a certainty that the order will not be misunderstood. This system also provides for an acknowledgment indicating when the order has been carried out.

All the switching apparatus with the exception of the excitation system is remote-controlled. The controller panels with all the necessary instruments are grouped in the operating-room in the form of a rectangle, facing inward so that the operator can see at a glance any panel in the room. The excitation switching is hand-controlled. The bus-bar for this is brought into the operating-room and placed between the two groups of switches controlling the engine-driven alternators and the turbine-driven alternators. The panels for the ground-detectors are installed alongside the excitation, but so that the operator has grouped at one end of the room all the apparatus which requires constant attention. The transmission-line panels, transformer panels, and others are scattered along down the room in the order that is most convenient for their installation, without reference to the sequence of the switches themselves down stairs. The excitation is furnished by one small steam-driven set of sufficient capacity to start up an engine-driven alternator in case the entire station should be shut down, three small motor-driven alternators located in the old engine-room having a capacity sufficient for all the engine-driven alternators, and three large motor-driven exciter sets, one in each of the individual turbine-rooms with sufficient capacity to supply the turbines. In addition to the motor-generator sets there is a storage-battery with a capacity of 1,000 amperes for an hour, floating on the excitation bus-bar. Besides the generator fields, there are fed from the excitation bus-bar a few other pieces of apparatus which are particularly necessary to the operating of the station, such as the motors operating the oil-switches, the relay-pumps or the step-bearings, and a few lights around the station which would be essential in case the general lighting system should give out.



Automatic Telegraph Transmitter

By means of the clockwork and perforated tape, this instrument reproduces the messages as accurately as an expert operator. The student can thus learn to read as well as to send. This instrument is supplied with the Electric Telegraph Course to students of the American School of Correspondence. A nominal deposit is required, which is refunded upon return of the instrument in good condition.

THE ELECTRIC TELEGRAPH.

PART I.

APPARATUS AND THE MORSE CODE.

In order to get the beginner's point of view, it is taken for granted that the reader knows nothing of electricity or the practice of telegraphy. If there is a slight knowledge of either of these, so much the better; but as a starting-point, we will consider that altogether familiar use of the electric current in the ringing of a door-bell by pressing on a button. In so doing the new arrival "telegraphs" the fact to the household, and asks for admission, and those within respond to his message, although neither the one nor the other may know a dot from a dash. The simple combination of battery, wire and apparatus by which this action is carried on is as truly a telegraph circuit as is the longest in the land, and a glance at its elements will serve as a stepping stone to the more complex apparatus of the electric telegraph.

The different parts of the electric-bell device may be seen in their relation one to the other by reference to Fig. 1. In the center is the push-button P, pressing upon which brings the point of spring S into contact with the metal strip R. On one side is the cell A, with its two poles C and Z; on the other is the bell, with its electromagnet M, its armature hinged upon a spring K, carrying a hammer H, to strike the bell. Attached to the back of the armature is a spring, making contact at D with a back-stop T. These parts are so adjusted that when the armature is attracted by the magnet the contact at D is broken. Looking now at the diagram, if the wiring is traced from the point C back to the point Z, but one break will be found in the continuous contact of the wire with the different parts, and that is between the spring S and the strip R.

If, by means of the push-button, S is forced against R, the break is closed; the current speeds from the point C of the cell through the wire back to the point Z, charging the electromagnet M, which attracts armature-carrying hammer H. But by this movement the contact, and therefore the electric circuit, is broken at D, the current ceases, electromagnet M releases the hammer H; contact of the armature and back-stop at D is thus restored; magnet M is again charged, attracting the armature; the result being a vibration of the hammer, continued as long as spring S is kept in contact with R. The energy is derived from the cell, but the control of it lies in the push-button; and the effect of the making and breaking of the circuit at R is such as to appeal to the ear. By means not very different the same organ is addressed in teleg-

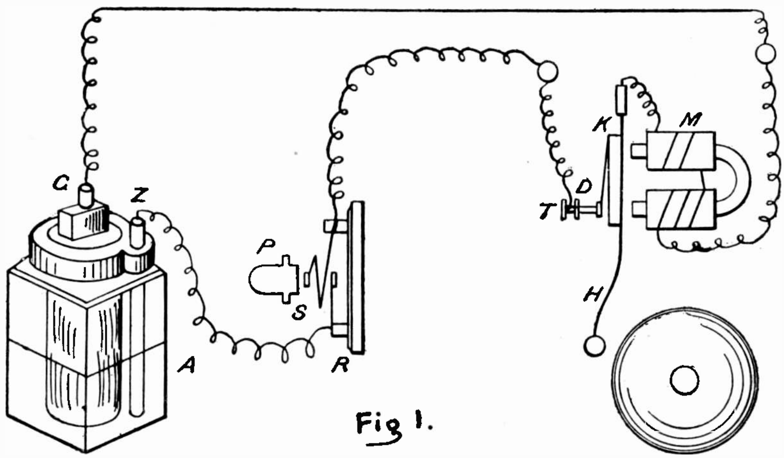


Fig 1.

raphy; but the appeal is of a kind legible only to the expert. The bell device serves the further purpose of bringing the learner face to face, at the outset, with the fact of the inconceivable speed of the energy he is employing,— a feature which allies it to light in the velocity of its movement.

Having now gained a general idea of the action of a current in moving an armature, we will suppose that the reader, if in a city, has stepped into one of the many branch offices of a great telegraph company, or it may be into a town or village office of the same, and for the first time is taking notice of the outfit. In such an office there will be seen (secured to the wall) a small switchboard, but the interest centers on the table or desk, where there are usually three forms of apparatus, known as the relay, key and sounder, with the wires connecting the various parts. On the window-sill, or under the table, is the battery of one or two cells, for the operation of the sounder, shown in the Instruction Paper "Elements of Electricity." The uninitiated, listening to its clicks for the first time, naïvely expresses surprise that they "can make nothing of them." This set of apparatus, installed in thousands of small offices all over the continent, and duplicated many times in the large offices, is shown in outline in Fig. 2. The relay, described in "Elements of Electricity," is not heard at all; the main battery which operates it may be scores of miles away; the current from it has its path in the main, or air, line

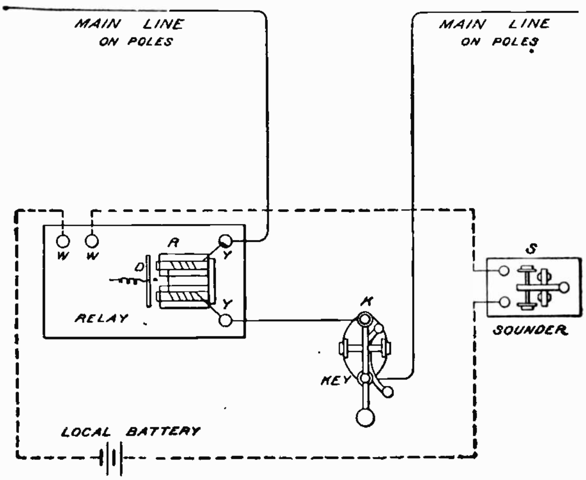


Fig. 2.

coming in from the pole in the street. Passing through the coils of the relays and the keys, it makes its exit through the office window, to resume its place on the poles which support it to the terminus of the line.

Examining Fig. 2 and comparing it with the bell-ringing device shown in Fig. 1, we find the cells of battery and the wiring common to both; the sounder corresponds to the bell proper; the key marked K answers to the push-button. The dotted lines in Fig. 2 represent the "local" circuit, and the cells are the "local" battery, so called because its action is confined to the place (Latin, *locus*) or station with which it is immediately connected. See the "Gravity Cell" in Elements of Electricity; the leads from the two poles being shown. If the *wherefore* of this pair of conductors and their connected parts is understood, the method of Morse telegraphy is within easy distance; and with the little light gained from the comparison of the electric bell with the telegraph circuits, we may take a step further in advance. For closer examination, therefore, this local circuit and its parts are reproduced on a larger scale in Fig. 3 and with more lettering. Each of the two cells of battery is surmounted by two projections called poles,— the terminal connections of two dissimilar substances, as copper and zinc, or zinc and carbon. The cell is explained in

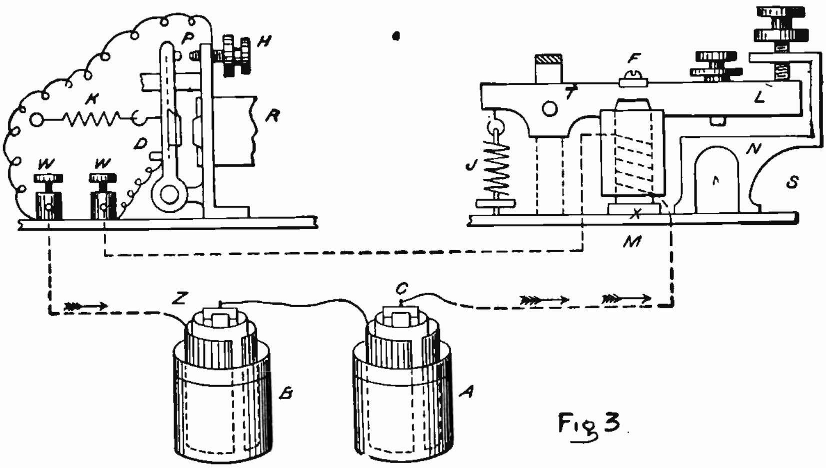


Fig 3.

"Elements of Electricity;" all that need be noted now is that by outwardly joining up the cells so that the unlike substances are in metallic contact, a current is the result. First the carbon terminal or pole of one cell is connected to the zinc pole of the other; then from the carbon pole C of cell A runs a wire (dotted line) which can be traced through the coil of magnet M; thence to the armature D, and local points at P of the relay R back to the zinc pole Z of cell B. Of relay R only the moving parts are shown. The thumbscrews, wherever found, have connected to them wires from the different parts of the instrument, and are merely conveniences for making contact with the outside wiring.

Besides the battery of two cells and the conducting wires (dotted lines), the circuit, as already intimated, includes an electromagnet, consisting of a pair of upright coils (only one is shown), which, with the surmounting armature F and its adjacent parts, constitutes the sounder S. Each of the two upright coils of wire has a core of soft iron with a strip of iron X, joining them underneath. Close to the upper ends of the cores, but not touching, is a strip of soft iron F, called the armature, secured to a lever L, moving on trunnions T, at one end, its free end moving between two stops, the spring J serving for its adjustment. The movement of armature D of relay R is also limited by stops, and, tracing our dotted line circuit, we find a point P, where the circuit may be "broken" by withdrawing armature D from the front-stop H; just as in the case of the push-button, the circuit is "made" by pressure on the button, and "broken" by the withdrawal of it. In other words, in this armature D, with its front and back stop, and spring K, we have a telegraph key in a form the simplest and most easily understood, but not the most easily operated.

In a local circuit arranged as in Fig. 3, when armature D of relay R rests against its front-stop H, the current magnetizes the cores of electromagnet M of the sounder; armature F is strongly attracted thereto, making a sharp click as it strikes the down-stop N; a reverse or upward movement is determined by spring J if armature D of the relay is withdrawn from the front-stop, giving a sound less sharp than in the downward movement. The difference in sound between the front and back-stroke of the lever is something of which the learner must early take note, because the front is the marking stroke, or the one from which he reads, the back-stroke being unintelligible. In the former case (armature D against the front-stop), the circuit is said to be "made" or "closed;" in the latter it is "broken" or "open." Closed and open are the terms in general use among telegraphers. In the case of the electric bell, the push-button puts us in control of the energy which attracts the hammer to the gong. In the local arrangement we have been considering, the control of the sounder S lies in the armature D, whether moved by the finger, or in the usual way by the current.

In this dotted-line arrangement the wires are the carriers or conductors of an energy which has its source in chemical action in the cells. In the poverty of language it is said to "flow" or "run" within the cell from the zinc to the copper plate, or from zinc to carbon; and in the external portion (dotted line) from copper or carbon to zinc. Moving thus along the conducting wire and through the connected instruments it is called a current (Latin, *curro*, to run) and in doing so it is said to make a "circuit," which may vary in length from a few feet to hundreds of miles. Its velocity is such that wherever a fitting pathway is afforded, it seems not so much to flow as to be omnipresent. In a series of tests made in New York by the United States Coast Survey, two separate wires were obtained to San Francisco, where they were joined, or, as telegraphers say, "looped." To each of the New York ends of the wire, instruments were connected, and signals sent on the one wire returned on the other in a space of time just perceptible. The current had traversed the continent and back in a small fraction of a second,— a kind of movement which the words "flow" and "run" hardly describe.

It is the purpose of this description, to explain to the reader how it is that the signals heard on the sounder can have a meaning to the operator; how it is that the down and up movement of the lever of the key K, Fig. 3, can transmit intelligence to a distant station; then, briefly at first, but later on more completely, to instruct him in the method of operation, use and adjustment of each instrument in the set, so that in a reasonable period of time he will himself be able to send and receive the signals which before were unintelligible. At this point a number of questions may suggest themselves to the thoughtful student. Some of them, it may be, cannot be answered; others may belong to the theory of the art; but our present aim is entirely practical, the point being to beget in the student the ability to translate writing and speech into the "Morse" language; the consideration even of the main-line circuit is therefore deferred.

Summing up the examination of the local circuit there are

(1) The cells of battery as the source of energy,

(2) The conducting wires,

(3) The sounder S, consisting of an upright electromagnet having for an armature a movable lever; and

(4) A point P in the circuit at which, by a movement of the armature D of relay R, we can control at will the armature of sounder S.

In speaking of the relay R, Fig. 3, and its armature, the remark was made that in it we have a telegraph key in form the simplest and most easily understood, but not the most easily operated. Remove the dotted line wires from the thumbscrews of relay R and insert them, as in Fig. 4, in the terminals of a key K′, described in "Elements of Electricity." We now have a "learner's outfit"—battery, key, sounder and connecting wires. Even with

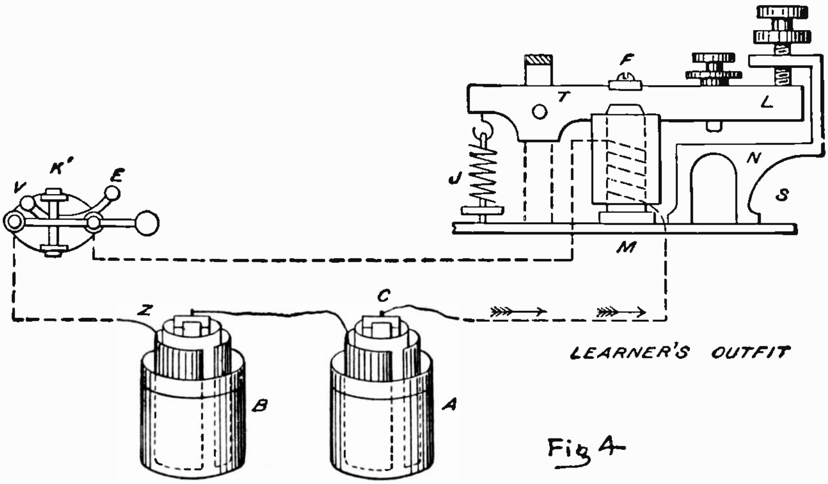


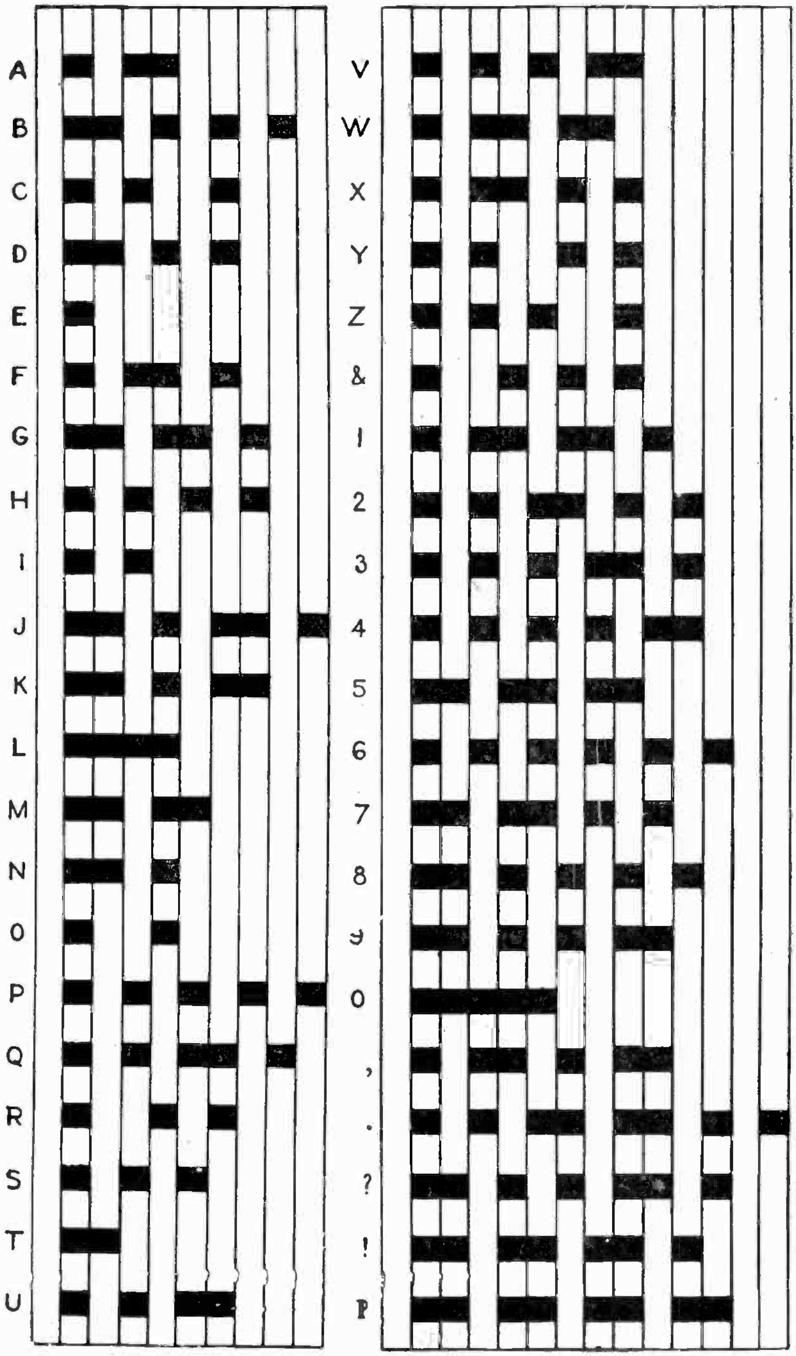
Fig 4

these, signalling to considerable distances can be carried on, and the medium for it is the Morse Telegraph Code, whose elements and their combinations to form letters are now to be taken up.

THE MORSE CODE.

It is taken for granted now that the student is provided with "a learner's outfit," comprising the apparatus shown in Fig. 4. The key K is provided with a curved arm E, hinged at V. By moving this to the right the key is opened. If, by tapping on the rubber knob of the lever, dots are made on the open key, it will be found that the armature of the sounder follows its movements. Having attained thus the control of an electromagnet, only a time element is needed in connection with the movements of the key to produce intelligible signals. In other words, if the open key is closed, by depressing the lever, now for a short, now for a longer time, or if the time between the moments of depression is varied, it is possible, by assigning the letters of the alphabet to different combinations of these movements, to make the instrument spell out the words of a language. To this end there was devised a system of dots, spaces and dashes, so arranged and combined that, singly or in groups, they are made to represent the different letters, figures and characters of the English language. If the learner (the key being open) hits the rubber knob a short, sharp blow with the finger, the sounder will give two clicks, one with the downward motion of the armature and one with the upward. The former has a sharp click, the latter a dull sound called the "back-stroke." The signal thus formed is called a dot, and its prolongation by a longer depression of the key is a dash; the down-stroke of the armature marks the beginning of a dot or dash, and the up or back stroke its end. In the movements for the production of the signals the time unit is the dot; by its duration all the dashes and spaces are measured. The single dot, produced as described, is the signal for the letter E, the letter in most frequent use having assigned to it an element the simplest and most easily formed. Prolong the dot to twice the time and we have the dash — the signal for the letter T; to four times the time, a longer dash, forming the letter L; to five times the time, and we have the signal for a cipher (0). To the hand the only difference between a dot and a dash is a longer depression of the key; to the ear the difference is in the interval between the down and up, or back-stroke of the armature. If the back-stroke were absent it would be impossible to distinguish E, T and L one from the other. It is not an uncommon thing for even the experienced operator to "get the back-stroke," in which case he dampens the up-stroke of the sounder with his finger until the ear catches the down-stroke again.

In the selection of the combinations which make up the code of signals, the principle, "the easy signal for the frequent letter," is observed throughout. The time value of the dot is constant, but the dash and space have each three different lengths. Two dots separated by a space of time approximately equal to a dot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represent the letter I, but two dots separated by a space equal in time to two dots represent O. The former is a mere interval, the latter is called the letter space; the word and sentence space are multiples of it — usually twice for the former and thrice for the latter. In naming the elements of the signal for the letter O, for example, they are read "dot, space and dot."

The entire scheme of the Morse Code, with its dots, spaces and dashes, their combinations and their relative time values computed according to the unit of time — the dot — and the letters, figures and characters they represent, is shown graphically in the accompanying chart, which the student must now, for a time at least, make his constant guide and reference.

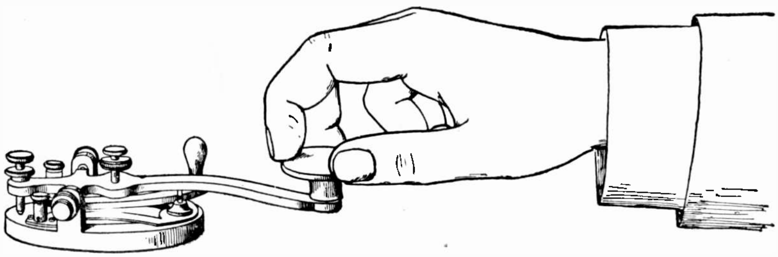


Fig. 5.

That we are able to present the alphabet in this preferred form is due to the courtesy of the D. Van Nostrand Company of New York, publishers of "Modern Practice of the Electric Telegraph" by F. L. Pope, to which manual, for details of nearly every topic in connection with telegraphy, the student is referred.

In this connection it may be of interest to state that the Morse Code, in the form in which it is now used, is the work of Alfred Vail of Morristown, N. J., and that in the selection of the signals for the different letters he was aided, so the story goes, by a chance visit to a printing-office, where he noticed that in the type cases the size of the different compartments was determined by the frequency of the use of the letter.

The attention of the learner having been called to the relative time values of the elements which go to make up the signals, he is now in a position to attempt for himself the making of them, and to take his first step as a sender. His instrument for this purpose is the key, with regard to which it has already been explained that it is merely a convenient device for the admission and non-admission of the current to the electromagnet of the sounder, according to a prearranged code. A suggestion as to the manner of holding the key can be gained from the cut (Fig. 5) given herewith. In it will be noticed the thumb pressing lightly upward against the rubber knob, the fore and second fingers curved, their tips slightly embedded in the knob, the wrist kept well above the line of the lever. This illustration, long familiar to telegraphers from its use in advertisements, and known among them as the "Catlin grip," is not intended for exact imitation. As in the case of handwriting, individual proclivities will assert themselves; but if the learner infers from it how to gain a firm command of the key, without cramping the fingers and forearm, he will have learned all that the text-book or a teacher can tell him.

At this stage some learners simply place the code chart before them and beginning at A, with its dot and dash, plod through the entire alphabet; then back and forth over the same ground, until they have obtained a certain mastery of the signals; and many good operators have learned in just this way. The writer has heard Mr. James D. Reid, "the father of telegraphers," relate that even on his way to assume his first position he re-enforced his limited practice by tapping out the alphabet with a pencil or a knife on the window of the railway coach or on the arm of a seat. But it seems more in keeping with up-to-date methods of instruction pursued in other branches to give to the exercises now to be entered upon a growing and developing character. With this end in view the different combinations of dot, space and dash are classified and arranged in six different modes—the signals for letters, figures, and common punctuation points only being considered at present. A mere glance at the chart will indicate to the eye the differences already noted in the lengths of the dashes; the letter L is represented by a dash twice as long as T; and the signal for a cipher is a dash two and a half times as long as T. It is as well for the beginner to observe these relative lengths; but in actual work the dashes undergo some shortening without danger of error.

1. Dot only, . E .. I ... S .... H ..... P
2. Dash only, — T—— L——— cipher — — M — — — 5
   — — — — paragraph
3. Dot preceding the dash, . — A .. — U ... — V .... — 4
   . — — W
4. Dot following the dash, — . N — .. D — ... B — — .. 7
   — .... 8 — — . G — — — . exclamation
5. A combination of (3) and (4) . — . F — . — . J — . — K
   .. — . Q . — .. X . — — . 1 .. — .. 2 ... — . 3
   — .. — 9 . — . — comma .. — — .. period
   — .. — . interrogation
6. Dot and space, .. . C . . O . .. R .. .. Y ... . Z . ... &

The method to be followed by the student looks to the repetition of the signals for these letters and characters, first in direct order as given, and then in reverse. In this way his work is graduated, and his ear will soon become accustomed to the difference as the elements increase or decrease. Especially is this true in regard to the first mode; and in connection with the second it is to be noticed that while the dot always has the same time value, the dash, as already stated, has three different values, as indicated by the length of the lines for T, L, and cipher in the chart. The T dash repeated gives us the letter M; used thrice, the Fig. 5, and four times, the signal for a paragraph.

The third mode includes those letters and characters in which a dash or dashes is preceded by a dot or dots. They represent the letters A, U, V, W, Fig. 4. And for mode four we have a reversal of the elements in the preceding one; dot follows dash, and signals are thus composed for letters N, D, B, G, Figs. 7 and 8, and the exclamation point.

In the fifth mode the order is miscellaneous; and the more complex and difficult signals thus obtained, have assigned to them the letters least often used. They are F, J, K, Q, X, figures 1, 2, 3, 9, the comma, the period and interrogation. Last come the so-called spaced letters — of all the signals, requiring in their formation and grouping the most care. They are C, O, R, Y, Z, &; and their persistent repetition, both singly and in combinations of short words, is enjoined upon the student.

The telegraphic equivalents of all the letters, figures and more common punctuation marks having been given, attention is next called to groups of letters having signals somewhat similar.

For the letters and characters in these groups the student can find for himself the signals in the code card. He can, by inspection, determine for himself the exact difference in each case, as, for instance, in the first of the following groups A differs from I by the change of a dot into a dash.

1. I, A, S, U, H, V.
2. A, F, X, comma, W, 1.
3. U, Q, 2, period, 3.
4. K, J, 9, ?, G, 7, !

The signals for these letters and characters having by repetition become familiar to the ear, the combination of letters into words, may next be taken up. In the course of the plodding thus far pursued, the learner may begin to think that the slow analysis by the brain and the mental noting of every signal must be an irksome task. But he will find as he advances that by degrees the analysis becomes mechanical; certain sounds come to mean letters, groups of sounds, words. The real alphabet of the expert telegrapher is largely one of words; to him the clicking of the sounder is a language, and its interpretation as easy as that of speech. It is theretore with the combination of letters into words that we have now to do. And in pursuance of the progressive plan the exercises revert at this point to the order in which the signals were classified; that is, words are made up first of dot letters, then of dash letters, and so on.

1. Of the dot letters can be formed the words is, she, ship, hips, his, pies, sip, pipe, sheep.

As it is not possible to furnish many words made up exclusively of the letters in each group, single letters from other groups are here and there borrowed to make up some exercise words; as for instance, in the old-time favorites with learners, pippin and Mississippi, in which N and M belong to another group.

Exercises in words containing dot letters:

Dishes, dispel, high, dipped, Spanish, spite, shipshape, diminish, dishevel, phase, dapple, hiss, hissing.

2. Dash letters: Met, tell, till, time, mill, pellmell, metal, limit, telltale, mamma, mammal, minimum, little, time, tittle, tattle, emit, timid, multiple, multitude, dimmed, mallet, skillet, skimmed.

3. Dot before dash letters: Awe, awful, awl, law, mauve, value, valve, wave, Eva, vault, view, lava, vamp, haul, pawl, squaw.

4. Dash before dot letters: Bend, bidden, gilded, laden, dined, begemmed, dunned, dabble, nab, ban, Denbigh, Big Indian, quagga.

5. Combination of (3) and (4): Julep, jungle, junk, Fiji king, fast bind, fast find, quit, equal, quaff, quake, exit, exist, ex-queen, exquisite, exhaust, skiff, piquant. Affix a k to kin and it is kink, bequeath, quaint, mujik, Ajax, Xanthine, jejune, jujube, keg, fix.

Thus far no words containing a spaced letter have been admitted. The hand and ear are thus first accustomed to the signals whose elements are separated by a uniform interval of time. By reference to the code card the learner will notice the difference in the spacing between s and c, i and o, s and r, h and y, h and z. The addition of the spaced letters makes the alphabet complete, and a number of excellent practice words omitted heretofore are now available.

6. Spaced letters: Or, err, to err is human, errant, corner, Corcyra, correct the error, eczema, corollary, co-operate, Corcoran & Co., coon, raccoon, circus, circle, cycle, bicycle, current, currant, cracker, firecracker, chronicle, coccyx, buzzard, zyrcon, correlate, physics, phantasmagoria, rhododendron, corrupt, cohesion, corduroy, road, dory, hippopotamus. There is no royal road to learning. The voice said Cry. What shall I cry? According to Sinbad the sailor, the roc's egg was enormous in size. Llewellyn, sassafras, crown, point, parallelogram, oyster, eyelet, icicle. ice-cream, puzzle, bamboozle, binocular, verdict, door, category, oracle, rollicking, moored, marooned, pirate, gyratory, circumstance, circumgyratory, paraphernalia, jiffy, effigy, equinox, quiz, Quixotic. Peter Piper's peacock picked a peck of pepper out of a pewter platter.

A few easy messages of ordinary commercial form are here introduced, attention being called to the fact that the destination occupies a line by itself. This is done so that the distributors in the larger offices can catch the "place to" at a glance.

116 B.	R N	M B	11 Paid.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Bar Harbor, Me., 12.

To Theo. Faulkner,

Jenkintown, Pa.,

Can give same room as last year—twenty-eight dollars. Answer.

(Sig.) J. S. LYMAN.

17 Ki.	M O	N D	7 Paid.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Kingston Depot, N. Y., 12.

To Mexican Gulf Agricultural Co.,

Dallas, Tex.

Arrive there Monday morning, 8.55.

(Sig.) ALLEN.

184	U D	B	20 D. H.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Mamaroneck, N. Y., 12.

To G. F. Harriman,

Pullman Co.,

Detroit, Mich.,

Empire Coupler Co. shipped car load of couplers to-day in D. L. & W. car 58,031.

(Sig.) H. M. WYATT.

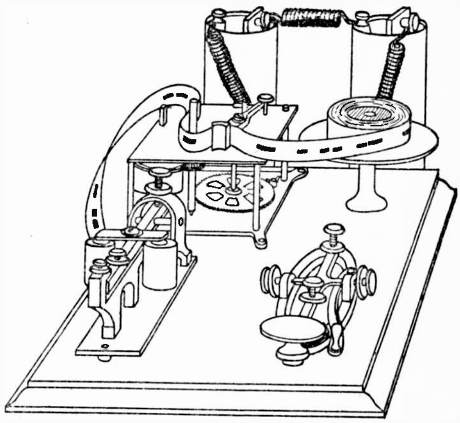
In the top line the first space contains the number, and generally the call of the sending station; the second and third spaces, the signals of the sending and receiving operators; the fourth, the check. In practice the signature is also on a line by itself.

By attention to the response of the sounder as he forms the letters on the key, the learner has now to some extent familiarized himself with the *sound* of the signals as he translates their form, as printed in the code card, into the key movements necessary to produce the dot, space, and dash. Reading the signals as they are embossed on paper by a "register," except for some special uses, has become obsolete in telegraphy, so that it is with the *sound* that the learner has entirely to deal; and the signals from which he must copy are those of a hand not his own on a distant key. In this, as in handwriting, there are individual differences; and the query whether operators can recognize one another over the wire by their "Morse" can be answered affirmatively. Since much depends on the initial practice in the formation of his style, the learner should, if possible, at the outset take a few lessons from an operator. That these remarks are practical and not perfunctory, the writer has personal knowledge at the present time of the contemplated removal of operators from some important circuits because of their defective sending. To aid in the formation of a correct style the signals have been presented in a graded form, beginning with the dot, which is the unit of time, passing on to the dash, then to the various combinations of dots and dashes, and lastly of dots and spaces; all with a view to their reproduction in words, phrases and sentences.

The Automatic Sounder Method. It was intimated that, for beginners, it was advisable to observe closely the relative length of the signals as indicated by the chart, especially the dashes, and that, on this account, it would be well for them to take a few lessons from an operator at the outset. In order, however, to do away with the necessity for this, there is brought to their notice a device of Mr. R. W. Elam of Valparaiso, Indiana, for the reproduction of signals the same in effect as if sent by hand, thus supplying in a great measure the guidance of an experienced teacher.

The apparatus is constructed by the National Automatic Transmitter Company and is furnished to students by the American School of Correspondence. In addition to the apparatus itself, the student is supplied with a set of records representing the letters and characters in the Morse code; the apparatus reproduces them in such a manner that, in the formative period, the learner may accustom his ear to the signals as made by an expert. These records are exact reproductions of the characters as made by hand; having been transmitted to the recording perforator by an expert operator through the use of an ordinary telegraph key. So natural are the messages thus reproduced that the individuality of the sender's "wire-writing" can be detected.

The Apparatus. In the form furnished to students it is mounted on a base, 11½ by 12 inches, made of quarter-sawed oak, finely finished; and comprises a learner's outfit consisting of a key, sounder and battery such as have been previously described; with clock-work and circuit-breaking mechanism through which moves a strip of perforated tape. To the axle of the clock-work, where it projects through the frame, is affixed a friction wheel which imparts its motion to the tape. Between the wheel and the tape holder is a curved pad against which the tape is pressed by an arm pivoted nearer to the end next the pad which we will call A; the other end we will call B. A slight deflection, therefore, of end A is quite marked at end B; the movement of the latter is limited by a stop similar to the armature of a relay. Like the relay also, at its end B the pivoted arm and the stop make connection with the poles of a local battery, so that when contact is made between the arm and the stop, the circuit through the sounder is closed; when the contact is broken the sounder is open.



AUTO-ALPHABET INSTRUMENT.

The slight movement of the arm needed to operate the sounder is effected by running the perforated tape between the end A of the arm, and the curved pad; when the end A is against the paper the sounder is open; it is closed whenever end A drops into an opening.

In the tape the student will readily see that the smallest openings represent the dots of the Morse code; the larger ones the dashes of different lengths.

Releasing the brake with which the mechanism is provided, the paper moves forward, imparting to the pivoted arm a series of movements which the sounder translates to the ear; the perforated tape acts as an automatic circuit breaker, producing the signals on the sounder precisely as the key does, and with greater accuracy as to relative units of time. In effect the signals are being sent by hand; to have them at his command is a great advantage to the beginner, some of whose tendencies to error are set forth in a later paragraph.

The course comprises a series of records capable of reproducing the work of an expert as effectively as if he were listening to the actual working of a wire. Another advantage lies in the fact that the speed with which the messages are sent can be varied over a wide range so that the student can use a slow speed when first taking up the work and, as he becomes more expert, can increase this to keep pace with his advance. The instrument can also be made to repeat any given message as many times as the student desires.

To insure good results the local points, where the arm touches the front stop, should be kept clean; and it may be necessary at times to pass a fine file lightly between them. The clockwork needs no attention beyond the winding up, and an occasional oiling.

The parts of the learner's outfit have been described elsewhere, and in such a manner as should make clear how closely it resembles the local circuit of the regular Morse Line. In placing the tape, see that the signals read in the direction away from the marking arm. The speed should be slow at first; the learner should note the perforations and mentally name the letters and characters as they pass toward the arm, so that when the sounder records them, the ear will associate the sounds with the signals.

A number of these strips are furnished the student; but the one with which he should first familiarize himself is that in which the exercises follow the course indicated below; the words are grouped according to the six modes just indicated; they are made up first of dot letters, then of dash letters, and so on. In pursuance of this plan the particular tape in question is perforated to render the following:

Is she ship his pies sip pipe sheep.

The learner may, if he chooses, stop the movement at this point, and, going back to the word "is," reproduce the series any desired number of times. Following upon the word "sheep" the sounder will reproduce the following words composed for the most part of dots:

Dishes dispel high dipped Spanish spite shipshape diminish pippin Mississippi dishevel phase dapple hiss hissing

Following upon this the sounder will render the exercise words in paragraph 2: Met tell till time mill pellmell metal limit telltale mamma mammal minimum little time tittle tattle emit timid multiple multitude dimmed mallet skillet skimmed; paragraph 3: Awe awful awl law mauve value valve wave Eva vault view lava vamp haul pawl squaw, and so on through paragraphs 4 and 5.

Paragraph 6: Or err to err is human errant corner Corcyra correct the error eczema corollary co-operate Corcoran & Co. coon racoon circus circle cycle bicycle current currant cracker firecracker chronicle coccyx buzzard zyrcon correlate physics phantasmagoria rhododendron corrupt cohesion corduroy road dory hippopotamus. There is no royal road to learning.

Some Faults of the Beginner. The learner may now, with key in hand held in the manner indicated, traverse once more the ground over which he has gone; but this time, he goes along with the notations of certain incorrect tendencies and faults which mark the beginner's work. He can take up those letters whose elements are simple dots, viz., e, i, s, h, p, and practice on the words already furnished, or upon combinations of his own. He will be interested at this point, to know that some experienced operators cannot make the five dots which form the letter P. and that many more cannot make the six dots of the figure 6. If the learner would avoid the "seven," "eight," and "ten-dot" habit, he should start in slowly, giving definite values to his dots, making the intervals uniform, until some approach to precision is reached. Avoid shortening or clipping the final dot, and make sure by actual count at first that the correct number for each character is made.

Following upon the dot mode are the four short dash characters for the letters T and M, the figure 5, the paragraph; and the elongated dash characters for L and cipher. Here, again, a tendency to shorten or lengthen the terminal dash and to space unduly the successive dashes should be guarded against. It is well to observe at first the relative time value of the dashes, but in practice the cipher and L dashes approach one another very closely without inconvenience. Occurring alone or among other letters the long dash is translated as L; among figures it is read as cipher. As between T and L, the usual inclination among learners is to make the T too long and the L too short.

In the next mode, in which the dot or dots occur first, the tendency is to separate too much the dot and dash elements. The interval between them should be appreciable to the ear, but no more. The places of these elements are reversed in the fourth mode to form the letters N, D, B, the figures 7 and 8, and the exclamation point. The first two should offer no difficulty, but B, 7 and 8 are troublesome, the tendency being to add in each case to the prescribed number of dots. There are operators who make the figure 8 for B, and a dash and five dots for 8; but no one careful of his work allows himself to fall into this habit.

Then there is that combination of the dot and dash elements which gives us the letters F, J, K, Q, A, figures 1, 2, 3, 9, the comma and the period. Of these, J and K are usually considered the most difficult, the tendency being to make a double N of the J, and the dashes of unequal length in both. The last mode brings us to the test of a good sender, in the deftness with which he makes the spaced letters unmistakable to the receiver; and he does this by such slight modifications of the space as the exigencies of the different combinations call for. The space in these characters is a prolonging of the necessary interval between the elements, and it should be just enough in excess of it to make the letters O, C, Z, for instance, distinguishable from I, S and H; and the spaces between the successive letters of a group of spaced letters should be slightly greater than the ordinary letter space. Some unfamiliar words, such as coerce, offer such a succession of spaced letters that it is usual for careful operators to repeat the word thus: coerce? coerce — the interrogation point implying "Did you get it correctly?" It should hardly be necessary to warn the learner against the stereotyped mistake of beginners — that of going over a great deal of ground and doing nothing thoroughly. The real progress lies in correct work as one goes along, and accuracy at first in the formation of the signals will lay the foundation for safe and rapid work. The student has already been apprised, by means of three examples, what the ordinary message form is; but something more than "a learner's outfit" is needed for the exchange of messages. The point has now been reached for the consideration of the main-line circuit, to which the electric bell and the local circuit have formed a kind of introduction.

THE MAIN-LINE CIRCUIT.

As compared with the local circuit, or learner's outfit, no new

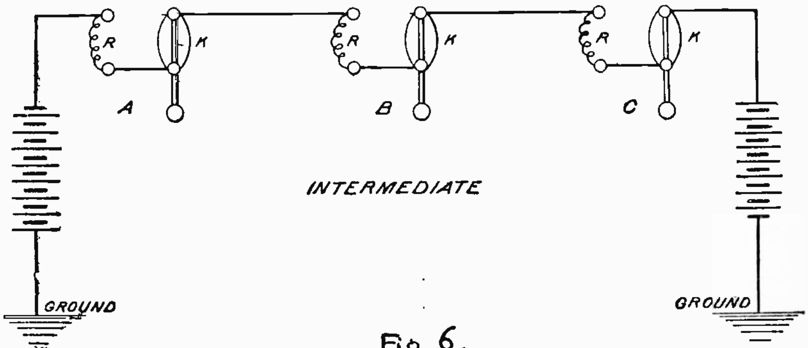


Fig 6.

principle is involved in its operation. The local circuit, with its few yards of connecting wire, has all the essential features of the longest Morse line working single; the differences are merely those of adaptation to new conditions.

First to be made clear is the difference between a metallic and a ground circuit, as exemplified in a local and a main-line; and the location of the latter battery with respect to the the main line. Reverting now to the battery in the local circuit (Figs. 3 and 4), it will be noticed that, where the sides of the cells adjoin, the two unlike poles are connected by a short piece of wire. This, with the longer piece passing through the instruments and connecting the other poles, forms what is called a metallic circuit, because the entire path of the current is of metal. If the short piece of wire between the cells be broken in two and both ends sunk in the damp earth, the circuit will be found intact

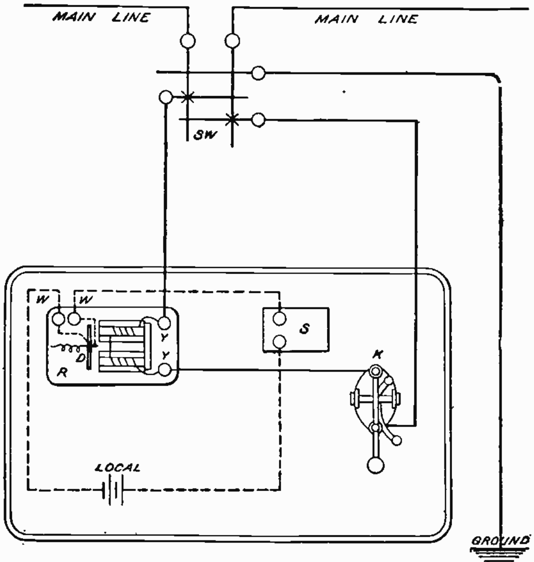


Fig 7.

as before, the current finding a path through the ground; and instead of a metallic we have what is called a "ground," or (in England) "earth" circuit. At this stage we must content ourselves with the fact that the earth acts as a return wire; the reason for it belongs to the theory of electricity. The main line is a ground circuit, not a metallic one; and the location of the main batteries relatively to the rest of the circuit is made plain in Fig. 6. In it are shown two terminal stations, each with main battery, relay R and key K; and between them is an intermediate station. The circuit here shown may be hundreds of miles in length. The cells at each terminal are usually about 150 in number; at terminal A in the drawing the copper pole is grounded, and the zinc goes to the main line; at terminal C these conditions are reversed.

Between the terminals there may be a score or more of intermediate stations, of which only one (B) is represented in the drawing; and as its position in regard to the main line is made clear, the details of an intermediate station, hitherto passed over, are now to be described. For this purpose attention is called to Fig. 7, in which is shown, more in detail than in Fig. 2, an intermediate or way-station, with its main lines appearing at the top, its switchboard, relay, key, sounder and local circuit (dotted line) all complete. As compared with the "learner's out-

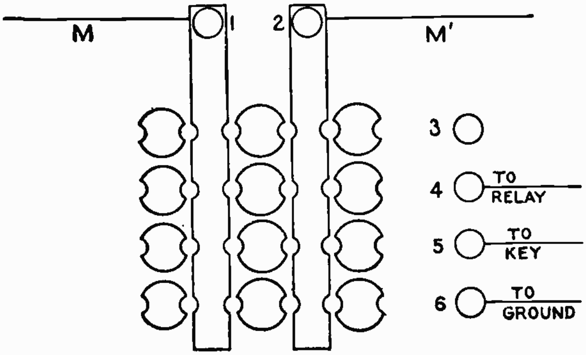


Fig. 8

fit" the additional parts are the relay and switchboard Sw. The wires marked "main line" are identical with those extending in either direction from station B in Fig. 6. In connection with relay R, Fig. 7, the dotted lines which are seen in Fig. 4 inserted in a key are replaced in the thumbscrews of the relay; and the armature and front stop of the relay are again a part of the local circuit. The coils of the relay cores, of which the thumbscrews Y Y are the terminals, form part of the main circuit, just as the coils of the sounder in Figs. 3 and 4 form part of the local circuit; but in the construction of the relay as compared with the sounder, some new features may be noted. The latter instrument is operated by a battery close at hand, for which only a few yards of wire are required; but the relay is only one of a number of similar instruments operated by a battery or batteries through hundreds of miles of wire — a problem in which the matter of economy is also a factor. The cells of battery at each main line terminal was given as 150; but even with this number a meter inserted in the main line of an ordinary telegraph circuit would show a very feeble current. If an ordinary sounder were "cut in" on such a line, there would be no response of the armature to the opening and closing of the circuit, for the reason that the winding of its coils is not suited to the conditions. But in the relay, in order to obtain a sufficient amount of magnetism, the coils are wound with many more turns of much smaller wire. To make room for the additional turns, the soft iron cores are made longer; because of their length they are placed parallel with the base instead of standing up, and the other parts are made to correspond. The winding of the relay coils has its terminals in thumbscrews Y Y, Fig. 7; and if from one of them the main line wire is detached and tapped firmly against the thumbscrew, not only will armature D of relay R respond to the action, but all the relays on the line, be they two or twenty, open and close in unison with the non-contact or contact of the detached wire with the thumbscrew. Then because the movement of the armature of the relay opens and closes the local circuit of each and every relay along the line, the sounder in each local circuit moves in unison with the home relay — a result brought about by merely tapping the thumbscrew of the home relay with the main line wire temporarily detached from it. But the detaching and tapping method has been resorted to only to emphasize for the learner the essential features of a telegraph circuit. In practice the tapping is done much more conveniently with the key, with whose use the learner is presumed to be already somewhat familiar. And as he either has one in his possession, or the use of one, he can examine its construction for himself, so that a description of it here is unnecessary. With the key in the main line circuit to do the work done by detaching the wire from the relay, it is plain that all the instruments in the circuit can be controlled by the movements of the key; when the operator opens the key by moving the curved arm from under the spur (see Fig. 4), all the relays instantly open; when he depresses the lever they all as instantly close. This result is possible because of the velocity of the current — the time consumed in traversing five hundred miles being inappreciable. It should now be plain to the learner how it is that the control of a key at any point in the circuit enables him to exchange signals with a distant station; and, in doing so, he "telegraphs" or, as the word means, writes at a distance; for telegraphy is distance writing, just as telephony is distance speaking.

Mention may be made here of a new form of key which in its construction and operation is a radical departure from the form hitherto in general use. The handling of the ordinary key for any length of time is a serious tax on the muscles of the forearm, resulting in some instances in an ailment known as "telegrapher's cramp." The new form of key was devised with a view to relieve the strain on the forearm by a form of lever which is not only initially different from the ordinary one, but admits of being instantly shifted into various positions, as the sender feels the need.

THE SWITCHBOARD.

One part of the apparatus of a way-station remains to be described; it is called the "switchboard," and is usually secured to the wall over the operating desk. It enables the operator to change the arrangement of the wires leading from the desk with respect to the main line, and to the ground. It is simply a board of well-seasoned wood, fitted in front with metal strips running vertically and terminating in thumbscrews; horizontally across the board are rows of small circles of metal, called discs, whose stems pass through the board, at whose back each row is connected together with a wire terminating in thumbscrews in front and at one side of the board. The strips and discs are so constructed with reference to each other, that connection can be made between them by a metal peg having a short handle of rubber. The switchboard is seen in position in Fig. 7, but is reproduced on a larger scale in Fig. 8. The different rows of discs (each row having a connecting wire at the back) have their terminals in the thumbscrews 3, 4, 5, 6, of which 4 and 5 make direct connection with the relay and key, and 6 makes connection with the ground. Suppose the way-station to be between New York and Albany;

let M represent the main line from New York, making connection with the thumbscrew 1; and M′ the wire to Albany connecting with 2. Look briefly at a few changes in the connections that can be made by means of two metal pegs. Suppose each of the discs in a given row to be numbered as shown on the right of that row. Connect with pegs 1, 3 and 3, 2. In this case the current would simply pass from bar to bar across the middle disc 3 without affecting the instruments at all; and in this position of the pegs they are said to be "cut out." Move the peg in 1, 3 to 1, 4 and the main line circuit is open because there is connection only between discs of the same row. Move the peg in 3, 2 to 5, 2 and the current has to pass through key and relay in going from one upright bar to the other, and the apparatus is said to be "cut in." The drawing represents the switchboard in its simplest form, and the operations indicated are the most ordinary; but if the learner will bear in mind that the discs are connected with each other only in straight lines across the board, he can trace out for himself other peg connections of discs and bars and the changes they bring about in the circuit. For instance, discs 6 all connect with the ground. Remove the peg from 1, 4 to 1, 6 and from 5, 2 to 6, 2; the wire from both directions is now grounded, with the result that there are now two independent circuits—one in each direction from the way-station whose operator could now work with either New York or Albany, but the stations named would be cut off one from the other. Restore the pegs to their original position in 1, 3 and 3, 2, and the terminal stations can work with each other, but the way-station is once more "cut out." This is the position in which the pegs should be placed when the operator leaves the office, or during a thunderstorm. But for the latter incident there is generally arranged a "cut out" outside the office. Many intermediate stations have more than one wire and switchboard to correspond, and it would be possible to fill pages with the combinations that might be effected; but sufficient explanation has been given to indicate the method which, when once understood, can easily be extended and applied to suit larger needs.

In the care and adjustment of his instruments, the operator should see that the local points of his relay and the points of his key are clean; he should be on his guard to see that the armature of his relay or sounder does not hit upon the soft iron of the cores. A good way to assure himself of this is to pass a piece of paper at times between the armature and the core. Instructions in the care of the local battery are now in order; but they differ with the kind of battery used, and are usually furnished in the book of rules of each company.

The purpose up to this point has been to give the reader an idea of the apparatus employed in telegraphy. It has been emphasized thus far that the essential features of the local circuit, viz., battery, electro-magnets, and connecting wires, are all reproduced in the main circuit, the differences being only those of adaptation to new conditions.

With this statement a reversion is now made to the practical —to the matter of the exchange of messages, of which some examples of the ordinary form have already been given. The greater part of the business handled by the commercial companies is of the kind exhibited; but the work of the operator would be easy if it consisted in exchanging only such messages as the samples. In addition to the ordinary form, there are those known among telegraphers by the following terms: Wire, service, forwarded message, repeated back, government, grain, transfer, cipher, number group, circular, C. N. D. (Commercial News Department), marine, and railway D. H. Then there is the press service, making use, in some cases, of fixed forms for a baseball score, golf score, and the like. Of ordinary press matter the volume on certain occasions, such as a presidential convention, is great. At the present time much of the press matter is handled on wires leased from the telegraph companies by the press associations, and their carrying capacity is increased by the use of a code which enables an operator to transmit as fast as an expert typewriter, at his highest speed, can copy. Of code telegraphy, some details will be given later on. In addition to all these the art has been specialized by railway companies in the movement of their trains and traffic, also by brokers and large commercial houses, to such an extent that even an expert operator must serve an apprenticeship in order to fit himself for the rapid work in these specialized forms.

Of the different kinds of messages just enumerated, the first two designations are self-explanatory, the former having to do with the assignment, arrangement, and cross-connection of wires; the latter with the forwarding, re-addressing, and delivery of telegrams. Service messages have to do with the movement of the despatch from the customer to the hands of the party addressed, and, if errors have been made, with their correction.

The following are examples of this form of message:

Marietta Pa ofs.

Give full address Oswald Denberg. We fail to locate your msg date signed National El. Co. S. Y. S. (sig) Munn, New York.

The use of abbreviations will be noted; and for some constantly recurring phrases, such as "see your service," only the initials are used. "Give better address" is similarly represented by G. B. A.

Munn, N. Y.

Pls D. W. C. from original yours today Carnegie Steel Co. signed Union National Bank, A. L. Dignam Cashier. Same reaches us dated Waterbury Conn.; Carnegie say think should be dated Watertown N. Y. Advise my care.

(sig) Phila., Pa.

In this case a "duplicate with care" is requested.

An extra-date message is one that has been received by mail at, say, Albany office; or, having come over another line, has been handed in to be sent forward, and takes this form:

116A Bn Mo 15 Paid

Berlin, N. Y. Oct. 26, via Albany Oct. 26

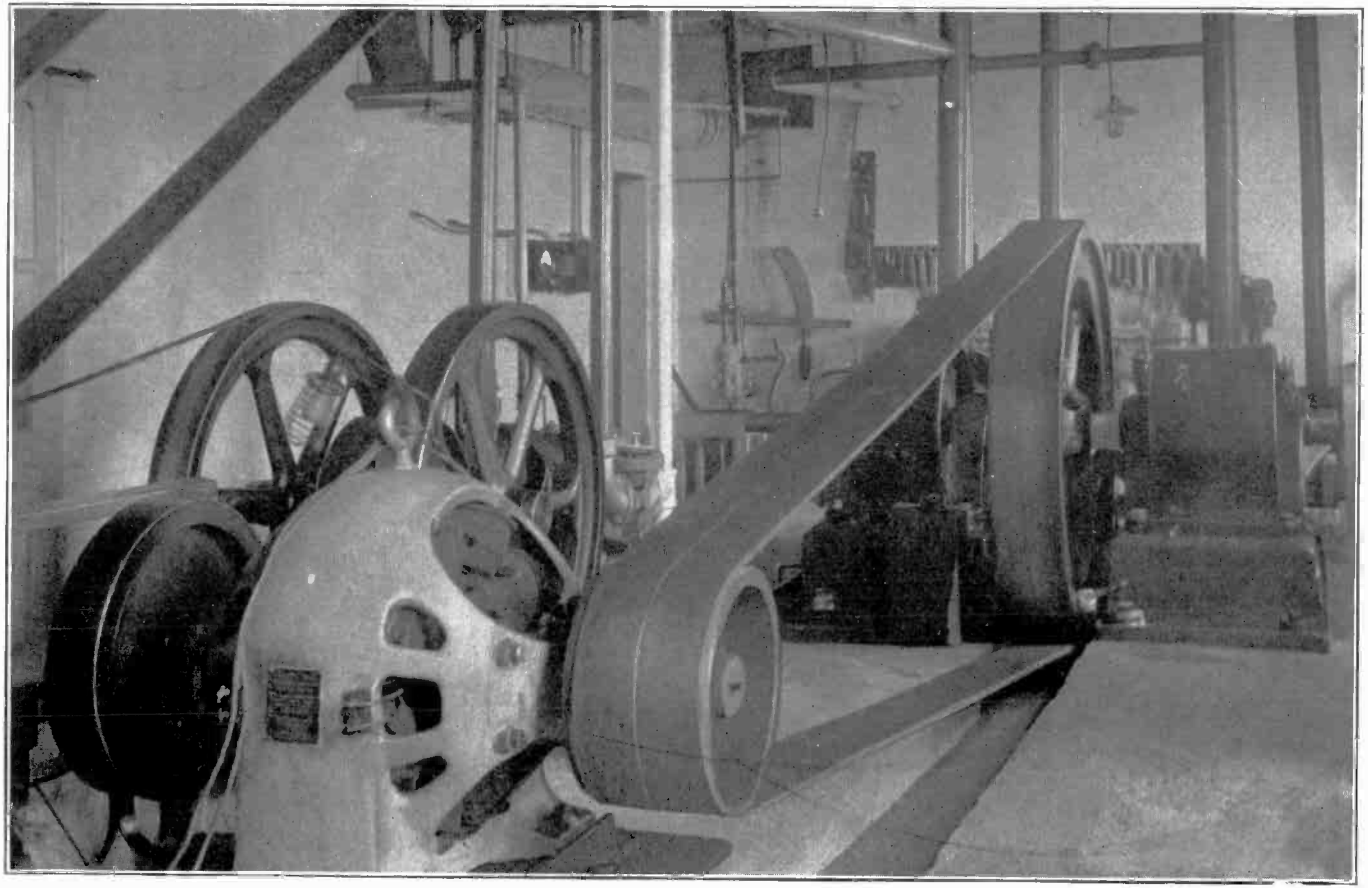
Adam Brown,

Bridgeport, Conn.

Have been unexpectedly detained. Meet me next Monday at ten. H. Brosnan.

In this case the five words "Berlin N. Y. Oct. 26" are added in and charged for as part of the message. It is customary when the party to whom a message is addressed has left town, to forward it to a given address, in which case the forwarding station, with the word *via*, appears in the date, and the originating station and date are charged for, the same as in the example just given.

Occasionally the sender of a message, to insure its correct-



ENGINE ROOM OF MARCONI WIRELESS TELEGRAPH STATION AT SOUTH WELLFLEET, MASSACHUSETTS

ness, requests a repetition, in which case the words "repeat back" are inserted in the check and included in the count. For such repetition a charge of a rate and a half is made. A "night message" does not differ in form from the examples of paid messages already given, except that it is always copied on a blank printed in red ink, and in the check is inserted the word "night," which is not counted. In all collect messages, whether day or night, the word "collect" is counted as if part of the body of the message.

Government messages are exchanged between the officials of the United States government and its employees, and differ from the ordinary form in that the address and signature are counted as part of the body of the message, thus:

197W Kn Mg 28 Paid Gov't

Washington, D. C. June 24

Col. H. K. Ames

Memphis, Tenn.

Forward to New Orleans all the tents and rations you can spare in aid of the flooded district.

(sig) E. M. Harrison,

Commissary General.

The text or body of this message contains only seventeen words; but the count of every word in the address and signature makes the check twenty-eight.

A prominent feature of commercial telegraphy at the present day is the facilities provided for the quick interchange of messages between Produce, Stock, and Cotton Exchanges in cities remote from each other, the circuit arrangements being such that the members of these bodies can carry on their trading with a celerity and correctness that leave little to be improved upon. Many of these traders have their own private wires; but the greater part of this class of business is carried on by the New York Produce Exchange with the different grain centres, such as Buffalo, Toledo, Detroit, Chicago, Duluth. In the forms of messages hitherto given each message is preceded by its number, the signals of the sending and receiving operators, and the check. In the exchange of grain orders all this, with the exception of the number, is dispensed with. To show the difference in usage between the ordinary and the exchange form, a message is given in both:

B123 Da Mo 7 Paid

Ex Chicago, May 18

J. C. Ladenberg,

New York.

Sell five July corn at sixty half.

(sig) M. J. ALLEN.

In practice this would be transmitted in abbreviated form, thus:

B186 7 Pd.

Ex. J. C. L. Sell etc. (sig) M. J. A.

Such work, of course, calls for experience on the part of the operator and great familiarity with the names of his patrons; these being granted, the volume of business that can be handled during exchange hours is large.

There has been evolved in connection with the telegraph service a great convenience to the business community in the order by wire to pay to one party money deposited by another — a transaction possible between cities on opposite sides of the continent. The instrument of this exchange is a message called a "transfer," of which the following is the common form:

B171 Dq Rn 17 Free

Hartford, Conn. June 19

J. D. Mallory,

Henderson, Texas.

Pay to N. D. Hilliard, Hotel Baldwin, gilt bald edgeways from E. L. Adams, Jr., Hartford. Vigilant

(sig) H. N. Tallman,

Transfer Agent.

It is a curious fact in connection with the "transfer" that in place of the very commonly used D. H. for "deadhead" in the check, the word "free" has always been retained. It is said that the use of this rather grim phrase with the meaning "no charge" dates as far back as the Roman times, when free admission to the circus and the theatres was gained by the presentation of a carved death's head furnished by the authorities.

THE CIPHER MESSAGE.

In the above message it will be noticed that the amount to be paid is indicated by words without meaning to the outsider; and it concludes with "Vigilant," which is understood to mean "identification is required." The "transfer" is, therefore, in part a cipher — a form of message much in favor among patrons of the telegraph. It involves the representation of a word or phrase by a word arbitrarily chosen, and therefore understood only by those concerned; and this is very nearly the dictionary definition of the word "cipher" used in the sense of a secret writing. Its use in telegraphy serves the double purpose of economy and secrecy; and incidentally some forms of it greatly tax the patience of the operator. As the meaning of the cipher is the concern only of the correspondents, there may be as many systems as there are patrons; but among business men the phrases in common use became so numerous that cipher-making itself became a business. At the present time quite a number of systems are in use; so that, to carry on a secret telegraphy, the patron needs only to buy two copies of any preferred code — one for himself, and one for his correspondent. As the words representing the different phrases are generally chosen arbitrarily, any number of English words chosen at random might be taken to form the text of a "cipher" message. But portions of two or three with fictitious addresses, are here given to bring the learner into touch with the reality.

B67 Ha Ks 10 Paid

New York, June 19

L. M. Hazeltine,

Boulder, Col.

Metemperic entire peasoup velvetleaf bondmaid eighteen birthsongs thalarctos each periwig.

(sig) Alpha.

B68 Pq An 11 Collect

North Adams, Mass. June 21

C. K. Thurber & Co.

New York.

Admixed unaided unbias aleak unapplied fetch andiron marauding maroon hairpin.

(sig) E. M. Seymour.

In this last, as in all messages similarly checked, the word "collect" is counted. Of the more difficult forms of cipher that in use by the large business houses of the West furnishes two examples:

C18 Mo Ns 20 Paid
Kansas City, Mo. June 21
L. M. Wetstein,
New York.
Molucris morbescunt desque cow dexterous demulsion facial gildos holzstoss hoodwink hymnifero hamaux marandara vetader no vetachtig motandos fatichera komplot salami.
(sig) Roburn.

D21 Aj So 15 Collect
Indianapolis, Ind. June 24
R. A. Clarkson,
Middletown, N. Y.
Asander unbespeak umsetzbar unbeing boneless maragnon monarch cervelat disallowed each car alamoth arrodeth absorb.
(sig) Schievelin.

Quite commonly these messages contain several hundred words, and no knowledge of English or of any other language is of much aid to the receiving operator; he must watch for each letter, and pen or typewrite the signals as they arrive. It should be apparent at a glance what an indispensable aid to this work the typewriter is. By means of it these unintelligible words are copied in a manner that makes them unmistakable to the reader, and the receiver has no need to resort to the old expedient of "writing in" the Morse characters under the letters imperfectly formed by the pen.

The Cable Message. The high tolls charged for cable service makes the use of cipher in their composition very common. The address and signature of each message is counted, and the former is often transmitted as a cipher word, which is duly registered for reference when needed; for instance, Havicam, London, might stand for Haviland, Campbell & Co., at any address in that city they chose to give. A single example only of a cable message need be given, as the one form is quite generally followed.

52 Yv Kn Duluth 10
Richfig,
Rotterdam.
Ascanilota apilatori makobojoss Koln luhoto
schizandra pythao (sig) Blockland.

Several of the words, it will be noticed, contain just ten letters. This is the permissable limit for one word; if exceeded, the word is counted as two, except in case of the destination, as Constantinople. The correct handling of cables involves many matters of detail in regard to the "count" which requires some little practice to master properly.

A unique form of cipher deserving of mention here, makes a message to consist entirely of groups of figures, usually five in a group and in this form: 17641, 75689, 84356, 09543, and so on through hundreds of groups. For the nought beginning the last group the signals for TW — dash, dot, dash, dash — are sometimes used. This form of cipher seems to be much used in correspond ence between the different governments and their representatives and agents.

The circular message, as its name indicates, has a number of addresses with a common text, or body. For this form the senders generally avail themselves of the night-rate service. Except for the plurality of the addresses, each one of which in sending is separately numbered, it does not usually differ in form from the ordinary message.

The "C N. D." The Commercial News Department message is as unique in appearance as it is different in form from the others. The department is an agency for systemized and detailed advice in matters of commercial interest as they transpire in the different exchanges, and in sporting matters to individual patrons and customers. For transmission by the operator the message is usually written either on a pink blank or on a sheet of yellow manifold. One such, picked up at random, reads: "Add Charleston. Quiet $8\frac{3}{4}$ Sales 50 . . . 2.31" This is a quotation of cotton, and the time when written takes the place of the signature. Another reads:

"Detroit close 2.25

"Dw 84b Red & m 81 N 76 U $75\frac{1}{2}$ . . . 1.15"

To the initiated this means: Cash wheat 84 bid; Red and mixed 81 July 76 September $75\frac{1}{2}$. 1.15 is the Detroit time; 2.25 is the time received in New York. Another, addressed to a summer hotel on Long Island, reads:

"Stocks A81$\frac{5}{8}$; St 175; MP109$\frac{5}{8}$; USS37$\frac{7}{8}$; U 105 . . . 10.16 A.M.," in which A stands for Atchison, Topeka and Santa Fé; St for St. Paul, and so on through the list.

These brief examples give the merest hint of the traffic of this elaborate system; and so diversified are its forms it takes weeks and in some cases months of training to make even a skilled operator master of the service.

The Marine Message. The natural interest of the friends of those at sea in the sighting of their ships, and their desire to know the probable time of their arrival at the dock in New York, led to the organization of the Marine Department, which, on payment of a certain sum, furnishes the information in the following form:

Marine Department, New York, June 2.

George Homer, 351 West 14th St., New York.

Steamer "Columbia" will arrive, unless detained at quarantine, about 6.30 P.M. (Sig.) Manager Marine Department.

This service is almost as old as the telegraph itself, and it remains to be seen how far the wireless system will modify it. It is certainly in this direction that the latter system should first make itself felt.

Of the railway D. H. a short example has already been given as one of the three specimens of the ordinary message. Its marks are the use of initials and groups of figures in which each digit is counted as a word. They are frequently of great length, and require some care in copying in order not to lose the count.

Abbreviated Telegraphy. A notable development of the art in connection with the fast-speed press work involves the use of abbreviations according to a system, and is known among the craft as Code Telegraphy. It was always more or less the custom among press operators to abbreviate familiar and frequently recurring words and phrases when sending to experienced mates; but the introduction of the typewriter gave such impetus to the art that a codified Morse, at the present time, is not far behind the speed of ordinary speech. Beginning with the Morse alphabet, figures and ordinary punctuation marks, the code system first provides an extended system of punctuation covering all the characters and marks that commonly occur in print, as follows: (See page 34.)

For an apostrophe the signal is the same as that given in this

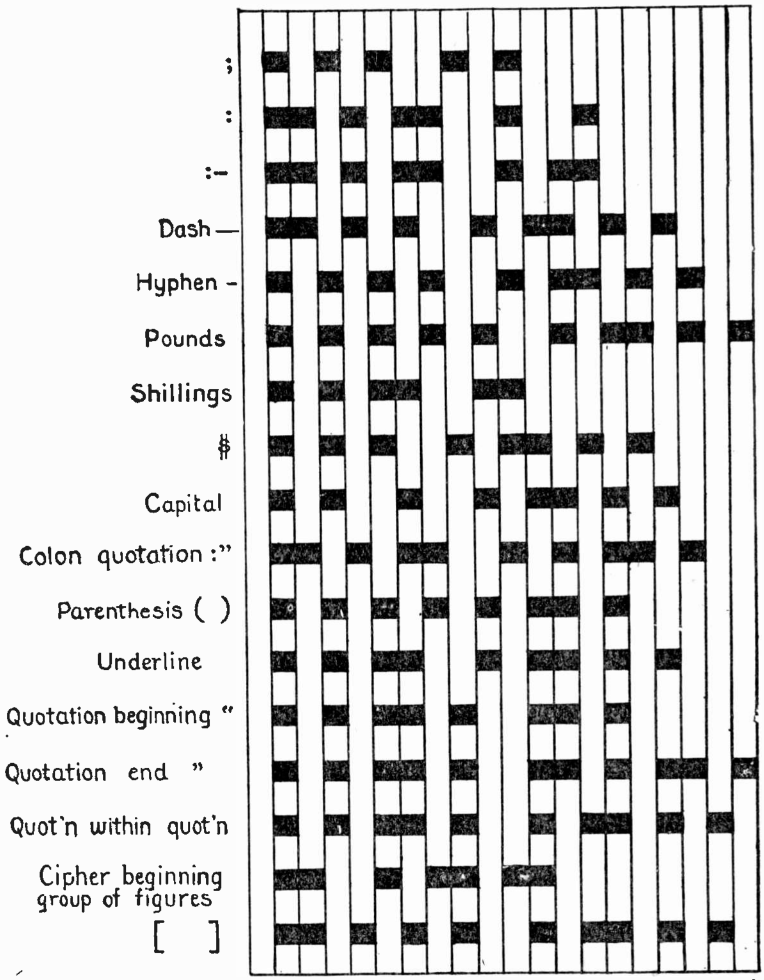


chart for quotation within a quotation; a parenthesis begins with Pn, and ends with Pq; a fraction, as $\frac{3}{4}$, is transmitted 3e4; a decimal, as 89.92, 89dot92; omitted words are indicated by a series of x's; and in sending one or more lines of verse a paragraph mark (– – – –) closes each line.

The system in general use among operators is the Phillips Code, from its inventor, Mr. Walter P. Phillips, general manager of the United Press; and in its arrangement it advances of course from the simple to the complex. Single letters are first made to represent common words and phrases: B, be; C, see; F, of the, K, out of the; Q, on the; and so on through a list that need not be reproduced here, because the entire code can be purchased in book form and contains, besides the code itself, hints for the memorizing and proper use of it. The single letter list is followed by the two-letter and three-letter contractions; and the learner will think it is a far cry from the jog trot of the ordinary text to such expedients as "fap" for "filed a petition," "sak" for "shot and killed," and "sbl" for "struck by lightning." The typewriter alone makes the use of such abbreviations possible. In order that beginners may catch the spirit of the system, the following exercise is written in the code text and then given in full:

"Bt Lafa Plc is smhw Lafa Plc stil. Its trnsfmatn into chp lodgmts is gradl tho su. T sieg gos stedly on, bt t bsiegd hv n yet sucmbd. Ey y t hansm cariags tt rol up & dwn its aves gro fuer and fuer si ey y its pavmts worn bi t fet o ded & gon Nikrbokrs r m fqd bi shaby Germns or slatrnly Italns."

"But Lafayette Place is somehow Lafayette Place still. Its transformation into cheap lodgments is gradual though sure. The siege goes steadily on, but the besieged have not yet succumbed. Every year the handsome carriages that roll up and down its avenues grow fewer and fewer; every year its pavements, worn by the feet of dead and gone Knickerbockers, are more frequented by shabby Germans or slatternly Italians."

Messages for Practice. To extend the student's practice, and further to familiarize him with the appearance and wording of the different forms of messages, the following specimens have been selected. They are arranged promiscuously, so as to afford exercise in naming the different kinds; attention should also be given to the different ways of counting in cable, government, collect messages, etc.

A116P IIk Wn 18 Free.
Portland Me. 27
J. E. Bierhardt, Transfer Agent,
Rome, N. Y.

Pay W. L. Dumont, Arion Club, Central Hotel, Rome N. Y. Japan Alms, Indent from Abner Gaylord, Portland. Caution.
(sig) Wm. Ellerby, T. A.

57 Av Uc 20 Collect
Tb Hartford Conn 4
Adam Mason & Co.,
Ottumwa, Iowa.
Manifoldly mensural parks nacrite distrust nacori crying nai-- medium mensural nalubu monitory treble namesake monk rudeness Naaman tourmaline, Hawaii
(sig) H. M. Allen & Co.

158N X Rs 17 Paid
Norfolk Va. 4
Chandler Elevating Co.
Great Bend Ind.
Skeptic W. H. McAlpin border route Norfolk western on tantrum tread affording chuckling offers chubby affray more
(sig) L. W. Jay & Co.

14 Wd Fr 12DH.
Marine Dep't, N. Y. 29
M. B. Goldfogle,
International Hotel, N. Y. City.
Steamer Campania will arrive, unless detained at Quarantine, about 8 A. M. tomorrow.
(sig) Manager, Marine Dep't.

273 W 125th St. N. Y.
D. F. S. Delivered ok your 23 today to S. S. Cooper sined Atkinson. (sig) Phila.

In this case "DFS" means destroy former service.

Danville N. J.
Yes have collected 25 cts for msg to Dickerson sined Hall
(sig) Garfield N. J.

191 Kf Gs . 16 Paid 8 Extra
Str. Campania off Sagaponack L. I. Nov. 29
via New York 29

Morris, 21 Flushing Ave.
Jamaica L. I.
All well. Dock early Sunday. Don't come down
(sig) M. N. Heldman

The above resembles one received by the "Wireless" and transferred by them to land lines at New York.

133 Ro Py 22 Paid Gov't
Washington D. C. 29
Morning Register,
Dallas, Texas.
Showers Sunday warmer except on the coast; Monday fair in northwest; showers in east and south portions.
(sig) Wells.

119 Fs Ki 11 Paid
Winnipeg Man 29
Lindsay & McDonald
Valley Stream, L. I.
Offer saltcat to saltpeter scalene throe garrulity en route or gallate. (sig) Robb & Parrish.

174 Wr Ta 6 Collect.
South Bend Ind 4
Champion Beef Co.
Pine Island N. Y.
Enkindle gratefully erupt none trundle.
(sig) Baker Packing Co.

114 Gu Ps 8 Paid Night
New Orleans 29
Mrs. S. Dorner, 118 West 119 St
New York.
Will be home Monday afternoon. Tell Ella. Love.
(sig) Joe.

128 F Kn Cable
Havana 6
Hammond,
Calumet (Mich)
Candelabra domiseda 780 calefying.

In the above, the State in parenthesis is supplied by the land line clerk, and is not counted; the group of figures is one word.

193 Yv Wr 12 Paid Repeat back
Philadelphia 31
R. B. Dignam
New Orleans.
Elmpole arundelian bags parable admit actuality rampallian Halpen aliped bags. (sig) C. Emslie & Co.

In this case the words "repeat back" are counted and charged.

... ... 7 Paid Charge

Newark N. J. 29

Adams Ilich & Co. Memphis Tenn.
A. N. Harriman Louisville Ky.
F. J. Farjeon Mobile Ala.
Walter N. Davis St Louis Mo.

No reds; best Jerseys eight twenty five.

(sig) C. W. Allison.

In transmitting messages like the above each operator numbers and times the address of the one which goes on his particular wire; then passes it on to another and so on until all, sometimes scores in number, have been sent.

To Albany N. Y. Dec. 15

B33 487½
34 484 (sig) 10.18

To Salida Colo.

N. Y. Metal Ex. Pig lead 412½
London Silver 22⅜ (sig) 9.10

To New Orleans and Mobile.

C. Adam
31 – 99 – 30 (Sig) 11.43

174 Ro Fc 44 DH

Bridgeport Conn 29

Agent L. S. RR. Co.

Cleveland Ohio.

From Paterson to Cleveland June 1st in D L car 27052 one case brass tubes number 2596 consigned Schneider & Fenkamp covered by Lackawanna line waybill 2774 advise date arrival and delivery quick. (sig) R. J. Camp

By way of introduction to the next topic—Railway Telegraphy—the above series of specimen messages concludes with one more example of a railway DH.

37 Av Ty 36 DH

Springfield Mass 20

E. H. Palmer,

Buffalo, N. Y.

File W, Adams to East Buffalo Wb 111 Dec 8 Christmas trees for D. H. Croley Dunkirk N. Y. deld N. Y. C Dec. 9 on B & A 2718. Please advise delivery. Rush.

(sig) H. C. McCarthy.

Railway Telegraphy. It is well known that the first telegraph line built in the United States was intended for commercial work; but the new art had not long to wait before it was enlisted in the service of the railway. Along their right of way the latter erected poles for the accommodation of their wires to which the commercial companies soon made additions; and, except in the larger towns and cities, one man usually did the work of both. As railways extended and towns multiplied, the work of the latter differentiated from that of the former so that today there are two well defined divisions in the craft; interchange going on between them, however, all the time.

In many places even yet by agreement between companies the railway operator covers the service for the commercial; the latter likewise transmits in great numbers over its wires the service messages of the railway, examples of which have just been given. As compared with these, the student will find that the railway message usually takes an ampler form, more nearly approaching that of a letter. In railway work all messages are "service," and concern the movement of freight and passenger traffic, and the dispatching of trains. All the stock phrases in use are shortened; initials, figures, and abbreviations occur in nearly every line; the "count" which serves as a safeguard to the commercial operator is dispensed with, so that there is all the more need for the operator to be on his guard against omissions.

Again, mention was made in connection with commercial messages of the use of *forms* for races, games, and the like; in railway service this is a marked feature, their number in the case of some leading railways exceeding one hundred.

Then, thirdly, in connection with the purely telegraphic part of the service is the very important work of handling the train orders; first as received from the dispatcher, and then repeated back with the signatures of the recipients.

On a single track railway a crossing order, at one time, commonly ran thus:—

To Conductor and Driver Train No. 21..................
Train twenty-one will meet and pass Special Freight, Conductor Holmes at.... 31
(sig) H. M. Wallace.

H. M. Wallace ....
32 Train twenty-one will meet, etc.
(sig) Conductor and Driver.

More recent usage however is indicated by the following forms; in connection with which it may be premised that the aim is simply to acquaint the student and prospective railway operator with the forms of the messages he will be called upon to handle; but, in order to make them intelligible, some details of the train despatcher's work must accompany them. This can be set down as consisting, for the most part, of (1) orders fixing meeting points for trains; (2) fixing the point for one train to pass and run ahead of another; (3) giving a train the right over an opposing train; (4) giving regular trains the right over a specified train; (5) providing for the use of a section of double track as single track; (6) providing for a single movement against the current of traffic on double track. Then there are (7) time orders; (8) orders for sections; (9) for extra trains; (10) for work extras, or auxiliaries; (11) holding orders; (12) orders annulling or cancelling a regular train; (13) annulling an order or part of an order; and, (14) orders superseding an order, or part of an order.

From the list of train movement forms thus indicated, some of the more important, viz., the first, second, fifth, eighth, ninth items are selected for illustration; the names chosen for the stations are fictitious; but the forms are those in actual use on some of the leading trunk lines.

Suppose a single track, of which Balmain and Allaire are terminals; Eden and Canton are intermediate stations. Train 334 going south is late; it is desired to advance on its time train 331 going north, Eden being the regular meeting place. The despatcher calls up Balmain, Allaire, and Eden and sends the following; C and E being the stereotyped abbreviation for Conductor and Engineer:

31 No. .. Operator, Eden.
31 No .... C & E No. 334, Allaire.
31 No. ... C & E No. 331, Balmain.

No. 331 has right of track from Eden to Canton
sig W. L. D. Sup't.

Each operator copying this message must repeat it back to the despatcher, and each one must listen to its repetition by the others.

Another form of crossing order for two trains, one at Eden the other at Balmain, would run thus:

31 No..... C & E No. 332 Eden.
31 No..... C & E No. 329 Balmain.
No. 332 and 329 will meet at Carrolton.

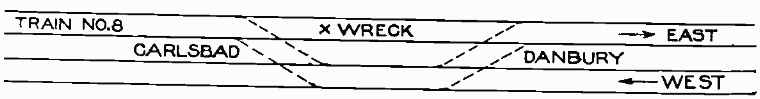
In this and the examples to follow a signature is taken for granted.

For the next movement, viz., the passing of one train by another, the procedure is less formal. It is desired that train 601 should allow No. 1 to pass. In this instance the co-operation of the signal towers, having control of the switches and side-tracks, is enlisted. The despatcher calls up the tower, say at Breslin, and tells the operator that train 601 is next to him, and that he is to side-track it for No. 1. The next tower beyond, say Ashley, is then notified that 601 is in the siding at Breslin for No. 1, so that he may know which train to look for first. Or, the passing may be arranged for in a formal manner:

31 No..... C & E Extra 594, Breslin.
31 No.. .. C & E No. 6, Breslin.
Extra 594 will run ahead of No. 6 Breslin to Dexter.

In this case the speed of No. 6 must not exceed that of Extra 594 between the points named.

The fifth item presupposes the blockade of one of the two tracks by a wreck—an incident by no means exceptional; the situation being indicated in the cut:—



The station next east of Danbury is Berber. The procedure is then:—

31 No..... C & E all west bound trains, Berber.
31 No..... C & E all west bound trains, Danbury.
31 No..... C & E Train No. 8, Carlsbad.

No. 8 Engine 914 will use west bound track from Carlsbad to Danbury; and has right of track over all west bound trains.

This message is repeated back by all three stations; and under its provisions no west bound trains can pass Danbury until No. 8, Engine 914, has passed east.

During the summer season it is a common incident of the despatcher's work to be called upon to divide into sections trains that, by the addition of extra coaches, have become too heavy for one engine. The two, and sometimes three, sections must be so protected one by the other that, so far as their right of way is concerned, they are substantially one train. Let us suppose train No. 8 at Corbin, going east, has too many coaches for one engine

31 No..... C & E No. 8, Corbin.
No. 8 will carry signals from Corbin to Jersey City for Engine 672.

Engine 672 then takes the second section, and proceeds to its destination under protection of the signal. If a third section is necessary a message similar to the foregoing would be addressed:

31 No..... C & E second section No. 8 engine 672.

A third engine named in this message then proceeds under the protection of the foregoing with a third section of the train.

The above is the method of procedure in case the need for the third section did not appear until after the first section had left Corbin. Otherwise the division into three sections would take this form:

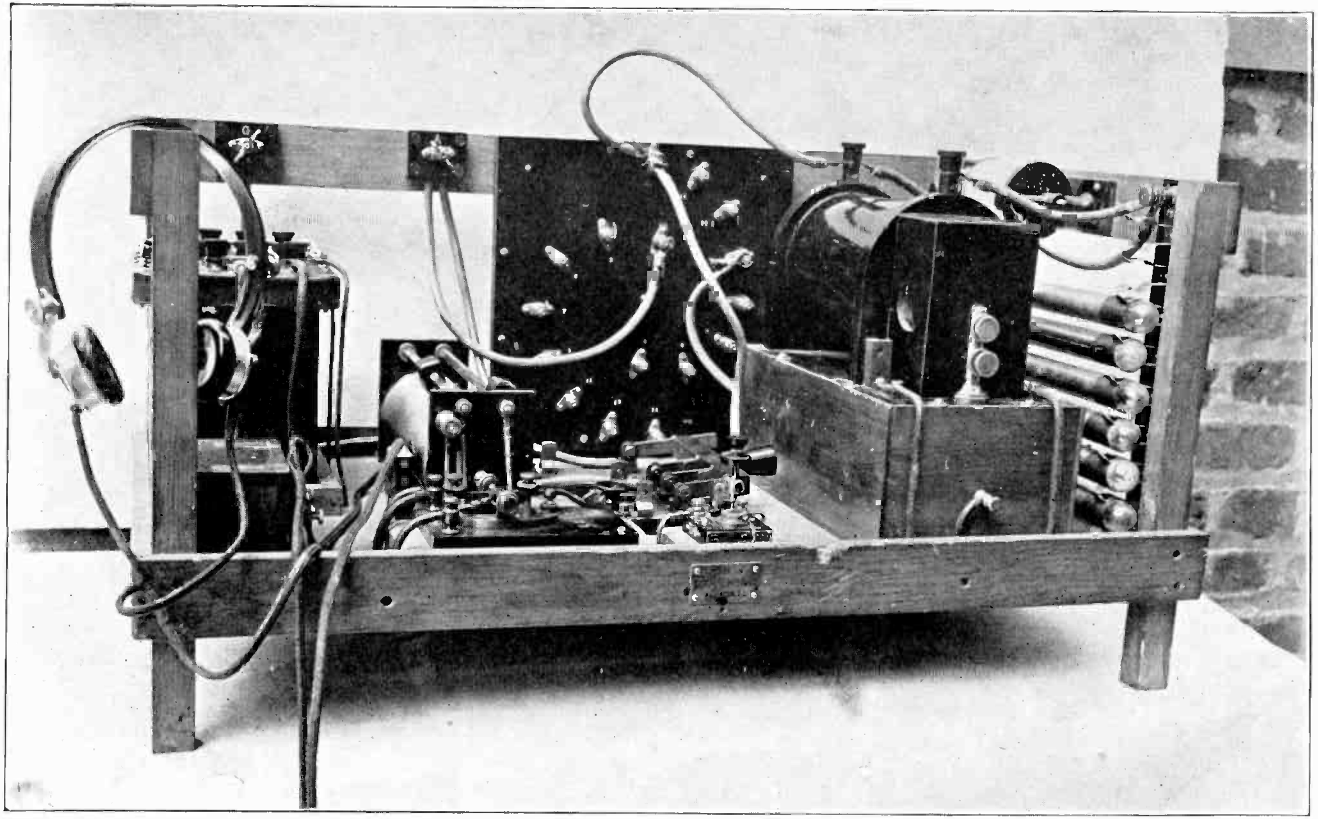
31 No..... C & E Engines 671, 672, 891, Corbin.
Engines 671, 672, 891 will run as first, second, and third section of No. 8 from Corbin to Jersey City.

This form implies the carrying of signals, one for the other, as prescribed by rule; and trains carrying such signals are regarded by other parts of the running service as practically one train.

For the starting of extra trains the signal "19" is used instead of "31" and the order runs thus:

19 No..... C & E Engine 587, Jersey City.
Engine 587 will run extra from Jersey City to Berber

If a regular train is late, and it is desired to give this extra a right to the time of the regular, it is done by inserting in the above message " No. 3 will run 30 minutes late from Jersey City to Berber." All these orders are copied on manifold paper; one copy is furnished to the conductor, another to the driver, while a third is filed by the operator for his guidance and future reference. These examples could be multiplied indefinitely, but it is believed these citations are sufficient to indicate to the learner the kind of service expected of the railway operator in co-operation with the work of the train despatcher.



THE NEW AËRIAL WIRELESS SET DEVISED BY GOVERNMENT ELECTRICIANS
Intended for Use with Aëroplanes and War Balloons.

THE ELECTRIC TELEGRAPH.

PART II.

The principal topics considered in Part I, were the "learner's outfit"; the "one-wire" office with its relay, key, sounder, and local circuit; and the switchboard for the cutting in and out of instruments, and the cross-connection of wires. There are scores of such offices, called branches, in the larger cities; and every town throughout the land has at least one.

An advance is now made to the more complex equipment of a junction station, or town office, to which a score or more of wires converge, and from which they radiate in all directions.

Instead of a "one-wire" set, there may now be noticed on the desks or tables, six, eight, or ten relays and keys; the sounders, possibly less in number than the relays, are operated by a current furnished by storage cells to which energy is supplied by an electric light circuit. The clock on the wall is probably of the "electric" pattern with two Leclanche cells inside. On a shelf are probably two or three sets of apparatus called repeaters; on another table are the duplexes or, it may be a quadruplex, whose principles and manner of operation need careful consideration; and in place of the diminutive single-wire switch of the city branch, or country office, is its more ambitious counterpart with fittings for some thirty, forty, or fifty wires. The handling and care of such a plant calls for skill and experience to which many a commercial operator, doing the work merely of a sender and receiver, is a stranger.

A consideration of the apparatus and methods of work in this larger office is the purpose of this paper; and the apparatus first to be studied is the switchboard. The one shown in Part I is a "single-wire intermediate"; but to accommodate the thirty or more wires now in view a greatly enlarged form is needed. The description of the small switchboard should be re-read, noting that in an intermediate switch two vertical strips are needed for a wire; that is, one strip for each direction of the wire, say north and south; in the switch of a terminal office a wire occupies only one strip.

Of the former class a common pattern is shown in Fig. 9; the diagram representing three pairs of strips out of a 50-strip switch for the accommodation of 23 wires; the gap in the middle represents 19 omitted pairs; the pair on the extreme right has a special use which will be explained later. In all respects the numbers on the small switch shown in Fig. 8, Part I, have been duplicated, except that the top row of discs is reserved for the ground wire; and for a review we shall go over, on this larger board, all the steps taken in connection with the smaller one.

In Fig. 9 the strips are numbered, for convenience, at the lower end from left to right; the disc rows are indicated by the figures down the center. In some patterns of boards the strips are so shaped at the bottom that to join them up in pairs a peg can be inserted. The switch is supposed to be at a station intermediate between Cincinnati and Chicago; strips 3 and 4 accommodate wire 1 South and 1 North respectively; strips 5 and 6, wire 2 South and 2 North; and so on. Disc rows 4 and 5 are connected on the left with one set of instruments; rows 6 and 7 with another set. In the drawing they are shown close to the board, but in practice the instruments are usually at some distance from the board on a desk to which the connections are made by means of office wire. Suppose, first, that the instruments are to be "cut out". Connect with a peg, strip 3 and disc 3; and strip 4 with the same disc 3; wire 1 has now no connection with either instrument, the current simply crosses on the disc from strip to strip. Move the peg in strip 3 to strip 3 disc 4; there is now no connection between disc rows 3 and 4, and the circuit in wire No. 1 is broken. Move the peg in disc 3 strip 4 to disc 5 strip 4; the current in wire 1 will pass through the relay and key connected up to disc rows 4 and 5; and the instruments are now said to be "cut in". In this larger board the ground wire occupies the top disc row, instead of the bottom, so that the discs marked 6 can be used the same as any other numbered row.

Reverting now to the changes indicated in Part I, page 25; for the sake of practice, move the peg from strip, or bar, 3 disc 4 to bar 3 disc G; and the peg from bar 4 disc 5 to bar 4 disc G; the wire from each direction is grounded. There are now two independent circuits each with a battery at one terminal only; Cincinnati and Chicago are cut off one from the other; the way-station instruments also are cut out. In order to "cut in" on the south section of wire No. 1, remove the peg from bar 3 disc G and insert it in bar 3 disc 5; put a peg in bar 1 disc 4, and another in

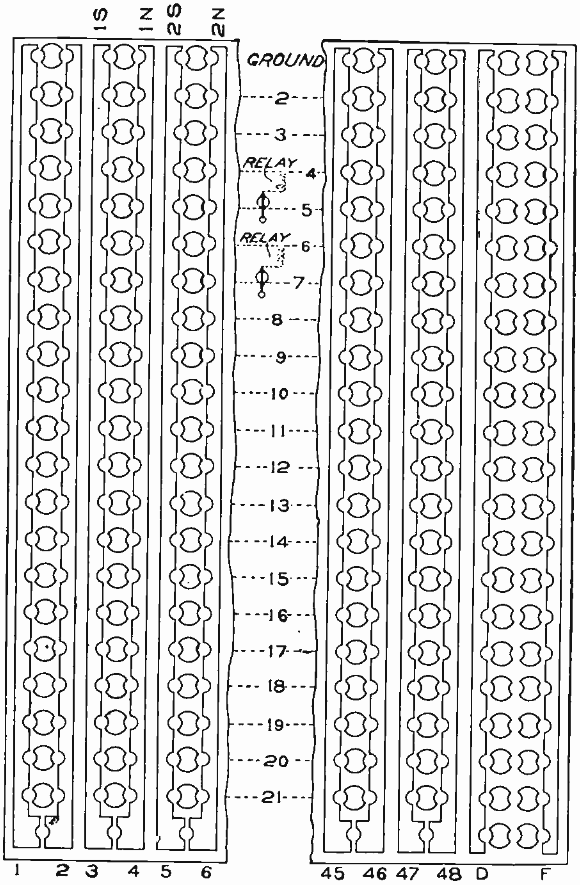


Fig. 9.

bar 1 disc G. The current from Cincinnati must now pass through the relay and key at the side of the switchboard before reaching the ground at bar 1 disc G. The peg having been restored to bar 3 disc G, the same set of instruments, or a different set connecting with disc rows 6 and 7, can, in a similar manner, be cut in on the north section. Restore the pegs to bars 3 and 4 disc 3, and the terminals Cincinnati and Chicago can now work with each other. but neither of the instruments at the side of the switchboard is in the circuit.

The letters D F on the extreme right hand of Fig. 9 stand for the words "double flip"—a device more commonly used in a terminal than in an intermediate office; but it may as well be explained here. In a board like that in Fig. 9, whether terminal or intermediate, each strip has underneath it a "flip", or spring-jack for the insertion of a wedge; usually the pairs of strips on the extreme left and right are set apart and joined in pairs by a wire behind the board. Strips 49 and 50 are practically one bar with two flips at the lower end—hence the name. A board like that in Fig. 9 is often part of a larger system; it may have a similar section on the right and left. The "double flip" enables the switch operator to desk and furnish battery to a wire coming in on another section, by running along on one of the disc rows. The twin discs shown in Fig. 9 have reference also to the presence of a companion section on the right-hand side; in such a case the discs on the extreme right of Fig. 9, row for row, would be connected with it; and, by inserting a peg between the twin discs, rows of like number in the separate sections may be joined, making them continuous across as many sections as desired.

Besides the cutting in and out of his own instruments, it is one of the duties of the intermediate station operator correctly to cross-connect wires at the request of the wire chiefs. He may be asked, for instance, to connect 1 North to 2 South, and 2 North to 1 South. Remove the pegs from bar 3 disc 3, and bar 4 disc 3. Peg bar 4 disc 2; bar 5 disc 2. Peg bar 6 disc 3; bar 3 disc 3. The current on 1 North crosses disc 2 to 2 South; the current on 1 South crosses disc 3 to 2 North. While this cross-connection stands, care must be taken to connect no other wires on either of the disc rows 2 or 3. The test station may have instruments, as shown in Fig. 9, connected up to disc rows 6 and 7. If it is desired to put this instrument in circuit on the wire 2 North to 1 South, remove the pegs from bar 6 disc 3, and from bar 3 disc 3. Peg bar 6 disc 6, and bar 3 disc 7. To facilitate the correct tracing of the different disc rows, it is common to alternate four rows of specially marked discs with four plain ones. To make any cross-connections and combinations of wires that may be needed, the operator needs only to get clearly before him the relation of bars and discs one to the other, remembering that the several rows of discs have no connection with each other or with the bars except by means of pegs.

Recent Form of Switchboard. The pattern shown in Fig. 9, although in very general use, has some defects for which a remedy is sought by a change of form. The connections for "in" and "out" on the top side only of the board require two strips to a wire—an arrangement which is wasteful of space. There has recently been installed in a suburban test office near New York an entirely new form of switchboard for intermediate stations in which the wires pass in at one side and out at the other. A 50-wire board of this pattern is seven feet in height, and thirty-three inches in width. The lower part resembles somewhat a long-distance telephone cabinet; the shelf is thirty inches from the floor, and the

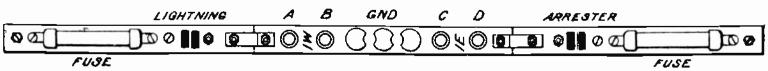


Fig. 10.

space underneath is taken up with the slack of the cords. On top of the cabinet are strips, like that shown in Fig. 10, placed one above the other to the number of say fifty, supported at the corners by four vertical bars of angle iron resting on the floor. The strips are of wood, one inch wide, each consisting of three parts. On each of the end parts are a fuse and carbon plate lightning arrester; in the middle part are four holes, A, B, C, D, for type jacks, and three discs. Between the holes for the type jacks is a tag for marking: the wires in the drawing are 1 West and 1 East. Extending up both sides of the switch are the wires contained in cables, parting with their conductors one by one and making connections with the fuses at each end of the strip.

The middle portion of each strip is ten inches long; and a side elevation is shown in Fig. 11. The four type jacks are connected in series as represented; between the two inner ones are three discs—the middle one grounded; a peg inserted on one side or the other of the center disc will ground the wire in the direction desired. The inner pair of jacks is for patching. In building up the switchboard the strip next above the one shown would be 2 West and 2 East. Each cord is fitted with an automatic slack take-up, as shown, and cross-connections are made by means of single cords and connection plugs F and H. To cross-connect 1 East to 2 West it is only required to place one of the plugs F in the patching jack marked 1 East, and the other plug H in the jack 2 West. In the diagram 1 West appears grounded by means

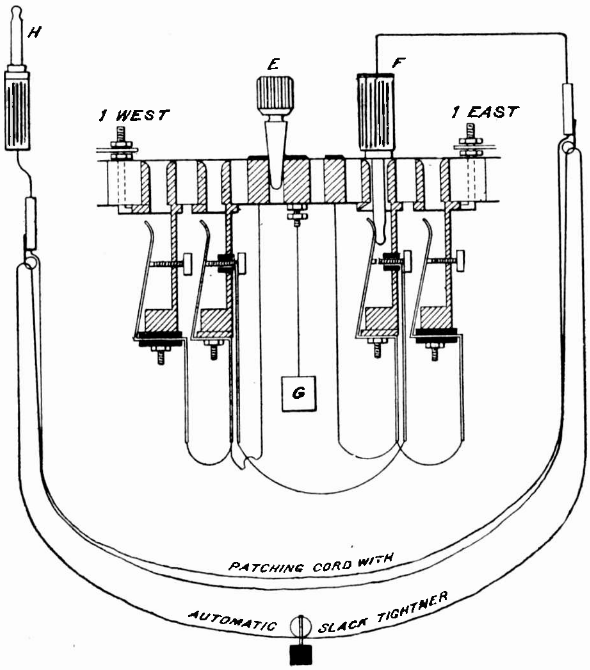


Fig. 11.

of peg E The outside pair of jacks is used for inserting loops; also to cut in test and desk instruments. The disadvantage in this form of switchboard is that the continuity of the wire depends on the perfect contact of the four springs with the pins behind them.

Figs. 10, 11, 12 and 13 are from a "Pocket Edition of Diagrams" by Willis H. Jones. They are reproduced through the courtesy of the publisher of *The Telegraph Age*.

An inspection of the diagrams in Part I yields a fair inference that each relay must have its own sounder; but the opening lines of this paper in which it is said that the sounders, possibly less in number than the relays, are operated by a storage current, hint at a departure from this rule. In former days the telegrapher sometimes made his first efforts at invention in a plan to economize, by making one sounder do duty, at different times, for three or more relays. But the field of devices for locals is well covered

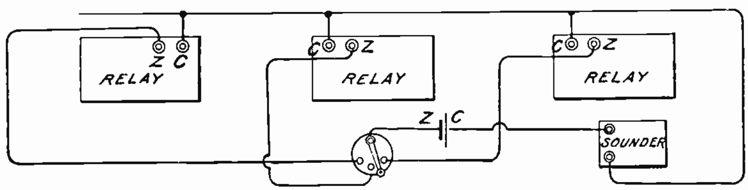


Fig. 12.

now; one of the results is shown in Fig. 12 which represents an arrangement of circuits in which one sounder can, by means of a switch, be worked in connection with three relays. The diagram needs no description, but the connections should be traced in each case; the lever resting on the right, middle, or left points cuts in the corresponding relays, in each case forming an independent local circuit. At junction stations, where passing trains are likely to make considerable noise, one sounder may be insufficient; in this

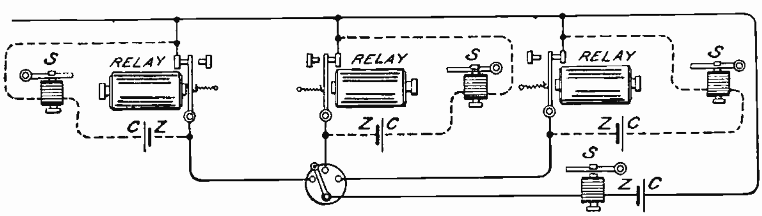


Fig. 13.

case an extra one with a local circuit of its own is sometimes provided. In Fig. 13 is shown how such an additional common sounder may be used in connection with three different circuits, each sounder having a battery of its own.

For local systems of this kind the form of battery most commonly used is that shown in "Elements of Electricity", called the Daniell, or "blue-stone", cell. Better still is the modification of it shown in the same paper known as the "gravity" cell in which the zincs can be so fitted, one into the other, that no portion of that metal needs to be thrown away or wasted. But not even the local battery system has escaped the spirit of change; and in many recently-equipped offices the zinc and copper type has been replaced by the storage cell, so called. The name implies the giving out of a current derived from another source—generally a dynamo—but the idea requires some modification, as will appear later on.

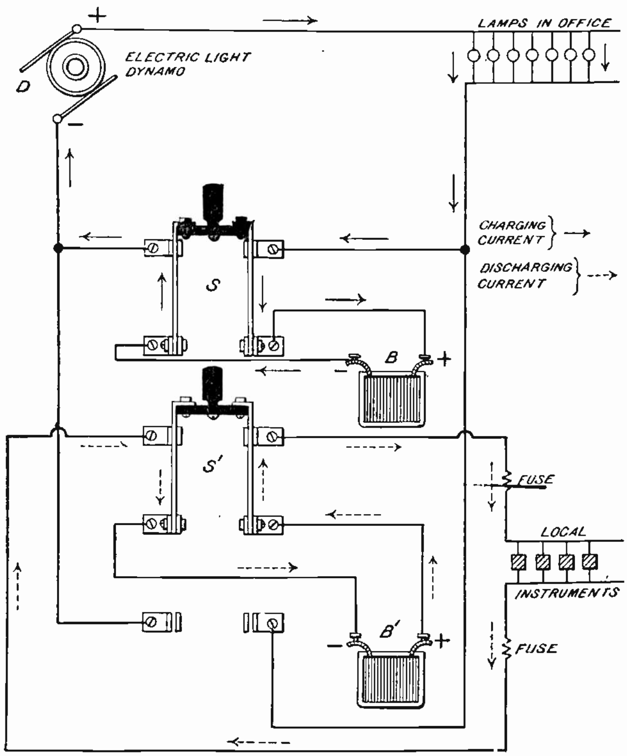


Fig. 14.

In Fig. 14 is shown a storage cell system fed by a dynamo which is also the source of energy for an electric-light plant. There are two storage cells, one of which, B Fig. 14, is in the same circuit with, and receives the current in the same manner as, the lamps. The other cell, B′, is disconnected for the time being from the dynamo, and is represented as supplying the current for a number of sounders arranged in multiple on the lower right. It will be apparent on examination that the method of connecting up the lamps in one circuit and the sounders in the other is the same.

In the opening paragraphs of "The Electric Current" the student has learned something of the laws of resistance. His attention is called at this point to the difference between the series and multiple arrangement of sounders. In the former, the resistance in ohms offered by the coils is the resistance of one sounder *multiplied* by the number of sounders; in the multiple system it is the resistance of one sounder *divided* by the number. A pair of knife switches, S and S′, shown in Fig. 14, is the means by which storage cell B,′ when it is exhausted, can be cut in on the same circuit with the lamps; its place in operating the sounders is then taken by the freshly charged cell B. In Fig. 15 the construction and action of the double knife switch is clearly shown. When turned from the position they hold in the diagram they make a new series of connections with the result already indicated.

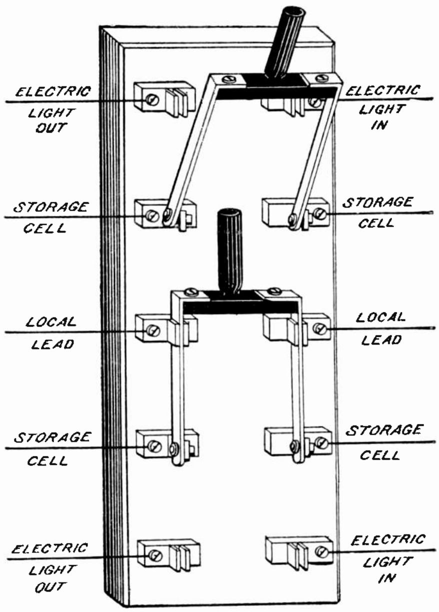


Fig. 15.

The Dynamo in Telegraphy. Within little more than a quarter of a century this appliance, regarded at first somewhat as a curiosity, has advanced to the place of an indispensable and well-nigh omnipresent help in the mechanical and technical world. In countless shops and factories its familiar hum and vari-colored sparking can be detected in out-of-the-way corners; while in power houses its more developed and, in some cases, giant form fully justifies the remark of the scientist Faraday when he saw the first dynamo in operation: "That was my child; but you have made a man of him." In the field of telegraphy its principal uses are to charge storage cells, and supply current for the main lines. In the former operation, the cell is said to be fed by the dynamo; and, as already illustrated, it is commonly carried on in combination with the supply for an electric-lighting system. The "feeding" consists of a chemical change in the cell, whose elements, when the charging ceases, give up in the form of electricity the energy thus imparted.

As the dynamo is the source of energy for the storage cell, and for the operation of the different forms of main line apparatus, the need arises for a brief statement of the principles underlying its construction. In so doing, some words and phrases not hitherto

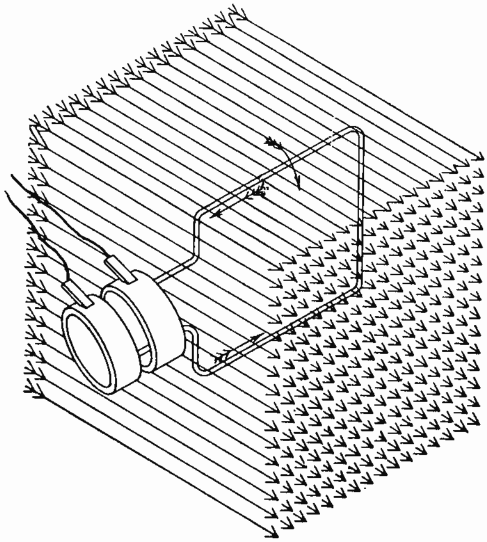


Fig. 16.

used come into view; and a definition of them, in connection with familiar forms, is first in order.

The *cores* in the electromagnet of the sounder, as the student knows, attract the armature. The free ends of the cores are the poles; and if a penknife is placed near, it is drawn towards the core with a force that increases as the distance lessens. Similarly, if a small piece of metal is held near the poles of a toy magnet in the horseshoe form, the attraction is marked. The space between the poles alike of the electromagnet and the toy magnet seems full of invisible stresses whose mechanical effect is like that of thousands of stretched rubber threads which tend constantly to contract. These stresses are called lines of force; and the space in which their influence is felt is called the field of force. These lines are inseparable from every form of magnet, permanent or electro; in the case of the earth, which is itself a great magnet, their effects are seen in the action of the magnetic needle placing itself parallel to the lines of force between the north and south poles; in the case of an ordinary magnet, the lines seem to appropriate to themselves any material which will shorten their journey through the air space; and, if the piece of metal is free to move, the lines tend to place it in the position which will shorten their pathway the most. Another, and the most common, name for the space occupied by the lines of force is the *magnetic field*. It is graphically shown in Fig. 16 in which is represented also the simplest form of dynamo. The arrows represent the lines of force between the magnetic poles; and, revolving therein, is shown a single conductor cutting the lines of force at right angles. Now comes the principle which underlies the generation of the electric current by means of the dynamo: If a closed conductor is rapidly revolved in a magnetic field an electric current is set up in the conductor. The collector rings and brushes conduct to the outside circuit the current thus generated.

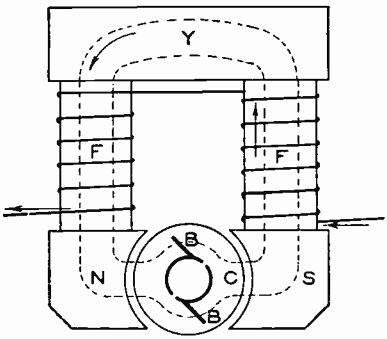


Fig. 17.

In Fig. 17 there is shown in outline form a simple dynamo; the yoke Y connects the field pieces FF, upon which are wound the field coils; the latter is charged by an external current in the direction of the arrows. In an intense magnetic field, between the pole pieces N and S, is the armature. It is made up of the core and a complete circle of conductors like the one shown in Fig. 16; a large number of conductors being needed to generate a continuous current. The conductors are made to terminate in a series of strips separated by insulating material, and bound together in a cylinder to form the commutator marked C; the collecting brushes BB correspond to the copper and zinc poles of a voltaic cell.

A gas or steam engine is usually the motive power for a dynamo; a common type is shown in Fig. 18 with the belt pulley at the left; in this form it illustrates the definition of a dynamo given in the text books as "a machine for converting mechanical energy applied at the pulley into electrical energy given off at the brushes."

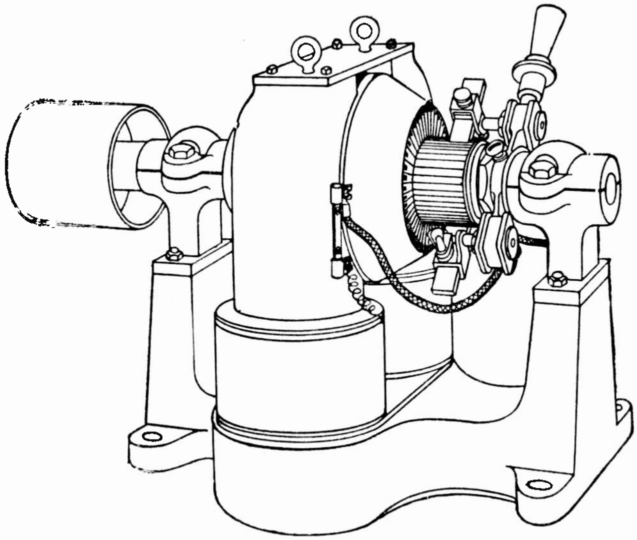


Fig. 18.

One use of the machine, namely, to furnish current for a system of local instruments, is illustrated in Fig. 14, but its more important function in telegraphy is the supply of the current for the main lines. The different circuits to be supplied may vary in length from 50 to 500 miles; and, as nearly the same quantity of current—say $\frac{1}{25}$ of an ampere—is required in each case, the voltage, or pressure, must vary accordingly.

A series of dynamos connected together upon the same principle as a series of cells in a battery is outlined in Fig. 19, showing how this may be done. One terminal of machine A is grounded, and from the connecting points of the brushes the wires 1, 2, 3, 4, and 5 are led to the horizontal rows of discs on the terminal switchboard. In practice they are commonly made a part of the larger board similar to that shown in Fig. 9; but, for the sake of clearness, it is represented here as distinct. Each vertical bar represents a main line wire; the horizontal lines are rows of discs to which are connected the wires carrying the current for distribution. In Fig. 19 wire 1, connected to one of the disc rows, furnishes 70 volts (the voltage of a Grove cell is about 1.5); wire 2, 140 volts; 3, 200 volts; 4, 260 volts; 5, 325 volts. It is necessary only to connect, with a peg, a disc and bar to supply any wire with any desired voltage. A plant of the capacity indicated in the diagram can be made to furnish current for 1,000 lines, yet its compactness is such that it may be installed in a small room.

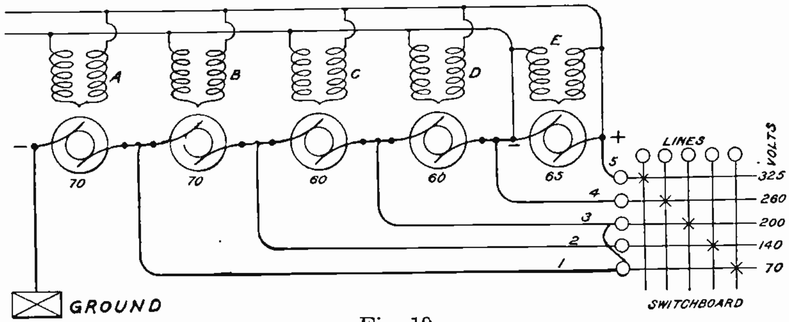


Fig. 19.

The advantages of the dynamo over the voltaic cell are:

(1) Its low internal resistance making possible the supply of so many wires.
(2) Economy in maintenance.
(3) The space occupied is much less.
(4) It does away with the unhealthy conditions of a fume-laden battery room.

The Open Circuit System. Before dealing with the topic of Single-Line Repeaters, let us discuss a system much used in England, known as the "open circuit", as distinguished from the one in general use in the United States, Canada, and Mexico, described in connection with Fig. 6, Part I. This is known as the "closed circuit", in which the circuit is first broken by opening the key switch as described, and the signals are transmitted in the manner now familiar to the student. The open circuit system is illustrated in Fig. 20; in it may be noted the difference in the connections of the key as compared with those of the American system. In the latter, as may be seen by reference to Fig. 6, Part I, the battery, key, and relay coils are in series; in the former, the ground connection divides, one branch passing through the relay coils to a point in the base of the key against which the lever carrying the main line normally rests. The other branch connects the battery to a different point of the base. It may be seen from the diagram that when both keys are making contact with the backstop there is no current on the line, and the relays are open. Depress one of

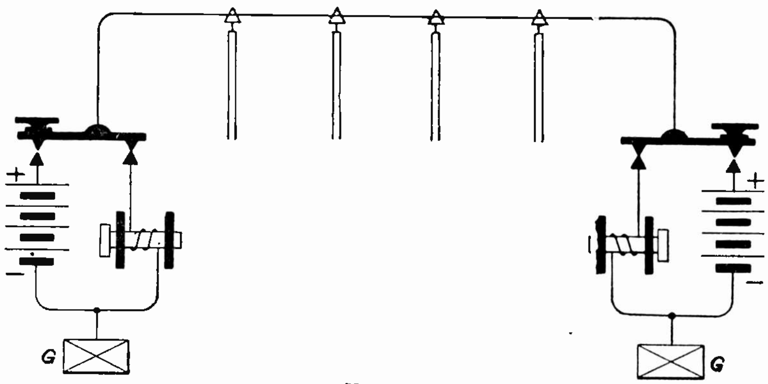


Fig. 20.

the keys and the current, passing directly to the line, closes the relay at the distant station.

In this arrangement there are two advantages over the American, or closed circuit, system:

(1) The battery is in use only when signals are transmitted.
(2) By the cutting out of the relay at the sending station the resistance of the circuit is reduced.

The disadvantages are:

(1) The operator hears his own sending on the key only.
(2) The system does not admit the cutting in of intermediate stations.

The closed circuit arrangement allows as many as twenty-five or thirty offices between terminals; and the batteries, placed one at each end of the line, are more likely to receive skilled attention.

SINGLE-LINE REPEATERS.

In the junction station, or town office, we now have in mind a set, or sets, of repeaters—an important feature in the equipment, and the one next to be considered. The limit of the Morse single line, in good weather, is ordinarily about 450 miles; it is one-half or one-third of that in rainy spells when extra repeaters are cut in. The repeater is a means by which the relay at a distant terminal of one circuit is made to operate a key in a second circuit. The distant relay of the second circuit may operate a key in a third; and so on. The circuit of say 1,500 miles has thus the advantage of batteries at needed intervals; the distance between repeaters being determined by the conditions already indicated; and it has not been found expedient to exceed very much the distance first given.

There are many different forms of repeaters; and from among the score or more that have been in use at different times selection is made of the three commonly regarded as the best—the Milliken, Atkinson, and Weiny-Phillips. The same result is attained in each, but by somewhat different means; all three are of the automatic class—so called because they permit the terminals to break without the aid of an attendant.

Fig. 21 shows the **Milliken** repeater in theory. It consists of two relays of special construction, two transmitters, two main batteries, M B, a pair of local batteries, L and L′, and a pair of extra locals. Tracing the connections of the local batteries, they are found to be wired through the local points of relays E and W, one for each; and through the coils of transmitters T and T′. The extra locals are wired through the back contacts of transmitters T and T′; and in the same circuit are the coils E′ and W′. In the construction of the relay the peculiarity is that, in combination with the electro-magnet and upright armature of the ordinary relay, there is an extra magnet with a pendent, or hanging armature marked P in one and P′ in the other, Each one is so placed that, when released from its magnet, the tension of a spring forces it against the upright armature and holds the local points closed. To aid the student in tracing out the different connections the extra local circuits are marked by dot and dash lines; the local circuits by dotted lines; the main lines are in full lines. The wires marked East and West

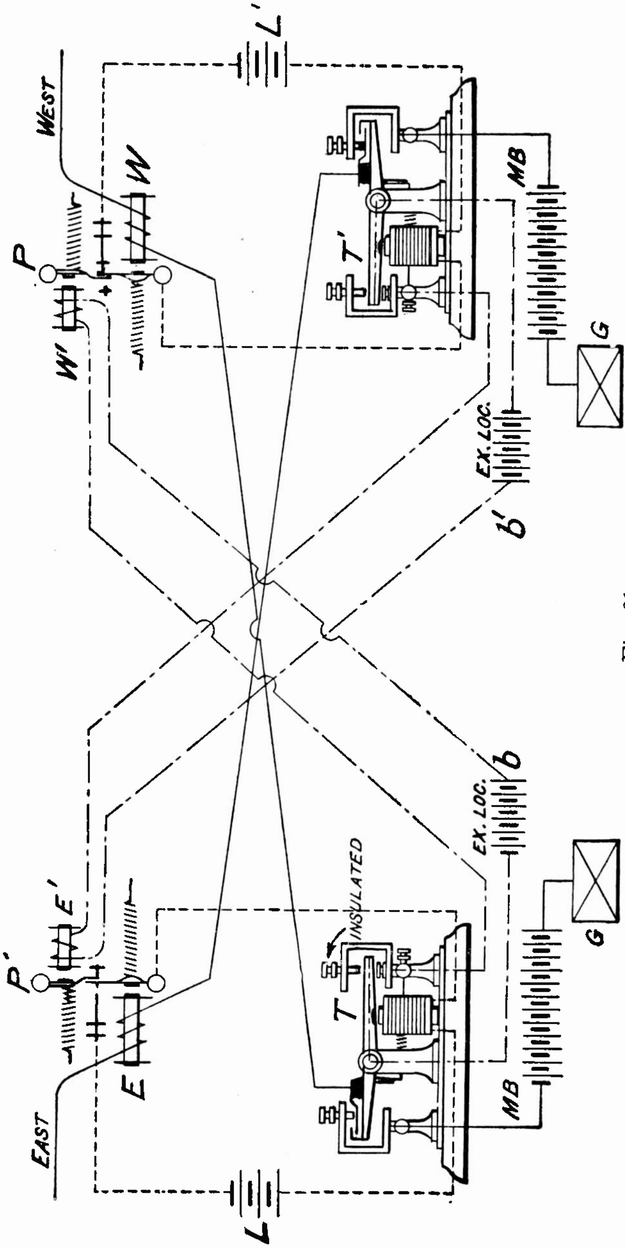


Fig. 21.

are supposed to extend in each direction to terminals, it may be, 400 miles distant. When the circuits are at rest, the armatures of the instruments are attracted by their respective cores, and are said to be closed.

Recall now the definition of a repeater, and notice in the description to follow how the transmitter in the East set acts as a key in the West wire, and *vice versa*. Suppose the distant East station opens and writes; the operator opens the local points of relay E, and this opens transmitter T; through its tongue and post passes the West wire, and it, therefore, is opened. The opening of the West wire should open relay W and transmitter T′; and the opening of transmitter T′ would open the East wire which passes through its tongue and post. But the opening of the East wire when the distant East is sending is just what the repeater is intended to prevent. When transmitter T opens, the extra magnet W′, held closed by battery *b* through the back points of the transmitter, also opens; the pendent armature P is released, falls back, and holds closed, by the tension of its spring, the upright armature of electromagnet W. This prevents the opening of transmitter T′; and the East wire is not allowed to open in the latter instrument. Transmitter T′ can be opened only by opening a key in the West wire, either at the repeater (key not shown in diagram) or, normally, at the distant West station.

When the distant West writes, the action begins with the West relay W the same course as that just described; in this case the pendent armature P′ holds closed the transmittter T, and the West wire passing through its tongue and post.

The Atkinson Repeater. Probably the best of all the repeaters in general use is the Atkinson, the theory of which is shown in Fig. 22. The apparatus consists of two relays of the common type, two transmitters, two main batteries, a pair of local, and another pair of extra local, batteries. The local batteries belong to circuits which, it will be noticed, are marked one with dots, the other with dots and dashes, the same as in the Milliken repeater. On the East set the battery is marked MB, relay E, extra sounder E′ (operated by battery *b*′), and transmitter T; the West set is lettered to correspond. The wires marked East and West extend, of course, in each direction to distant terminals. Suppose the dis-

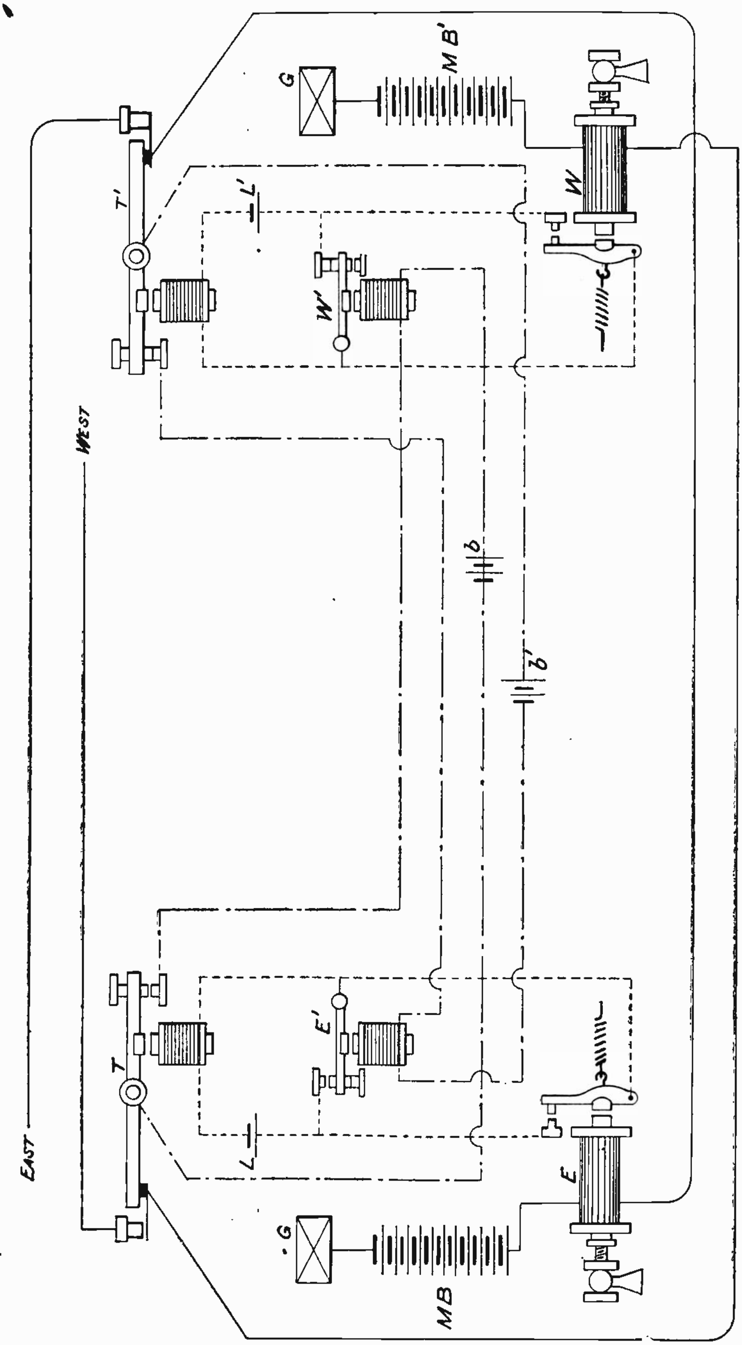


Fig. 22.

tant East opens his key; he thereby opens in rapid succession relay E and transmitter T, which, in turn opens the West wire and relay W. The opening of the local points of the latter instrument would ordinarily open transmitter T', and therefore the East wire which passes through the tongue and post of transmitter T'. But here again the opening of the East wire, when the East side is sending, is prevented by a device characteristic of this repeater. When transmitter T opens, the current passing through W' is broken; the armature of W' is released and, falling against the backstop, it bridges the points of relay W, so that transmitter T' is held closed and, with it, the East wire. As in the Milliken, transmitter T' can only be opened by opening the key on the West wire either at the repeater or, normally, at the distant West station.

When the latter opens his key the action begins, as already described, with the West relay W and follows precisely the same order, in the latter case the magnet E' holds closed transmitter T. Notice that, in describing the action of this repeater, the language used is very similar to that employed in connection with the Milliken.

These two forms of repeater afford illustration sufficient for a good understanding of the principle; one more kind is added because, up to a recent date it was in general use by one of the large telegraph companies; and, more especially, because its construction involves the principle of differentiation in magnet coils which plays so important a part in duplex telegraphy. A description therefore forms a convenient stepping stone to the subject of multiplex work, which opens up a new and interesting field.

A theoretical diagram of the **Weiny-Phillips** repeater is shown in Fig. 23. As in the Milliken, there are three distinct sets of circuits in duplicate; that is, one set represents the East, the other the West side of the apparatus; and in all three diagrams, Figs. 21, 22, and 23, the parts performing like functions are similarly outlined and lettered. The connections of the main line (full line), and of the local (dotted) circuits are identical with those of the Milliken. But, instead of the extra magnets E' and W' and the pendent armatures P and P' of the repeater last named, there is a device which effects the same end; and, for the reason already indicated, it requires some attention because of the new principle involved.

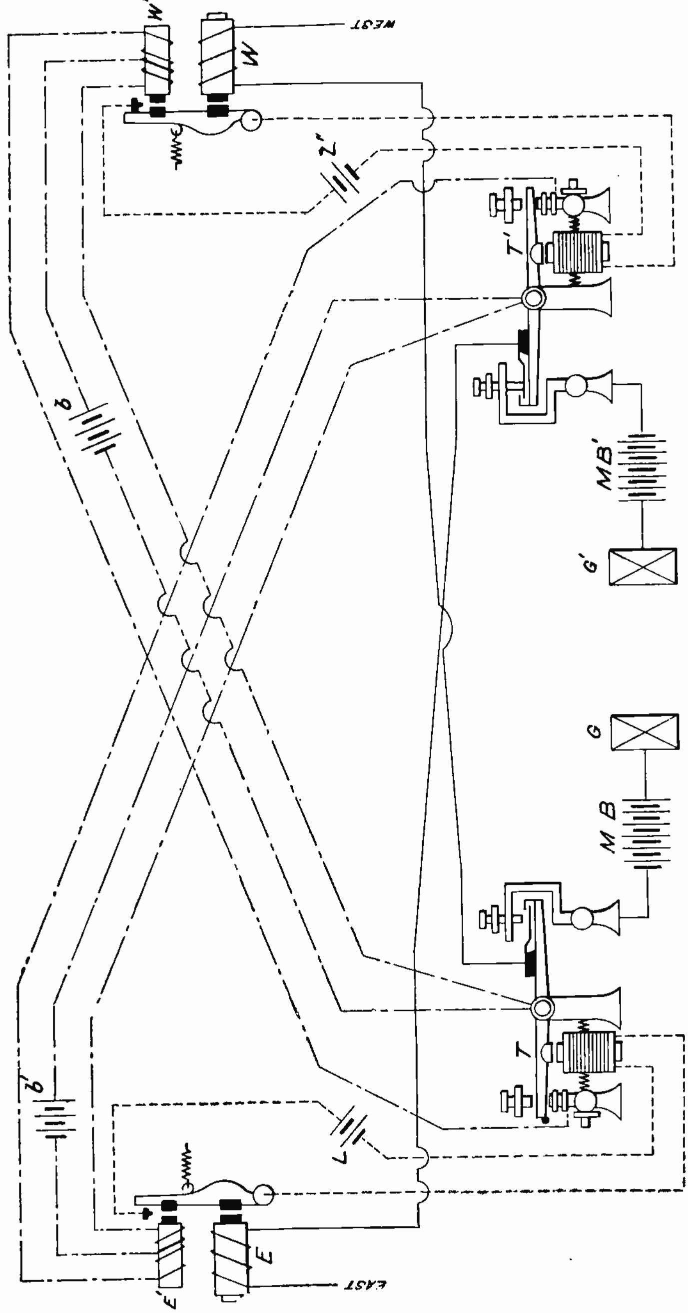


Fig. 23.

In E′ and W′ we have an iron shell enclosing a straight iron core and its winding. The combination of shell and core performs the same functions as the parallel cores in the common type of relay. Trace the wire from battery *b* to the core W′; at a point just above the core the circuit splits; one part winds round the core to the left, and goes to the middle point of the lever of the transmitter; thence back to the zinc pole of battery *b*. The other part goes to the right, and back to transmitter T at the under-stop of the lever. Each division of the magnet coil contains the same number of turns of wire round core W′. When transmitter T is closed, since the lever makes contact with the under-stop, the current from battery *b* traverses the coils of core W′ in opposite directions; the result being that no magnetic pull is produced in the core. But note the effect when transmitter T is open. One of the circuits that passes round the core is open; the neutralization of the current in the other division of the circuit is impossible; the core at once becomes an electromagnet capable of holding the armature at the needed moment. A winding of this kind allows the core to be energized by the *difference* in the strength of the currents in the two divisions; such a core is said to be differentially wound. If currents equal in quantity pass round the coils of core W′ in opposite directions, their magnetic effects are nil; if the currents are unequal, or if one current is nothing and the other any given quantity, the core is energized and will attract its armature.

Notice now the operation of this repeater, in effect identical with that of the others. The distant East station opens his key; this opens relay E, then transmitter T, the opening of which opens the West wire passing through the points of transmitter T. The opening of the West wire would open relay W, transmitter T′, and therefore the East wire which passes through its points. The last opening is the one the repeater is planned to avert. When transmitter T opens, one circuit round the core of W′ is opened; the core is energized and holds the armature of relay W closed, so that transmitter T′, through whose points passes the East wire, does not open.

When the distant West breaks and sends, the same action begins with the West relay and follows the same course. The distant East and West can then work with one another through the repeater, and have the benefit of the main line batteries at the repeating station. This is the sole purpose of a repeater; in every other respect it is a disadvantage, introducing in a circuit two sets of apparatus which need careful adjustment and considerable attention.

MULTIPLEX TELEGRAPHY.

The Stearns Duplex. In the description of the Weiny-Phillips repeater, the differential winding of a single core was illustrated; and the fact explained that such a magnet is operated by the difference in the strengths of the currents passing through the coils. If the two cores of a single-line instrument are wound in the manner described, we have a form of relay known as the

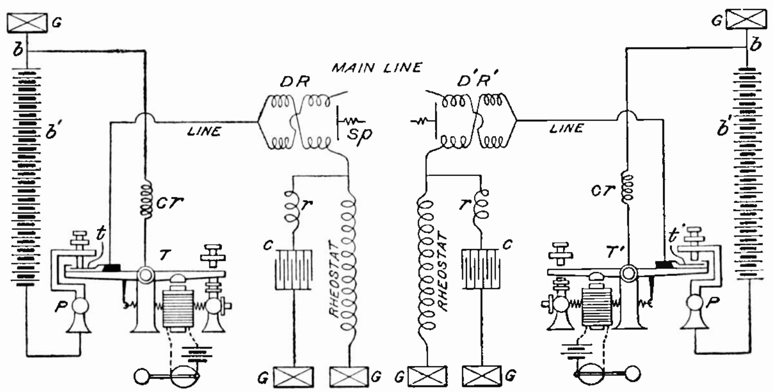


Fig. 24.

Stearns differential; with this and a few accessories a line can be made to carry signals in opposite directions at the same time. In other words, the wire can be duplexed; and the theory of it can be explained and understood from the diagram, Fig. 24, in which the apparatus and connections for both terminals are shown. D R and D′ R′ are the differential relays; the gap between them is supposed to be bridged by the main-line wire, which may be 450 or 500 miles long.

In addition to the relays and batteries, the essentials for each terminal are a transmitter, rheostat, some resistance coils, and a condenser. Each of these may be seen in its place in the diagram; the rheostat marked in full, the others with the first letter of the name; the local circuits for the relays are not shown. One pole of each battery is grounded; the other makes contact with the post P of the transmitter; and, as the sets are duplicates, one only needs to be described.

The lever of transmitter T makes contact with the ground through a coil *c r*, which compensates for the internal resistance of the battery, making the resistance of the circuit the same whether the transmitter is closed or open. The lever carries, on an insulating pedestal, a spring or tongue *t*, to which is attached the line wire; it makes contact with the post P (battery) when the transmitter is closed, and with the lever (ground) when the transmitter is open. This instrument is seen to be a device for transferring the line wire from the battery to the ground contact without interrupting the circuit; and it is operated, as shown, by means of a key in a local circuit. The line wire can be traced from the tongue *t* to the point of division—technically known as "the split"; the little semicircle in the diagram indicates in every case no connection with the wire underneath; each division of the circuit passes through two spools of the relay; one branches off to the main line, the other through the rheostat to the ground. By way of introduction to the apparatus last named, take the case of a motorman of a trolley car in motion. His left hand controls a radial arm surmounting a box which extends down to the platform, and contains a number of lengths of coiled wire through which the current passes on its way from the trolley wire to the motor. Every move of the radial arm in one direction or the other means more or less of current, and therefore more or less of speed in the motor. The coils resist the passage of the current, and the box is therefore a current retarder, or rheostat, which is the same thing. In a similar manner, either by a radial arm or, more commonly in a duplex, by means of pegs making contact between discs in which the resistance coils terminate, the current may be regulated in the circuit of which the set of coils marked "rheostat" is a part; that portion of the circuit from the point of division to the ground being called the artificial line.

The purpose of the rheostat is to divide the current passing through the relay coils equally between the main and artificial lines; and, as already intimated in connection with the repeater this can be done by making the resistance in the rheostat equal to that of the 450 or 500 miles of wire in the main line—anywhere from 5,000 to 10,000 ohms. When this condition is established it does not matter, within working limits, what the size of battery is; the current will pass through the relay with no appreciable magnetic effect upon it; and the duplex is said to be "balanced".

How to Balance. Suppose the terminals to be provided with duplex sets and batteries as shown in the diagram, and a main line connecting them. First approximate the balance by pegging the rheostat to 5,000 or 6,000 ohms in clear weather for a line 450 miles long. Ask the distant office to "open". Notice in connection with transmitter T′ that this opening grounds the wire at the distant end. There is now no battery on the line but your own; lower the tension on the spring *s p* and, by means of the pegs, vary the resistance in the rheostat (the home key being closed) until the cores of the relay show no appreciable attraction for the armature. This done, open and close the key a number of times; a slight click of the sounder with each movement of the key will probably be heard—an effect which it is necessary to eliminate. It is with the dynamic, or current, form that, up to this time, we have been dealing; but the false signal just mentioned in connection with the duplex brings to notice, for the first time, electricity in the form of *charges* upon the wire, and therefore called static. It presents itself as a disturbing element in connection with duplex work; and the remedy for it is a movement in the artificial line round the relay coils in a direction opposite to that which causes the 'kick'; the means for producing it is the apparatus in Fig. 24 marked C, for condenser.

For a statement of what static electricity is, and certain forms of the condenser, see "Elements of Electricity". In the diagram, the lines represent sheets of tin foil; the spaces mica, paraffined paper, or some insulating material; one set of the sheets makes connection with the line; alternating with them, as shown, is another set which makes contact with the ground. The sheets, with the insulating material, are enclosed in a box, and the connections mentioned are made in one case by means of a bar, and in the other by means of a set of discs so placed that, with a few pegs, the number of sheets in actual use can be varied; and, by means of an adjustable set of coils r, the charge and discharge can be assimilated to that of the main line.

On the condensers commonly used in telegraphy the discs are usually five in number, and are marked 40, 32, 16, 8, 4 to denote the percentage of tin-foil area connected to the disc. If pegs are inserted uniting the bar with discs marked 4, 16, and 40, 60 per cent of the capacity is in use, and the charge and discharge will be in just that proportion. A condenser usually bears a stamp as 2.5 M F, or 3 M F. The M F stands for micro-farad, which is the practical unit of capacity; and is about equal to that of three miles of an Atlantic cable.

With the duplex in operation there is, on the closing of the transmitter, a charge through each pair of relay coils and, on the opening of the transmitter, a discharge through each pair of relay coils the same in quantity and at the same instant; and in each case the movement in one pair of relay coils neutralizes that in the other.

When the "kick" has been cleared, the distant station is asked to write; and it will be found that the outgoing signals do not interfere with the incoming, because the duplex has had a static, in addition to its first, or ohmic, balance. The distant station then goes through with the same process, and the sets are ready for service.

All the accessories having been described, it remains to trace in detail the effects of the currents on the relays in every position possible to the transmitters. In the diagram, on the left, the battery has zinc to the post and copper to the ground; at the other terminal, on the right, copper is to the post and zinc to the ground. The duplex would work if the batteries had like poles to the line; but we shall consider them in the manner shown. In operation, four conditions are possible, and they may be tabulated as follows:

T closed	— to line	T′ closed	+ to line	D′ R′ closed	DR closed
T open	G " "	T′ closed	+ " "	D′ R′ open	DR closed
T closed	— " "	T′ open	G " "	D′ R′ closed	DR open
T open	G " "	T′ open	G " "	D′ R′ open	DR open

It will appear from this that the differential relay at one terminal obeys the transmitter at the other. We shall see how this works out in practice. A line 450 miles long usually has a voltage of at least 150 at each terminal; and, as only 25 cells are represented in the diagram, each cell must be supposed to represent 6 volts.

First, when T and T′ are closed; the batteries unite their energies, giving on the main line a current of $\frac{1}{25}$ ampere, or 40 milliamperes. On the artificial line, in the relay coils at each terminal, there is a current from the battery at that terminal through a resistance in the rheostat equal to that of the line, say 20 milliamperes, because the voltage in each case is only one-half that of the united batteries on the main line. In the coils of each relay there is a difference of 20 ma and both remain closed.

Next, open transmitter T. The battery at the left is cut off, and the line is grounded through a compensating resistance C R equal to the internal resistance of the battery. On the artificial line in relay D R there is no current; on the main line there is a current of 20 ma from the distant battery; relay D R remains closed. On the artificial line in relay D′ R′ there is a current of 20 ma which neutralizes the current of 20 ma on the main line, and the relay D′ R′ opens; in other words, it obeys transmitter T.

Next, close transmitter T and open T′. This is the phase shown in the diagram, and it should be traced with special care. The line is now grounded through the tongue *t′* and lever of T′ on the right; and the only current on the wire is from the battery at the other end. At the terminal where T′ is there is no current on the artificial line, and the current of 20 ma on the main line closes the relay D′ R′. But at the other terminal, where T is, the current in the coils of the artificial line neutralizes the current on the main line, and the relay D R opens; in other words, it obeys transmitter T′.

Lastly, when both transmitters are open. The battery at each terminal is off; there is no current in either the main or artificial line at either terminal, and the relays stand open. In this way are verified the results set down in the table; the relay in each case is unresponsive to the home instrument, but responsive to the distant transmitter; and signalling in opposite directions at the same time is practicable.

In explanation of the part played by the condenser in the long distance duplex, it may be said that when current flows in a wire, a portion of it collects and becomes static on the conducting material; and it will discharge instantly in any direction a path offers. In duplex work, the transmitter makes a line contact first with the battery, then with the ground; the conditions are present for a static charge and discharge of the wire; and the extent to which it is capable of these effects is called its electro-static capacity. On short lines it is small; so that, in the duplexing of such wires, the 'kick' is not noticeable; but there is a difference between a main line wire 450 miles in length, and the fine wire with which the coils of the rheostat are wound. So far as *resistance* to the current is concerned, the coils in the box are capable of reproducing exactly the conditions on the wire; but the main line wire has electro-static capacity; the fine wire of the rheostat coils has not. The initial charge in the line, therefore, will not, unless the condenser is used, be offset by an opposite movement in the artificial line; nor, at the termination of the signal, when the line is moved from the battery to the ground, will the discharge be offset by an opposite movement in the artificial line. A form of duplex was invented in Germany, and known in America as early as 1855; but it was worked only on comparatively short lines. The duplexing of long lines by the aid of the condenser was made practical in 1872; and the credit is due to Joseph B. Stearns of Boston. His was one of the notable achievements in the history of telegraphy, for by means of it the value of most of the wires of the telegraph companies was doubled at a stroke.

In the diagram, Fig. 24, there is indicated a connection from each transmitter through a coil *cr* to the ground at *b*. Before leaving the subject of the Stearns duplex, it is proposed to make a change in this circuit, and note results with a view to future reference and use. In each circuit move the wire from the point *b* to the point *b′*. When the transmitters are closed the *cr* circuits are open, so that the change to *b′* makes no difference on the line; but when a transmitter is open, the line has in circuit about one-third of the battery before it reaches the ground. Under these conditions, instead of the main and artificial lines being free of current, there would be on the main line coils in each relay, say 16 ma of current; and opposed to it in the artificial line coils about 8 ma. The difference (8 ma) would be sufficient to close the relays; but, according to the four-phase table, when the transmitters are open the relays should be open. Under these conditions, to open the relays it would be necessary to increase the tension on the armature spring. Now, if for any reason, we wish to maintain a weak current always on the line we could use for the purpose a portion of the battery, and counteract the effects of it by giving the spring *sp* sufficient tension to overcome the magnetism induced by the weak current; or, as the operators express it, the relay can be "turned up" above the weak current. This done, the operation of the duplex can be carried on as usual; the only difference is that the springs of the relays have tension sufficient to make them unresponsive to the weak currents. It is possible, therefore, to work a duplex of the Stearns pattern when the connections are such that the movement of each transmitter sends alternately to the line the whole battery and only one-third of it. This statement made, let us leave it for the present. It will be fitted into its place later, when we come to deal with the quadruplex in connection with which the statement just made plays an important part.

It remains only to gather up the terms and phrases used in describing the duplex; from this time on they must be a part of our vocabulary. We have had to do with the differential winding of a single core, the differential relay, main line, artificial line, rheostat, compensating resistance, transmitter, condenser, retardation coils marked *rr*, internal resistance (usually of a battery), the split, the balance, tension (of a spring), the static and its kick, charge and discharge, electrostatic capacity. If the reader will note in the diagram, as far as possible, each object named, he should get a better idea of its theory and function than could be obtained from a definition.

It thus appears that the characteristic instrument of the Stearns duplex is a relay, in appearance not very different from the ordinary relay of the single-line type; it can be constructed from it by a change in the winding from the simple to the differential form as represented in the diagram, Fig. 24. For the sake of simplicity all the thumbscrew connections, the front and back stop, and apparatus of the local circuit are omitted from the drawing; only the essential parts—the differential coils with the armature and spring—are shown. It will be noticed that the main line has a number of turns around one core, then around the other; the same with the artificial line. In practice, the points where the main and artificial lines enter and leave the instrument are fitted with four thumbscrews; two more are provided for the local points—one making connection with the armature, and the other with the front stop—forming parts of a local circuit as in the ordinary single-line relay. These omitted parts will be supplied in Fig. 29; but in dealing with first principles the fewer the details the better.

The Polar Duplex. In the same manner as we took the single-line relay and changed it to one of the differential type, so now it is proposed to take the latter, to make some changes in its construction; and, with a view to one more advance, to introduce a different form of armature and note the results. The yoke which, in the working instrument, joins the cores at the ends furthest from the armature is supposed to be removed; next take away the armature and turn end to end the cores that faced it, so that the coils, instead of lying parallel, are in a straight line. With a space of one-quarter or one-third inch between them they will present the appearance shown in Fig. 25, in which C and Z, C′ and Z′ represent the terminals of the coils; one core is marked D A, the other B E; and for observation the student is supposed to take up a position in the space between the cores. First, a current in the wire C Z encircles the core D A in a direction opposite to that of the hands of a clock, that is, from right to left, then it encircles the core B E in the direction of the hands of a clock, that is from left to right. If the student will imagine himself in place between the letters A and B he can readily understand this.

Heretofore we have been content merely to state the fact of the attraction of a magnet for its armature; the point has now been reached where it is necessary to state the law of the formation of magnetic poles in cores around which a current is passing. In "Elements of Electricity" are shown magnets marked N and S; in the text relating to the same it is explained that N stands for north-seeking, S for south-seeking; and there is further stated the law that like poles repel, while unlike poles attract, each other. Reverting now to what was said of the passing of a current round a core, let us, for the sake of brevity, call the directions just mentioned anti-clockwise and clockwise. At the end of the core, at which one is looking "end on", magnetic poles are formed according to this law: When the current passes anti-clockwise, N polarity is induced in the near end, S polarity in the far end; when the current passes clockwise, S polarity is induced in the near end, N polarity in the far end. In the instance shown in Fig. 25 in the line C Z, there will be formed at A and D, N and S poles respectively; at B and E, S and N poles respectively. There is therefore on one side of the space between the cores an N magnetic pole; on the other side an S pole; it remains to provide something on which they may act.

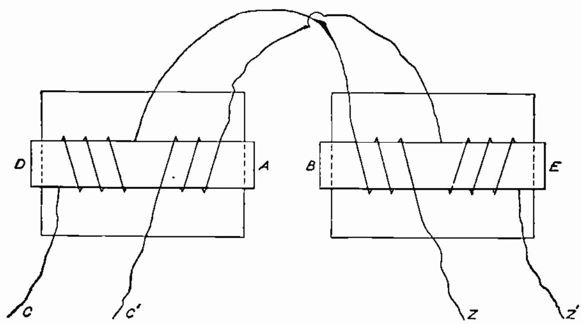


Fig. 25.

In Fig. 26 let S be the end of a permanent magnet semicircular in shape; a strip of soft iron for an armature is so pivoted that it can move freely between the stops at the upper end. In the armature the induced poles are marked with the small letters *n* and *s*, in accordance with the principle stated in "Elements of Electricity". With no current in the wire C′ Z′, a current in the wire in the direction C to Z will induce, according to the clock rule, at A, N magnetism; at B, S magnetism. The N pole, according to a law already stated, attracts the *s* pole of the armature; the S pole repels it; the armature is strongly moved towards front stop F. The current ceases, let us suppose; but the armature has no spring, and its position remains unchanged until a current flows through the same wire in a direction from Z to C. Under its influence there is formed at B, an N pole; at A, a S pole; the effect on the *s* pole of the armature is to move it from the front to the back stop. Every time the current changes its direction the armature changes its position from one stop to another; and we have a *polar* relay. It is one in which a magnetized armature is moved from point to point under the influence of magnetic poles changing as the effect of changes in the direction of the current around the cores.

One step more and we have a *differential* polar relay. In the diagram, Fig. 26 is an extra wire with a number of turns around each core. Its terminals are C′ Z′; but it is so wound that a current from C′ to Z′ passes round the cores in a direction different from that in the line C to Z. The current from C′ passes first

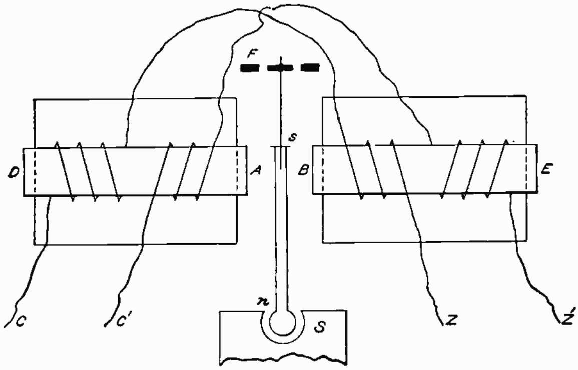


Fig. 26.

clockwise, then anti-clockwise around the cores; and from what has been said it is plain that if currents of equal strength flow in the wires C Z and C′ Z′ they will induce at A and B magnetic poles such that they will neutralize each other; provided, of course, there is the same number of turns in each coil. The effect on the armature will, in that case, be nil. But if the currents in C Z and C′ Z′ are not equal, the armature will obey the stronger current with a pull determined by the difference between the two. The result is a differential polar relay, by means of which that very perfect system of signalling in opposite directions—the polar duplex—is possible. The relay is made in different forms, but it consists essentially of a permanent magnet in which is pivoted a strip or tube of soft iron called the armature. This is placed between two cores around which are wound, in the manner shown in Fig. 26

two independent circuits. The windings terminate in four thumbscrews, with two more for the local points, making six thumbscrews for the polar relay. The spools may be wound in various ways;

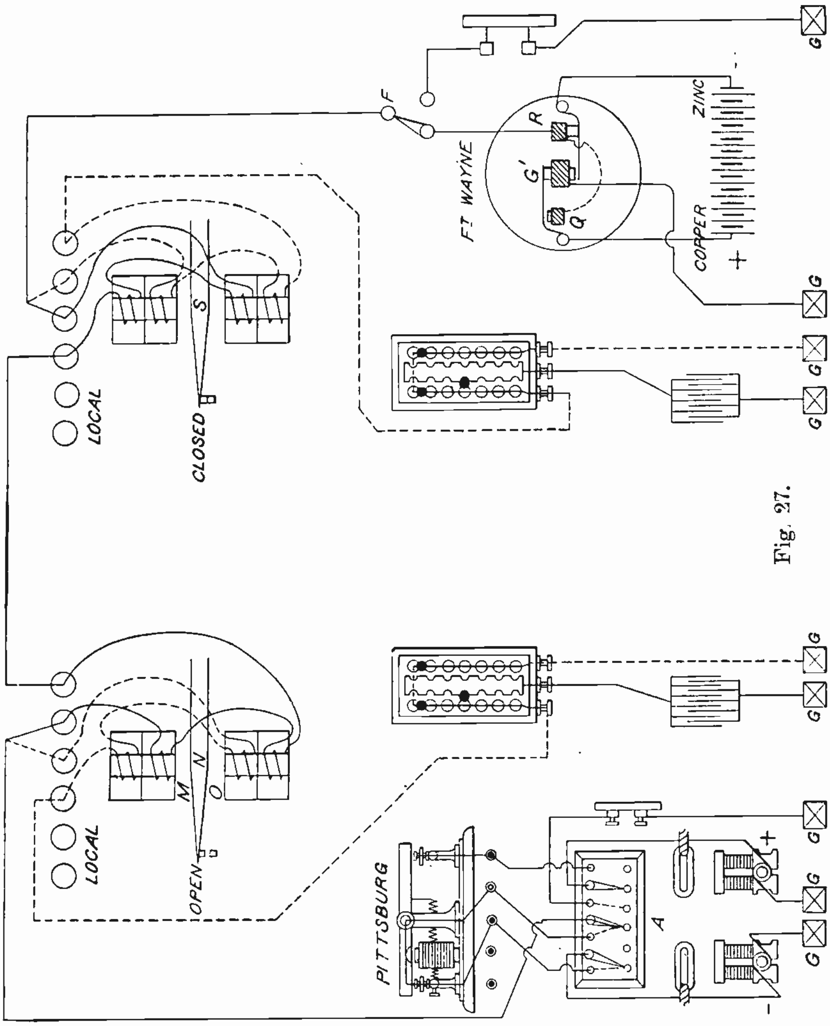


Fig. 27.

the wires may be laid side by side throughout the length of each core; or, as in the diagram, Fig. 27, in equal compartments separated by discs at right angles to the core. In the relays most commonly used each division of a spool contains 2,400 turns of wire, and has a resistance of 200 ohms; so that, in each circuit there is in the relay coils, a resistance of 400 ohms. This is equal to 42 miles (very nearly) of No. 6 iron wire, such as is commonly used in the construction of telegraph lines.

A differential polar relay, then, is one whose armature, polarized by contact with a permanent magnet, is operated by the difference in the strength of the currents, the direction of whose course is constantly being changed.

The instrument by which the direction of the current is reversed at will is called a *pole changer*, which, with the polar relay, the dynamos, lamps, and dynamo switch connected up, is shown in Fig. 27. These, with the rheostat and condenser described in connection with the Stearns apparatus, form a duplex set for one terminal. There is shown in the drawing one set for each terminal, and, for convenience in description, the left-hand station is called Pittsburg; the other Fort Wayne. The latter, as compared with the former, shows a different arrangement of battery and pole changer, of which explanation will be made later on. The Pittsburg pole changer is operated by means of electromagnets. These are part of a local circuit (not shown) and controlled by a key in the same way as the sounder in the learner's outfit. To the end posts of the pole changer are connected wires from dynamos supplying, let us suppose, a 200-volt current. It is made to pass through lamps and a switch; negative to the left, positive to the right. To the center lever of the switch is connected the main line. With the center bar of the switch to the left, connection is made with the lever of the pole changer, so that when the latter is closed a zinc current goes to the main line; when open, copper.

The lamps are placed between the dynamo and pole changer so that in case of a short circuit, by the lever of the pole changer accidentally making contact with both posts, a resistance of 1,200 ohms will be interposed until the short circuit can be broken and thus injury to the dynamo is prevented. The purpose of the dynamo switch is to provide means for readily cutting off the currents from the pole changer when any cleaning of the points or adjustment is required, or in case of a short circuit through the lever. With the center bar of switch A turned to the right, the main line goes to the ground through a resistance equal to that of each lamp, or 600 ohms; it makes no difference, therefore, in the *resistance* of the main line whether the center bar is to the left or to the right. From the switch the wire may be traced to the 'split' near the polar relay. At this point, as in the Stearns duplex, the current divides; one-half of the Pittsburg battery passing through two coils to the main line; the other half also through two coils to the rheostat, thence to the ground. The function of the rheostat, and its companion, the condenser, was explained in connection with the Stearns duplex; and it might be well to review that part of the text.

How to Balance. First approximate the balance by pegging or unpegging the rheostat to about 5,000 ohms for a line 450 miles long; in wet weather two-thirds of that. Ask the distant station—in this case, Fort Wayne—to ground; ground also at Pittsburg—the home station. Adjust, by means of the set screws, the armature of the polar relay so that it remains on one stop or the other as placed, or else vibrates freely under the influence of the slight current which the nearness of other wires on the poles may induce. Turn the switch from the ground to the pole changer connection. There is now on the wire no current of any account but your own; and the rheostat must now be so adjusted that the current from the home battery—in this case the Pittsburg—divides equally between the main and artificial lines. When it does this the armature of the home relay will vibrate freely as before.

In other words, the home current has no effect on the armature and the relay stands ready to respond to the current from the distant, or Fort Wayne, battery. Tell him to "cut in"; he does this by moving the lever of switch F from the right to the left-hand lower point; and when his key is closed your relay should close. Now, if you open and close your pole changer by means of your key the static "kick" will probably be noticed; and the remedy for it is the same as that described in connection with the Stearns duplex. This done, the "kick" disappears; the distant station writes, and it will be found that the signals sent from the home station by reversing the pole changer do not interfere with the incoming signals. Fort Wayne then asks you to ground and proceeds to balance his end; the duplex is then ready for service. In the hands of experts the operation of balancing both ways does not ordinarily require more than three minutes.

The right hand, or Fort Wayne, terminal shows an arrangement of battery and pole changer in vogue for many years before the use of the dynamo current in telegraphy; and it still obtains in a few places where a machine current is not available. The diagram represents the combination of a chemical battery of say 150 cells and the old-fashioned continuity-preserving, or clock-face, pole changer. The latter is retained here and described because it is also as an essential part of the phonoplex—the topic with which this book deals last.

In the diagram only the clock-face portion is shown; the part G′, in the center, represents the end of a lever operated like that shown in the Pittsburg pole changer, making contact with the ground. The poles of the battery connect with two springs as shown; the latter with the point-bearing blocks, Q and R are suitably insulated from the supporting material which is usually of brass. Q and R are connected to each other and to the main line. The connections made when the lever is closed are shown in the diagram. The left-hand spring is grounded, lifting it up from Q; the right-hand spring is free from the ground, but is making contact between the line and the zinc pole of the battery. When the pole changer is open, the center block drops down; the line makes connection with copper; zinc goes to the ground. In both forms of pole changer the results are therefore the same—zinc to the line when closed; copper when open—and this is the rule for their arrangement in practice. Care must evidently be taken for the adjustment of the pole changer in either form. "Clean and close" is the rule for placing of the points—as close, that is, as they can be worked without short-circuiting and sparking. Of pole changers and sounders alike the armatures must not be allowed to beat upon the magnets; to make sure they do not, a piece of paper should at times be passed between them.

As in the Stearns duplex, the polar duplex in operation has combinations of current four in number; and a description of the latter will not be complete without giving in detail the reason for the response of the relays in each combination. In advanced telegraphy there is no instrument in more general use than the polar relay; the principles involved are everywhere used; and a thorough understanding of them is necessary to a mastery of the more complex forms of apparatus and their latest applications. The changes in magnetic poles, as the result of changes in the direction of the current, will occupy our attention now; but before entering upon this we must consider the conditions which determine the direction of the current.

Much has been said about positive and negative currents, and the signs + and — are conventionally used to represent them; but these terms are not meant to convey the idea of strong and weak; a negative current may be strong or weak the same as a positive. In surveying it is convenient to consider "sea level" as a zero point from which to measure heights or depths, so in electrical potential the earth is taken as a neutral point and arbitrarily called zero; a current flowing into it is called positive; a current flowing from it, negative. If this seems unsatisfactory, perhaps an analogy may help us. Suppose we regard the air at rest as zero. Confine a rotating fan within a closed iron frame with a single tubular opening. Revolve the fan and, at the opening, a pressure will at once be felt of say 50 pounds to the inch. A few feet away the pressure will be 25; further away 15; and so on until no disturbance of the air is felt; the pressure is practically zero. Reverse the direction of the fan's motion so that instead of pressure outward there is suction inward, and at like distances effects like those just mentioned will be felt, but in an opposite sense. At the opening the suction is 50; whereas before there was an outward pressure of 50. In the one case we have the air at rest, the pressure, and the suction; these have their electrical analogies in the earth considered as zero potential; the positive current, which always sets towards the earth; and the negative, which always sets from it. The common direction of a thunderbolt is from a cloud to the earth, in this case the cloud must be positively charged; but instances have occurred where the direction of the bolt was from the earth to the cloud; in which case the cloud was negatively charged. In other words, and for the present purpose, the direction of the current is always + to zero, + to —, and zero to —; or, as stated, always from the higher potential to the lower. It is taken for granted that the same amount of current is supplied to the line at each terminal; in a duplex circuit 400 or 450 miles in length this is generally 150 or 200 volts. With these statements in mind the investigation of the combinations possible in duplex telegraphy may be taken up.

	Pgh key.	To line.	FtW relay.	FtW key.	To line.	Pgh relay.
1	Closed	—	Closed	Closed	—	Closed
2	Open	+	Open	Closed	—	Closed
3	Closed	—	Closed	Open	+	Open
4	Open	+	Open	Open	+	Open

In phases 1 and 4, the two stations present like poles to the main line; in phases 2 and 3 unlike poles.

Combination, or phase 1. Pole changers at terminals closed; zinc to the main line. In the diagram, the main line is solid black; the artificial line is dotted. With like poles of equal strength to the main line there is no current on the solid black line. Under these conditions on the artificial (dotted) line a current sets in from the ground through the rheostat, along the dotted line, through the pole changer to the zinc (—) of the dynamo in accordance with the law just stated. In the Pittsburg relay it forms first an N magnetic pole on the end of the core at M; then an S pole at O. If we enclose an N thus $\overline{\underline{N}}$ to represent the polarity of the Pittsburg armature, the magnetic conditions may be graphically represented: $\begin{matrix} n \\ \overline{\underline{N}} \\ s \end{matrix}$ closing the relay in accordance with the law that like poles repel, unlike poles attract each other. Similarly, at the Fort Wayne end, by means of a current from the ground to the zinc of the battery the magnetic conditions are: $\begin{matrix} s \\ \overline{\underline{S}} \\ n \end{matrix}$ also closing the relay.

Combination 2 shows Pittsburg +, Fort Wayne — to line; current direction on the main line is from Pittsburg to Fort Wayne. On Pittsburg artificial (dotted) line, current is from + to ground through the rheostat; on Fort Wayne artificial line it is from ground through the rheostat to — of the battery, the same as in combination 1. But the current on the main line is twice that on either of the artificial lines; because in the former case the current is from + to —, while in the latter case it is from + to ground at one terminal and from ground to — at the other.

The magnetic poles induced in the cores by the current on the main line are therefore twice as strong as those induced in the cores by the current on the artificial line. If we represent the magnetism induced by the main line current by a capital, and that induced by the artificial line current by a small letter, and indicate the polarity of the armature as before, the magnetic conditions in the Pittsburg relay may be typographically represented thus: $\begin{array}{c} Ns \\ \overline{\underline{N}} \\ nS \end{array}$ the stronger poles closing the relay; in the Fort Wayne relay $\begin{array}{c} Ns \\ \overline{\underline{S}} \\ Sn \end{array}$ the stronger poles opening the relay.

Combination 3. Pittsburg — to line; Fort Wayne + to line. Current in opposite direction to that in combination 2; but on main line twice as strong as on either artificial line; in the Pittsburg relay the conditions are $\begin{array}{c} Sn \\ \overline{\underline{N}} \\ Ns \end{array}$ opening it; in the Fort Wayne relay $\begin{array}{c} Sn \\ \overline{\underline{S}} \\ Ns \end{array}$ closing it.

Combination 4. + to the main line at each end; no current on the main line; relays actuated as in combination 1 by current in artificial line; in Pittsburg relay $\begin{array}{c} s \\ \overline{\underline{N}} \\ n \end{array}$ opening it; in Fort Wayne relay $\begin{array}{c} n \\ \overline{\underline{S}} \\ s \end{array}$ also opening it. The Fort Wayne relay might have an N armature the same as Pittsburg, but it was purposely made different to afford exercise in tracing out the effect of the current.

The student should now be master of at least the theory of the two forms of the duplex—the original Stearns and the later and more perfect polar. The former came into general use in 1872, the latter about 1880. In making comparison between the two it can be seen that the superiority of the polar duplex lies in the *relay* whose action is determined, not, as in the Stearns, by a current attracting the armature in one direction and a spring drawing it in the other, but by a current directing its movement first to the front then to the back stop. This makes the polar duplex almost independent of weather conditions. The occasions are rare, the relay being so sensitive, when sufficient current does not get past the escape to record the signals. The resistance of 450 or 500 miles of No. 6 gauge iron wire is, in dry weather, about 5,000 ohms; in damp or rainy weather this is often reduced to two-thirds, or even one-half. This is a good point to remember in adjusting the rheostat to get into communication initially with a distant station before the correct balance is taken. Less condenser, also, is needed in moist weather than in dry, because a part, sometimes nearly all, of the static charge escapes into the moist air.

With a clear wire and apparatus in good condition, the polar duplex is a well-nigh perfect instrument capable of a speed, when working the Morse system, equal to that of the fastest typewriter; and when operated by the Wheatstone Automatic system it has attained a speed of 250 words a minute each way—nearly ten times as fast as the ordinary speed by hand.

THE QUADRUPLEX.

The quadruplex—among telegraphers known always as the quad—permits the exchange of four messages at the same time; two in each direction. In the diagram, Fig. 28, presenting the theory of the quad, there is much that will seem familiar to the student; the text has been so arranged and the drawings so made as to give the impression of previous acquaintance. The neutral relays are a reproduction of the instruments made prominent in the Stearns duplex; the polar relays are those which we have just studied in the polar duplex. The rheostats—the same in principle as those already shown—are represented by a simple coil; and, shunting each, is the now familiar condenser, H and J, each with its retardation coil Rc. The batteries and pole changers are a reproduction of those shown in connection with the polar duplex.

At the left hand, or Pittsburg, end the dynamo switch has been omitted for the sake of simplicity; everything, in fact, has been left out except the parts needed to illustrate the fundamental principles on which the quad is arranged. The details which make the quad appear so complicated can be filled in later. In the diagram the one new feature is the introduction at each end of

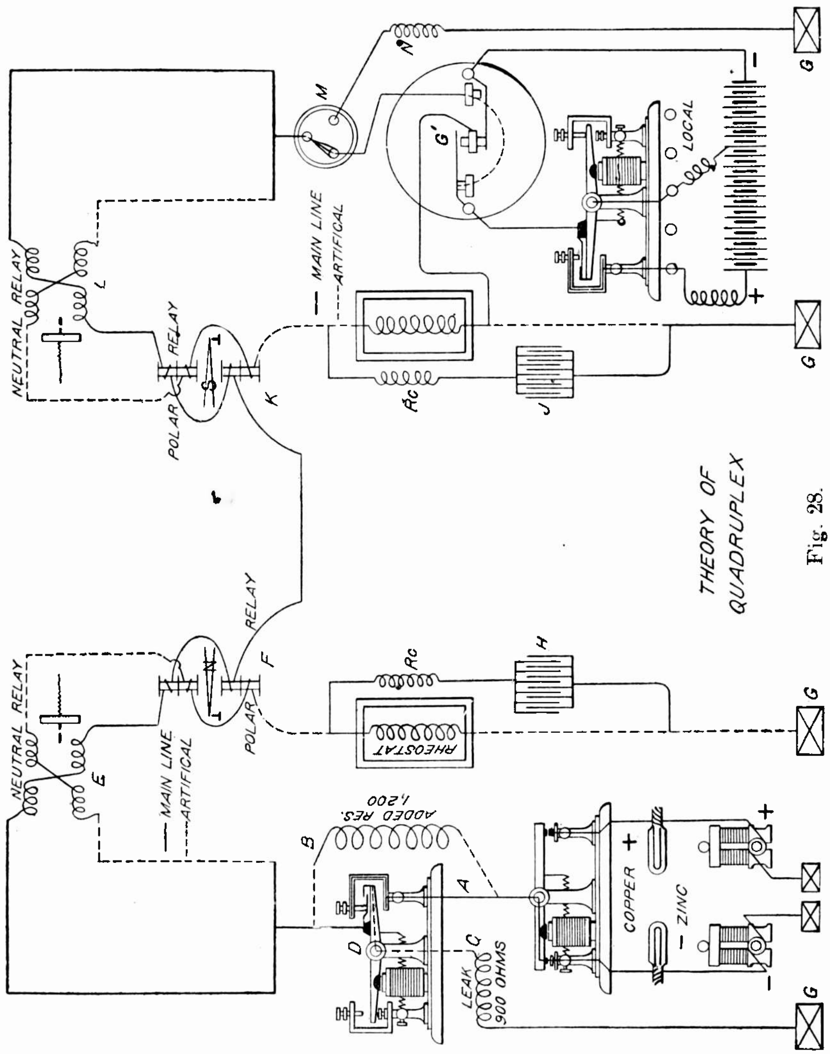


Fig. 28.

a transmitter in combination with the pole changer; at the Pittsburg end it is between the pole changer and the split; at the Fort Wayne end between the battery and the pole changer.

We have seen that it is the function of the pole changer to alter the *direction* of the current; it is the function of a transmitter, like those shown in Fig. 28, to alter the *strength* of the current within certain well-defined limits. Now the pole changers are evidently in position for the purpose of operating the polar relays; the transmitters can therefore be in place only to operate the neutral relays. The instruments heretofore designated as polar and neutral are also called polar and common; the sides on which they are worked are sometimes called by the numbers 1 and 2, and sometimes by the letters A and B.

From what has been said, the student may already have inferred that a neutral relay is one operated by the strength of the current without reference to its direction; he knows that a polar relay is operated by the direction of the current without reference, within reasonable limits, to its strength; and *in the combination of these two principles* lies the theory of the quad, as it is commonly known. There are other forms of the quad; but our present business is with the one still in general use.

The student is now asked to recall and review an experiment made in connection with the Stearns duplex, and intended for introduction at this point. It was made clear that, by the simple expedient of "turning up" on the relay spring, the Stearns duplex could be operated even when a weak current remained continuously on the main line; or, as it was expressed in a former paragraph, "If, for any reason, we desired to maintain a weak current on the line, we could use therefor a portion of the battery and counteract the effects of the weak portion by giving the spring sufficient tension to overcome the magnetism induced by it." The need has now arisen for maintaining at least a portion of the current continuously on the line; and the reason for it is that changes in the direction of a comparatively weak current will operate a polar relay as readily as the reversals of a current three or four times as strong. The neutral relay can be made unresponsive to the weak current, but responsive to a strong current without reference to its direction; in other words, the quadruple is merely a combination of the Stearns duplex, in a form modified as shown in the text, with the polar duplex. It remains only to explain some details of the combination.

The operation of the pole changer at the right, or Fort Wayne, end is identical with that described in connection with the polar duplex; but it will be noticed that the battery and transmitter connections are such that it depends on the opening and closing of the transmitter whether a third or the whole of the current is admitted to the reversing process. If the transmitter is open, as shown in the diagram, that portion of the battery between the two coils—nearly two-thirds of the whole—is "dead"; the other third (called the short end) is admitted to the pole changer through the lever and tongue of the transmitter. In the diagram the Fort Wayne pole changer is open; through the tap wire the copper of the "short end" is to the main line, and zinc to the ground. This position of the Fort Wayne pole changer opens the Pittsburg polar relay; the Pittsburg neutral relay too is open, because the short end only of the Fort Wayne battery is to the line and the spring of the relay is "turned up" above it. Close the Fort Wayne pole changer; now, at Fort Wayne, zinc is to the line, and short end copper to the ground; the Pittsburg polar relay closes in accordance with a change in the direction of the current; but the Pittsburg neutral relay remains open, and will not close until the Fort Wayne transmitter closes and admits the entire battery to the main line. In closing the transmitter the tongue breaks its connection with the lever and makes connection with the left-hand post so that the whole battery goes to the line.

The placing of the tap wire, as shown in the drawing, effects what is called the proportioning of the current; the proportion is usually 3 to 1, but can be made 4 to 1; that is, the transmitter, when closed, admits four times as much current to the line as when open.

At the Pittsburg end, the dynamo current requires a different arrangement in order to proportion it; but the effect is precisely the same. When the transmitter is open, one third of the battery goes to the line; two thirds escapes through a "leak" to the ground; when the transmitter is closed, as shown in the diagram, the entire current goes to the line. The Pittsburg pole changer is closed, sending zinc to the line; the effect of this, in connection with the Fort Wayne short end copper to the line, is to set up a current Fort Wayne to Pittsburg. In the Fort Wayne relay there is induced in the upper core S polarity; in the lower N; the effect of these on the S armature is to close it; the effect of the transmitter closed at Pittsburg is to close the Fort Wayne neutral relay. The number of phases or combinations possible to the eight instruments (four at each end) of the quad is sixteen; and one of these has been traced out with the results described. The general result in every case is that the Fort Wayne neutral relay obeys the Pittsburg transmitter; the Fort Wayne polar relay obeys the Pittsburg pole changer, and *vice versa*.

How to Balance. The operation of balancing the quad is the same as that followed in connection with the polar duplex, except that the static is eliminated by watching its effect on the neutral relay instead of the polar. Approximate the resistance in the rheostat to that of the main line: Pittsburg then asks Fort Wayne for his ground, and goes on the ground himself. Center the relay so that the armature remains on the front or back stop as placed; or vibrates freely under the influence of slight extraneous currents. Turn on the home, or Pittsburg, battery and adjust the rheostat until the polar relay vibrates freely as before. Now wedge the sounder of the polar relay in order to silence it temporarily. Turn down on the spring of the neutral relay; close the transmitter and dot slowly on the pole changer. Commonly a kick will be felt on the neutral relay which can be removed by adjusting the plugs on the condensers; turn down further on the spring and readjust the condensers; turn down still more if necessary and readjust the plugs until all trace of the kick is removed. Now restore the spring to its normal pull, and ask Fort Wayne to cut in. Ask him to write on the common, or No. 2, side and dot on the polar side. Pittsburg does the same, and, if his balance is correct, the signals from Fort Wayne on each side of the quad will be clear-cut and readable. Pittsburg now grounds for Fort Wayne, who goes through the same routine, and tests the result in the same way. This done, the quad is ready for service and is capable during a day of $9\frac{1}{2}$ hours of carrying 300 messages each way on the polar side, and 250 each way on the common side.

The slower work on the No. 2 side has its source in a defect in the quad which has never been entirely overcome. In the operation of the pole changer, even of the clock-face kind, when the direction of the current is changed it is plain there must be a very brief moment of time when there is no current on the line; at such moments there is a tendency on the part of the armature of the neutral relay to fall away from the magnets. If the local contact were on the front stop this would record a false signal; and the greater the length of the wire worked in the quad the more apparent is the interval.

On all long-distance quads, with a view to eliminate the false signal, there is interposed (see Fig. 29) between the relay and the recording sounder, what is called a repeating sounder; the device, however, is not an entire success, and the signals on the common side lack firmness to an extent which affects the speed.

Troubles of the Quad. It is usual in text books dealing with this subject to devote considerable space to the troubles of the quad. An expert quad man is not he who sets up quadruplexes—that is generally done by the office lineman—it is one who keeps the quad in working shape, and who, when any stoppage or defect arises, can locate the trouble and remove it. In the language of the craft, a defect in the set is called a "bug"; and those who deal with them are known as "bug hunters." It would be possible to fill a book the size of this with the ailments of the quad; how to locate and remedy them; the reader might study it attentively, but if his knowledge of the principles underlying the quad arrangement was hazy he might, and probably would, be worsted by the very first trouble he met; on the other hand, if he is thoroughly versed, as it has been the aim in these pages to make him, in first principles, each experience of trouble and its removal will prepare him to cope with the one that next presents itself. A prime qualification for anyone who aspires to be a defect hunter is a persistence in the search which never flags until the root of the trouble has been found and removed.

A very insidious defect in a quad, because, slight at first, it may gradually grow worse, is that of unevenness in the coils, producing what is called a "lop-sided" relay. It is well to make tests, at stated times, of the relay coils with a current other than that of the quad. It need hardly be said that the batteries for the quad must be kept up to the standard; that the ground wires and their resistance coils, which are a part of the circuit when a balance is taken, should have all their connections intact. If, when Pittsburg took a balance, Fort Wayne gave him a defective ground, it would add to the normal resistance of the line the resistance of the Fort Wayne rheostat, and making a working balance impossible by the ordinary method. It is not an uncommon occurrence for one pole of the battery to fail, particularly if the current is furnished by a dynamo. If Fort Wayne suspects this he will ask Pittsburg to open his key; this means, in other words, "give me your copper current". Fort Wayne writes and the relay does not give back his signals. Then he asks Pittsburg to close his key. Fort Wayne writes and finds his own relay following the key, which it should not do, because, when the battery and wire are intact and the line balanced, the relays do not respond to the home key. Fort Wayne then tells Pittsburg the result of the test, and that his zinc pole is not coming to line.

Caution is once more enjoined against the practice of allowing the armature of the pole changer or transmitter to hit upon the magnets or come in contact with them.

The proper way to make a test of a quad set is, of course, to put an ammeter in the circuit and see if the currents are going out in their normal proportions. If a meter is not available, a rough test of the currents can be made by using the polar relay for a galvanometer. Remove the main line wire from the binding post of the polar relay, the armature of which is supposed to be centered. Close both keys and with the finger feel the pull of the armature; what you feel is the attractive force of the entire zinc current. Open the pole changer and see how the pull of the copper current compares with that of the zinc. It should be the same. Now open the transmitter, and the weaker pull of the short end copper is felt; close the pole changer and the pull of the short end zinc should equal that of the copper. By this process the short and long ends of each pole, through the coils of the artificial line, have been tested. Remove the artificial line from its binding post and attach it to the main line post, from which the main line wire has previously been removed, and a test can be made of the currents through the main line coils under all the conditions noted.

In the hands of a person to whom experience has given some nicety of muscular sense, this method, in the absence of a meter, gives fairly satisfactory results. In an office where two quad sets are available, and occasional cessation in their use gives opportunity, the following plan for familiarizing one's self with the quad and its troubles is suggested by an expert. Select a station 200 miles away and ask him to "loop", that is to join together, two wires which you name. Connect the two wires to adjacent sets in your own office. Balance them as though they were distant sets. Now introduce into one set any form of interference or disconnection that would be likely to occur in practice, and observe the effect on the other set; experience may be gained in this way that would aid in the location of trouble when it occurs in practice.

Duplex Repeater. In wires worked on the duplex or quadruplex system, the static capacity of the wire places a limit on the number of straight miles a circuit can be worked. But the distance between stations can be greatly extended by the use of repeaters in which, by a perfectly simple arrangement of local circuits, the pole changer of a second circuit is controlled by the relay points of the first, and *vice versa*. For example, in the text, a duplex Pittsburg to Fort Wayne was described; call it the first circuit. For a second circuit suppose Fort Wayne has a duplex to Chicago, and that Pittsburg wishes to be put through direct. By means of switch-jacks and cords provided for the purpose, Fort Wayne makes the electromagnets of the pole changer of his northern set a part of the local circuit which passes through the points of the polar relay of his Pittsburg, or eastern, set; he also makes the electromagnets of the pole changer of his eastern set a part of the local circuit which passes through the points of the polar relay of his northern set; Pittsburg and Chicago can then work duplex. The longest regular circuit in the United States is that worked between New York and San Francisco with six repeaters; another long circuit is that between New York and Heart's Content, Newfoundland, with repeaters at Boston, St. John, and North Sydney. In a few seconds these two circuits could be repeatered at New York; San Francisco and Heart's Content could then work duplex through nine repeaters—a circuit from ocean to ocean where the continent is widest.

The Repeating Sounder. *Duplex Loops.* Fig. 29 shows the local connections of the common side of a quad and the method of

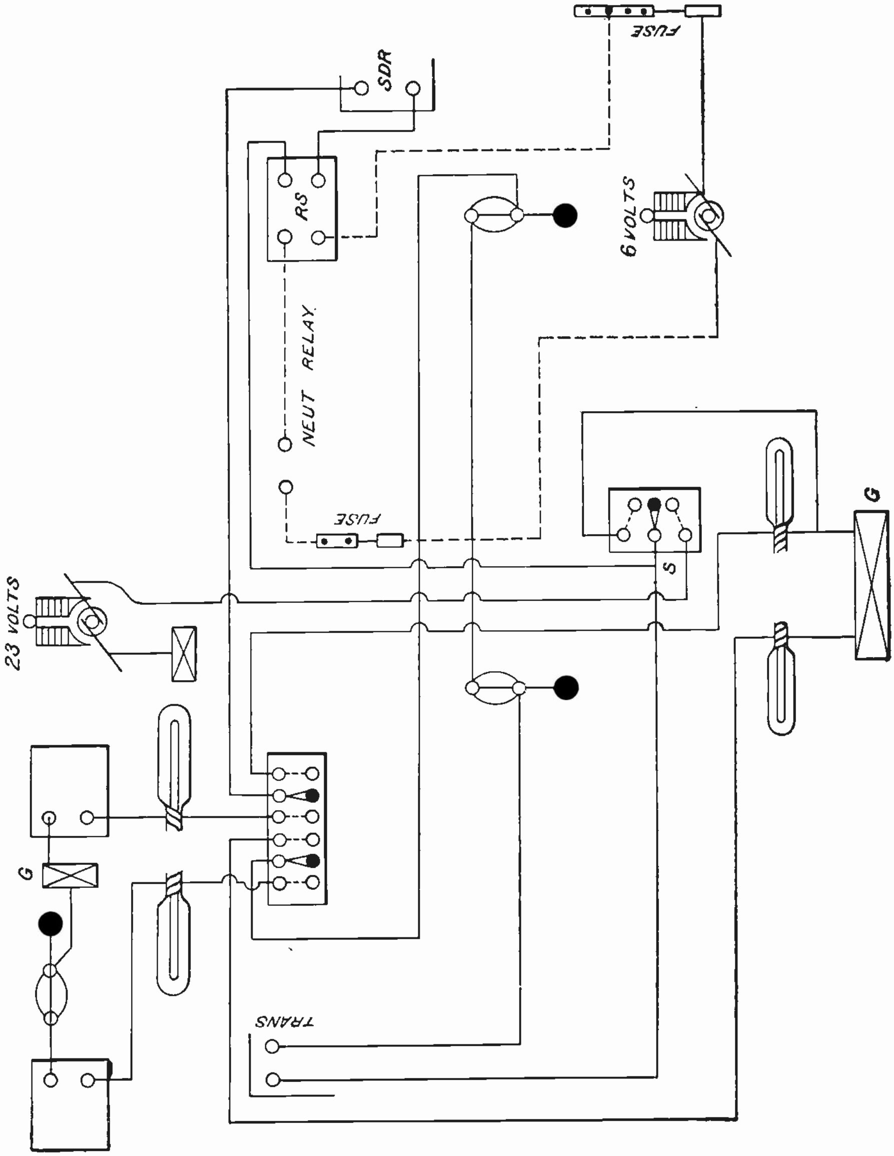
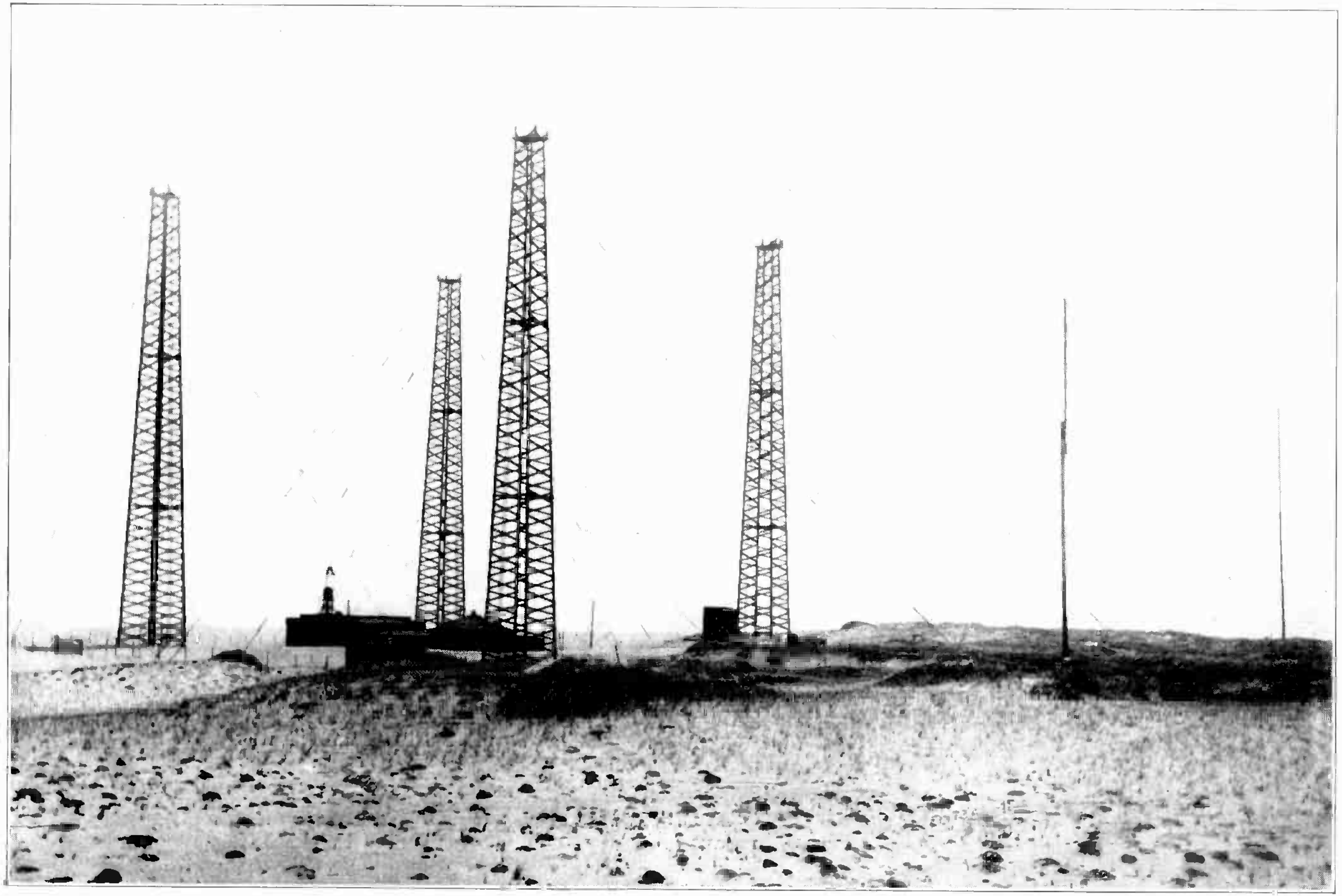


Fig. 29.

current supply which, it is seen, is from two independent sources. The common side is shown preferably because it exhibits, in place, the repeating sounder, to which reference was made in a preceding paragraph, in the receiving, or relay, side. The current supply is a 6-volt dynamo, from one pole of which a wire extends through a fuse to the armature of the neutral relay. From the *back*, not the front, stop of the relay it passes through the coils of the repeating sounder, through another fuse, back to the dynamo, thus completing a metallic circuit. When the neutral relay is on the front stop, the *repeating* sounder is open; but its points, between the lever and the up stop, are closed, permitting the 23-volt current to close the other sounder from which the signals are read. When the neutral relay points open, the repeating sounder is closed, but the receiving sounder is open; the reason for this arrangement has already been given in the text on the quad.

The regular local system of a duplex, or one side of a quadruplex, is not a metallic circuit; it is a grounded system supplied, as the drawing shows, by a 23-volt dynamo. The reason for the ground arrangement is that in all the principal offices by far the greater number of the duplex and quadruplex sets are fitted up so that while the sets themselves are in the main office, where they can receive expert attention, they can be operated in branch offices by means of what are called "loops", or "legs". By suitable switches the loops can be cut in or out as desired.

The current from the 23-volt dynamo runs first to a fuse block (not shown); thence to a small 3-point switch, the lever of which, if turned to the left, connects the battery with the set; if turned to the right it connects the set with the ground. The latter connection is made in "setting up" a duplex repeater. With the lever to the left, the current is seen in the drawing to divide at the point S; one branch can be traced through the points of the repeating sounder, through the coils of the receiving sounder; thence (with the lever of the 6-point switch to the right) through a lamp of about 96 ohms resistance to the ground. The other branch can be traced through the coils of the transmitter; through two keys; thence (the lever of the 6-point switch to the right) through a lamp to the ground. The purpose of the lamps is to make the resistance in the circuits the same in either position of the levers of the 6-



MARCONI WIRELESS TELEGRAPH STATION AT SOUTH WELLFLEET, MASSACHUSETTS
Towers 215 Feet High.

point switch. Above this switch are the connections and outfit of a branch office for the operation of a duplex; or, what is known as a duplex loop. It shows one wire connecting a lamp and the coils of a sounder to the ground; another wire connecting a lamp, sounder and key to the ground for the sending side; the first mentioned sounder is that of the receiving side. To cut them in, turn the levers of the 6-point switch to the left; the relay then operates a receiving sounder in both main and branch offices; the branch office can operate the transmitter and work duplex with another city or a branch office therein similarly equipped. The word "loop", though commonly used in this connection, is a misnomer. In telegraphy, loops connect an outlying office, which may be rods or miles away, with a single Morse circuit. To do this, the pair of wires leading to the distant relay, which makes the loop properly so called, terminates in a wedge which can be inserted in the spring-jack of any wire in the main switch. In the duplex arrangement the wires operating the branch instruments are merely extensions of the sending and receiving sides of the local system.

There are many matters of detail in connection with the setting-up and operation of a quad which do not properly fall within the scope of this work. For special works on the duplex and quadruplex the reader is referred to Thom and Jones' Telegraphic Connections; to Jones' Pocket Edition of Diagrams; and to Maver's American Telegraphy: Its Systems and Operation.

THE PHONOPLEX.

Among contrivances for increasing telegraphic facilities a worthy place is occupied by the device known as the Phonoplex—an invention of Mr. Thomas A. Edison. In its mode of operation it will be found to differ materially from anything heretofore presented; its essential feature being the superposition, without noticeable interference, of the high-tension impulses of a magnetic coil upon the current or currents of the Morse system. Even when all the wires on the route are crossed or grounded, not excepting the one upon which the phonoplex is working, it admits of serviceable operation.

It can be worked in connection with the duplex and quadruplex systems; but its usefulness is greatest as an adjunct to the single-line service of the railways, providing, in a sphere where

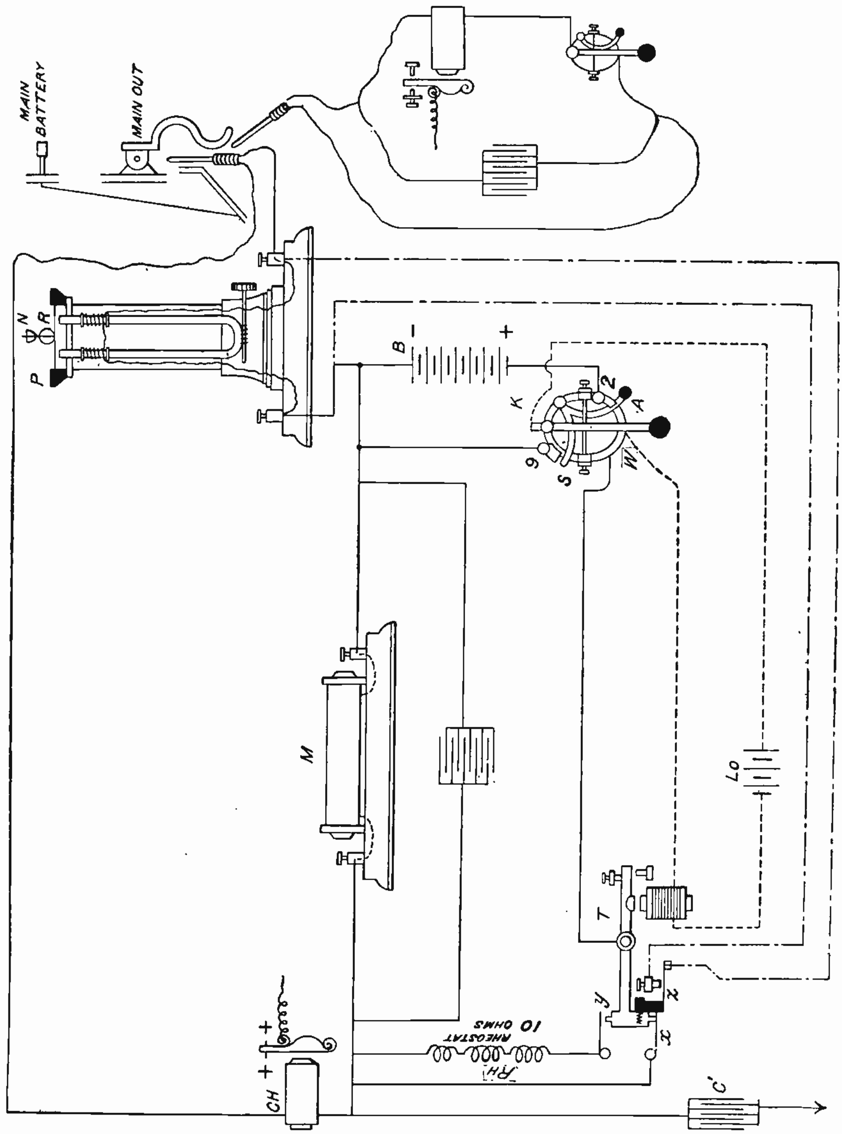


Fig. 30.

the number of wires is usually limited, an extra circuit which is at all times available. The apparatus is adapted for use between intermediate, as well as between terminal, points; but the diagram (Fig. 30) presents, and the text describes, the arrangement of a terminal station where the single wire takes its battery. As it embodies some new features, the details require more than usual length in their description. Referring now to the diagram—on the right is seen the spring-jack of a terminal switch, showing main battery and line connections. Two wedges are inserted in the jack; one carries the conductors to the phonoplex; the other cuts in a main-line key and relay which are bridged by condensers; the bridging arrangement obtains also at every intermediate station. This use of condensers makes feasible the operation of the phonoplex in the presence of crossed and grounded wires—a feature to which reference has already been made.

The phonoplex requires for its operation, two batteries—one. B, of at least five 2-volt cells, and one, L*o*, of three cells; a key and transmitter, each of peculiar construction; a small rheostat containing five coils of two ohms each; a simple magnetic coil, bridged by a condenser of small capacity, to quicken the impulses sent out from the coil; an ordinary Morse relay and condenser; and, lastly, the characteristic phonoplex instrument itself, marked P in the diagram. The latter consists of a circular wood base supporting an upright cylinder containing an elongated horseshoe magnet, upon each pole of which is wound a small coil of insulated copper wire. Above the poles, and covering them, is a metallic diaphragm like that used in the telephone. A split steel ring R rests upon this diaphragm, or moves freely upon a threaded vertical pin N, at the top of which is placed an adjustable nut. Each agitation of the diaphragm causes the steel ring to be thrown up against the nut, producing an excellent imitation of the well-known "click" of the sounder. Between magnetic coil M and the main battery is an ordinary 150-ohm Morse relay C H, which acts as a choke-coil; to it is tapped a condenser C′, and a ground. R*h* is a small adjustable resistance box containing five coils of about 2 ohms each. This resistance is introduced into one of the circuits bridging the magnetic coil, in order to weaken the current so that one stroke of the phone recorder may be distinguished from the other; otherwise the "back-stroke" effect would ensue, and the signals would not be readable. Of the wires bridging the magnetic coil two, on the left-hand side, terminate in springs between which moves the hammer-headed lever of the transmitter operated in the usual manner by means of local battery L*o*, and key K. The lower end of the hammer-head also has an attachment which acts on spring *z* for a purpose which will be explained later.

It is difficult to represent in a diagram the insulated portions of key K; in order to understand its working a detailed description is necessary. The key and its attachments control two independent circuits. The ordinary circuit-closing switch is absent; the local circuit (dotted) is always "open" except when signals are being sent. One conductor of the local circuit makes connection with the anvil post W which is insulated from the base, and is fixed underneath the lever. To the further end of the lever is attached the other end of the local circuit conductor, so that when the key is depressed, the transmitter is closed. To the near end of the base of the key is connected a wire leading to the lever of the transmitter T. Attached to the base by means of a screw, which serves also as a pivot, is a curved arm A, at the pivoted end of which is a curved spur *s* reaching across the base of the key. At 2 and 9 are small spurred thumbscrews attached to, but insulated from the base; so that, in the position shown in the diagram, the arm A puts 2 in contact with the base; but if the arm is withdrawn from 2 a sufficient distance then 9 makes contact with the base through the spur *s*.

To understand the working of the apparatus it must be borne in mind that the transmitter, unlike that of the Stearns duplex, produces the effects of dots and dashes by the "breaks", and not by contacts. In the diagram, the lever of key K, and that of transmitter T are open; the current from B flows from + to 2, through the base of K and the lever of T, through spring *x* and the coil M, to – of battery MB, thereby charging the coil with the full strength of B. The act of depressing the key lever breaks the contact at *x*, coil M discharges, and a loud "snap" is heard in the distant phone or phones. When the lever T strikes the upper spring *y*, the current flows through *y* instead of *x*, thence through resistance R*h*, charging coil M less strongly than before; so that, when the upward movement, or opening, of the key breaks the contact at *y*, a less pronounced snap is heard on the distant phone; thus obviating, as already stated, the effect of the "back-stroke".

It will be noticed that, during this sending operation, the curved arm is to the right, which is the position of an ordinary key when an operator is sending. When he begins to receive on the phone, he moves the curved arm to the left, which movement corresponds to the "closing" of an ordinary key; but in this case the movement simply disconnects the battery B from the transmitter, and the spur *s* makes connection between 9 and the base, shunting the magnetic coil, so that the phone may be affected by the maximum of charge and discharge from the distant magnetic coil.

One feature remains to be described. Leading from the terminals of the phone may be noticed a shunt circuit (in dots and dashes) terminating in spring *z* and a contact point above. The position of spring *z* is such that when the transmitter is open and its lever in a downward position, the shunt circuit is open; but when the hammer end of lever T is raised, and so long as it remains so, the phone is shunted. This automatic shunting of the phone during the time when the lever is "breaking" the charging currents of the coil, obviates annoyance from the discharges of magnetic coil M to the operator who is sending in proximity to the home phone.

GUGLIELMO MARCONI
Inventor of the Marconi System of Wireless Telegraphy.

WIRELESS TELEGRAPHY

INTRODUCTION

As a first step into the subject of wireless telegraphy it may be well to consider the meaning of the term. Wire telegraphy is characterized by the employment of extended metallic lines or conductors over which it is possible to transmit intelligence electrically by means of an arbitrary code of signals. Wireless telegraphy is characterized by the absence of such lines in the accomplishment of the same end. Many have confounded wireless telegraphy with the system invented by Marconi; but the latter is only one form out of many: the term was used to describe other systems years before Marconi's spectacular success added it to the popular vocabulary. As a matter of fact any system of telegraphy which successfully substitutes some other medium for the connecting wires, may properly be called "wireless." The systems of wireless telegraphy so far proposed may be classified as follows: Conduction Systems; Induction Systems; and Radiation Systems.

The history of the subject follows very closely the above sequence in point of time. First came the conduction systems—the attempt to substitute the earth and bodies of water in place of the connecting lines. Then came the induction systems, taking advantage of those peculiar electrical phenomena known as electrostatic and electrodynamic induction: here the substituted medium was the ether—that invisible, intangible substance which is supposed to fill all space. Last came the radiation systems, which also make use of the ether, but in a different way, namely, by disturbing it in such a manner as to produce far-reaching waves which can be detected at distant points. It is the last type, known as *radiotelegraphy*, which is today paramount, having superseded the other two by reason of its superior utility and effectiveness. Its startling development during the past ten years may justly be called a "fairy tale of science." The earlier systems are important, however, as they mark the birth and the development of an idea.

CHAPTER I

EARLY FORMS

Conduction Systems. The essential feature of all conduction systems is that *some other form of material conductor is substituted for that of wires.* These substitutes have been in all cases either earth or bodies of water, because they are the only natural conductors which are sufficiently common and extensive to be utilized.

Work of Steinheil. Today it seems glaringly obvious that the earth may be used as a conductor, but in 1838 when Steinheil, a Bavarian, accidentally discovered this fact, it created quite a sensation. He had been experimenting with the steel rails of a railroad trying to utilize them as substitutes for the wires of a telegraph circuit, but was unable to obtain sufficient insulation. He was surprised to discover, however, what a high degree of conductivity the earth possessed, and was led to conceive that he might employ it instead of the return wire hitherto used. He made the experiment, and with complete success, thus introducing into telegraphy one of its most important features—the earth circuit. Expanding the idea, Steinheil wondered if it were not possible to telegraph through the earth without using metallic conductors at all. This experiment, which was successful over very short distances, is said to have been the first attempt to telegraph without wires. Steinheil, however, being unable to signal farther than 50 feet, gave up this method, convinced that it was inexpedient for telegraphy.

Morse System. S. F. B. Morse, who is famed as the inventor of wire telegraphy and of the code which still bears his name, was, by a strange coincidence, also one of the pioneers of telegraphy without wires. In 1844 he addressed a letter to Congress in which he related his experiments in this field and gave an interesting account of his inception of the idea. A portion of the document, considerably abridged, is as follows:

In the autumn of 1842, at the request of the American Institute, I undertook to give to the public in New York a demonstration of the practicability of my telegraph, by connecting Governor's Island with Castle Garden, a distance of a mile; and for this purpose I laid my wires properly insulated beneath the water. I had scarcely begun to operate, and had received but two or three characters, when my intentions were frustrated by the accidental destruction of a part of my conductors by a vessel which drew them up on her anchor and cut them off. In the moments of mortification I immediately devised a plan for avoiding such accidents in the future, by so arranging my wires along the banks of the river as to cause the water itself to conduct the electricity across. The experiment, however, was deferred until I arrived in Washington; and on Dec. 16, 1842, I tested my arrangement across the canal, and with success. The simple fact was then ascertained that electricity could be made to cross a river without other conductors than the water itself; but it was not until the last autumn that I had the leisure to make a series of experiments to ascertain the law of its passage. The diagram, Fig. 1, will serve to explain the experiment.

A, *B*, *C*, *D*, are the banks of the river; *N P* is the battery; *G* is the galvanometer; *W W* are the wires along the banks, connected with copper plates *f*, *g*, *h*, *i*, which are placed in the water. When this arrangement is complete, the electricity, generated by the battery, passes from the positive pole *P* to the plate *h*, across the river through the water to plate *i*, and thence around the coil of the galvanometer to plate *f*, across the river again to plate *g*, and thence to the other pole of the battery *N*.

Morse here appends a table of his results, "showing," as he says, "that electricity crosses the river, and in quantities in propor-

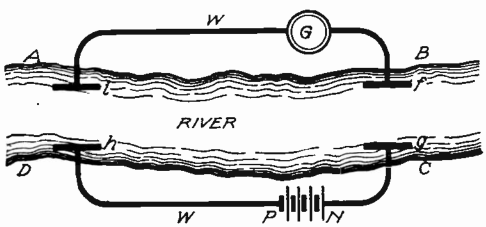


Fig. 1. Experiment of Morse

tion to the size of the plates in the water. The distance of the plates on the same side of the river from each other also affects the result." This distance he states elsewhere should be three times greater than that from shore to shore across the stream.

Morse's plan contains in a simple form all the essential features of all later endeavors to telegraph by the conduction method whether utilizing water or earth as the medium. Lindsay, Highton, Dering, Stevenson, Preece, Smith, and others subsequently worked out more elaborate and extensive methods all resting primarily on the same principle as above. None of them succeeded in signaling much farther than three miles. These early results indicate the inherent limitations which have ever remained as insurmountable difficulties to the commercial adoption of this form of wireless telegraphy.

Induction Systems. Induction is an electrical influence exerted by a charged body or by a magnetic field on neighboring bodies without apparent communication. The laws of it are well known to electrical science through the classic researches of Faraday. Induction comprehends two classes of phenomena known, respectively, as *electrostatic induction* and *electrodynamic induction:* the former is that property of the electrostatic field which produces an electric charge in a conductor when brought into the said field; while the latter is that property of the magnetic field by virtue of which electromotive forces are created in conductors by a relative movement between said field and such conductors. Without attempting to go further into the matter here, it suffices to say that investigators were not slow in appreciating that induction offered a means of communication which could be classified as "wireless."

Dolbear System. What is now generally considered to be an extreme case of electrostatic induction is the remarkable system of wireless communication invented by Prof. Dolbear of Tufts College, Boston, in 1882. This system is of especial historical interest owing to its startling resemblance to the system devised later by Marconi. Dolbear's invention may be best explained by referring to Fig. 2. The left side represents the transmitting circuit and the right, the receiving circuit. *B* is a battery connected through a carbon transmitter to the primary winding of an induction coil, the secondary terminals, *A* and *C*, of which are connected, respectively, with an elevated wire and the ground. The receiving end consists essentially of a similar elevated wire *A* connected to one terminal of a telephone receiver, the companion terminal of which is connected directly with the earth. The higher these wires are raised, the farther signals can be transmitted, so that Dolbear was prompted to attach them to kites. This is a curious anticipation of Marconi's antennae. Dolbear later made many modifications in his apparatus in an endeavor to reach greater distances by employing condensers raised to a considerable height and charged by batteries; but the system remained in all important respects the same as shown.

The apparatus works as follows: The diaphragm of the telephone transmitter is set into vibration by talking or whistling, thereby producing variations of resistance in the powdered carbon; this constantly varies the amount of current which flows into the induction coil; and consequently the wire A is charged to potentials which are constantly fluctuating in value, the degree of fluctuation depending on the degree of variation of resistance in the transmitter. The wire A' at the receiving station follows by electrostatic induction all the fluctuations of A; and with every change of potential, currents flow between A' and the ground through the telephone receiver R.

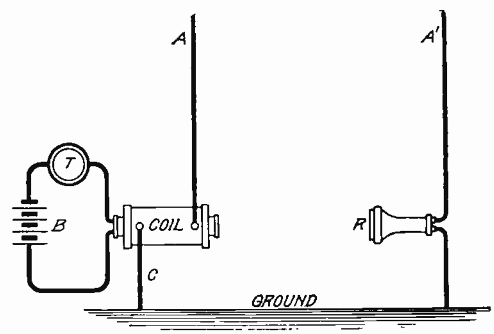


Fig. 2. Diagram of the Dolbear System

The latter consequently repeats all the vibrations set up in the transmitter, and the corresponding sound is reproduced. This particular method of operation is telephonic; but it will be seen that the same, or rather better, results could be obtained by a Morse key and telephonic receiver.

Edison System. Edison patented, in 1885, a system of inductive telegraphy, the particular purpose of which was to effect communication with moving trains. The ordinary telegraph wire, which commonly runs parallel to a railroad track, was utilized for one of the inductive circuits, and the train was equipped with another. The latter consisted mainly of a large, metallic condensing plate set on the roof of the car and connected to the secondary terminals of an induction coil, to the primary terminals of which were connected suitable transmitting and receiving instruments. When the Morse key in the primary circuit was depressed, the large condensing plate received static impulses and these acted inductively on the neighboring telegraph wire, which thereby received and conducted equivalent impulses to the nearest station equipped with proper receiving instruments. Or in case another train equipped as above were traveling on the same track, it could pick off the message inductively from the telegraph wire. In this manner two moving trains might communicate. This ingenious system was put into practical operation on the Lehigh Valley Railroad in 1887, and worked with undoubted success; but from a business point of view it proved a failure as there was no public demand for such service.

Work of Preece. One of England's most successful investigators in the field of wireless telegraphy was Sir Wm. Preece, chief electrician of the British Postal Telegraphs. He performed numerous experiments which added greatly to the theory of all forms of inductive and conductive communication. One of his most successful achievements was to effect inductive communication between Gloucester and Bristol on the banks of the Severn, a distance of nearly five miles. Parallel to the two shores were stretched on telegraph poles two closed wire circuits extending about 14 miles each. One of these circuits was traversed by a rapidly interrupted current of about .5 amperes. A telephone receiver inserted in the companion circuit responded to the frequency of the current in the other by a continuous sound upon pressure of the transmitting key. This form of communication was at one time resorted to quite frequently between stations separated by bodies of water under which it was inexpedient to lay cables.

Such systems may be characterized as "wireless" only through courtesy, since they demand an amount of wire which far exceeds that required by any ordinary wire system covering the same distance; they come under the classification of wireless telegraphy, however, since the wire conductors are not continuous, some other medium being interposed.

In the year 1885, Preece carried on very extensive investigations upon the possibilities of induction as an agency of communication, and summarized his observations as follows:

Although communication across space has thus been proved to be practical in certain conditions, those conditions do not exist in the cases of isolated lighthouses and light-ships, cases which it was specially desired to provide for. The length of the secondary must be considerable, and, for good effects, at least equal to the distance separating the two conductors. Moreover, the apparatus to be used on each circuit is cumbrous and costly, and it may be more economical to lay a submarine cable.

These conclusions are equally true to the present day. The necessity for a large base area remains the prohibiting factor in the adoption of electromagnetic induction systems. For a very painstaking review of the various early attempts at this form of telegraphy, the reader is referred to J. J. Fahie's excellent book, "A History of Wireless Telegraphy."

Summary. The conduction and induction methods of wireless telegraphy, although of great historical and experimental value, are of little practical value. Today their use is most exceptional because their utility is too limited—the supreme test for any system of wireless telegraphy being the test of long distance. They have been superseded by a type of wireless telegraphy which can achieve communication across an ocean if necessary—a type which is the product of an entirely different principle, the principle of electromagnetic radiation. In order to differentiate it from other forms of wireless telegraphy, this system is best denominated by the term *radiotelegraphy*, and a discussion of its underlying theory, its operation, and the arrangement of necessary apparatus will be found in the following chapters.

CHAPTER II

ELECTRIC WAVES

Electromagnetic Theory of Light. In order to understand radiotelegraphy with any degree of completeness one must first have a comprehension of the theory of electric waves, including the electromagnetic theory of light. This theory, with its verification, was one of the most notable scientific achievements of the last century. However, let it be remembered that, having adopted a working hypothesis—the most tenable one at present—to account for the ether and the *modus operandi* of ether waves, it is necessary as well as convenient to use the terms and implications of such hypothesis positively and with consistency throughout. Such unqualified use of terms might give foundation to the charge of scientific dogmatism were it not remembered at all times that we are dealing with a theory, generally accepted, it is true, but subject to the trials and mutations which such theories have undergone in the past. The reasonings from the working hypothesis are valid for the purpose for which they are here employed; but no true scientist will at present claim that such reasonings should or can be extended to the higher realm of absolute truth. In the words of H. Poincaré, "It matters little whether the ether really exists; that is the affair of metaphysicians. The essential thing for us is that everything happens as if it existed, and that this hypothesis is convenient for the explanation of the phenomena."

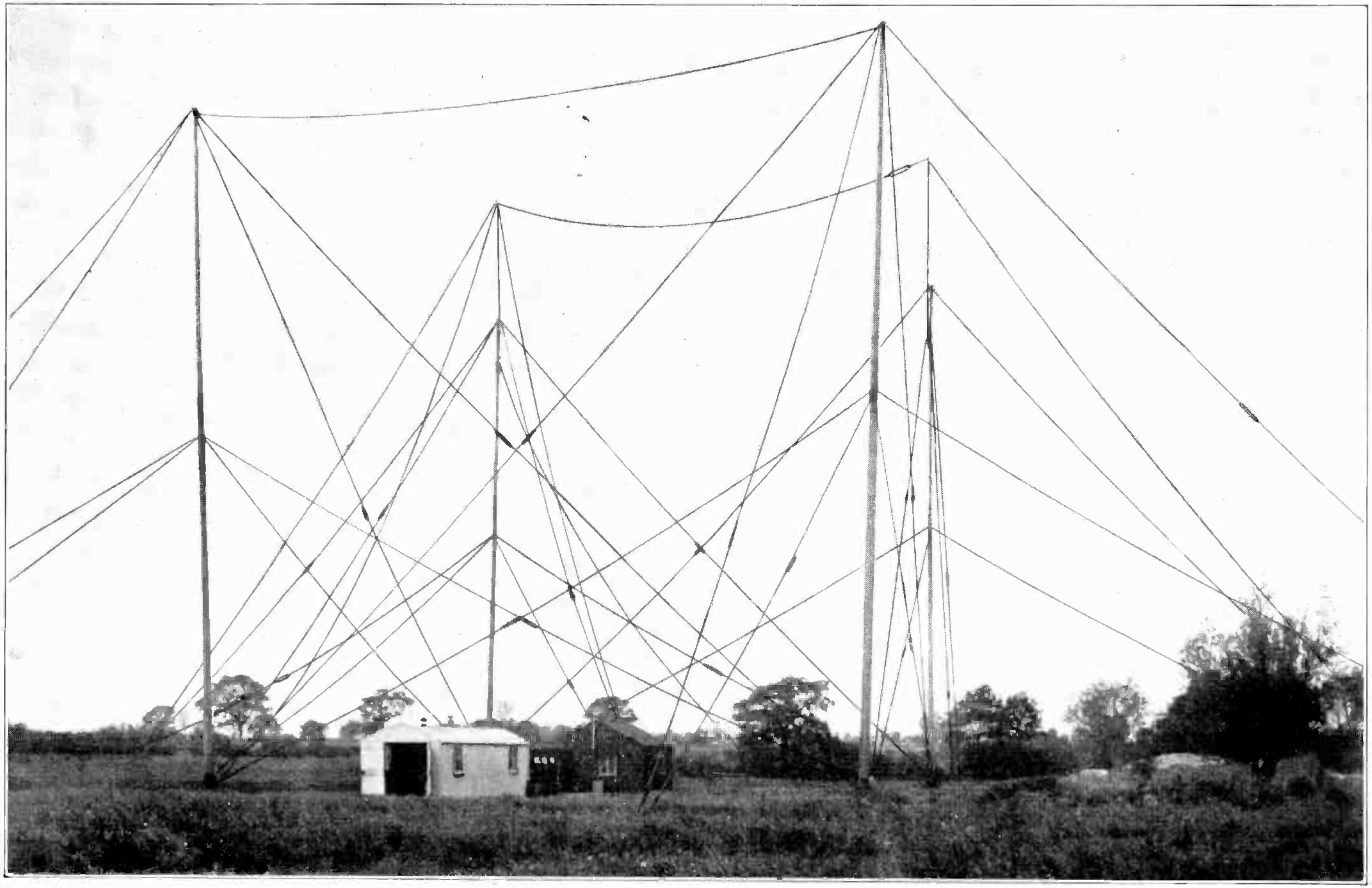
The electromagnetic theory of light was first completely stated in 1864, when James Clerk Maxwell, an English mathematician, sent to the Royal Society a paper entitled "A Dynamical Theory of the Ether," wherein he demonstrated his conviction that light and electricity were phenomena of a kindred nature—in fact, that light was an electrical manifestation. Maxwell's paper came as the result of a long series of investigations which had been carried on in two different departments of Physics--Optics and Electricity. These investigations had led on the one hand to a theory of a light-bearing medium called the *luminiferous ether*, and on the other hand to a theory of an electromagnetic medium also called the *ether*. Maxwell made a synthesis of these two theories, demonstrating that the hypothetical medium was the same in both cases, and that it was governed by electromagnetic laws.

The Luminiferous Ether. When we observe that light takes time to travel from place to place, and that it comes to the earth from the sun and stars across vast spaces which are not, so far as we know, filled with tangible matter, the inference necessarily follows that light is either a substance transmitted bodily, like a stone hurled from one place to another, or a physical state propagated through a stationary medium in the form of waves. Various investigators have demonstrated that light is a phenomenon of the latter description—that it is a physical state, or change of state, propagated through a stationary medium in the form of undulatory waves, the velocity of the waves being approximately 186,500 miles per second. Investigators agreed to call this medium the ether, prefixing the adjective "luminiferous" which means "light-bearing." They had neither seen nor felt the ether—directly or indirectly—but they reasoned that the ether must exist, else the facts of Optics were inexplicable. They held that it must be some peculiar form of matter which interpenetrated all ordinary forms of matter, and must also be distributed everywhere throughout the space of the universe. Up to Maxwell's time, however, they knew almost nothing of the ether itself, except that it behaved like an incompressible liquid, extremely tenuous but exceedingly rigid, and that the waves were of the kind classed as "transverse."

The Electromagnetic Medium. In the department of Electricity a theory of an electromagnetic medium had also grown up, following on the researches of Ampère, Henry, and Faraday. The fact that electrified bodies or magnets attracted or repelled each other at a distance, and that electric currents could create other currents in wires at a distance, and that these actions were not fundamentally dependent upon the presence of any material substance in the space between, led these investigators to conceive that there must be an electromagnetic medium by means of which such actions were transmitted across apparently empty spaces. They named this medium the ether, the same name adopted by investigators in the department of Optics; but it was a long time before anyone even surmised that there was any kinship between the luminiferous medium and the electromagnetic medium.

Work of Faraday. The first man to hint at the above possibility was Faraday, who, in 1845, discovered the singular fact that the magnet exercises a peculiar action on light, the plane of polarization of a polarized beam being rotated when the beam passes along a magnetic field. This seemed to show that there was some relation between electricity and light. Faraday persevered in these experiments. He wrote a paper entitled "Thoughts on Ray Vibrations" wherein he expressed his belief that radiation of all kinds—light, heat, etc.—were due to a high species of vibration of the lines of force in the magnetic field. Faraday's speculations may be said to have been the inception of the electromagnetic theory of light; he is indeed entitled to a large share of the credit; but his were only speculations, unformulated and incomplete, and it remained for another man to elaborate them into a complete theory mathematically demonstrable.

Work of Maxwell. When Maxwell, in 1864, sent his paper on "A Dynamical Theory of the Electromagnetic Field" to the Royal Society, one of his first steps was to acknowledge his debt to Faraday. He writes, "The conception of the propagation of transverse magnetic disturbances to the exclusion of normal ones is distinctly set forth by Prof. Faraday in his 'Thoughts on Ray Vibrations.' The electromagnetic theory of light as proposed by him is the same in substance as that which I have begun to develop in this paper, except that in 1846 there was no data to calculate the velocity of propagation." Maxwell then proceeds to give new equations to express the relations between the electric and the magnetic displacements in the medium and the forces which result from them. He shows that when magnetic methods of measurement are used, the unit of electricity arrived at has a certain value; but when purely electrical methods are used the unit proves to have a different value. The relation between these two units is dependent on the "electric elasticity" of the medium, and when measured proves to be a certain velocity—186,500 miles per second. This velocity, in other words, is that velocity with which an electromagnetic disturbance is propagated through the electromagnetic field. It will be remembered that the velocity of light was already known to be about 186,000



MARCONI WIRELESS STATION AT BROOMFIELD ROAD, CHELMSFORD, ESSEX miles per second. Maxwell comments on the startling similarity as follows: "This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations, if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws." In short, Maxwell's theory assumes that the entire material universe lies in one all-pervading electromagnetic field, called for convenience *the ether*, and if this field be disturbed at any point, the disturbance is propagated throughout the field in the form of waves. All those forms of radiant energy which we call light, heat, etc., are in reality electromagnetic disturbances propagated in the form of electromagnetic waves.

Once an electromagnetic field is established, any change which alters the prevailing conditions is said to be an electromagnetic disturbance. When a current of electricity increases in strength, the field around it increases also, the lines of force spreading out from the conductor like ripples in a pond; but when the current is decreased, the lines of force contract, closing in around the conductor, and the energy of the field shrinks back into the system. If this process be augmented so that the periodic reversals of current produce oscillations of extremely high frequency, then, at each reversal, part of the energy of the field radiates off into the surrounding medium as electric waves and only part of it returns into the system. The frequency with which such periodic reversals of current take place determines the distance between the crests of the waves radiated into space from such a system. Waves created in the ether by this means are called *electric*, or *Hertzian, waves*, after the German physicist, Heinrich Hertz. Before entering upon a more detailed consideration of waves of this character, the subject of waves in general will be considered.

Nature of a Wave. When a disturbance is made at any point in an elastic medium, the particles of the medium are set into vibration and the vibrations are passed on to the neighboring particles, so that waves are formed; and these waves travel with a uniform velocity depending on the nature of the medium, with a result that the disturbance is propagated to considerable distances from its point of origin. There are in general two classes of waves, known as *longitudinal* and *transverse*, the distinction between them depending on the direction in which the particles vibrate. When the particles vibrate along the line in which the disturbance is traveling, the wave is said to be longitudinal; when the particles vibrate at right angles thereto, the wave is said to be transverse. The general equation for determining the velocity of waves of either class is

$$v = ln$$

where v stands for the velocity, l for the wave length, and n for the frequency, or number of vibrations per second.

This equation holds equally true for ether waves which manifest themselves as light, and for the longer waves produced by high-frequency oscillations of an electric current, both of which are of the transverse variety. Indeed all forms of radiant energy are, according to the present belief, due to ether waves, differing from one another only in length. As the velocity of propagation is the same for all—namely, 186,000 miles per second—the frequency varies through a wide range. Ether waves varying between certain definite lengths are visible and produce the sensation of light; others much longer falling upon matter raise its temperature, thus manifesting themselves as heat; still others, of a wave-length extremely small even in comparison with visible rays, are capable of penetrating matter as X-rays; and others again, of a length of half a mile or more, are flashed across the Atlantic, conveying intelligence from the Old World to the New.

As there are many methods of producing waves in gross matter, so also are there many methods of producing waves in the ether. The production of electromagnetic waves of a length measuring from a few inches to many rods need only concern us here, as it is with the production of such waves that the science of radiotelegraphy deals. As before stated, a part of the energy of a very rapidly alternating current is radiated off into space in the form of electric waves. Under what physical conditions such disturbances are created will now be considered.

Electric Oscillations. If a charged condenser, or Leyden jar, is discharged through a conductor of *high resistance,* the opposing polarities slowly neutralize each other by a current flowing in one direction. If, however, the condenser is discharged through a conductor of *low resistance,* such as a coil of wire of a few turns, the effect is wholly different. Under these conditions the discharge consists of a number of excessively rapid oscillations of the nature of a high-frequency alternating current, caused by the self-induction of the coil, in consequence of which the current once set up tends to persist. The first rush of current more than empties the condenser, and charges it to the opposite polarity; then follows a series of similar discharges of diminishing amplitude until the energy of the charge is entirely dissipated. This process is represented in Fig. 3.

The spark produced by the discharge of a condenser under these conditions appears to the eye as a single flash, due to the rapidity with which the successive discharges follow one another. In reality it consists of several distinct sparks lasting but an exceedingly small fraction of a second.

The law governing condenser discharges is as follows: *If a condenser of capacity K is discharged through a resistance R and self-induction L, the result is a uni-directional discharge or a series of oscillations according as R is greater or less than* $2\sqrt{\frac{L}{K}}$.

A rapid oscillatory discharge sets the electromagnetic medium in vibration much as a tuning fork sets the air in vibration in pro-

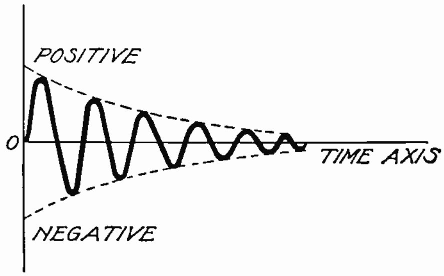


Fig. 3. Curve Representing an Oscillatory Discharge

ducing sound-waves. Such discharges provide a simple means for creating electric waves in the ether. An understanding of condenser action is, therefore, of great importance in a comprehension of the principles of radiotelegraphy.

The oscillatory nature of condenser discharges was known when Maxwell promulgated his electromagnetic theory, but it was not until twenty-five years after the announcement of the theory that scientists were able to detect the presence of electric waves. They knew the conditions under which such waves should arise, but none were able to devise a means to demonstrate their presence. It remained for Heinrich Hertz, a pupil of the illustrious von Helmholtz, to solve the mystery and give experimental verification to a theory which must ever remain one of the greatest achievements of inductive reasoning. Hertz succeeded not only in producing and detecting electric waves, but in demonstrating that such waves possessed all the essential characteristics of light.

The Work of Hertz. It was in 1888 that Hertz, then thirty years old and professor of Physics in the University of Bonn, carried

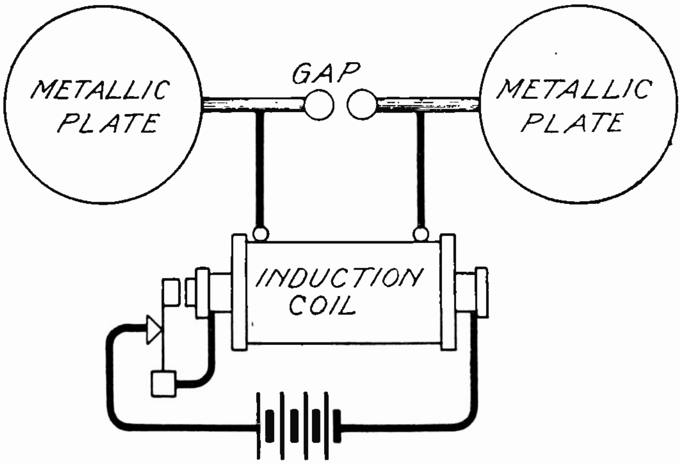


Fig. 4. Hertz Oscillator

on the epoch-making series of experiments which have proven to be the foundation of the art of radiotelegraphy. His apparatus was of the simplest construction. To generate electric waves he employed what is now known as a *Hertz oscillator*, Fig. 4. This consists of two metallic conductors in the shape of plates or spheres, each attached to a small rod terminating in a polished metal ball. These were connected to the secondary terminals of an induction coil and the two balls brought into close proximity, thus forming a small spark gap. It will be seen that the arrangement has the essential features of a condenser whose plates are widely separated and whose dielectric extends into the surrounding air. When the charge is accumulating on the large metallic plates, a strong electric displacement is set up between them, and, as the potential difference rises, a point is reached where the insulation of the air gap breaks down and a spark passes across the gap. During the passage of this spark the air becomes highly conductive and the whole oscillator becomes one conductor for the time being. The potential difference between the charged plates immediately begins to equalize itself, after the manner of all oscillatory condenser discharges, by a series of rapidly damped surges, and with every oscillation a wave is radiated into space. The waves emitted by a device of this character are intermittent, each complete discharge of the oscillator

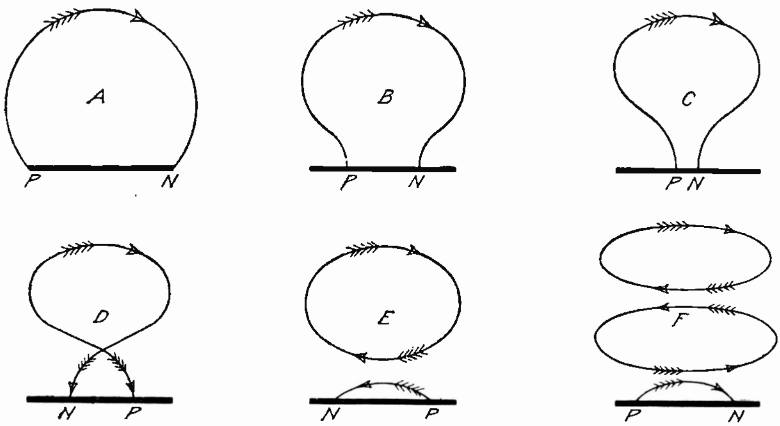


Fig. 5. Formation of Closed Loops of Electric Strain

sending out a rapidly damped train, or group, of waves. The frequency with which such trains follow one another depends upon the frequency of the charging source.

It cannot be said that the exact sequence of events in the formation of an electric wave is definitely agreed upon, further than that the production consists in sending out closed loops of force as shown by Hertz, Dr. F. Hack, and others. The subject is very difficult to present briefly, but an idea of the process may be had by reference to Fig. 5.

The curved line represents the form and the direction of one of the many lines of electric strain existing between the two plates of a Hertz oscillator. Every line of electric strain according to the electronic theory of electricity must be a closed line or loop, or else must terminate on an electron and a co-electron. The figures *A*, *B*, *C*, *D*, *E*, and *F* represent the successive stages in the production of closed loops of electric strain. As the charges oscillate to and fro the lines of electrostatic strain are crossed, making a closed loop which is immediately pushed outward by the following loop; with the result that the direction of strain around each loop is alternately in one direction and in the other, as shown in *F*. In addition to these lines of electrostatic strain there are at right angles to them other self-closed lines of force of a magnetic nature, due to the current passing during discharge. These magnetic rings of flux alternate in their direction at each oscillation, thus forming a series of closed loops of magnetic flux co-axial with the oscillator. Hence we are called upon to imagine the space around a Hertz oscillator as filled with concentric rings of magnetic flux periodically reversing in direction and having their maximum values at instants when the electrostatic strains are at their minimum values. These complementary modes of energy periodically varying in regard to time and space form an electric wave.

Energy of an Oscillator. As a portion of the energy imparted to an oscillator in the form of an electric charge is expended in heating the metallic balls, in creating a bright light, and in producing a noise at the discharge, it is evident that the entire energy of the system is not expended in the formation of electric waves. The total amount of energy which it is possible to potentially store in an oscillator in the form of electrostatic stress depends on its electrical capacity, and is equivalent to the amount of energy which could be stored in a condenser of the same capacity. The storage of energy in a condenser is proportional to the square of the voltage to which it is charged; which is another way of saying that a very great amount of energy could be stored in a very small condenser if it were possible to maintain the insulation under exceedingly high potentials. The dielectric strength of the material used for the dielectric thus places a limit upon the amount of energy it is possible to store in such a device. A small oscillator could likewise have a large amount of energy imparted to it by enlarging the spark gap enough to allow a higher potential to be reached before the insulation of the gap breaks down, were it not for the fact that the increased resistance of the lengthened gap renders the spark non-oscillatory.

A limit is therefore placed upon the potential which it is practicable to employ in the charging of oscillators or any form of condenser. As the capacity of a condenser increases in direct proportion to the area of its plates—other factors remaining the same—it is evident that the dimensions of an oscillator of the Hertz type determine the amount of energy it is possible to utilize in the generation of electric waves.

Hertz Resonator. The most important contribution of Hertz to the subject of electric waves was the discovery of a simple means for detecting the presence of such radiations. The fundamental character of the discovery is apparent when it is observed that the device consists simply of a single turn of wire forming a ring, provided with a spark gap between two metallic knobs, the distance separating these terminals being adjustable by a screw. The device, called a *resonator,* is shown in Fig. 6. Hertz discovered that electric waves falling upon such a conductor were capable of inducing therein alternating currents of the same frequency. By holding his resonator within a few yards of an active oscillator he found that it became the seat of induced secondary oscillations which were strong enough to be manifested by minute sparks visible between the metallic balls. Following up this clue he carried on a very extensive series of experiments, all tending to prove that such waves possessed all the characteristics of light—that they were indeed but "invisible light." Hertz' resonator may be said to be the first "wireless detector" known. The further development of this pregnant idea plays an important part in the evolution of the systems of wireless telegraphy.

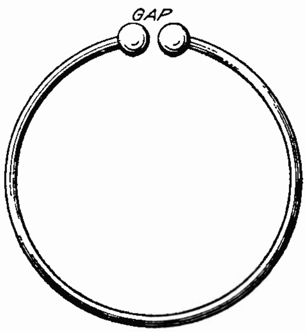


Fig. 6. Hertz Resonator

Resonance. A definite period of vibration is characteristic of many things in nature, including all sonorous bodies such as strings under tension, as in the case of the piano and all stringed instruments; confined portions of air, as exemplified by the organ pipe; and in fact all bodies which, when displaced by the application of an external force, tend to return by virtue of their elasticity and execute free vibrations until they gradually come to rest. If very feeble impulses be applied to a pendulum at rest at intervals exactly corresponding to its natural period of vibration, it may be made to swing through an arc of considerable amplitude. Bodies capable of executing vibrations by virtue of their own resiliency may likewise be set into powerful vibration by a series of impulses keeping time with their own natural period. Thus a tone from a violin may draw forth a responsive note from a piano, and by the same reason a piano will often set into sympathetic vibration some fixture or article of bric-a-brac. Also impulses communicated through the air from a sounding tuning-fork and falling upon another of the same pitch, will cause the latter to hum a note in unison. This phenomenon is called *resonance.* Resonance is thus an increase, or amplification, of a periodic motion by an intermittent force of the same time-period.

Resonant effects are not confined to the vibrations of gross matter, but may also be observed in connection with the flow of electricity in a circuit. This would seem to indicate that an electric circuit possessed something analogous to a natural period of vibration—which is the case. This time-period is due to certain characteristics of the circuit, namely *capacity*, and *inductance.* The quantity of electricity required to charge a conductor up to unit potential or, in other words, the ratio of the charge on a conductor to its potential, is called *capacity.* The unit employed to measure capacity is the farad. *Inductance* is that quality of an electric circuit by virtue of which the passage of an electric current is necessarily accompanied by the absorption of energy in the formation of a magnetic field. The analogy to mechanical inertia is very close, and, for convenience, inductance may be thought of as electromagnetic inertia by reason of which an electric current resists any sudden change. The unit of inductance is the henry. In all circuits possessing capacity and inductance there is a storage of electrostatic energy due to the potentially charged capacity, and a storage of electromagnetic energy due to the formation of the magnetic field by the current. Any electrical change taking place in such a circuit requires a readjustment of this stored energy. Such an adjustment takes place in the form of an oscillatory current of diminishing amplitude until equilibrium is restored. The time-period of such oscillations of energy is dependent upon the capacity and the inductance of the circuit, and is expressed by the equation

$$T = 2\pi\sqrt{LK}$$

where L is the inductance in henries, and K is the capacity in farads. The number of such oscillations per second, *i. e.*, the frequency, is, therefore, $n = \frac{1}{T}$. For purposes in connection with wireless telegraphy this equation is better expressed in microseconds, microhenries, and microfarads.

The phenomena of electrical resonance were first illustrated by Sir Oliver Lodge in his well-known experiment with his so-called *syntonic jars*. Two Leyden jars, Fig. 7, are placed a short distance apart. A bent wire connected to the outer coating of one serves as a discharging circuit (as shown) with a short air gap between polished knobs at the top. A circuit of wire whose inductance is rendered adjustable by a sliding cross-piece—making connection between two conductors—is connected permanently with a second jar. This

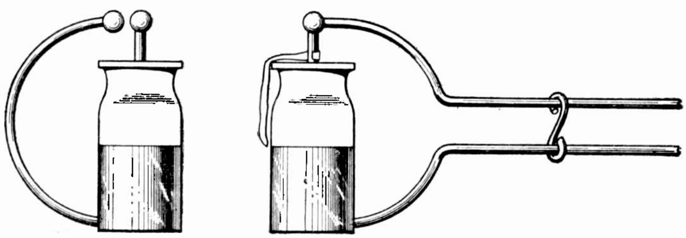


Fig. 7. Lodge Syntonic Jars

jar is also provided with a spark gap formed between the outer coating and a small piece of tin-foil extending from the inner coating over the lip of the jar to within a short distance of the outer coating. By continually discharging the first jar by connection with an induction coil or other suitable source of high potential, and by manipulating the sliding cross-plate in the circuit of the other jar, a point may be found where the latter will also discharge in syntony with the first. The two circuits are then said to be in tune, in syntony, or in resonance. When the product of inductance by capacity is the same for two circuits, they have the same natural period of oscillation.

As any circuit possessing inductance and capacity tends to oscillate electrically at its own frequency, it becomes the seat of an induced oscillatory current when subjected to the influence of electric waves of that frequency, each wave giving a slight impulse to the readily excited oscillations, with the result that the induced electromotive forces will be amplified in intensity, just as the swing of a pendulum is amplified by the application of properly timed, though feeble, touches. Circuits possessing inductance and capacity connected in series are thus capable of being "tuned" to a required frequency by a proper adjustment of these two factors. Such circuits are called *oscillatory circuits* and may be of many forms, but can be classified under two heads known as *closed* oscillatory circuits and *open* oscillatory circuits. Those circuits having their capacities in the form of condensers whose capacity areas are closely associated are called "closed," and those having their capacity areas widely separated in such a manner as to cause the field of electrostatic stress to extend out into the surrounding space are called "open." In the first, Fig. 8, the capacity is represented by the two metallic disks separated by a dielectric of air, and connected by a circular wire representing the inductance of one turn, while the "open" type, Fig. 9, is shown by the two metallic capacities connected by a rod which is cut in two at the center to form a gap. Either may or may not have an air gap introduced therein.

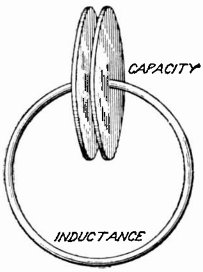


Fig. 8. Closed Oscillatory Circuit

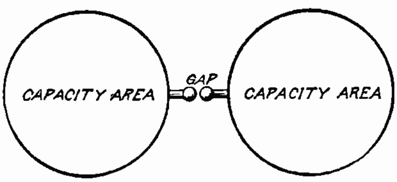


Fig. 9. Open Oscillatory Circuit

The similarity to the Hertz oscillator and resonator is apparent at a glance. This is, indeed, more than a similarity, for the Hertz oscillator was nothing more than an open oscillatory circuit, and his resonator a closed circuit of the same variety. By separating the plates of a condenser after the manner of a Hertz radiator, thereby forming an open oscillatory circuit, a large part of the energy of the charge is radiated away in the form of electric waves by reason of the dielectric extending out into the surrounding air. **Circuits of this** type are, therefore, excellent radiators but not very persistent radiators, because the oscillatory current is damped quickly by the rapid dissipation of energy in the radiation. Conversely, circuits of the closed type are persistent vibrators, but poor radiators. The train of waves emitted by the open type may be compared to the note given forth from a piano string when the finger is immediately removed from the key allowing the damper to rapidly extinguish the vibration. The closed type is comparable to a note struck on the same instrument but with the damper raised by the sustaining pedal. As it requires an increment of time to start oscillations in a tuned circuit, it is obvious that the closed type is preferable if it can be made to radiate sufficiently. If the damping of the oscillations in a radiator takes place too quickly, the energy of the charge will be dissipated at the first or second surge, in which event the exact tuning of a resonating circuit is unimportant. With a persistent oscillator, however, syntony between the two circuits is of the utmost importance, as otherwise the exciting circuit will tend to destroy at one moment the oscillations it set up a moment earlier. Syntony is of great practical value in the application of Hertzian waves to wireless telegraphy in that it permits of selective signaling to a certain extent by the employment of different wave-lengths, or the tuning of a receiving station to the frequency of a sending station.

Wave-Lengths. As before mentioned, the waves created by a Hertz oscillator are of very much lower frequency and are proportionally longer than light waves, but their velocity is identical. Furthermore, the relation between the velocity of propagation, frequency, and wave-length of ether waves was shown to be expressed by the equation

$$v = ln$$

In order to obtain numerical values for these quantities, it is evident that the value of v must be determined by reference to the best available experimental data. Numerous investigators have agreed upon 3×10^{10} centimeters per second as representing the most probable value for this constant. Knowing this, and by assigning the correct values to the factors *capacity* and *inductance* in determining the natural frequency, it becomes a simple matter to calculate the length of wave emitted by a radiator; and, conversely, by employing the proper capacity and inductance a radiator may be constructed to give any desired wave-length within wide limits. Capacity and inductance may be considered to be the electrical dimensions of an oscillator, and they determine the length of wave emitted, just as the note emitted from an organ pipe depends upon the dimensions of such a pipe.

The waves created by Hertz with various forms of his oscillator varied between a few inches and a few feet in length. He determined these lengths not only by mathematical computation as explained above, but by direct experimental test. He set up at the far end of his laboratory a large sheet of metal to reflect back the waves, and then went about the room with his resonator, exploring the space to find at what points sparks were produced. He found that when waves are thus reflected back upon themselves there are nodal points, just as there are nodal points in sound-waves and in light-waves when similarly reflected. Measuring the distances between these nodal points he was able to determine the wave-length precisely.

With the simple instruments at his command Hertz carried on many other experiments which are little short of beautiful in their adaptation of means to ends; but we cannot go into them here more than to say that they all tended to prove the main contentions of Maxwell's theory. The unqualified success of these experiments won the admiration of scientists all over the world. But few, if any, realized at the time that Hertz, in addition to giving indisputable proof to Maxwell's famous hypothesis, had also laid the foundations for a new and triumphant system of wireless telegraphy.

CHAPTER III

THE DEVELOPMENT OF RADIOTELEGRAPHY

It is evident that when Hertz constructed an apparatus which could transmit electrical manifestations to a distance, without wires, he possessed the elements of a system of wireless telegraphy. All signaling at a distance whether by wire or without, requires the presence of three fundamental factors: a device to produce the signal; a medium to carry the signal; and a device to receive the signal. Hertz' apparatus with its oscillator, electromagnetic medium, and resonator, easily fulfilled the requirements, and its use as a system of wireless telegraphy was merely a matter of time.

The main line of development was to be an extension of the distance over which signals could be transmitted; for as we have seen in the consideration of earlier systems—notably induction systems—distance is the important factor. Any system which cannot transmit messages to a considerable distance is of small practical service to the world. Hertz with his apparatus never succeeded in producing waves which were detectable at more than a score of meters or so; consequently we need not wonder that he never suspected that one of the largest fruits of his achievement was to be a system of wireless trans-oceanic communication. When asked by a civil engineer of Munich whether he thought telephonic communication could be effected bymeans of electric waves, he replied in the negative, as he considered that the alternations of current in the telephone were not of a nature to be detectable. He could not, of course, foresee the improvements which were destined to be made, rendering his apparatus immeasurably more sensitive and serviceable.

All the scientists of Europe were stirred by the announcement of Hertz' discoveries, and many set about to repeat the experiments. With so many minds bent upon a kindred purpose it is not surprising to learn that much new light was thrown upon the subject and many improvements made in the form and efficiency of the Hertz apparatus. Both the radiator and the detector were signally bettered.

The Righi Oscillator. One of the disadvantages of Hertz' radiator lay in the fact that the sparks in a short time oxidized the little knobs and roughened their surfaces, resulting in irregular action. Prof. Righi of Bologna overcame this difficulty by partly enclosing two metal spheres, *A* and *B* in Fig. 10, in an oil-tight case so that the outside hemispheres of each are exposed, the inner hemispheres being immersed in vaseline oil with only a minute gap between them. In a line with these spheres are ranged two smaller spheres, *C* and *D*, which form the secondary terminals of the induction coil. Thus three sparks are produced: one between *C* and *A*, another between *A* and *B*, and another between *B* and *D*. It is between *A* and *B* in the oil gap that the oscillatory spark takes place, the other two sparks serving merely to charge the large spheres. This arrangement not only produced a more constant spark by preventing the pitting of the electrodes but greatly extended the range of wave-lengths which it was possible to employ in investigations of this character. The dimensions of the oscillator could thereby be reduced and the amplitude of the oscillations greatly increased by reason of the fact that higher potentials could be reached before the energy was released by discharge. Righi obtained oscillations of a frequency of 12,000,000,000 vibrations per second by the use of small spheres *A* and *B* eight millimeters in diameter.

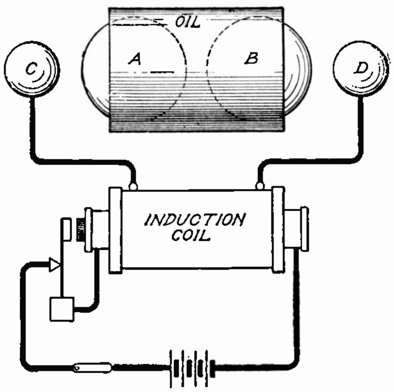


Fig. 10. Righi Oscillator

The Branly Coherer. The next important advance pertained to an improvement over the Hertz resonator as a means of detecting electric waves. It was based on the discovery of M. E. Branly and others, that the enormous resistance offered to the passage of an electric current by powders and metal filings is greatly reduced under the influence of electric oscillations. The resistance of such conductors may drop instantly from thousands of ohms to hundreds by the action of induced oscillations, retaining this conductivity until "decohered" by a mechanical blow. It will be readily seen that this provides a simple means of effecting the operation of a translating device by acting as a valve in turning on, as it were, a greater current in a local battery circuit. By utilizing this property of increased conductivity Sir Oliver Lodge succeeded in causing the deflection of a galvanometer. The device employed by Lodge consisted of a glass tube in the ends of which were sealed terminal wires connected to metallic electrodes of the same diameter as the tube, and between the electrodes was placed a small quantity of iron filings, as shown in Fig. 11. This device is known as a *coherer*, a name suggested by Lodge. In various modified forms the instrument has been employed up to the present day in different wireless systems. Its practical application will be fully considered later in connection with the work of Marconi.

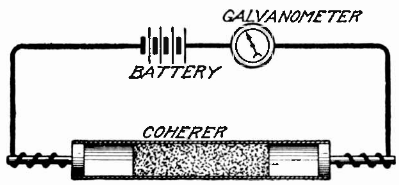


Fig. 11. Lodge Coherer

Radiotelegraphy First Suggested. As the Righi oscillator and Branly coherer were immeasurably more efficient than Hertz' corresponding apparatus, it necessarily follows that waves could be sent and detected over much longer distances and the time was getting ripe for the application of these devices to the purposes of wireless telegraphy. The first man to suggest this possibility is said to have been Sir Wm. Crookes, the eminent English chemist and physicist. In a magazine article which appeared in 1892 he made the following marvelous forecast of Radiotelegraphy:

> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog; but electrical vibrations of a yard or more in wave-length will easily pierce such media, which to them will be transparent. Here is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfillment. At present experimentalists are able to generate electric waves of any desired length, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so to direct a sheaf of rays in a given direction. Also an experimentalist at a distance can receive some, if not all, of these rays on a proper instrument, and by concerted signals, messages in the Morse code can pass from one operator to another.
>
> What remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the

shortest, say a few feet, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; and thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space, and fading away according to the law of inverse squares. . . .

At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send the waves out in all directions, and it would, therefore, be possible for anyone living within a mile of the sender to receive the communication This could be got over in two ways. If the exact position of both sending and receiving instruments were known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, 50 yards. I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw, or alternating the length of a wire, so as to become receptive of waves of any preconcerted length. Thus, when adjusted to 50-yard waves, the transmitter might emit, and the receiver respond to, rays varying between 45 and 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for the most inveterate curiosity would surely recoil from the task of passing in review all the millions of possible wave-lengths, on the remote chance of ultimately hitting on the particular wave-length employed by those whose correspondence it was wished to tap. By coding the message even this remote chance of surreptitious tapping could be rendered useless.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe, that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. . . .

The purposes and problems of radiotelegraphy are admirably stated in the above. Some of those problems have not even yet been solved, as we shall see. When Crookes wrote, the idea of radiotelegraphy was in the air, and many men indeed were striving to turn the possibility into a reality. Several Englishmen almost achieved the desired end, but, strangely enough, faltered or failed when success was within easy reach. Among these, mention must be made of Prof. D. E. Hughes, who, but for a combination of bad luck and human fallibility, might have been today the accredited discoverer not only of radiotelegraphy but of electric waves as well.

MARCONI WIRELESS TELEGRAPH STATION AT SEA GATE, N. Y.

Work of Hughes. As far back as 1879, when experimenting with his celebrated microphone (which is in reality nothing other than a Branly coherer reduced to its simplest elements) Hughes observed peculiar electrical effects operating at a distance, and he concluded that they were due to invisible electric waves. He did not, however, so far as we know, relate these phenomena with the theories of Maxwell, as Hertz did, and was consequently at a loss to fully account for them. He investigated the subject for several years and actually succeeded in telephoning wirelessly over considerable distances. These experiments were repeated before Prof. Stokes, the president of the Royal Society, and Prof. Huxley; but these gentlemen expressed doubts as to the nature of the phenomena, with the result that Hughes became infected with their scepticism and abandoned his efforts, believing himself on the wrong track. If he had persisted in his researches he might have gathered the laurels that later went to Hertz and Marconi. It has been said that "Hughes' experiments of 1879 were virtually a discovery of Hertzian waves before Hertz, of the coherer before Branly, and of wireless telegraphy before Marconi and others," and the truth of the statement must be admitted to some extent.

Work of Lodge. Mention must be made of the great debt which radiotelegraphy owes to Sir Oliver Lodge for his many valuable contributions both to practice and theory. He has been in the forefront of every advance made in the science of radiotelegraphy, and might in all truth be called its patron saint. To him is due our knowledge of the principles of syntony which forms such a vital part of all modern systems. He was the first man to employ the Branly coherer as a detector of Hertzian waves, and while engaged in demonstrating the discoveries of Hertz was sending signals over distances measurable in hundreds of feet. That such signals could be utilized to convey intelligence by the simple application of the Morse telegraphic code did not occur to him; if he had realized this possibility he might have antedated Marconi's invention of wireless telegraphy.

Work of Marconi. Passing over Popoff, Rutherford, Jackson, Minchin, and others, several of whom did important and original work, we come to Marconi who, in the popular mind, is credited with the whole achievement of radiotelegraphy. It is true that

Marconi carried radiotelegraphy through to practical success; or, as A. T. Story puts it, "he carried forward into the domain of practical reality what had only floated indistinctly before the minds of others, or had served them for modest experiments." But as regards those vital and fundamental developments of theory and practice without which radiotelegraphy would still be a thing unknown, Marconi is only an able follower and not one of the pioneers. The history of radiotelegraphy might be shortly indicated by the following list of names: Faraday, Maxwell, Hertz, Righi, Lodge, Marconi. The theory of electric waves originating with Faraday and expanded by Maxwell, was experimentally demonstrated by Hertz. Then came Righi and Lodge with their improvements on the Hertz apparatus, greatly extending its sphere of utility; and finally Marconi, who brought together the results achieved by his predecessors and, adding something of his own—"a far-seeing initiative where others had not gone beyond timid projects or tentative research"—produced a successful system of wireless telegraphy. Marconi, who is an Italian by birth, first became interested in Hertzian waves when a student under Prof. Righi at the Bologna University. He was not long in seeing their possible application to telegraphy, and made some experiments with that purpose in view. Becoming convinced of the feasibility of the project, but finding no one in Italy ready to take it up, he set out for England to try his fortune. Arriving there, he applied to the Patent Office for protection on his ideas, and then took the proposition to Sir Wm. Preece, chief of the British Postal Telegraphs. Preece gave Marconi ready encouragement, and he was soon conducting experiments under the auspices of the British Post Office.

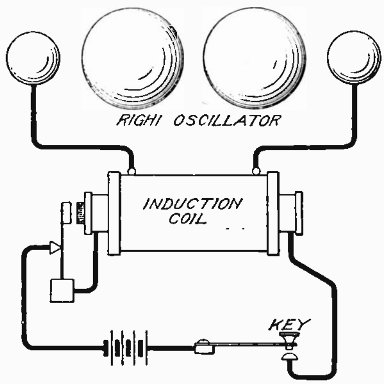


Fig. 12. Early Marconi Transmitter Circuit

Early Apparatus. The early apparatus of Marconi consisted essentially of a Righi oscillator and Branly coherer, disposed in suitable circuits for generating and recording the flow of waves. The transmitting arrangement consisted of an induction coil producing the requisite high potential with which to charge a Righi oscillator, and a Morse key of heavy construction with which to break the primary circuit of the coil, connected with a battery of about five cells. The actual transmission of messages was effected by the intermittent movement of the Morse key which, upon completing the circuit, started the interrupter of the coil which remained in

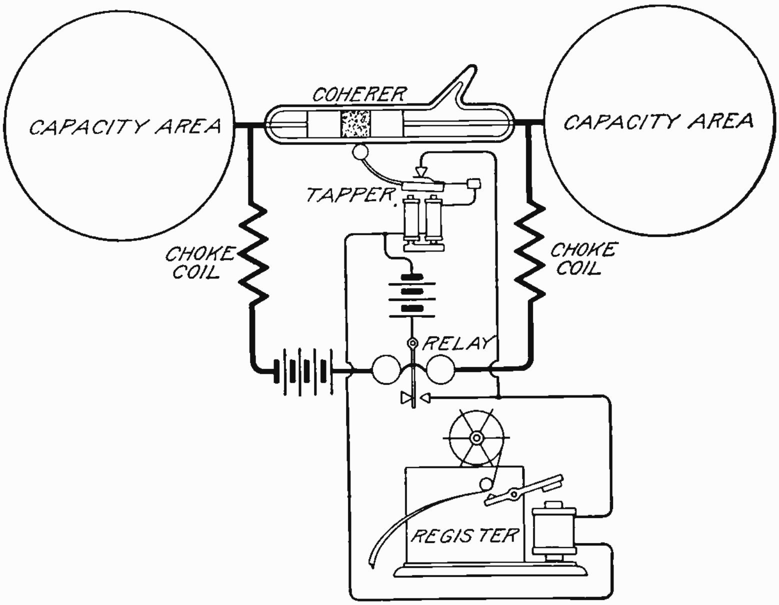


Fig. 13. Early Marconi Receiving Circuit

operation as long as the key was held down; thus the duration of waves from the oscillator was made dependent on the position of the key. It was thus possible by the proper manipulation of the key to send a series of long or short wave trains corresponding to the dots and dashes of the Morse alphabet. Fig. 12 represents diagrammatically these features of the sending station.

The receiving apparatus, indicated in Fig. 13, consisted principally of the Branly coherer somewhat modified in construction and associated with suitable auxiliary apparatus for recording the duration of the received wave trains in the form of dots and dashes upon a moving paper surface after the manner of the Morse recorder, well known in wire telegraphy. As the coherer retains its low conductivity even after the cessation of a train of waves, it becomes necessary to provide means for automatically imparting a slight blow or jar to the tube in order to restore its receptiveness after each and every signal. Such a device was used by Lodge and is known as a "tapper." It is generally in the form of an electric trembling mechanism, such as an electric bell, operated by a local battery when thrown into the circuit by a Morse relay—the latter acting in response to the increase of current when the coherer acts.

The coherer used by Marconi at this time was his own special modification of the Branly-Lodge type. It consisted of a glass tube

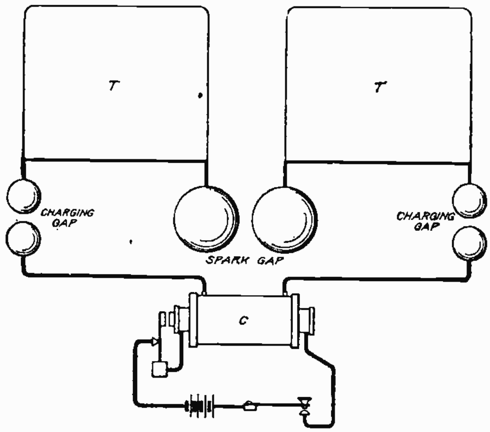


Fig. 14. Marconi "Capacity Areas"

about 4 centimeters long and 2.5 millimeters in diameter, into which were tightly fitted two silver terminals separated to a distance of one millimeter, this space being filled with a powdered mixture of 96 parts nickel to 4 parts silver, worked up with a trace of mercury. The tube was exhausted of air and hermetically sealed. To the terminals of this coherer were connected two resonance plates, or strips of copper, whose dimensions were such as to bring the system into resonance with the oscillator. Also connected to the terminals of the coherer were two choke coils, whose function was to confine the oscillations to the coherer; and a Morse relay in series with a battery of one cell. Fig. 13 plainly shows the arrangement.

In addition to the above a tapper was provided to decohere the metal filings, and also a signal recorder. The tapper was in the form of a small electric-bell mechanism whose clapper continuously tapped the glass tube as long as the Morse relay completed the circuit in which the tapper was placed. The Morse relay thus acts as a switch by means of which the signal recorder and tapper are operated simultaneously. It might be well to state that the coherer holds its conductivity during the passage of the oscillations even though in vibration from the tapper.

Capacity Areas. A very significant step taken by Marconi at this early period was his employment of "capacity areas" in the circuit of his oscillator, Fig. 14. The essential features of this innovation were as follows: *T* and *T* are metal plates joined to the balls of the oscillator; *C* is the induction coil. The object of this arrangement was to give greater energy to the oscillations, the carrying power of the apparatus being found to increase with the size of the capacity areas, and with the distance of the same from each other. Two similar plates were also attached to the coherer at the receiving station. Though this arrangement of capacity areas was soon abandoned, it marks, nevertheless, the inception of an idea which developed, as we shall see, into one of the most important features of modern aërial telegraphy, namely, the antenna.

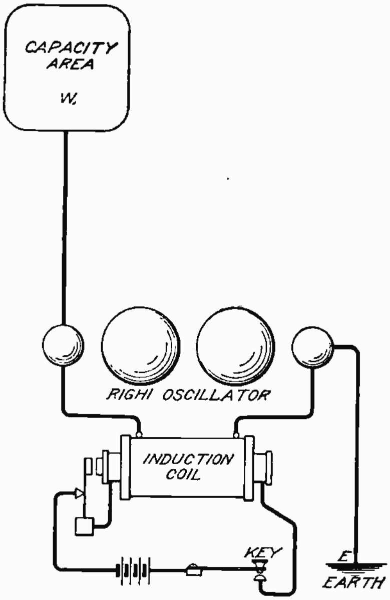


Fig. 15. Diagram Showing the Earthed Oscillator

Development of the Antennae. Endeavoring to increase the effectiveness of his capacity areas by enlarging them and separating them as much as possible, Marconi conceived the idea of utilizing the earth for one of the plates, and of raising the remaining plate to a considerable height in order to increase the distance between them.

The arrangement, Fig. 15, then took on the following aspect: coil and oscillator are of standard type; *E* is the earth connection; and *W* the elevated plate. The higher the capacity area *W* is situated, the greater the distance to which communication can be carried; so it will be seen that the capacity area might with great advantage be attached to a kite, or captive balloon. The latter were, indeed, employed by Marconi and with very good effect. Corresponding changes were made at the receiving station also, by employing a similar arrangement of capacity area, shown in Fig. 16.

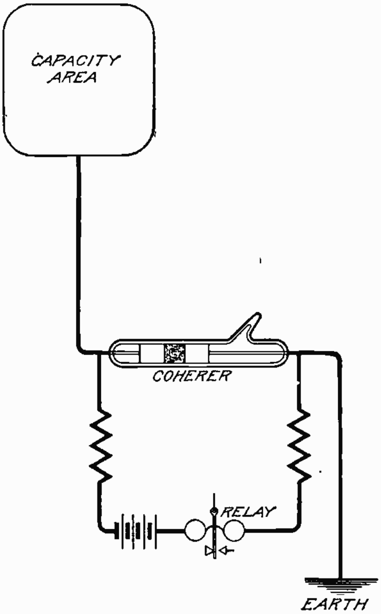


Fig. 16. Earthed Receiving Circuit

Later Marconi became convinced that the effectiveness of his aërial line was due not to the capacity at the end of the wire, but to the length of the wire itself; consequently he abandoned the capacity area altogether and held simply to the form of vertical wires attached to poles or kites, or even to high buildings or towers. These were called antennae, or aërials. The antenna consisting of a single wire later developed into the multiple antenna of several wires, each additional wire adding to the capacity of the system. The antennae of many large stations are formidable structures of great complexity, as the picture of the South Wellfleet station, Fig. 17, will indicate.

Inductive Receiving Antennae. Another of Marconi's early and important modifications was the introduction of inductive antennae into the receiver arrangement. The antenna was cut out of direct conductive connection with the coherer circuit and allowed to act on the latter only by induction through the agency of an oscillation transformer called in common parlance a *jigger*, the theory of which cannot be fully discussed here. Mention will be made, however, of the fact that such a transformer properly designed in regard to the wave-length used not only steps up the voltage so as to increase its effect on the coherer, but also enables the coherer to be placed at a nodal point of the secondary oscillations. As this form of detector

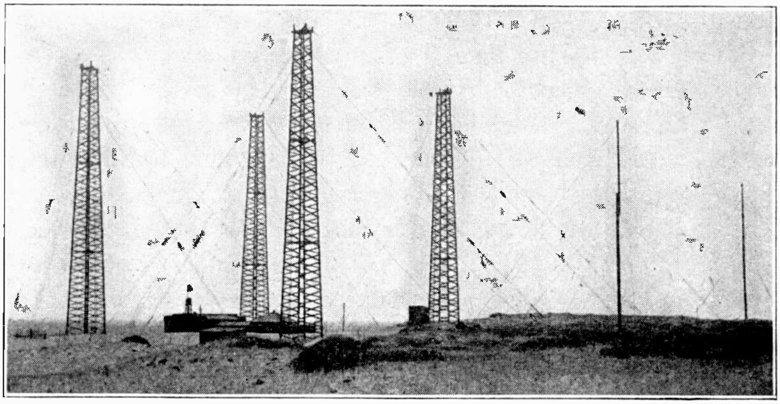


Fig. 17. South Wellfleet Wireless Station

is of the potentially operated variety, the practical importance of the modification is apparent. A coherer placed in series between the antennae and ground, as in former arrangements, is poorly located, as at the base of an aërial the potential is a minimum and the current a maximum. Marconi increased the distance over which it was possible to signal nearly ten times by the employment of this simple

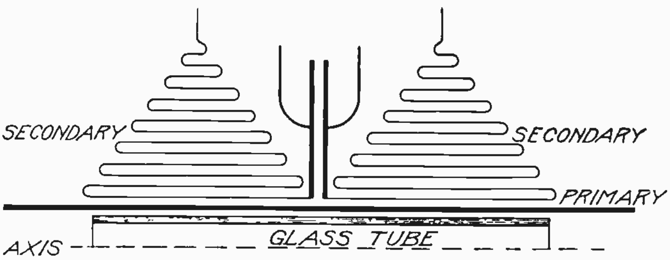


Fig. 18. Diagram of Oscillation Transformer Winding

device. His patents on this improvement bear the dates of 1898 and 1899. Fig. 18 shows a diagrammatic cross-section of the jigger, the zigzag lines representing the successive layers of the windings wound in such a manner that the inner layers have the greatest number of turns, the primary having about 100 and the secondary about 1,000 turns. Fig. 19 shows the receiver-circuit with the jigger embodied therein. It will be noticed that the local-battery circuits are the same as used before, but the jigger necessitates a slight modification in the location of the coherer. A condenser is connected to the inner terminals of the secondary, the outer terminals of which are connected to the coherer. The local battery circuit is also connected to the inner ends of the secondary and across the condenser.

Inductive Transmitting Antennae. It has already been shown that the early capacity areas had given place to the extended wire raised to a great height; and it soon became evident that transmission could be further facilitated by devising a more persistent oscillator than that which was employed with the directly connected aërial. It was possible to store a fair amount of energy in the old type of aërial, but the direct connection entailed the disadvantage of permitting the apparatus to radiate its entire amount of energy almost instantly instead of radiating such energy in the form of a more continuous train. This was not a quality tending to make for a clearly defined resonance between the sending and receiving circuits, and means were sought to accomplish a more persistent, or less damped, series of oscillations. The early form of open-circuit oscillator, therefore, gave place to what is known as the Marconi-Braun type of closed oscillating circuit which, while not so powerful a radiator, was a very much more persistent one. The method was due to Prof. Braun, but in a modified form was first used by Marconi. The diagram of Fig. 20 makes clear the fundamental idea, an idea which has proven to be of great value. Though modified in numberless ways by subsequent inventors, the broad idea of associating the aërial with a closed oscillating circuit has become almost universal.

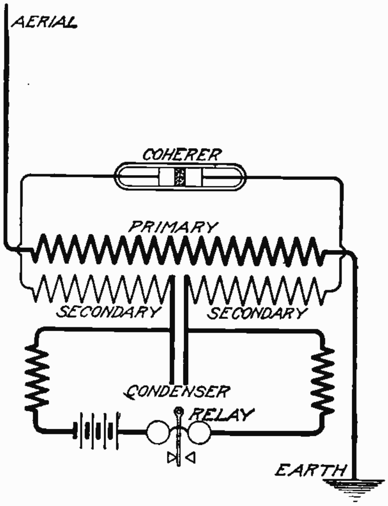


Fig. 19. Marconi Receiver-Circuit with Jigger

The transformer used for this purpose is very different from the ordinary induction coil or alternating-current transformer employed in connection with low voltages and low frequencies. It will be fully described later under the head of oscillation transformers; for the present it is sufficient to say that it forms an inductive couple between the two oscillatory circuits, the closed circuit being but a means of charging the open circuit of the antennae. The antennae circuit, having a certain amount of capacity and inductance depending on its design and position, possesses a natural time-period of its own; so in order to induce in such a circuit oscillations of a maximum amplitude, the primary circuit associated therewith must have the same natural time-period. In other words, resonance must be established; two circuits, as before mentioned, being in resonance when the product of capacity and inductance is the same for both. The Marconi-Braun method of charging the aërial permits of the employment of very large capacities, with proportionally larger energy-storing ability and smaller inductances in the primary circuit, so that the product of these two factors can be made to equal the product of the corresponding factors in the antenna circuit. The efficiency of the transformer thus very largely depends on the establishment of syntony between the closed oscillatory circuit forming the primary and the open oscillatory circuit forming the secondary.

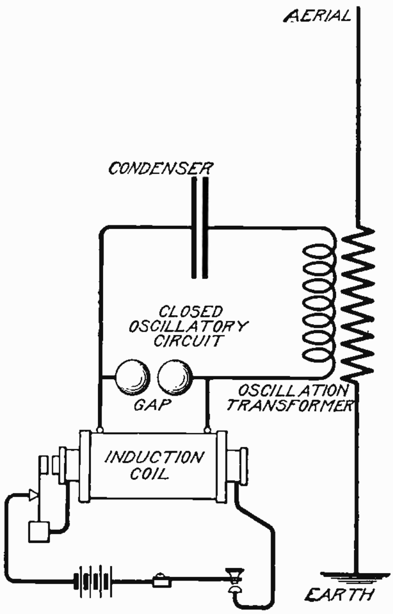


Fig 20. Marconi-Braun Inductive Transmitting Antennae

Another method of associating the radiating aërial with a closed oscillatory circuit, possessing many of the advantages of the Marconi-Braun inductive couple, is shown in Fig. 21, and is known as the direct-coupling method. An inductance of several turns of wire is, in effect, introduced in series with the aërial and the ground. A certain portion of the inductive turns is included in a closed oscillatory circuit composed of a condenser and spark gap shunted around the said portion. When the closed energy-storing oscillatory circuit and the open radiating circuit of the aërial are adjusted to the same periodicity the scheme becomes effective. The method of direct coupling has been subjected to many changes at the hands of inventors, in some cases becoming almost unrecognizable, but upon analysis the fundamental idea shows through. It is to be noted that with both the direct and inductively coupled systems, syntony between the open and closed circuits is essential.

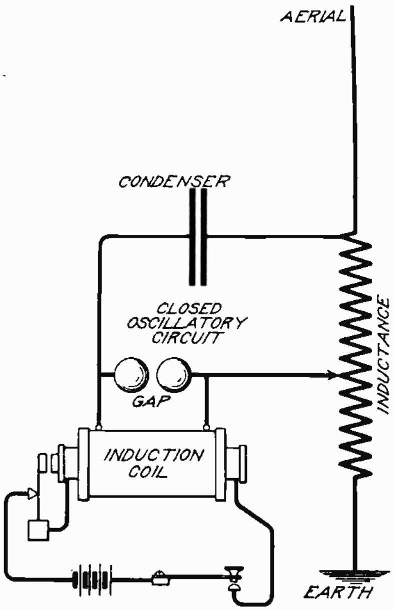


Fig. 21. "Direct-Coupled" Inductive Antennae

Both of the foregoing arrangements allow the possibility of creating in the aërial far greater charging electromotive forces which, in properly proportioned antennae, increase toward the top where they may reach a value equivalent to hundreds of thousands of volts in the larger installations. Hence, with the adoption of this form of transmitting arrangement, it became possible to radiate a series of well-sustained oscillations of much greater energy than ever before, thus still farther extending the distance to which communication could be carried. This improvement may be said to be one of the greatest advances in the history of radiotelegraphy.

Propagation of Waves from a Grounded Oscillator. The theory of the propagation of electric waves from a Hertz oscillator before given, assumed a perfectly symmetrical isolated oscillator suspended in space. The employment of the grounded oscillator in the form of an earthed aërial now exclusively used in radiotelegraphy necessitates a modification of the above theory in order to meet the problems arising under the changed conditions. The new arrangement was, in effect, the substitution of the earth for one of the capacity areas of a Hertz radiator, and the extension of the companion area into a vertical wire possessing capacity with regard to the earth from which it is separated by an air gap. The type of wave radiating from such a system differs in many respects from the form of disturbance emanating from a simple isolated oscillator, and presents theoretical difficulties which cannot as yet be said to be satisfactorily explained. The electric waves from a grounded oscillator apparently follow the curvature of the earth. One of the theories purporting

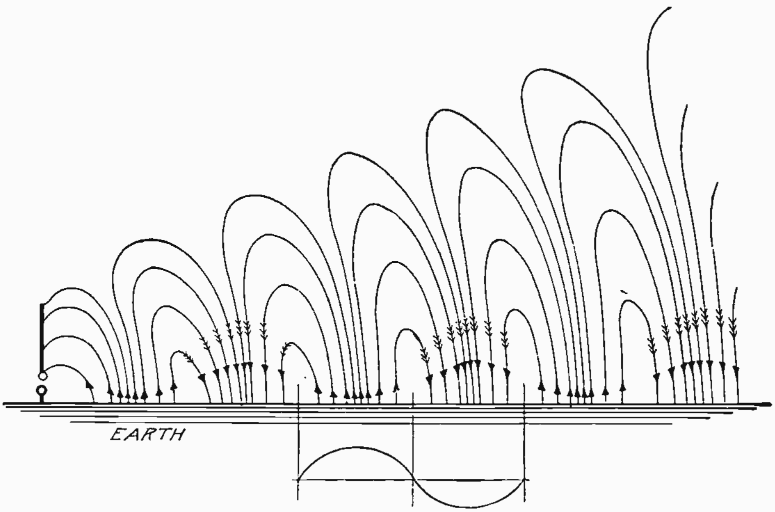


Fig. 22. Diagrammatic Representation of the Sliding-Wave Theory of Propagation

to account for this phenomenon assumes that such waves are not ordinary free electric waves consisting of closed loops of electric strain, but on the contrary consist of half loops traveling over the surface of our globe with their ends remaining always in contact with the surface. This view is supported, it would seem, by the electronic theory of electricity. It is roughly represented in Fig. 22. The detached semi-loops of strain are shown by the lighter lines, and the simple grounded oscillator by the heavier. A wave-length would be represented on the horizontal line by the distance included between any two positions thereon where the direction and intensity of strain (shown respectively by the arrows and the proximity of the lines) is identical. This is the *sliding-wave theory,* said to have been first promulgated by J. E. Taylor. Other theories have been advanced to account for the wave-transmission following the curvature of the earth, one such assuming that the waves are radiated in a straight line but reflected back from a semi-conductive envelope formed by the upper strata of the earth's atmosphere.

Selective Signaling. The problem of directing a message to its proper destination was felt by early investigators to be of vital importance, if radiotelegraphy was ever to be a commercial success. Some method must be discovered to effect selective signaling—else how would it be possible for a plurality of stations to be transmitting at once? The solution of the difficulty was thought to be found in the principle of resonance.

The history of the subject records at a very early date efforts to achieve the desired end by employing definite wave-lengths corresponding to the electrical time-periods of the various stations it was desired to place into communication. Thus among a plurality of active sending stations any number might communicate simultaneously in pairs without interference by arbitrarily assigning a definite frequency, or wave-length, to each pair. Selection by this method assumes that it is possible to "tune" receiving instruments so they will respond to a particular "pitch" and to no other; but as the number of possible non-interfering wave-lengths is limited, it cannot be said that resonance offers an entirely satisfactory solution of the problem.

By the employment of two or more receiving circuits connected to the same aërial, each tuned to a different frequency corresponding to as many different sending stations, the simultaneous reception of two or more messages is theoretically possible. As early as 1900, Marconi achieved some very remarkable results of simultaneous non-interfering communication when he received by the same aërial two messages, one in English and the other in French, which were simultaneously transmitted over a distance of 30 miles.

It was to be expected that the last few years would bring in their train great improvements in this respect as well as in others, so that it may be said today that selective signaling is feasible to a certain extent and that the remaining obstacles will be removed by further developments of the art; but until those advances are made, so that much more can be accomplished with respect to selective signaling than at present, the field of operation for radiotelegraphy will be confined mostly to communication between ships, between ships and shore, and across large bodies of water.

Conclusion. The application of Hertzian waves to the purposes of telegraphy as outlined above, covers what might be called the foundation and early development of the art. Every step taken at this early period was vital and significant. Since then enormous advances have been made; the distances over which it is possible to telegraph have been greatly extended, and the apparatus rendered more sensitive and certain in every way; but these results have been accomplished more by a refinement of detail—the development of more sensitive instruments, and the closer connection between theory and practice—rather than by the application of fundamentally new ideas. The twentieth century ushered in a new and tentative method of telegraphic communication called radiotelegraphy, and the first ten years have witnessed its establishment as one of the permanent adjuncts of civilization.

CHAPTER IV

RADIOTELEGRAPHIC APPARATUS

It is obviously impossible within the scope of the present work to give a detailed description of all the apparatus pertaining to radiotelegraphy. In view thereof it is assumed that the reader is familiar with the ordinary instruments and physical appliances commonly used in electrical work and not in any way peculiar to wireless telegraphy. It is also assumed that the elementary facts of electrical phenomena are known. The descriptions of the apparatus in this chapter will be given without reference to their grouping together in the formation of a complete system, but will be given singly with such theoretical considerations as may seem necessary. The chapter following will be given over to the assembling of apparatus into complete systems under their proper appellations, together with some account of their performance.

Sources cf Energy. In any system of radiotelegraphy the prime desideratum is to associate with the aërial a maximum amount of energy available for radiation. It was early recognized that the most obvious way to accomplish this was to increase the capacity of the aërial or to employ condensers associated in various ways in order to store temporarily the electrical energy to be radiated. The main function, therefore, of the source of energy employed in the transmitting station is to properly charge a given capacity. The greater this capacity, the greater the amount of initial energy required. Expediency determines largely the nature of the source of energy, whether derived from storage batteries, a generator, or from power mains. The energy consumption ranges from a few watts up to 50 to 100 kilowatts, so it is evident that the sources of current are subject to a wide range of choice. The trans-Atlantic stations of Marconi at Cape Breton employ generators of 65 horse-power.

Charging Devices. To create the required electrical oscillations in the aërial, it is necessary to have appliances which shall generate the requisite high-potential electromotive forces for charging the aërial and its associated capacity. Such an appliance should create not only a high potential but also an appreciable current. This charging e. m. f. is generally effected by the use of the induction coil or the alternating-current transformer.

Induction Coils. It is not deemed necessary to give an extended discussion of the induction coil, but to call attention to the important modifications to be incorporated therein for use in wireless telegraphy. The purpose for which the coil is employed is to charge a condenser of some form rapidly. The time required for a condenser to attain the same potential as the charging source to which it is connected depends largely upon the resistance of the charging source. In order to secure a small time-constant for the charging circuit, it is highly desirable to have a secondary of as low resistance as possible. The lower the resistance of the secondary, the greater the capacity that can be rapidly charged by a coil of a given number of turns. It must be borne in mind that, in order to charge a condenser to a given potential, current is required. The usual small induction coil is wound with very fine wire on the secondary—No. 36 or finer. It goes without saying that this is not at all suited for use in wireless telegraphy. Considerable data on coils suitable for the use herein considered is available. The core should be composed of well-annealed, Swedish soft iron wire of small diameter—about No. 24—wound with a primary of comparatively few turns of coarse copper wire—about No. 12—double cotton-covered and well insulated from the core. It is not practical to wind the secondary with coarser wire than No. 32 or No. 33 B. & S. gauge. Special attention should be paid to the insulation of the secondary as it is of great importance that this be able to withstand the high impulsive electromotive forces of short duration which occasionally manifest themselves. Late design seems to be in the direction of longer cores—about twice the length of the secondary winding.

Tesla called attention to a fact of importance in connection with induction-coil design, as far back as 1893, viz, that a condition of resonance between the primary and the secondary circuits greatly adds to the efficiency of the device. This has the practical result of greatly decreasing the resistance of the secondary and also the number of turns, with a result that much more current is deliverable from such a coil. In the primary circuit there is usually large capacity and small inductance, while in the secondary there is small capacity and large inductance.

Even with the above added efficiency, induction coils are not as suitable in many respects for commercial radiotelegraphy as alternating-current transformers. The utility of the induction coil is limited by reason of the fact that the details of design are so largely a matter of compromise that it is impracticable to obtain the desired charging current at the required voltage. The efficiency of induction coils is at best but slightly above 50 per cent, and there are reasons for believing it much lower.

The three important adjuncts of the induction coil are the primary condenser, the interrupter, and the signaling key.

Primary Condenser. The principal function of the primary condenser is to absorb the energy that manifests itself at break in the form of an arc, due to the self-induction of the primary circuit. As the secondary e. m. f. is due largely to the suddenness of the rupture in the primary, it is of the utmost importance that this arc be prevented from forming. The primary condenser is, therefore, placed across the break in such a manner as to be short-circuited when the circuit is closed, but at the instant of break it is placed in the circuit and absorbs the energy which would otherwise be dissipated in the formation of an arc, and which would very greatly increase the time of rupture. Fig. 23 indicates the arrangement of the circuit. The best value for the primary condenser is that capacity which will annul to the greatest degree the sparking at the points of the interrupter. Experiments have shown that if the primary be broken with sufficient rapidity, as for instance with a rifle ball, no condenser is needed. A condenser is not needed with a Wehnelt interrupter.

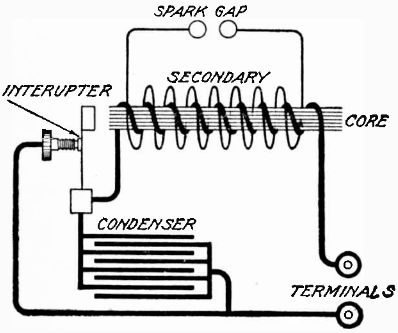


Fig. 23. Diagram of Induction Coil Showing Condenser Circuit

Interrupters. Interrupters perform the sole function of causing a rapid succession of sudden breaks in the primary circuit. The commonest as well as the oldest form of break is known as the *hammer*

LOCATION OF WIRELESS STATION ON THE DREADNAUGHT CLASS OF AMERICAN BATTTLESHIP
It is located at the Base of and Inside the New-Style Tower.

break, probably invented by Neef. Its action is perhaps best shown by referring to the common electric door-bell. An electromagnet, in attracting an armature, causes an interruption of the current energizing the electromagnet, whereupon the armature falls back by reason of its spring tension and again completes the circuit; this energizes the magnet once more, which again attracts the armature, and the whole operation is repeated. The armature is thus kept in continual vibration with consequent interruptions of the current. Fig. 24 shows this device—which is subject to almost endless variation—in a form having as one of its decided advantages the ease with which it is adjusted by simple regulation for different frequencies. Fig. 25 shows another form with the contacts made in small cups of mercury, known as the *Foucault break*. It is obvious that the break can be produced independently of the current in the primary circuit by means of a small electric motor acting on a lever which is made to dip into a cup of mercury, thus completing the circuit any desired number of times per revolution. Such a break is called the *motor break*. The rotary, or turbine, break has been used very successfully on large coils requiring considerable amperage for their operation. The simple hammer break does not operate well with voltages over 16 or 20; therefore, when it becomes necessary to utilize commercial pressures such as 110 and

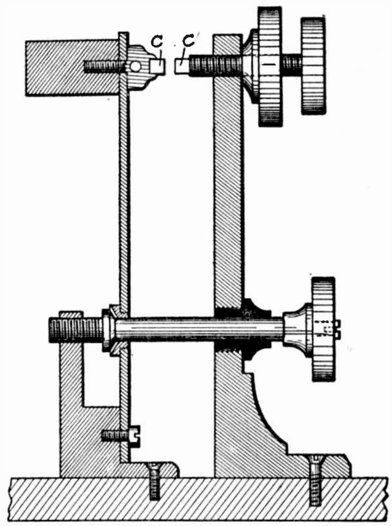


Fig. 24. Neef Hammer Break

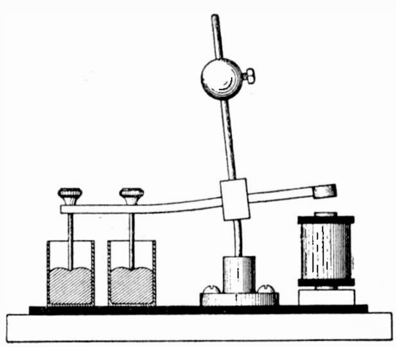


Fig. 25. Foucault Mercury Break

220 volts, some form of mercury turbine interrupter is found to be preferable. One form of this interrupter is shown in Fig. 26.

Dr. Wehnelt of Charlottenburg invented, in 1899, a form of interrupter for use with induction coils, operating on an entirely different principle from those described above. Taking two electrodes of very different size, such as a large lead plate and a small piece of platinum wire projecting from the end of a closely fitting glass tube, and placing them in an electrolyte of dilute sulphuric acid, he discovered that an electrolytic action takes place when the

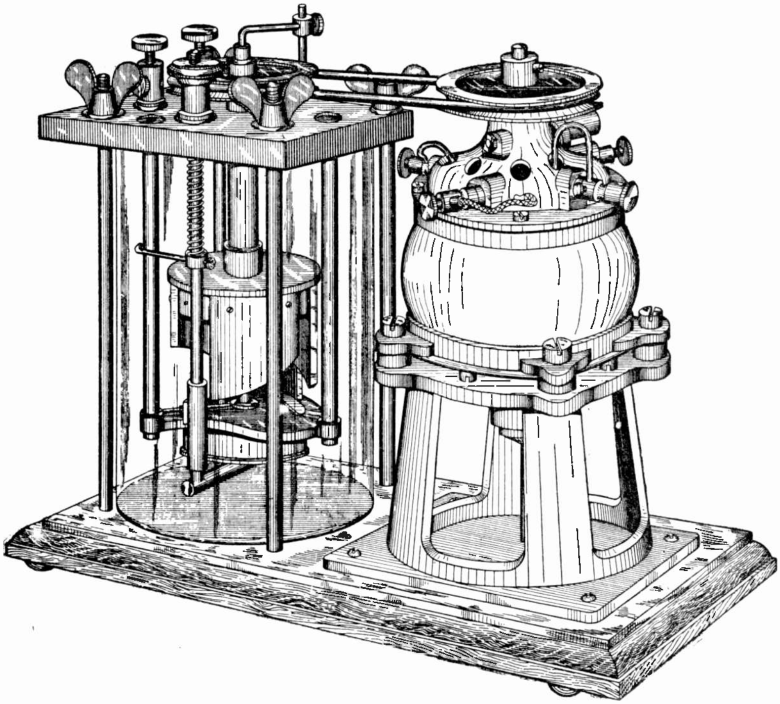


Fig. 26. Mercury Turbine Interrupter

large lead plate is made the negative pole, this action interrupting the current periodically when the device is connected to a source of 40 to 80 volts. Fig. 27 gives an idea of the device, showing one of the many modifications it has undergone in its commercial design. The positive platinum electrode can be seen protruding slightly from the end of the porcelain insulating tube immersed in the liquid, which must be a solution of about one part sulphuric acid to ten parts of water. The cut shows a water-cooling jacket, which is an advantage as the apparatus becomes very warm under continued use. Experiments have shown this device to be capable of producing an intermittency of over 1,800 per second. As mentioned above, no condenser is necessary when operating an induction coil with this form of interrupter. The character of the secondary discharge is somewhat changed by the use of the Wehnelt cell, rendering it more like the alternating arc than the usual disruptive spark. It cannot be said that an entirely satisfactory theory has ever been given for the action of this cell. The Wehnelt interrupter has not been used very commonly in connection with radiotelegraphic work, its greatest field of usefulness being in Röntgen ray work.

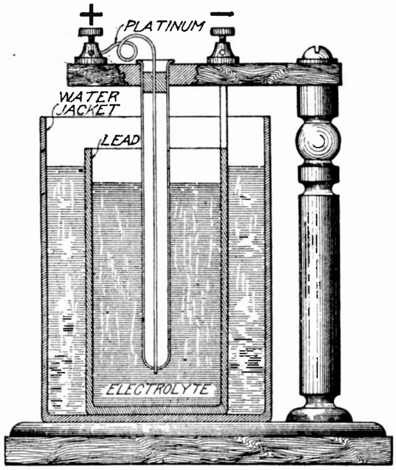


Fig. 27. Wehnelt Interrupter

Keys. In order to transmit messages by means of an arbitrary code consisting of long and short trains of waves representing the Morse alphabet, an adequate means of controlling the torrent of sparks between the electrodes of the spark gap must be employed. The key problem in this form of telegraphy is somewhat more complicated than in the ordinary wire systems, primarily by reason of the fact that a much greater current must be controlled. The common Morse key need not open more than a fraction of an inch, $\frac{1}{64}$ being ample; but it becomes necessary in wireless work to rapidly break currents of several amperes in circuits of considerable inductance, under which conditions the Morse key would not answer at all. The speed of signaling depends largely on the rapidity of the key, a wide movement greatly cutting down the efficiency of the system as a means of communication; therefore, short-range keys must be provided, with some means of annulling the heavy spark on break. Many suggestions have been made and a number of patents taken out purporting to accomplish this end. The magnetic blow-out has proved the most generally useful; though some systems employ a short-circuiting resistance around the break, and others a condenser to absorb the arc. One form of Marconi key simultaneously breaks the primary current and disconnects the aërial from the transmitting apparatus. Many keys are designed to cause the break to take place under oil or other highly insulative substances. Lodge and Muirhead employ an electromagnetically operable key which is actuated by current in a local circuit interrupted by an ordinary Morse key. A common form of such a key, which is of very heavy construction and of extra wide movement, is shown in Fig. 28.

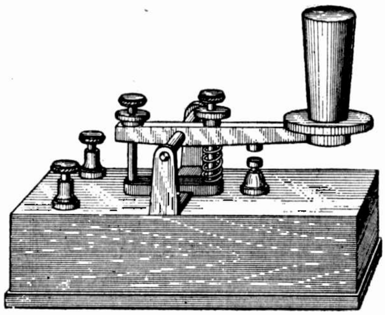


Fig. 28. Long Range Morse Key

Alternating-Current Transformers. In nearly all high-power stations it has been found advantageous, if not absolutely necessary, to discard the induction coil as a means of charging the high capacities used, substituting the alternating-current transformer. This involves the employment of an alternating-current as the initial source of power. Transformers designed for this purpose are wound for a high ratio of transformation, generally for a secondary voltage of at least 20,000 volts, and often 30,000 to 50,000. A difficulty experienced with the use of the transformer is the liability of forming an alternating arc between the balls of the gap in place of the proper oscillatory spark. The practical short-circuiting of the transformer by this action causes a great rush of current through the primary, which, if it has not been guarded against, is liable to cause great havoc with the generator, blowing out the fuses and possibly working other damage more serious. When the capacity of the condenser is of the exact value to take up in the form of a charge nearly the entire energy of each half-wave of the periodic current, no alternating arc will arise and the discharge across the gap will be due entirely to

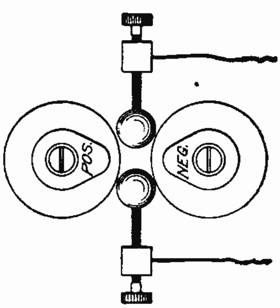


Fig. 29. Tesla Magnetic Blow-out

the condenser, in which case no external means for extinguishing the arc are necessary; but this relation is very hard to effect permanently, so that numerous plans have been devised to prevent the formation of this arc. The one due to Nikola Tesla, which has undoubtedly proved to be the best, utilizes a strong electromagnet so that its lines of force pass transversely between the spark gap. This arrangement is called a *magnetic blow-out.* Fig. 29 shows the scheme. Elihu Thomson achieves the same end by directing a strong blast of air on the gap from a nozzle. This permits the oscillatory spark to form at the proper time, but completely extinguishes the alternating arc, or rather prevents its formation. The noise incident to the operation of a large transformer producing a heavy oscillatory spark is deafening and some precaution must be taken to protect the ears of an attendant if the gap is not enclosed. The light from such a spark is also very hard on the eyes.

Oscillation Transformers. Transformers designed for high-frequency, high-potential, oscillatory currents are in many respects different from the transformers suitable for use on low-pressure, low-frequency, electric-light mains. The most striking difference is the absence of an iron core and the small number of turns of wire employed. The transformer used by Marconi with the Marconi-Braun type of closed oscillator was constructed as follows: The primary consisted of but one turn on a stranded conductor of low resistance with a secondary of thinner wire laid over the primary in about ten turns. The coils were immersed in highly insulating oil. In commercial practice oscillation transformers are of various design. It is of the utmost importance that transformers of this character be specially well insulated, particularly when the primary and the secondary are in close inductive relation. The use of oil in this connection is the common practice. Late forms of oscillation transformers are made in such a manner that the distance between the primary and the secondary may be varied, thus alternating their inductive relation, a so-called "loose couple" being produced by separating the two components.

Condensers. The condensers employed in radiotelegraphy, as in other departments of electro-technics, are chosen with regard to the voltages to which they are to be subjected. The capacity used in connection with receiving circuits requiring no high insulating properties generally takes the form of paper or mica condenser supplemented by a variable-capacity condenser consisting of a number of fixed metallic plates interspaced in air between an equal number of moveable plates, whereby the effective capacity areas of the plates may be varied within wide limits.

In the transmitting circuit where the condenser is employed to temporarily store the energy preparatory to the sending of a signal, a form of condenser must be used which will withstand the electrostatic strain of a very high potential. This necessitates the use of glass, mica, or oil, as experience has proved these materials to be almost the only dielectrics practicable for the purpose, glass being, all things considered, the best of all. The higher the voltage, the greater the thickness of glass needed; and as the storing power of a

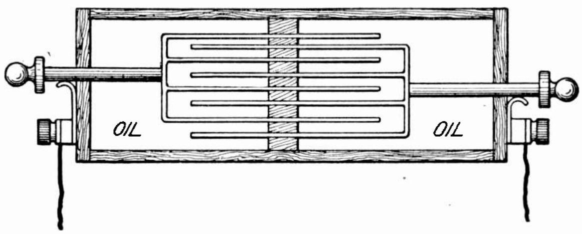


Fig. 30. Adjustable Condenser

condenser varies directly with the square of the potential to which it is charged, it is evident that there exists a definite relation between the dielectric strength of the medium (glass) and the volume per unit of energy which it is desired to store. This is equivalent to saying that a great amount of energy could be stored in a very small condenser if the dielectric could stand an exceedingly high potential. Hence, the object to be attained in the designing of condensers for radiotelegraphy is a maximum energy-storing ability with a minimum of cost, size, and weight of glass. In practice it is better to use a good grade of glass free from lead and other impurities. Oil condensers are sometimes used, constructed of sheets of brass or zinc, and immersed in "transformer oil." Adjustable condensers, made as shown in Fig. 30, are often used for purposes of tuning; their capacity may be varied by withdrawing the plates, thereby reducing the effective area. Braun employed small condensers made of test-tubes covered with tin-foil inside and out for short-distance low-power stations.

Quart or gallon Leyden jars are often employed, lending themselves very well to the requirements.

Tuning Coils. In order to facilitate the tuning, or syntonizing, of the oscillatory circuits included in a system of radiotelegraphy, some apparatus for varying the electrical dimensions of such a circuit is usually employed. These tuning devices consist simply of a variable inductance, or of an adjustable condenser to vary the capacity, or of both embodied in a single piece of apparatus. As the inductance factor lends itself more readily to a simple method of variation, numerous forms of adjustable inductance coils have been devised, the design of which depends upon the circuit they are to be employed with.

Tuning coils for use with the transmitting side of a station are characterized by a comparatively few turns of very heavy wire or metal ribbon wound spirally on an insulated drum or ebonite cylinder. Connection is made at any point on the spiral conductor either by means of flexible connecting cords provided with metallic clips, or by the use of a sliding connection so arranged as to permit of any desired length of the inductive conductor being included in the circuit. Many systems utilize the space within the turns of inductive resistance for the placing of the condensers, thus greatly economizing the room otherwise required for these two portions of the apparatus.

As the receiving circuits usually possess much less capacity than the transmitting circuits, the tuning coils designed for connection therewith have a much larger number of turns. Such coils are generally constructed with several hundred turns of rather fine wire wound on a large bobbin having two sliding contacts so arranged as to include between them any desired number of turns. These coils are made in a great variety of ways.

Spark Gaps. An important element of the transmitting station is the gap, across which the stream of sparks takes place. In a previous chapter attention has been called to the resonator of Hertz and to the metallic balls between which he produced his oscillatory spark. In his book on "Electric Waves" published in English in 1894, he advises that these balls be highly polished. For the small amount of energy used by Hertz this was no doubt advantageous, particularly in the production of short waves; but with the further development of the art it became evident that it was impossible to maintair such surfaces when employing sparks of great volume. The essential condition to be fulfilled is that the discharging surfaces shall maintain a permanent condition and not be burned away and pitted by the rapidly recurring heat of the spark. With the utilization of radiators of high power, and with the employment of transformers capable of charging large capacities, the need of a means for maintaining a constant condition of the spark gap became imperative. Special appliances were devised to prevent the pitting of the balls and their consequent destruction.

Marconi early adopted the Righi oscillator plan of placing the balls in a chamber of oil, or other highly insulative medium, thereby excluding the oxygen of the air from the balls and preventing oxidization. He soon found, however, that the insulating fluid was rapidly decomposed under the influence of the more powerful discharges and abandoned the idea in favor of a "dry" ball system.

Numerous inventors have contrived many so-called multiple-ball exciters, among whom is J. S. Stone, whose oscillator is shown in Fig. 31. R. A. Fessenden has conducted numerous experiments which seem to indicate that there is great advantage to be gained by causing the spark to take place in a compressed-air chamber. This is explained by the fact that the effective potential between the balls is thereby raised without rendering the spark non-oscillatory. Better radiation is possible also, according to Fessenden, and it is undoubtedly a great improvement in reducing the ear-splitting noise of the customary discharge. Various compressed gases have also been used with varying success.

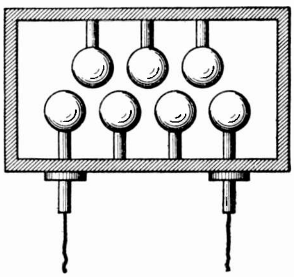


Fig. 31. Multiple-Ball Exciter

Among the various forms of exciter which have more or less successfully fulfilled the requirements, mention must be given to one other fundamental form employed by Marconi. It took advantage of the important fact that though it is exceedingly difficult to create a true alternating arc between two relatively moving surfaces, nevertheless an electric oscillation from a condenser can readily take place even though the movement be exceedingly rapid. Marconi, therefore, devised what is known as the *high-speed disk discharger*, shown in Fig. 32. It would seem that this design of gap possesses many advantages as attested by the extensive employment of it at the trans-Atlantic stations. The illustrations make clear the connections. The apparatus consists of two metallic disks *A* and *B*, revolving at high speed, and a second larger disk at right angles to the axis of the other two and between them, also revolving at high speed. There are thus two gaps where sparks may take place. The closing of the key charges the condensers *C* and *D*, in series between which is connected the condenser *E*, which discharges the energy across either

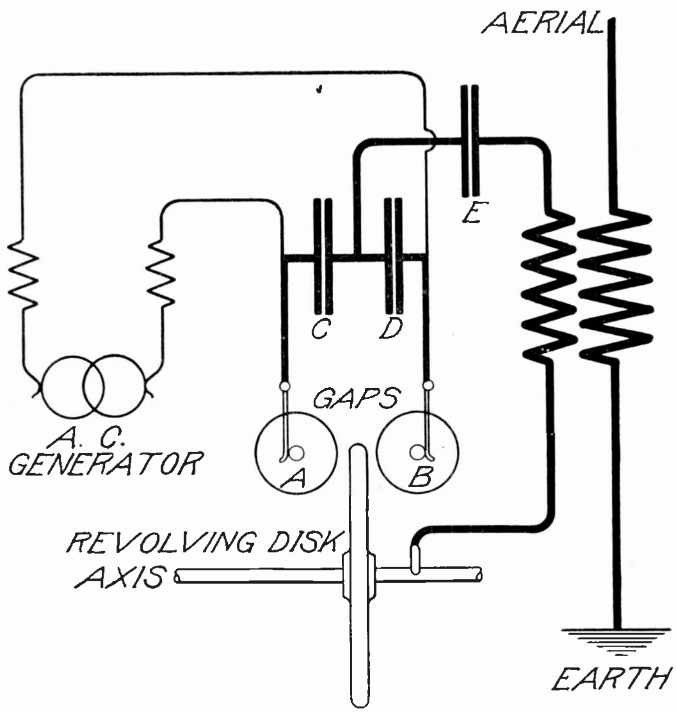


Fig. 32. Diagram of Marconi High-Speed Disk Discharger

gap between the rapidly revolving terminals. Another modification of this device, shown in Fig. 33, is characterized by the fact that it is designed for use with a direct current. The mechanical construction is similar to that of the form previously described, with the exception that the large disk has a row of metallic studs placed equidistantly around its circumference in such a manner as to greatly shorten the length of the air gap between the two revolving terminals when the said studs occupy a position in a line with the plane of their rotation. The office of these studs is to shorten the air gap at predetermined and equal intervals, thus discharging the condensers, which are immediately charged by the direct current. In both forms of the device the arc is prevented by the rapid rotation of the revolving parts. It is claimed that the Marconi dischargers permit of great rapidity of signaling. The last described produces, when run at very high speed, an almost continuous train of oscillations.

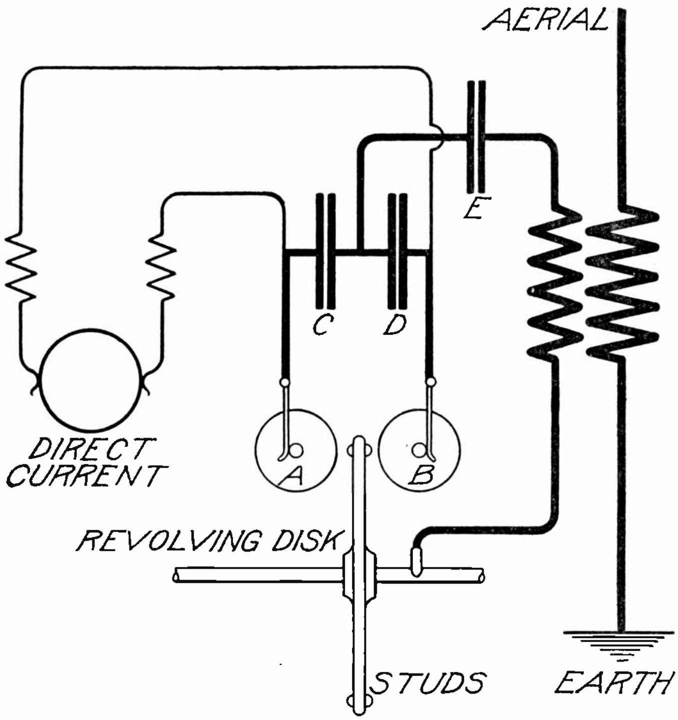


Fig. 33. Disk Discharger for Use with Direct Current

High-Frequency Alternators. It was known at an early date in the history of radiotelegraphy that a much greater efficiency could be achieved if a means were devised for creating a continuous train of undamped oscillations. The Morse dot, which is the minimum signal, was seen to be composed of a considerable number of separate trains of waves, each rapidly damped. Could these "gaps" in the wave train be filled up, the received signal would not only be stronger, but selective signaling would also be greatly facilitated and precise tuning be more easily accomplished. A moment's thought will suffice to convince that a continuous train of undamped oscillations would be the exact equivalent of a continuous alternating current of extremely high frequency; and this opens up the possibility of employing generators which might be connected directly with the aërial, thus doing away with the intermediate condenser and spark gap.

Many attempts have been made to construct generators of sufficiently high frequency, the majority of them having been of the inductor type. An exceedingly small electrical output seems to be the characteristic of all attempts thus far to produce such a machine. Great speed of rotation of the disk armature is required in this type of generator, and as there are limits beyond which it is unsafe to push the rotation, fundamental difficulties arise which have not as yet been surmounted with any degree of commercial success. Fessenden claims to have produced an alternator giving a frequency of 80,000 cycles. The wattage is said to be about 250. The ingenious German inventor, Ernst Ruhmer, has also constructed an alternator of the inductor type having a frequency of 300,000 and an output of but .001 watt; and W. Duddell has succeeded in producing a frequency of 120,000 with somewhat greater power. Until it is possible to greatly increase the output of such machines, their use will be limited to laboratory experiments, or at most to short-distance work in connection with radiotelegraphy. Their development at the present time seems to be in connection with radiotelephony.

The Singing Arc. Much more successful have been the attempts to produce a continuous train of undamped oscillations from a direct current. Elihu Thomson applied, in 1892, for a United States patent on a method intended to effect such a transformation, Fig. 34. A source of direct current is connected to a circuit having a very high inductance, and a spark gap across which is shunted a condenser, and smaller inductance in series. The inventor claims in his patent specifications that the gap, inductance, and capacity can be so adjusted that the condenser is periodically discharged across the gap at frequencies as high as 40,000 per second.

The form that this apparatus has since taken is known by the name of Duddell singing arc, on account of the further developments introduced by him in 1900. Duddell substituted a carbon arc for the gap, and found that such an arrangement produced a clear

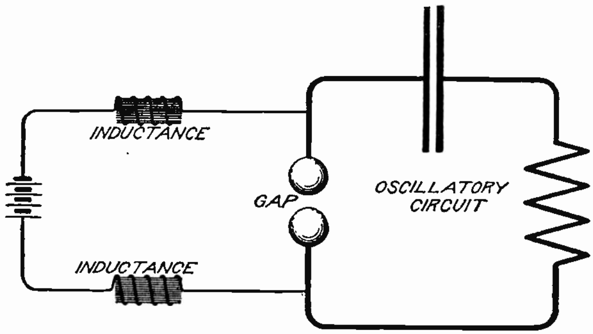


Fig. 34. Thomson Direct-Current Method of Genera'ing Oscillations

musical note plainly audible some distance away, the pitch of the note depending on the value of the capacity and the inductance in the oscillatory circuit—the latter is represented by the heavier lines in Fig. 35. The best effects were obtained by the use of solid rods of

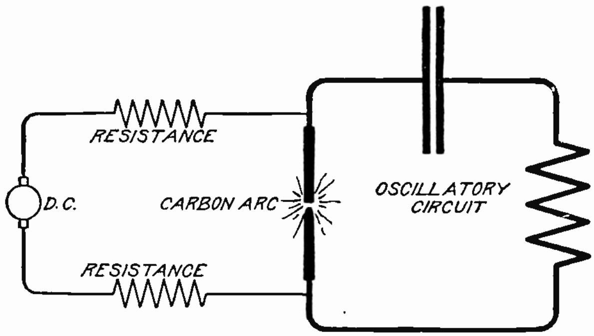


Fig. 35. Duddell Singing Arc

carbon. The resistance of the inductance in the oscillatory circuit must be low—about 1 ohm. Duddell found it difficult to produce oscillations of any considerable power above a frequency of about 10,000; although other experimenters have succeeded in reaching a frequency of 400,000 with small capacity and little energy.

It remained for Valdemar Poulsen of Copenhagen to make the greatest improvement in the direct-current arc method of producing oscillations. Fig. 36 shows Poulsen's arrangement. In the first place, he enclosed the arc in an air-tight chamber filled with coal gas, and used a water-cooled positive electrode with a carbon negative. He also introduced into the chamber the polar projections of two powerful electromagnets in such geometrical relation as to cause the lines of force to pass directly between the electrodes as shown in the diagram. The connecting lines make clear the circuit. The fundamental similarity to Thomson's circuit is apparent. It is possible to produce very powerful undamped oscillations with this apparatus, the frequency of which may, by the proper adjustment of the capacity and the inductance, be made as high as 1,000,000 or more. There is a particular length of arc, called the "active" arc, which gives the best results. Poulsen's device is operable with many other gases besides the one mentioned. The magnets *S* and *N* must be very powerful. 500 volts seems to be a practical voltage for use with this device.

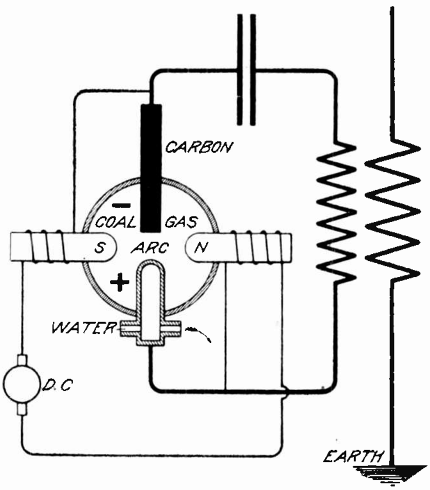


Fig. 36. Poulsen Direct-Current Method of Generating Oscillations

Aërials. The aërials at present used are of many kinds, ranging from the short length of weatherproof wire extending from an upper window to a nail in the chimney, proclaiming the abode of a juvenile experimenter, to those enormous structures taxing the resources of modern engineering in their construction, which achieve trans-Atlantic communication. It was early recognized that the radius of communication was greatly extended by increasing the capacity of the aërial; which fact has led to the employment of multiple-wire antennae. Figs. 37, 38, 39, and 40, show some of the commoner forms, conditions usually determining the choice. It was found by experiment that the capacity of two wires suspended in the air was not twice the capacity of one, nor four wires twice the capacity of two, if such wires were placed near together. The reason, therefore, is apparent why in many of the aërials the individual wires are separated to comparatively great distances.

It is of extreme importance that the upper end of suspended radiator wires should be exceptionally well insulated, and the reason is obvious. Specially designed porcelain or glass insulators are used, having two holes through which the ends of the wires are bound.

Aluminum wire serves excellently for the purpose of antennae when the strain upon it is not too great. Its low tensile strength

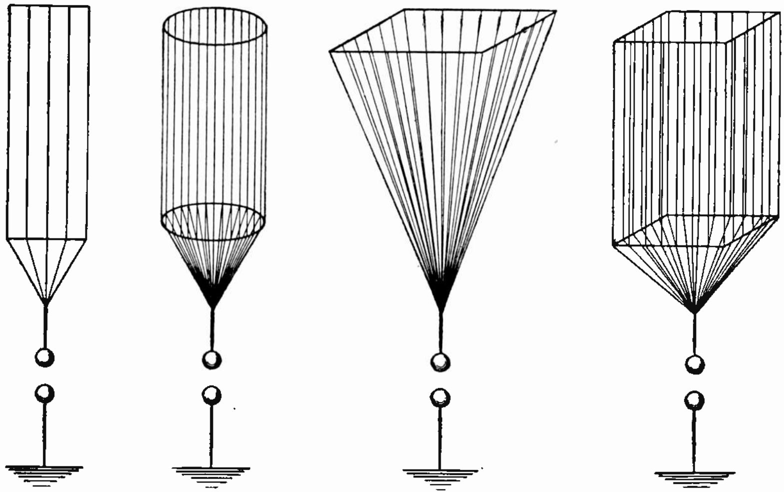


Fig. 37. Fig. 38. Fig. 39. Fig. 40.

Standard Forms of Aërial

precludes its use in some cases. A simple manner of suspending a single-wire experimental aërial is shown in Fig. 41. The mast, or short flag-pole, may be lashed to the tallest object available and the wire carried out of perpendicular a sufficient distance to prevent it from hitting the pole. In army field-equipment, kites or captive balloons are often used to elevate the aërial wire, which is carried wound upon a reel. Many aërials are arranged with a tail block on a cross-tree in order that they may be let down from a high mast for inspection purposes. Such aërials are of the cage variety shown in Fig. 38. An idea of the construction of antennae when designed for use in connection with high-power stations may be gained from Fig. 42.

Directive Antennae. Many efforts have been made to direct the transmission of radiotelegraphic signals to any desired point or locality, but with indifferent success. Early attempts embodied the use of large reflectors behind the oscillator; but the most encouraging results have been accomplished by the use of what are known as *horizontal antennae*, the subject of a patent granted to Marconi and dated 1904. DeForest has also met with some success along this line. The results obtained by these investigators are not formulated well enough as yet to warrant a description of them here.

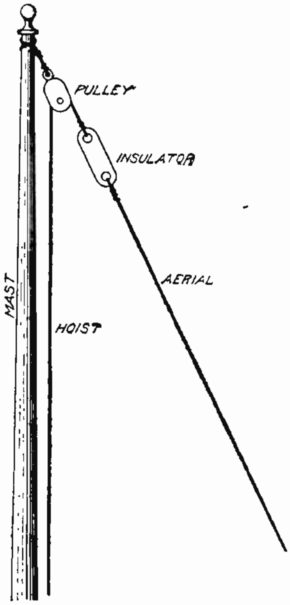


Fig. 41. Single Wire Experimental Aërial

Detectors. The subject of the reception of wave-trains and the transformation of their energy into visual or audible signs through the agency of suitable translating devices will now be taken up and described. It is helpful toward a comprehension of this part of the subject to get clearly in mind the primary effect of a train of waves upon a receiving aërial, namely, the creation of an

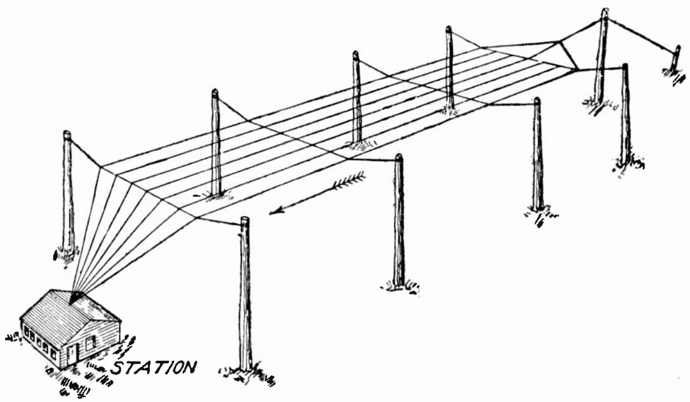


Fig. 42. Antennae Construction for High-Power Station

alternating electromotive force. And the prime function of a receiving device is broadly to detect the presence of a high-frequency alternating current of minute value. Volumes could be written on the history of the various forms of receiving devices which have occupied the attention of the various investigators in this interesting field of experiment. In the present instance attention will be called to those forms only which have proved themselves of practical value.

Wave-detecting devices may be classified for convenience according to the physical principle on which they act, such as thermo-electric, magnetic, electrolytic, chemical, photo-electric, physiological, etc.* This course will be followed as far as practicable.

Coherers. Coherers work on the principle of imperfect contact and are called self-restoring and non-restoring according as their sensi-

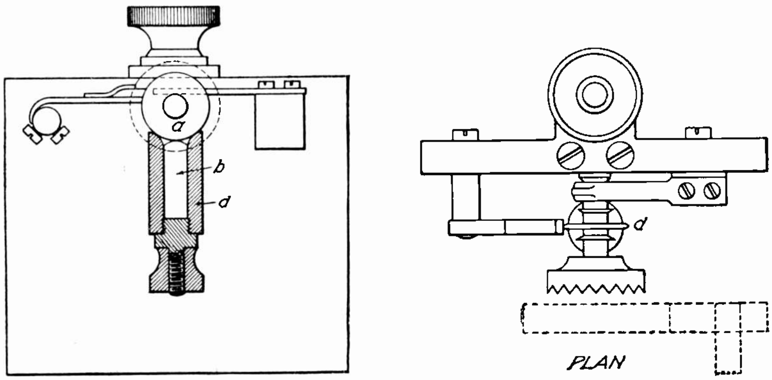
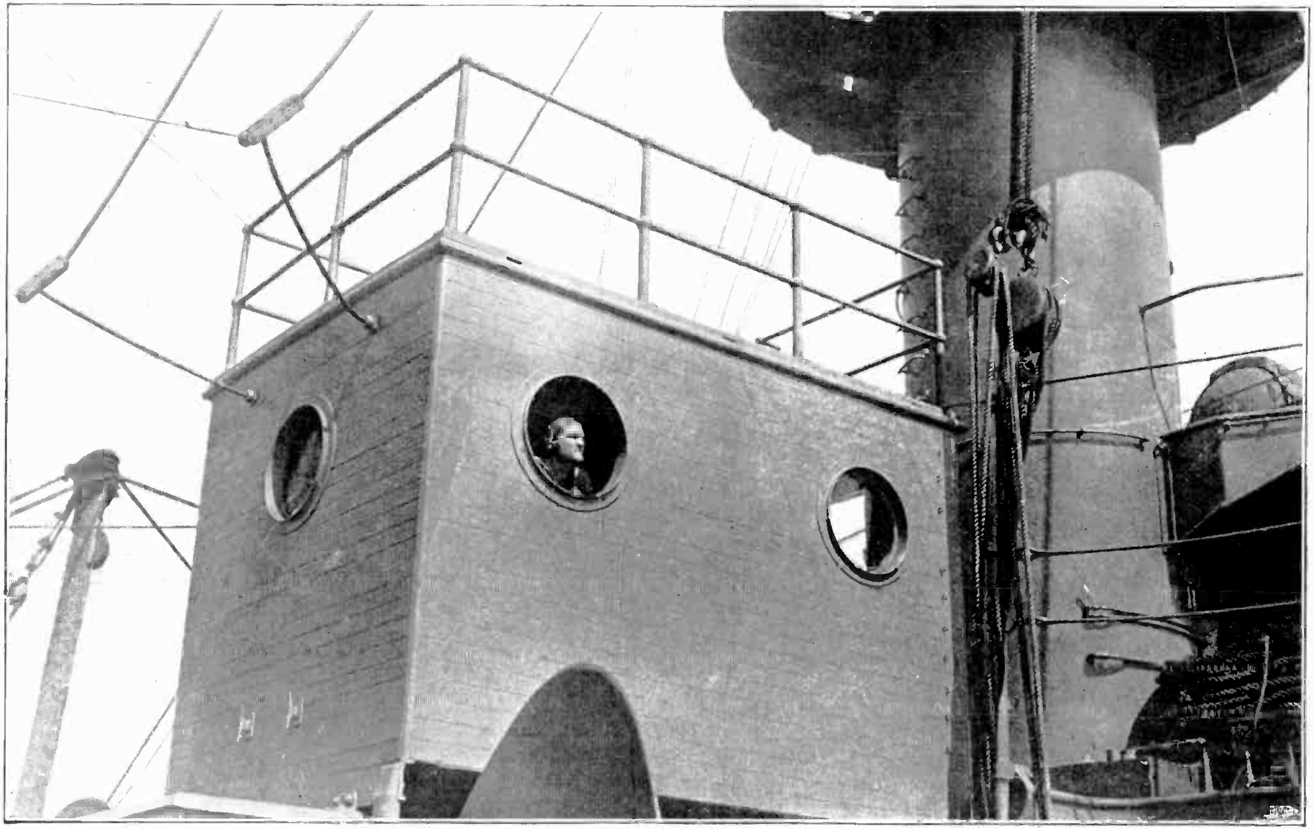


Fig. 43. Lodge-Muirhead Detector

tiveness is automatically reassumed after the passage of a train of waves, or must be superinduced by some external agency. Commercially the coherer has become almost obsolete.

Branly Coherer:—It is unnecessary at this point to give more than passing mention to the Branly coherer, as it has been fully described in a previous chapter. As improved by Lodge and Marconi it performed a very important function in the early days of radio-telegraphy, but has now fallen into disuse.

Lodge-Muirhead Coherer:—An interesting form of contact detector is shown in Fig. 43, devised by Lodge and Muirhead. It consists of a slowly moving steel disk *a* whose sharpened edge is prevented from coming into contact with the small globule of mercury *b* by means of a thin film of oil interposed between the mercury and the steel and contained in the recess *d*. Oscillations passing through the oil cause a breakdown of its high resistance,



TYPICAL NAVAL WIRELESS STATION ON SHIPBOARD

View taken on Board the U. S. S. "Tennessee."

permitting a translating device to operate by reason of the improved conductivity. Upon cessation of the oscillations, the movement of the disk re-establishes the initial receptivity.

Italian Navy Coherer:—The Marconi Company used with success for a time the so-called "auto-coherer" invented by Signor Castelli, and often referred to as the Italian Navy coherer. The

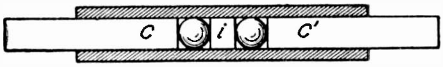


Fig. 44. Castello "Auto-Coherer"

action is entirely automatic. In Fig. 44, i is an iron cylinder separating two globules of mercury; c and c' are of carbon. Cohesion between the mercury globules and electrodes exists only under the stimulus of the oscillations.

Tantalum-Mercury Coherer:—The tantalum-mercury imperfect-contact detector invented by L. H. Walter is the simplest as well as one of the best of the self-restoring coherers. A small portion of the filament of a tantalum incandescent lamp is connected to a piece of platinum wire for terminal purposes, and the tip of the tantalum is immersed in mercury, which thus forms the other terminal. The whole may be sealed up in a vacuum to avoid oxidization of the mercury. The contact offers very high resistance to a small e. m. f., but falls very low under the influence of the received oscillations. It is rapidly self-restoring. Telephone receivers are often used with this class of detector instead of the Morse relay and recorder, thus allowing the detection of signals from much greater distances owing to the extreme sensitiveness of the Bell instrument to minute differences of current. Such a receiver responds by a buzz to the Morse dash from the distant station.

Valve, or Rectifier, Detectors. One of the difficulties of detecting electric oscillations is the fact that they are of an alternating nature. With the present means at our disposal it cannot be said that we can detect the presence of minute alternating currents with the ease with which we can detect direct currents of equal value. This has led to endeavors to rectify the high-frequency alternations of the received oscillations. Detectors of this type are known as valve, or rectifier, detectors, and one of the simplest means of detecting radiotelegraphic signals is afforded by such devices. To their extreme simplicity is due to a large extent the present number of amateur wireless installations to be seen on all sides. The action of the silicon detector, shown in Fig. 45, is due to the fact that a considerable number of substances in nature possess the property of unilateral conductivity, or the property of conducting electricity freely in only one direction. H. H. C. Dunwoody discovered that carborundum possessed this property to a very marked degree, and would act as a detector if introduced into a receiving circuit in place of a filings coherer. He later observed that no battery was necessary when using a telephone receiver shunted by a small condenser, as shown in Fig. 46. The following substances will all act in place of the carborundum: copper pyrites, iron pyrites, galena, silicon, zinc oxide (perikon), molybdenum sulphide, and titanium oxide. G. W. Pierce has found that the resistance of these substances may be 3,000 times greater in one direction than in the other. The theory of this peculiar action cannot as yet be said to be complete.

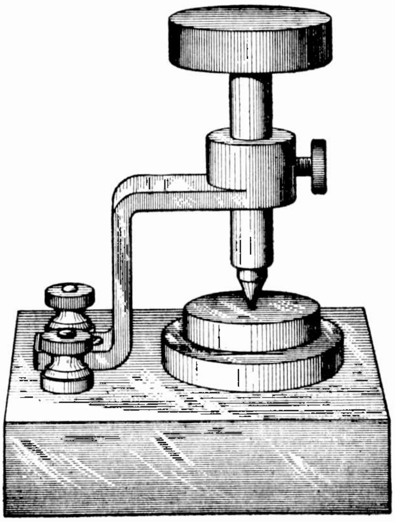


Fig. 45. Silicon Detector

Carborundum, silicon, and perikon seem to be the most satisfactory, particularly silicon, which makes a very sensitive and inexpensive device. Such materials used as detectors of electric waves allow but one-half of each wave to pass, thus giving rise in the telephone to a rapidly pulsating current in one direction to which the telephone can respond. The energy of the oscillations, therefore, directly achieves the audible signal. It has been found, however, that in some cases better results are obtained with a shunted battery cell in the circuit. It is important when using any form of valve detector that excellent connection with the crystal should be maintained at least on one terminal, a deposit of some suitable metal often being employed, thus permitting of a large area of contact. The adjustable contact is preferably pointed and securely held.

Glow-Lamp Detector:—The glow-lamp detector, invented by Prof. J. A. Fleming, was one of the first valve detectors. The theory of its operation may be understood from the inventor's description and with reference to Fig. 47. "An ordinary incandescent lamp with carbon filament has a metal plate included in the glass bulb, or a metal cylinder *C* placed round the filament, the said plate or cylinder being attached to an independent insulated platinum wire *T* sealed through the glass. When the carbon is rendered incandescent by electric current, the space between the filament and the plate, occupied by a highly rarefied gas, possesses a unilateral conductivity, and negative electricity will pass from the incandescent filament to the plate, but not in the opposite direction. This effect depends upon the well-known fact that carbon in a state of high incandescence liberates electrons or negative ions; that is to say, point charges of negative electricity. These electrons, or corpuscles, are constituents of the chemical atom. Hence a carbon filament in an incandescent lamp is discharging from its surface negative electricity, which may even amount to as much as an ampere or even several amperes per square centimeter. If, then, an incandescent lamp made as described has its filament rendered incandescent by a continuous current, and if another circuit is formed outside the lamp connecting the negative terminal of the filament with the insulated metal plate or cylinder in the bulb, and if oscillations are set up in this circuit, negative electricity will be able to move through this circuit from the filament to the plate inside the bulb, but not in the opposite direction."

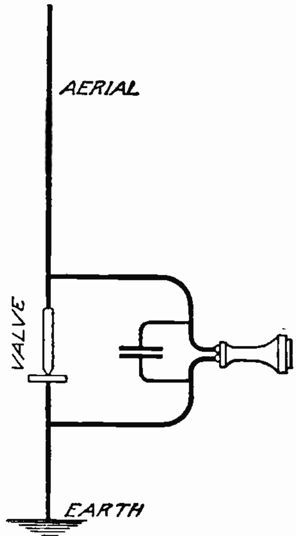


Fig. 46. Diagram of Dunwoody Detector

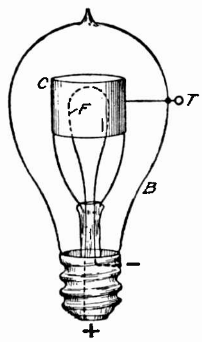


Fig. 47. Fleming Glow-Lamp Detector

It is evident from the foregoing that there are present in the glow-lamp device the essentials of a valve detector. Fig. 48 shows a receiver circuit employed by Marconi making use of the Fleming lamp. Instead of passing the rectified uni-directional impulses directly through the telephone, they are passed around the secondary of a large induction coil in series with a condenser, to the primary of which the telephone receiver is connected. Prof. Fleming is authority for the statement that this arrangement, when suitably adjusted, is "one of the best long-distance receivers for electric waves yet devised."

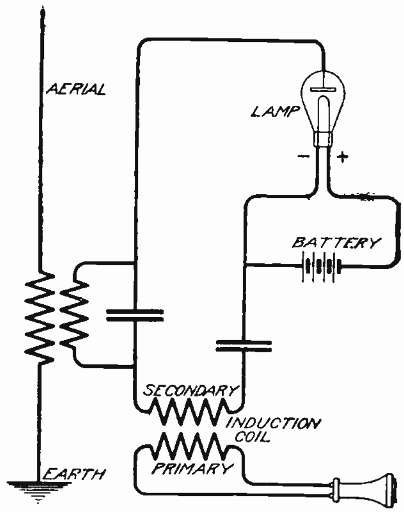


Fig. 48. Marconi Circuit Using Fleming Detector

Audion:—The so-called *audion* of DeForest is a modification of the Fleming detector just described. Fig. 49 shows its connection in a receiving circuit. The lamp used has a low-voltage tantalum filament with two wings, or terminals, sealed in the bulb, as shown. This detector is said to be fairly sensitive, though of short life.

Magnetic Detectors. During the summer of 1902, Marconi was successful in receiving signals sent out from Poldhu on the coast of Cornwall to Flace Bay, Nova Scotia, by means of a remarkably ingenious magnetic receiving device invented by himself and called a *magnetic detector*. Since that time many devices have been patented depending for their operation upon the magnetic effects of the electric oscillations. There has been much discussion relative to the action involved in the Marconi device as well as in other modifications based on the magnetic phenomena

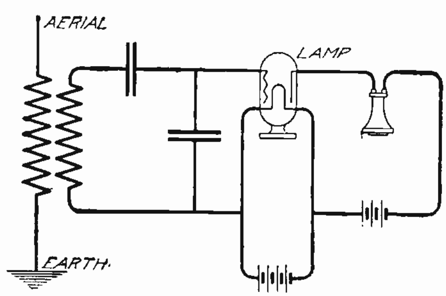


Fig. 49. Receiving Circuit with Audion Detector

associated with oscillatory currents. The explanation advanced by Marconi himself will, therefore, be given here, which in substance is as follows, reference being made to Fig. 50.

The aërial and ground are connected to a few turns of rather heavy wire wound upon a glass tube *T* over which, but insulated from it, is another coil inductively related to the first and connected to the terminals of a telephone receiver. Two strong permanent magnets are placed with like poles together, as indicated. *P* and *P′* are two pulleys carrying on their periphery an endless belt composed of several fine wires of about No. 36 gauge, which are made to pass

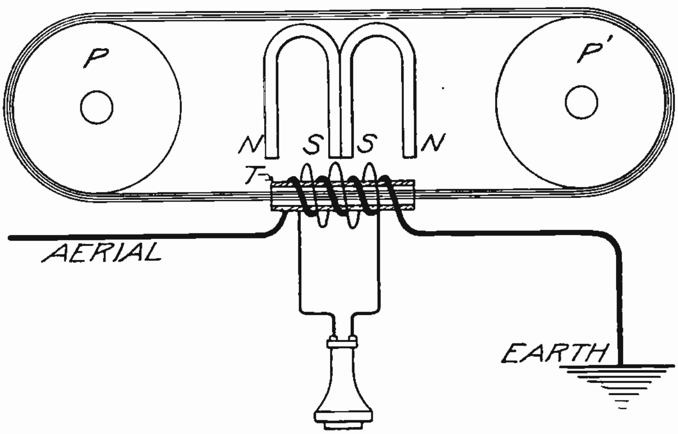


Fig. 50. Diagram of Marconi Magnetic Detector

continually through the axis of the coils by a train of gears not shown. Owing to the hysteresis of the material of the band it tends to retain its magnetism for a short period after it has passed out of the strongest part of the field; but if a train of waves from the aërial is passed through the primary coil to the ground, the effect is to annul the hysteresis and thereby to hasten the demagnetization of the iron wire. This action results in a variation of the flux in the secondary winding, thus inducing electromotive forces in the secondary coil, which make themselves audible in the telephone as a series of sharp ticks. This is said to be one of the most sensitive devices ever made.

A diagrammatic drawing of a magnetic detector, invented by H. Shoemaker, which very closely resembles the early embodiment of the Marconi apparatus is shown in Fig. 51. There have been many variations of the magnetic detector but space will not permit of a description of less important forms.

Thermo-electric Detectors. Comprehended under the head of thermo-electric detectors are those instruments which depend for their action on the heating effects of the oscillatory currents. These

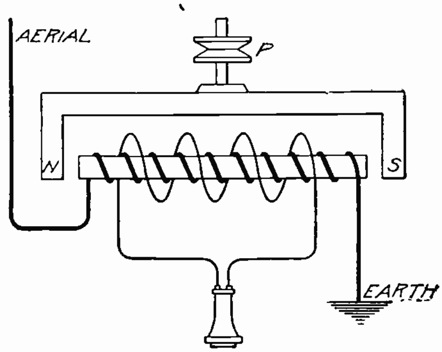


Fig. 51. Shoemaker Magnetic Detector

detectors are especially useful in making quantitative measurements of the amount of energy received under a given condition, and indeed find their greatest utility therein. Fessenden has given great care to his investigations of this form of detector with the result that his so-called "barreter" shown in Fig. 52 is of the same order of sensitiveness as the coherer. It consists of a short piece of exquisitely fine platinum wire connected to suitable terminal wires and the whole enclosed in a vacuum bulb. The temperature rises rapidly under the action of the oscillations, causing an increase in resistance which is indicated by a Wheatstone bridge, in the circuit of which the detector is connected as one of the arms. Attempts have been made to apply the phenomena of the *thermo couple* in this connection, but with only qualified success. It would seem for many reasons that thermo-electrical detectors will not be able to compete with other forms in long-distance work.

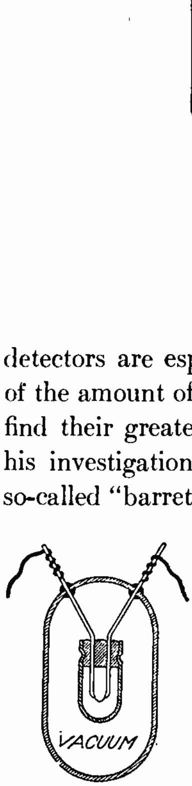


Fig. 52. Fessenden Barreter

Electrolytic Detectors. It remains to take up the class of detectors known as *electrolytic.* DeForest's name is associated with this variety of receiving device, as it was first extensively used by him in a form invented by himself. It consists of a glass tube $\frac{1}{8}$ inch in diameter enclosing conductor plugs after the manner of the Branly coherer. In the interspace is placed a paste composed of rather coarse filings worked up with an equal quantity of oxide of lead in glycerine or vaseline with a trace of water or alcohol. Its resistance increases during the passage of the wave train.

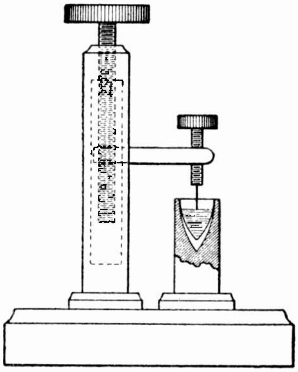


Fig. 53. Liquid Barreter

Fessenden Liquid Barreter:—The most sensitive and practical electrolytic detector is the liquid barreter invented by Fessenden, Fig. 53. It consists essentially of a small containing vessel filled with nitric acid into which projects a platinum wire electrode, which is of extremely small diameter. The apparent resistance of the cell is greatly reduced by the oscillations. The exact nature of the action is not agreed upon by investigators. It was with a refined form of this detector that trans-Atlantic signals were first received from Scotland by the National Electric Company at Brant Rock, Massachusetts.

Hozier-Brown Detector:—The Hozier-Brown system of wireless telegraphy employs a detector classified by some as depending on imperfect contact, but by others as being electrolytic in its action. It consists of a small portion of peroxide of lead held between terminals of lead and platinum, Fig. 54. The lead terminal is much smaller than the other, being a blunt point rendered adjustable by a knurled screw. A two-volt accumulator connected in series gives the best results, according to the inventor.

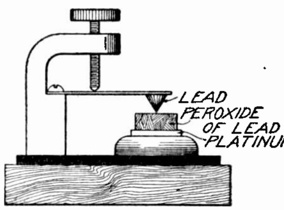


Fig. 54. Hozier-Brown Detector

Electrodynamic Detectors. Mention might be given in passing to the electrodynamic detector devised by Fessenden, although it has never been used extensively. It is designed to operate on the principle that a metallic disk, suspended in a circular coil through which an alternating current is flowing, and at an angle of 45 degrees to the plane of winding of the coil, tends to turn so as to take up a position at right angles to the plane of the coil. This was a fact discovered independently by Elihu Thomson and J. A. Fleming. Fessenden used an extremely light disk hung by a quartz fiber, and he succeeded in obtaining marked deflections of a beam of light reflected from a small mirror fastened to the disk. This device, like the thermo-detector, has been of great service in making quantitative measurements of oscillatory currents.

Auxiliary Apparatus. It would be beyond the scope of the present work to give an extended discussion of the various small devices used in connection with the local receiving circuits, as many of the instruments are not in any way peculiar to radiotelegraphy, being the common adjuncts of wire telegraphy. Mention will only be given to a few points of importance wherein such appliances differ from those commonly employed.

The relay supplied by makers of telegraphic instruments is usually wound with an insufficient number of turns to be efficiently used in connection with a coherer and local battery as a means of actuating a Morse recorder. Rewinding is, therefore, often resorted to. Polarized relays are found to be the best suited to this class of work and should be wound to a very high resistance in connection with all potentially operable detectors. No. 40 wire is often employed.

Sparking at the contacts of the relay is often prevented by the employment of four or five so-called "polarized" cells shunted across the contacts. They are made by inserting a pair of platinum wires through the cover of a small containing vessel partly filled with dilute sulphuric acid, allowing the solution to cover the ends of the electrodes thus formed.

The telephone receivers for use with many forms of detector are much more efficient if wound to a higher resistance than is necessary in the common commercial instrument. Receivers are manufactured in a great variety of forms, only differing from one another in some slight structural modification. The kind known as *operator's double-head receivers* of the watch-case design wound to a resistance of about 500 or 1,000 ohms are well adapted to the requirements of radiotelegraphy.

Dry cells developing an electromotive force, when fresh, of about 1.5 volts are generally used in the local recorder and tapper circuits. One such cell is frequently used in the relay and the coherer circuit.

Measuring Instruments. Perhaps in no department of electrotechnics are the quantitative values of the electrical measurements of more vital importance than in the science of radiotelegraphy. A well-equipped station, therefore, possesses efficient instruments for the measurement of the various electrical factors involved. Besides the common appliances of this nature, such as the voltmeter, ammeter, Wheatstone bridge, etc., it is highly advisable to have the requisite means for making accurate determinations of capacity and inductance. Wave-lengths can be measured by wave-meters, or *cymometers*. These devices are now on the market and are of great utility in a wireless station.

CHAPTER V

SYSTEMS OF RADIOTELEGRAPHY

The history of radiotelegraphy repeats once more the old story that is so often connected with great inventions. The world being possessed of a new scientific principle, many minds in many parts of the world are simultaneously bent upon its practical application, with the result that the fundamental principle finds embodiment in various methods of accomplishing a similar purpose. The startling nature of the discovery of electric waves was bound to give rise to unprecedented activity in the field of experimental investigation; and such experiments as were particularly successful were bound to prompt investigators to seek patent protection on their modifications; and this in turn gave rise to numberless "systems" of radiotelegraphy.

A voluminous list of names could be given of those who have contributed to the advancement of radiotelegraphy in regard to both theory and practice. Among the best-known American investigators are Fessenden, DeForest, Clark, Stone, and Massie. Each of these men has devised a system which bears his name. In England the work has been carried on by men of such unqualified distinction as Lodge, Alexander Muirhead, Fleming, Thomson, and Rutherford. Slaby, Arco, and Braun are the names best known in Germany. The French are represented by Ducretet, Branly, Rochefort, and Tissot, besides other men of lesser fame. We have seen how largely Italy has contributed to the subject; besides Marconi and Righi, mention should be made of Solari, Castelli, and Tommasina. Baviera in Spain, Popoff in Russia, Schafer in Austria, Guarini in Belgium, and Ricaldoni in the Argentine Republic have all invented systems which have been more or less used in their respective countries. The Japanese have also devised a system that successfully stood the test of service in the Russo-Japanese war.

The development of the art in the various countries has been carried on largely by representative investigators, and in many instances the governments have adopted a system exploited by their subjects. The United States government, however, has purchased and experimented with most of the prominent systems offered, and as a result the army and navy equipments comprehend quite a variety of apparatus of different makes.

Telegraphic Codes. Before beginning the description of the more important systems of radiotelegraphy in use at the present time, we will consider the telegraphic codes employed in wireless correspondence. There are three alphabetical codes commonly used at the present time, viz, the Continental, the Morse, and the Navy

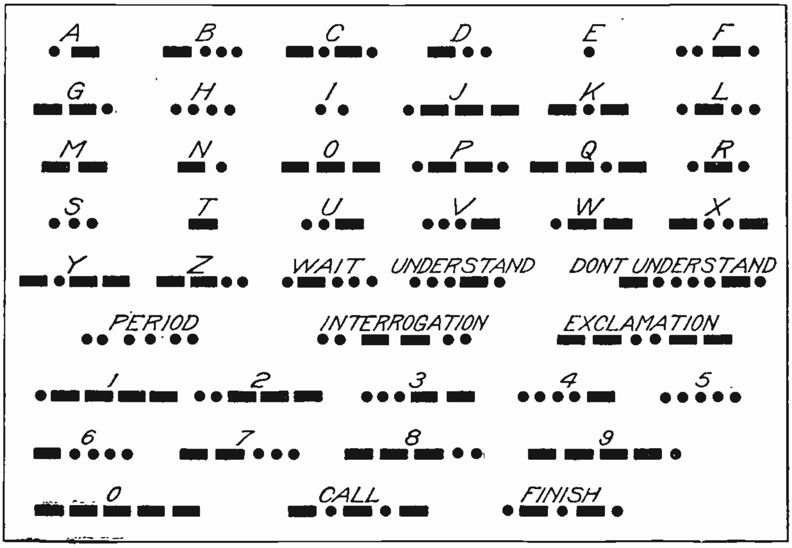


Fig. 55. Continental Code

codes. By far the greatest amount of business is carried on in the Continental code, especially between ships and shore stations. The Morse is more commonly employed for overland service, while the Navy code is confined to naval purposes. Abbreviations of the commoner words are often made use of in transacting the ordinary run of business. The three codes are shown in Figs. 55, 56, and 57.

Marconi System. A detailed description has already been given of the Marconi system as it was about the year 1900. Since then the system has been developed to a remarkable degree so that it stands today a commercial factor of large pretensions. The Marconi stations are scattered in many parts of the globe and are operated in conjunction with all the large telegraph and cable companies.

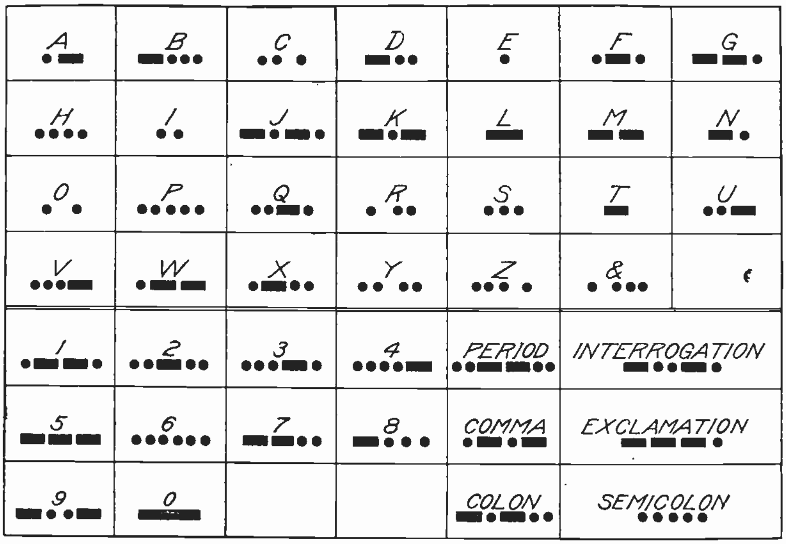


Fig. 56. Morse Code

In addition to the numerous land stations a very large number of vessels are equipped with the Marconi apparatus, including the

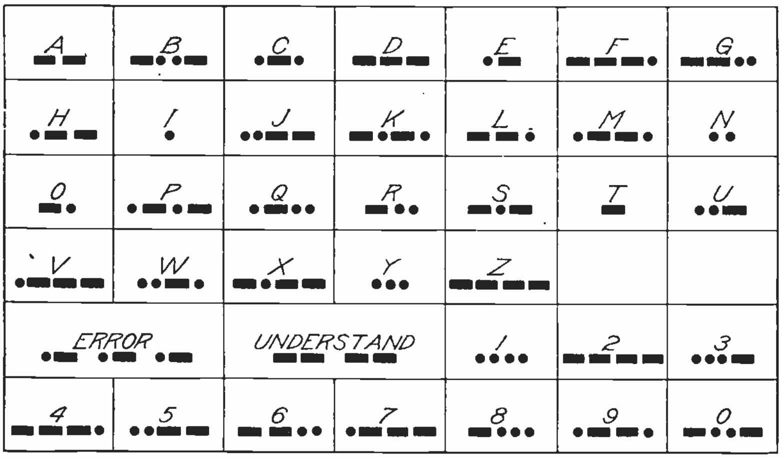


Fig. 57. Navy Code

ocean liners of nearly all the large steamship companies, such as the Cunard line, the Hamburg-American line, the Norddeutscher Lloyd, and many other lines too numerous to mention. Three stations are in operation in China.

For short-distance equipment to be used over a few hundred miles, such, for instance, as is usually installed on Atlantic liners, the Marconi Company employs an induction coil with mechanical break to charge a battery of six to twelve Leyden jars. Two coils and two sets of jars are often supplied in order to readily produce two different wave-lengths. A single spark gap is now used. The Marconi magnetic detector is generally employed, owing to its great simplicity and ease of adjustment. An important improvement evolved by the meeting of practical difficulties is known as the *X-stopper*, *X* being the name given to certain irregular atmospheric disturbances of an electromagnetic nature which manifest them-

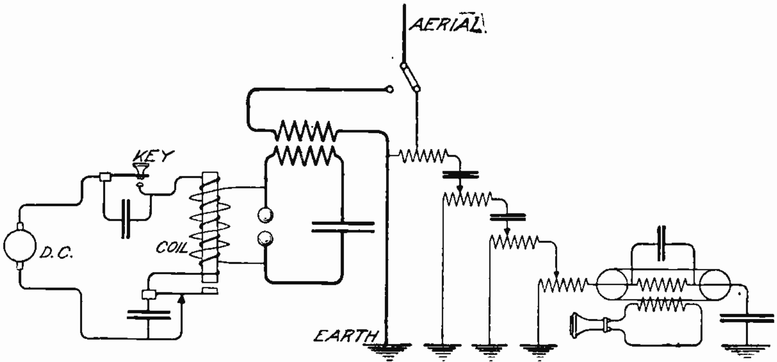


Fig. 58. Complete Marconi Sending and Receiving Circuit

selves as stray signals of sufficient energy to cause confusion in the reception of messages. The means devised by Marconi for overcoming these objectionable interruptions may be seen in diagram in Fig. 58, which shows one form of the complete sending and receiving circuits employed by the Marconi Company. The lower end of the receiving aërial is connected with a plurality of adjustable oscillatory circuits of varying periodicity which terminate in the primary oscillation circuit of the receiving device. The operation of the contrivance depends upon the ability of the first three grounded circuits to perform the function of leading to the ground waves whose frequency does not accord with the periodicity of the system as a whole. It will be noted that the closed type of oscillatory circuit inductively coupled to the aërial as before described is used in the transmitting arrangement of apparatus. The later form of oscillation transformer used at the sending station is designed to provide means for varying the closeness of the inductive couple. This possesses many advantages.

The Marconi Company has equipped several high-power trans-Atlantic stations. The modifications of the short-distance apparatus made necessary for long-distance signaling pertain largely to means for controlling a much larger amount of energy at the transmitting station and the employment of longer wave-lengths. Communication was established the latter part of 1907 between Cape Breton, Nova Scotia, and Clifden, Ireland, by waves 12,000 feet in length generated by means of the Marconi high-speed disk discharger used in conjunction with a condenser of 1.16 microfarads charged to 80,000 volts. Horizontal, or directive, antennae are used with their free ends directed away from each other at the two stations, the horizontal portion being about 1,000 feet long and raised about 200 feet in the air. The Marconi magnetic detector, and also a modification of the Fleming glow-lamp detector, have been used as receptors in this class of work.

An ingenious form of signaling key for use in connection with high-power installations employing alternating current has been patented by the Marconi Company. The fundamental feature of the invention consists in the use of a laminated electromagnet through which the current to be broken is conducted, so placed as to hold the key closed by the attraction of an armature on the key until the current reaches the zero value, at which time the key is allowed to break connection unaccompanied by a spark. The connection may be made and maintained at will, but upon release of the key the circuit is broken at the instant when the current reaches the zero value; the frequency of the alternating current being at least such that this occurs about 100 times per second, the maximum lag of the key behind the movement of the operator's button is inappreciable.

Fessenden System. Fessenden undoubtedly holds a position of first rank among scientific investigators in the field of electric radiation. Moreover, he has proven himself to be an inventor of exceptional originality. His experiments in radiotelegraphy date back to the early days of the art. The National Electric Signaling Company now control the long list of patents resulting from his researches beginning in 1897 and covering a great variety of subjects pertaining to every part of radiotelegraphic equipment as well as to radiotelephony.

The National Electric Signaling Company completed in 1905 two trans-Atlantic stations for communication between Brant Rock, Massachusetts, and Machrihanish, Kintyre, Scotland, a distance of more than 3,000 miles. Successful communication was established on Jan. 3rd, 1906, the detector used being the liquid barreter, already described. An interesting feature of these long-distance stations is the design of the aërial. This is in the form of a vertical steel tube 3 feet in diameter and 415 feet long, resting upon an insulated foundation, and supporting an "umbrella" formed of wires at the top. This structure is held in an erect position by sixteen guys insulated to withstand a voltage of over 150,000. A 25-kilowatt, 60-cycle, boiler-engine alternator supplies the energy.

Fessenden has devoted much time to the problems of selection, interference, and tuning. As a result of his labors in this field, the Fessenden system may be said to represent the highest development in this respect yet achieved.

The National Electric signaling equipment comprises a transmitting device of the direct-coupled aërial variety, characterized by the arrangement of the sending key which, by cutting out a certain amount of inductance in the oscillatory circuit, alters the frequency of the waves emitted—instead of interrupting the primary circuit and causing a cessation of the waves, as in common practice. This requires that a receiving station be tuned with great accuracy, in order to respond to a slight difference of wave-length only, an untuned circuit being thus unable to receive any signals other than a continuous dash. It is claimed that a difference of wave-length occasioned by the operation of the key, amounting to less than one per cent is sufficient to achieve perfect communication. This exceptional freedom from interference is due largely to the employment of what is called an *interference preventer*, diagrammatically represented in Fig. 59, which shows an improved Fessenden receiving circuit. The aërial is connected through a variable inductance to a divided circuit and thence to the ground. In each half of the divided circuit is placed a condenser in series with the primary of an air-core oscillation transformer. The secondary terminals of the transformer are united by a condenser A, a signal translating device consisting of the liquid barreter B, a potentiometer C, and a telephone receiver D—all in series. The secondary terminals of the transformers are connected up so as to oppose each other, after the manner of a Hughes induction balance. The aërial and one-half of the divided circuit are tuned to the desired frequency, the other half being momentarily disconnected; then the latter is connected again and the capacity of the condenser E is adjusted until the disturbing signals are eradicated. The operation is theoretically as follows: Signals of the proper wave-length pass almost entirely through the side of the divided circuit which is tuned to correspond, while waves of any other frequency pass with equal ease through both sides of the divided circuit, thereby acting differentially on the secondary oscillation circuit because the secondary windings of the oscillation transformers oppose each other. It is said that this arrangement will differentiate between waves differing but one per cent in wave-length.

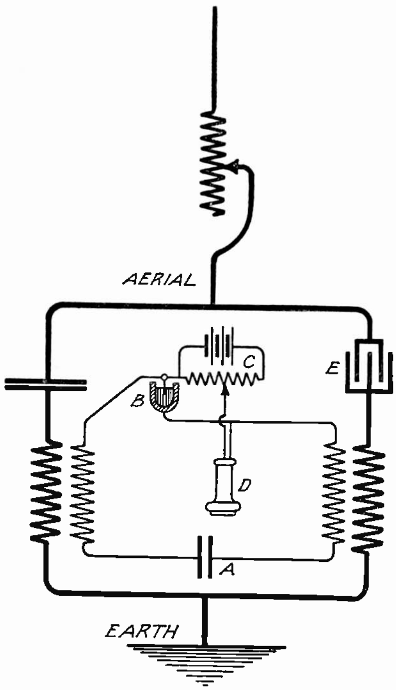
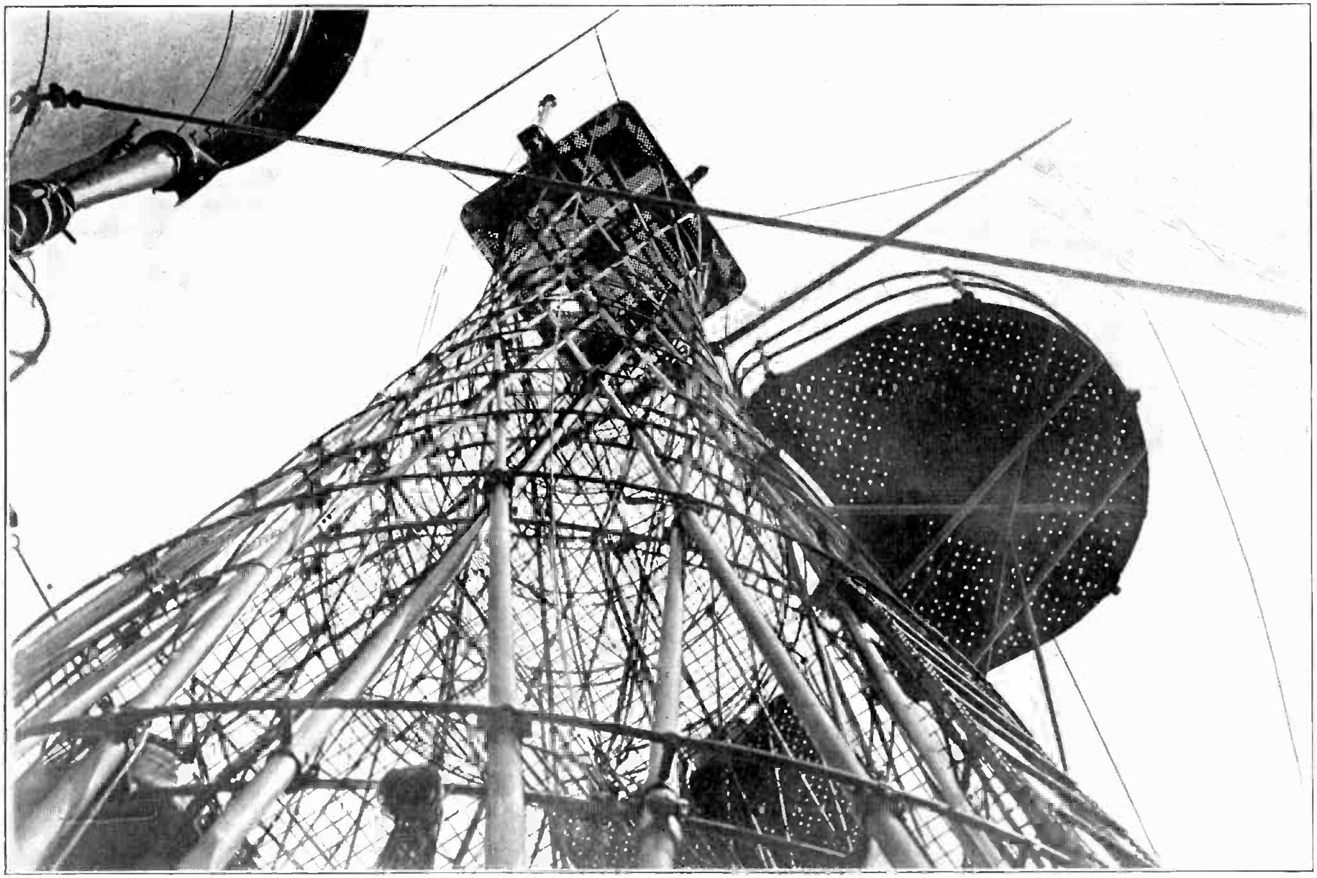


Fig. 59. Fessenden Interference Preventer

Fessenden apparatus is sometimes supplied with a so-called *intensity regulator* for modifying the intensity of radiation without affecting the frequency. This is for use in communicating with nearby stations.

Telefunken System. The system designated by this title is the result of an amalgamation of two formerly separate systems of radiotelegraphy. After patent litigation in the German courts, die Gesellschaft fur Drahtlose Telegraphie (Wireless Telegraph Co.) of



NEW STYLE OF BATTLESHIP MAST OR AËRIAL

Showing Construction of the Type of Tower which now carries the Wireless. Photograph was taken from Base of Mast.

Berlin was formed to take over the conflicting interests represented by the Slaby-Arco system and the Braun-Siemens-Halske system. This company is operating under patents granted to Dr. Rudolph Slaby of Berlin, Count Georg von Arco, and Prof. Ferdinand Braun of the University of Strasburg, each of whom has made important contributions to the subject of space telegraphy. The Telefunken system has been developed to a remarkable degree, due largely no doubt to the powerful influence of the German government, and possesses stations all over the world—numbering more than 500.

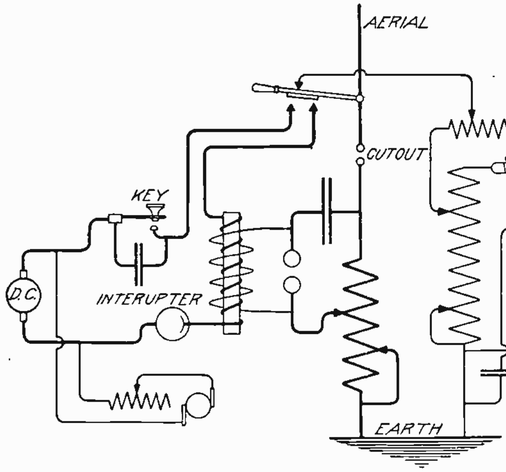


Fig. 60. Circuit Diagram, Telefunken System

Their equipment is sold outright and is noted for excellence of workmanship. The earlier sets of apparatus were furnished with a Morse recorder operated by a coherer of the nickel filings type, but latterly an electrolytic detector and head telephone are furnished as a means of reception. As the recorder and associated apparatus cut down the speed of signaling to a degree that seriously impairs their value for commercial work, the employment of the telephone is becoming almost universal practice. The recording mechanism is, however, preferred by many naval authorities over the telephone, as it eliminates the personal equation of the operator and leaves no possibility of error in the received messages.

A complete wiring diagram of the connections of the Telefunken system is shown in Fig. 60. The aërial is coupled directly onto the closed oscillatory circuit. A small air gap, or cut-out, is located in the transmitting aërial to prevent the received oscillations from flowing through the transmitting circuits. Such a gap offers no hindrance to the high-potential oscillations surging through the radiating circuit of the antennae. Means is shown for adjusting the inductance in the closed circuit of the transmitter, and the inductance between this circuit and the earth.

The Telefunken Company has more recently announced the so-called *singing-spark* system of radiotelegraphy, which is based on the discovery of Wein that exceedingly powerful discharges, possessing useful properties for radiotelegraphy, may be obtained from very short spark gaps. The air gap in this new modification of the Telefunken system is divided between a plurality of copper or silver disks kept apart by rings of mica. This form of oscillation generator is called by the German firm a *quenched spark.* When in operation the device gives forth a clear musical tone, which gives the system its name. The detector employed is of special design and said to be more sensitive than the electrolytic type. It is claimed for the singing-spark system that shorter aërials may be used and that a greater percentage of the energy of the source can be rendered available for radiation; also that the tuning of stations is greatly facilitated.

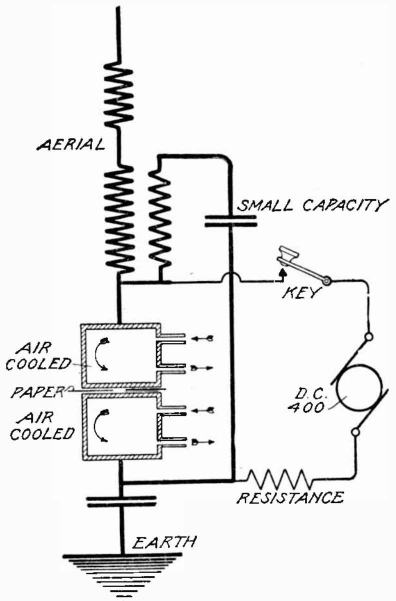


Fig. 61. Von Lepel Oscillation Generator Circuit

Von Lepel System. It has been claimed by the German experimenter, Von Lepel, that he applied the discovery of Wein to practical radiotelegraphy prior to its adoption by the Telefunken people. However this may be, the discovery referred to seems to be of importance, and though this method of producing oscillations is still in the experimental stage, the system of Von Lepel based thereon is of interest. The oscillation generator designed by him is shown in Fig. 61. It consists essentially of two copper-box, air-cooled electrodes about 5 inches in diameter, separated by a thin (.002 inch) disk of paper with a ½-inch hole in the center for the spark. The paper serves to keep the arc from running out to the edge of the electrodes. This paper constantly burns away, but a piece will last about three hours. The connections are indicated in the diagram, which shows a direct-current generator, but an alternating current will also operate the device. *L* and *L′* are inductively coupled inductances, the value of *L′* being very small. The capacity in series with *L′* and bridged across the gap is also very small. A satisfactory explanation accounting for the effects obtained has not yet been put forth. Tests thus far applied to this system have shown advantages not possessed by other systems; but it remains to be seen whether this idea is capable of the extended development it promises.

Lodge-Muirhead System. Reference has already been made to the great service rendered to the art of radiotelegraphy by Sir Oliver Lodge at that early time when its future depended on the elucidation of obscure theoretical points and on those important practical innovations which could alone make possible a commercial development of the idea. Lodge was very early impressed by the fact that periodic currents are amplified under conditions of resonance, and was of the opinion that wireless telegraphy by the early induction method could be facilitated by properly syntonizing the primary and the secondary circuits. He accordingly experimented in this direction and successfully verified his belief. He soon abandoned the notion of inductive telegraphy, however, and joined forces with Dr. Alexander Muirhead, endeavoring to effect wireless telegraphy by means of Hertzian waves. Always keenly aware of the advantages of syntony between the sending and the receiving apparatus, it is not surprising to find that his

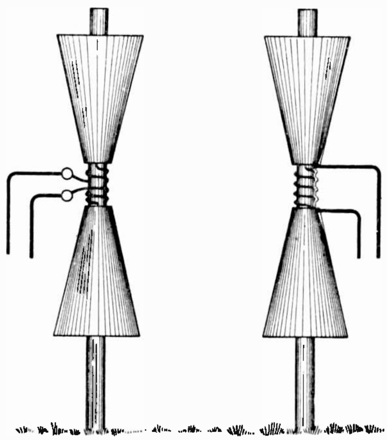


Fig. 62. Lodge Conical Capacity Areas

earliest patent specifications were very copious on this point. To facilitate accurate tuning, large conical capacity areas supported by a suitably insulated frame structure were employed, as shown in Fig. 62. This form of open oscillatory circuit later evolved into the horizontal wire areas now commonly associated with the Lodge-Muirhead system, which is further characterized by being "ungrounded," the lower capacity being in some cases placed several feet above the earth.

One form of a Lodge-Muirhead sending and receiving station is diagrammatically represented in Fig. 63, which makes clear the form of capacity areas more recently adopted. The transmitter is a form of direct-coupled closed oscillatory circuit, and the receiving circuit of the closed inductively coupled type. The auxiliary ap-

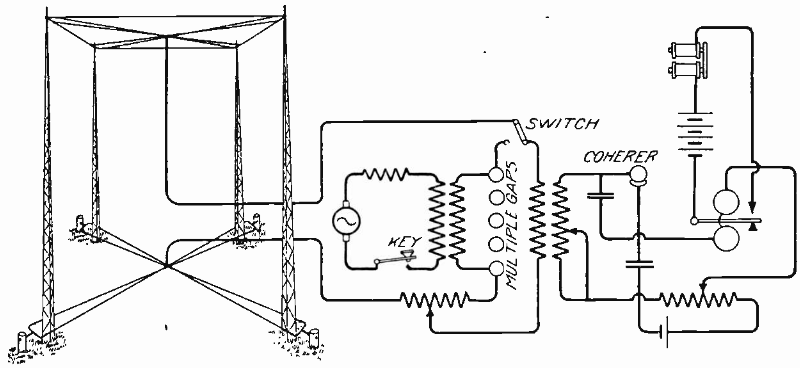


Fig. 63. Lodge-Muirhead Sending and Receiving Circuits

paratus used in conjunction with the Lodge-Muirhead steel-disk coherer previously described is not shown in the drawing. Dr. Muirhead, endeavoring to render the system serviceable in connection with the ordinary forms of telegraphic signaling apparatus, has applied a syphon recorder directly connected with the coherer. A Morse register has also been employed, or a telephone, as occasion suggested. Automatic transmission by means of perforated tape is sometimes used, a perforator being furnished with their equipment.

The Lodge-Muirhead system has never reached the large industrial development achieved by some other systems, notably the Marconi and the Telefunken; but it is, nevertheless, in commercial operation in many parts of the world. Communication was established in 1904 between the Andaman Islands and the mainland of Burma, and has given excellent service since. The distance is slightly over 300 miles. The adverse conditions incident to a tropical climate were here admirably met.

DeForest System. One of the best known American systems is that developed by Dr. Lee DeForest of Chicago. The DeForest interests have many stations located in the eastern States and along the Atlantic seaboard, one of the largest of which, located at Manhattan Beach near New York City, has successfully effected communication with Porto Rico and Colon, Panama, the latter a distance of more than 2,000 miles. A large number of merchant vessels are equipped with this make of apparatus. The United States navy also possesses a number of sets.

DeForest was among the first to employ an alternating-current transformer to charge the requisite capacity. The earlier form of his apparatus included a small motor-generator set delivering current at 500 volts, which was stepped up to 25,000 to 50,000 volts by means of an oil-immersed transformer, the secondary terminals being connected to the aërial and ground with condensers across a gap of the disk type. The receiver circuit used in conjunction with this apparatus was of the untuned kind, the detector being of an electrolytic nature called a "goo" responder, an invention of DeForest and E. H. Smythe. A "needle" anti-coherer of extreme simplicity was used with the earlier equipments, consisting of a light steel needle upheld by a retractile spring against two small aluminum rods. A telephone was employed to respond to the fluctuations of current in a local battery circuit caused by the increased resistance of the needle contacts under the action of the received oscillations. Great simplicity was aimed at in the design of the entire apparatus. No attempt was made to accomplish selection.

Electrolytic and thermo-electric detectors have been the subject of extended investigation by DeForest and his co-workers. As a result thereof a detector was evolved, consisting essentially of a small containing vessel filled with a suitable electrolyte into which projects the tip end of an exceedingly fine platinum wire. This "cell," under the influence of oscillations, exhibits a marked difference in its resistance to a local current. The similarity to the Fessenden liquid barreter is apparent. Much controversy has arisen relative to the theoretical operation of these detectors, DeForest contending that the action was electrolytic, while Fessenden and others have held to the view that the observed effect was due to the thermal action of the oscillations. Whatever the correct explanation may be, the fact remains that the "electrolytic" detector became, in the hands of DeForest, an exceedingly sensitive device and has contributed largely to the success of his system.

DeForest later devised a syntonized system based upon the principle involved in the so-called "Lecher Wires," which reflect waves bearing a definite ratio to the length of such wires. This arrangement, exhibiting anti-nodes of potential and current, possesses de-

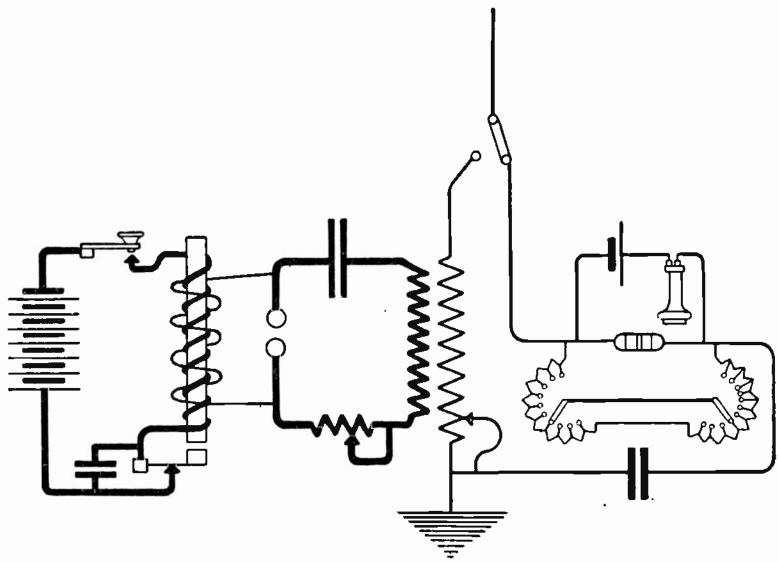


Fig. 64. Clark Sending and Receiving Circuits

cided advantages when applied to the receiving circuit, as it permits a potentially-operable or current-actuated detector to be placed at a point of maximum effectiveness. Possessing also a very definite time-period, this form of circuit was found to lend itself admirably to tuning purposes.

Clark System. The Clark Engineering Company manufactures a form of radiotelegraphic apparatus designed by Thomas E. Clark, which is usually supplied as a portable equipment, contained in oak cases provided with shoulder straps for carrying. Many such sets have been purchased for the Signal Corps of the

United States army, for which service they are especially intended. The aërial wire is preferably raised by means of a kite. The transmitter is of the inductively coupled type, consisting of an induction coil, two one-half gallon Leyden jars, the oscillation transformer, and the necessary auxiliary apparatus, such as secondary batteries, an interrupter, etc. This portion of the equipment is made to be contained in three cases, while the receiving equipment is economically arranged within a fourth oak box covered with canvas. The receptor employed is of the auto-coherer variety, operating under

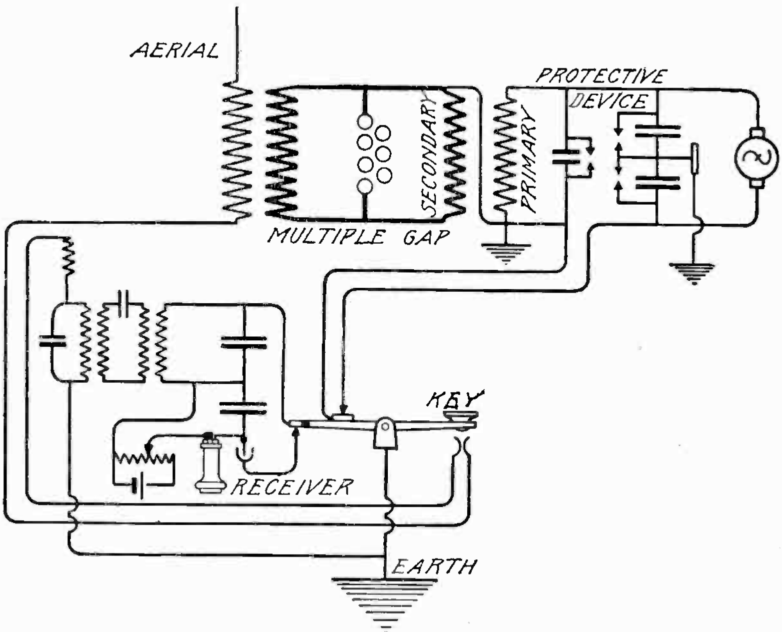


Fig. 65. Stone Sending and Receiving Circuits

the variations of resistance of the imperfect contact between two conducting plugs of steel with a small quantity of carbon granules interposed between them. A head telephone receiver and one dry-battery cell are shunted around the auto-coherer. The complete sending and receiving circuits of the Clark system are shown in Fig. 64. It will be noticed that the system presents nothing of novelty beyond the fact of its admirable adaptability to the requirements of a portable equipment. It can be readily packed on the back of a transport mule, or carried by men in a military campaign.

Stone System. Another American system, which is curiously enough little referred to, is the Stone system, invented by J. S. Stone, who has been granted nearly one hundred patents in this country alone, besides their equivalents in European countries. His specifications cover the widest possible range of subjects pertaining to radiotelegraphy and proclaim him to be the possessor of an extraordinary understanding of the more recondite problems connected with the science. Several of his patents cover the inductive coupling of aërials, something after the manner of the Braun-Marconi method. It is

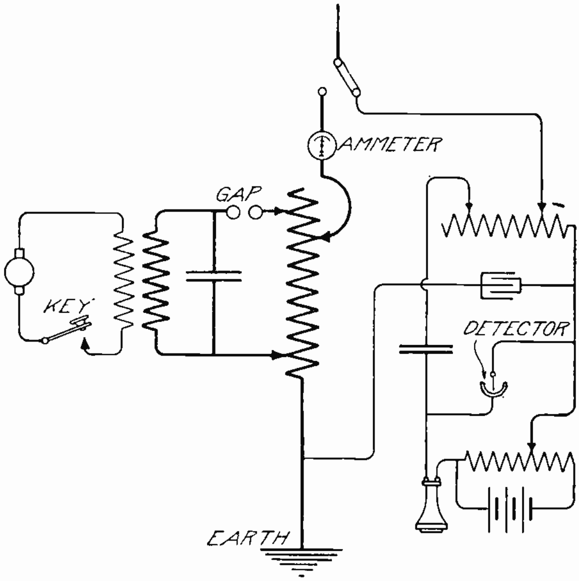


Fig. 66. Massie Sending and Receiving Circuits

difficult to believe that any large proportion of the specifications have ever been tried out in practice; in which case they may represent but "anticipatory" patents. One of the Stone arrangements for the sending and receiving stations is shown in Fig. 65, which embodies features of interest particularly from the viewpoint of the "wireless" operator. Reference is made to the multiple function of the sending key which allows an operator to be "broken in upon" while sending, by reason of the fact that the receiving circuit is broken by the depression of the key but instantly closed upon release. The aërial is inductively coupled to the closed oscillatory circuit containing a multiple-spark gap. Various forms of detectors have been used by Stone, especially electrolytic and thermal devices. In one of his patent applications he describes a thermopile of platinum and gold for use as a detector. The Stone system has never been widely exploited although such equipments are occasionally used in this country and doubtless may be found elsewhere.

Massie System. Walter W. Massie of Providence, R. I., has developed a system of radiotelegraphy which bears his name. While the system has never been exploited on a large scale, numerous sets of apparatus have been purchased by the United States government, and many private concerns find use for this make of apparatus. Massie is well known among the amateur wireless experimenters as the inventor of an exceedingly simple detector of the imperfect contact type, which has rendered many a home-made outfit at least operative where a more complicated receptor would have been prohibitive. The device goes under the name of the *oscillaphone*, and consists simply of a common sewing needle placed carefully across two sharpened carbon edges. A small horseshoe magnet is sometimes located under the needle in order to exercise a slight attraction and maintain good connection. In the Massie equipments supplied for long-distance use, an electrolytic detector is employed. The Massie circuits are shown in Fig. 66. The aërial is direct-coupled.

Poulsen System. A remarkable system due to the genius of Valdemar Poulsen of Copenhagen has of late years attracted great attention, as it undoubtedly marks a decided advance in the art. Poulsen has accomplished by means of a modification in the Duddell arc a method of creating an almost continuous train of undamped oscillations resulting in an equivalent train of electric waves. The ability to generate such a persistent train of waves offers great advantages in the syntonization of stations and in the problem of selective signaling. As before mentioned, the Poulsen system is characterized by the employment of hydrogen under pressure as the surrounding medium for the arc. The receiving device used is the invention of Pederson, and a very full description of it may be obtained by referring to the *Electrician* for Nov. 16, 1906.

Other Systems and Inventors. Numerous other systems of radiotelegraphy have been exploited in various countries, but space will not permit of a detailed description of them here. The patent files of every government contain numberless specifications pertaining to the art; indeed, it is doubtful if any other improvement in electrical communication has called forth in so short a time a more voluminous patent literature.

The *Rochefort-Tissot system* in France has met with considerable success. Perhaps the most distinctive feature of this system is the form of induction coil employed, called a "unipolar transformer." The equipments are manufactured by Ducretet, the French instrument maker.

In Belgium the *Guarini system* has been installed in various localities with moderate success. The inventor has great faith in the possibility of relaying radiotelegraphic messages to accomplish long-distance transmission. He has devised a relay for such purposes, which seems to promise good results.

The Russian government has experimented with several systems, but the *Popoff system* is now almost exclusively used. Considerable interest attaches to this system on account of its historical importance. As early as 1895, Prof. Popoff communicated to the Physico-Chemical Society of St. Petersburg the details of a device employed by him for graphically registering atmospheric disturbances of an electrical nature by means of a coherer introduced between an elevated "exploring rod" and the ground. A relay and tapper were also employed, the former serving to operate a Richards register. It is thought by many that sufficient credit is not given Popoff for these innovations.

Sir H. M. Hozier and S. G. Brown in England have developed a system bearing their names, which differs little from the other systems, with the exception of the detector and method of directly connecting the same to a syphon recorder. The Hozier-Brown detector has been described elsewhere.

A system of selective signaling which seems to promise well, is that named after the inventor, Anders Bull. Resonance is not employed as a selective agency; instead, the receiver is designed to respond only to a group of wave-trains which are separated by certain unequal and predetermined intervals of time. The mechanism effecting the transmission of such properly timed wave groups is called the *dispenser*, and the companion device at the receiving end, the function of which is to translate the wave groups into printed

Morse characters, is called the *collector*. Tests conducted by the United States navy with this system were highly satisfactory as regards secrecy and freedom from atmospheric disturbances. The complicated nature of the apparatus will possibly prohibit the extensive use of this system, although it possesses advantages not even theoretically possible by resonance alone.

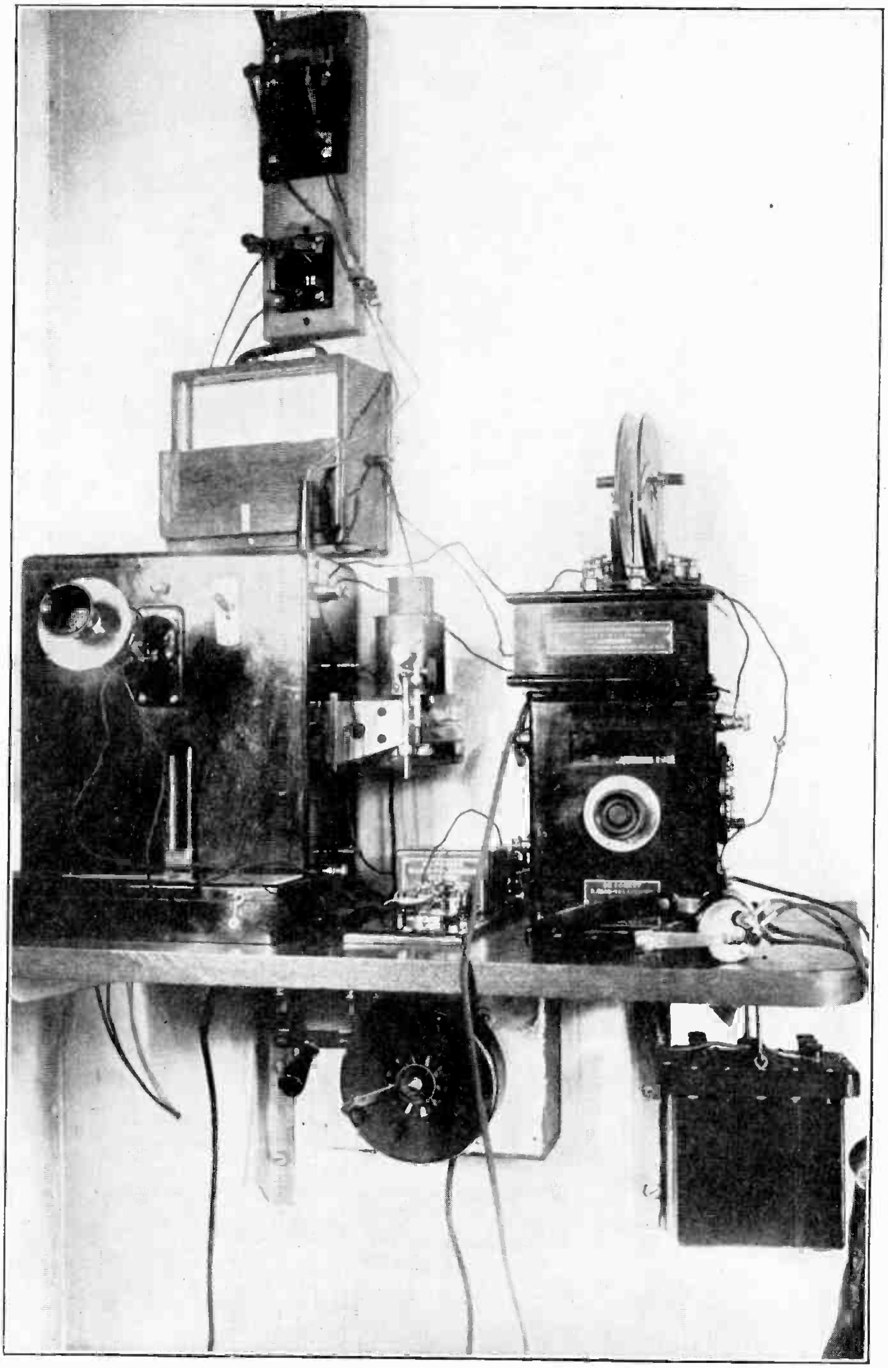
Conclusion. During the twenty years or so since Hertz made his famous discovery of electric waves, radiotelegraphy has made many substantial advances toward the goal of perfection; and it stands today a conspicuous and brilliant example among the many resources which Science has contributed to modern civilization. Its uses are many and important. To mention its life-saving power alone is to secure for it a high claim to consideration. Its success in this regard has been spectacular in more than one instance; and it is not too much to say that radiotelegraphy has saved hundreds of lives since the "wireless" installation of ships has become prevalent. To travel on the ocean with a "wireless" equipment on board, knowing that in case of peril the assistance of vessels within a radius of hundreds of miles can be instantly summoned, adds not a little to the comfort and security of the passenger. Radiotelegraphy may indeed be said to have struck a vital blow to the terrors of the sea. The sea, it would seem, has become the chosen sphere of wireless telegraphy, since it fills a want never supplied before. Formerly ocean-bound vessels were isolated from the world for days at a time; but now they can communicate with land or with other ships at almost any point in their course, some of the large ocean liners keeping in such close touch with events that they publish daily bulletins giving the world's latest news.

Another startling achievement of radiotelegraphy has been its success in effecting trans-Atlantic communication. Messages are sent between Europe and America across a void of air and water some 3,000 miles in extent. And they are not mere test messages, but regular press telegrams such as might be sent by cable. Here radiotelegraphy has become the direct rival of the old method of wire transmission. Whether the one will ever supersede the other is a question open to debate. The probabilities seem to be in favor of wireless, especially if the present rate of progress continues; but, for the present at least, there is room for both methods.

Wireless telegraphy promises to be of great service in times of war; in fact, all the leading nations have equipped their armies and navies with radiotelegraphic apparatus. Battleships will have a facility of communication never before possible, and land forces will be equally subserved. Heretofore, one of the first moves of a belligerent force was to cut the enemy's telegraph wires; but to cut off an electric wave will not be such an easy matter. The Japanese constantly made use of wireless telegraphy in the late war with Russia. The Japanese have their own method of effecting radiotelegraphic communication, the details of which are kept secret; but that it works successfully, they have well demonstrated.

Concerning the utility of radiotelegraphy for communicating across land areas, much that is favorable and promising can be recorded; but there is still something to be desired with respect to ease and certainty of operation. The progress thus far made has brought to light many problems which await solution and recorded many phenomena relative to transmission over long distances, especially over land, which cannot as yet be accounted for or controlled. The screening effect of intervening mountains and cliffs exercises a marked difference in the energy of the received signals; long stretches of exceptionally dry ground seem to have the same effect. This probably accounts for the fact that the greatest distances to which signaling has been carried have been over salt water. Signals seem to be more easily effected at night than in daylight; so marked is this effect that communication carried on with perfect success at night has often been permanently interrupted by the advent of daylight only to be resumed the following night. J. J. Thomson has put forward a possible explanation of this, but space forbids its inclusion here. Again, certain conditions of the atmosphere seem to render but comparatively small energy necessary in the accomplishment of long distances at times.

Thus radiotelegraphy, like all forms of telegraphy, as well as telephony, has its limitations and unsolved problems; but, judging by past achievements, it is not well to dogmatize too emphatically as to the finality of these limits.



THE FIRST SET OF WIRELESS TELEPHONE INSTRUMENTS FOR THE UNITED STATES NAVY

Installed on the Flagship "Connecticut." The "Audion" Receiver with Tuning Device on the Top at Right, the Transmitter on the Left.

WIRELESS TELEPHONY

Wireless telephony is not so new—almost unborn, indeed—as is generally supposed. Like its companion art, wireless telegraphy, it began its existence well back in the nineteenth century. Its inception is contemporaneous with that of wire telephony, for Alexander Graham Bell was the originator of both. It is a singular coincidence that Bell, the inventor of the telephone, and Morse, the reputed inventor of the telegraph, should each have been among the first to accomplish their respective modes of communication wirelessly. The history of wireless telephony follows very closely that of wireless telegraphy. The extreme sensitiveness of the telephone receiver to small variations of current very naturally suggested its employment as a receiving device in connection with the inductive and conductive methods of wireless telegraphy, and attempts were made at an early date to accomplish the transmission of articulate speech by these same means. The results obtained however, were very meager; the inherent difficulties characterizing these methods proved to be even greater with the application of telephone principles, due to the diminution of energy made necessary by the nature of the process. As in the case of wireless telegraphy, the solution of the problem lay in the application of the method of electric radiation.

Bell's Radiophone. One of the earliest attempts at radiotelephony was not of an electrical nature, judging by the usual appearances, but depended on the thermal effect of a variable beam of light directed upon bits of burnt cork enclosed in a small glass tube to which was connected a rubber tube to be inserted in the ear of a listener. This device is shown in Fig. 1. The light from a convenient source was reflected from a thin silvered diaphragm and caused to fall upon the burnt cork. When this diaphragm was set into vibration through the agency of the voice, the light reflected therefrom was subjected to a corresponding variation of intensity, and, being directed upon the blackened cork, produced therein minute changes of volume due to the variations of temperature;

and such changes produced air-waves which were manifested in the form of sound and audible within the tube. This simple device, invented by Alexander Graham Bell, was called by him a *radio-phone.* He later greatly improved the apparatus by substituting selenium as the means of reception, the peculiar electrical property of which substance was then first attracting attention.

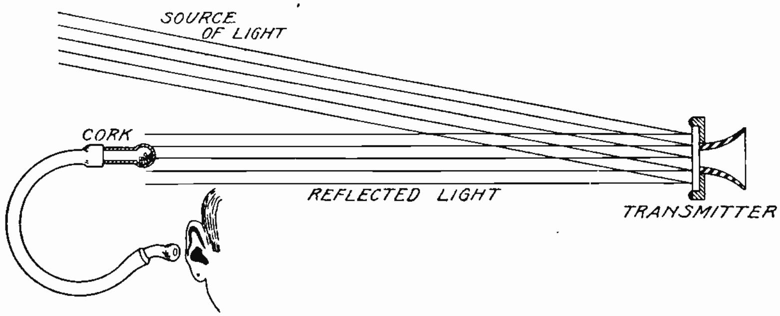


Fig. 1. Bell's Radiophone

Selenium Cell. In 1873, Willoughby Smith discovered that the resistance of metallic selenium was greatly reduced by exposure to light. The light from a small gas burner was found to exercise a marked influence on the conductivity of short rods of selenium used as resistances in a series of cable tests then in progress. The discovery caused widespread interest in the scientific world. Among the many men attracted by this peculiar property of selenium was Prof. Bell, who, in conjunction with Sumner Tainter, succeeded in producing the first useful so-called "selenium cell." This device consists essentially of selenium spread over the surface presented by the edges of alternate disks of metal separated by thin sheets of mica after the manner of a condenser, thereby greatly enlarging the area of contact between the selenium and the electrodes formed by the alternate disks. By connecting such a cell in series with a battery and telephone receiver, the current passing through the circuit is largely dependent upon the degree of conductivity possessed by the selenium cell, which in turn depends upon the amount of light falling thereon. Any variation of the light directed upon the cell is, therefore, capable of causing a corresponding variation of the current flowing through the receiver, with the result that such variations become audible therein.

Bell's Photophone. In 1878 Bell put forward a most ingenious application of the selenium cell for the purposes of radiotelephony, which he called a *photophone*. The arrangement of apparatus is shown in Fig. 2. The selenium cell *C* is placed in the focus of a parabolic reflector *R* and is thus interposed in the path of the rays reflected by the mirrored surface of a diaphragm *D* from any suitable source of light *S*. The resistance of the selenium cell was approximately 1,200 ohms in darkness, and about half that when fully illuminated. The mode of speech-transmission is so similar to that of the radiophone that further description is not necessary.

The photophone, as proposed by Bell, may be made to transmit speech perfectly over short distances, but it is obviously limited by reason of the inefficient means employed to effect the variation of the intensity of a source of light. As the employment

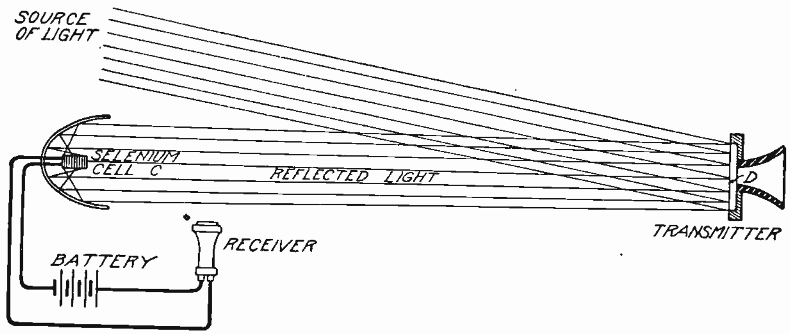


Fig. 2. Bell's Photophone

of the device for distances relatively long necessitated the use of powerful sources of light and adequate means for controlling the same, the invention remained but a beautiful laboratory experiment until the discovery of the speaking arc by Simon in 1897 opened up the possibility of future development.

"Light Telephony." Prof. H. T. Simon of the Physical Institute of the University of Erlangen discovered, toward the end of the year 1897, that a direct-current arc may be made to give forth musical tones and even speech by superimposing a telephonic voice current upon the arc current. This discovery suggested the possibility of using Simon's arc as a transmitting arrangement for the Bell photophone. With this end in view, numerous experiments were carried on, principally in Germany, aiming to increase the efficiency of the apparatus when operated in conjunction with powerful search-lights, and also to develop the selenium cell to a point of greater sensitiveness. Wireless telephonic communication by this means has become known as *light telephony,* and has reached its highest development in the hands of that most ingenious German investigator, Ernst Ruhmer. The German navy has several vessels equipped with the Ruhmer apparatus for intercommunication. It is said that a distance of twenty miles is, under favorable weather conditions, the limit of operativeness with this form of radiotelephony. The use of the system is necessarily restricted to open spaces, and dependent upon clear atmosphere.

Telephony by Means of Hertzian Waves. The success achieved by Marconi in telegraphing without wires inspired many investigators to apply the Hertzian-wave method to the problem of telephony. As early as 1897 various workers became imbued with the idea and, as a result, a number of systems of radiotelephony have grown up contemporaneously with those of radiotelegraphy. It cannot be said, however, that the results accomplished by the early experimenters in this field gave more than a promise of future usefulness for this method of communication, the distances covered being extremely small in proportion to the complexity of the apparatus involved. In many instances, however, the inventors of such systems had a clear perception of the fundamental requirements, and felt confident that the development of the art on its practical side would ultimately make possible a successful application of their theories.

The principal difficulty encountered in the application of Hertzian waves to the problems of telephony was found at the start to reside in the transmitting portion of the apparatus. The receiving end offered no great obstacle, since it was known at an early date that many of the detectors used in connection with radiotelegraphy would prove suitable for the reception of speech—providing that a means could be discovered to effect the emission of wave-trains whose energy should vary in accordance with the vibrations of the human voice. The fundamental problem of radiotelephony is practically the same as that met with in ordinary wire telephony—*to cause a* *distant diaphragm to repeat sympathetically the vibrations of a diaphragm against which the energy of the sounds to be transmitted is directed.* In both cases the efficiency of the various transformations of energy involved in the process is of prime importance. The current-carrying capacity of the carbon transmitter places a limit on the amount of energy possible to utilize telephonically. This restriction is felt to a marked degree when the device is associated with the necessarily large amount of energy required for Hertzian-wave radiation over any considerable distance. In view of the foregoing, it is not surprising to find that early experiments in radiotelephony were directed almost exclusively toward a solution of the problem of an efficient transmitting apparatus.

Many attempts were made to accomplish this end by placing the ordinary microphone transmitter in the primary of an induction coil, thus serving the purpose of an interrupter, as exemplified in Dolbear's early wireless telegraph system. Such experiments only sufficed to show that nothing was to be gained in this way, largely by reason of the before-mentioned inherent limitations of the telephone transmitter. The problem was then attacked in another manner, viz, by endeavoring to modify telephonically a train of waves of a constant intermittency radiating from a continuously operating source of oscillations, such, for instance, as a simple radiotelegraphic transmitter without a primary signaling key. Though this method allowed a much greater amount of energy to be utilized, it soon became evident that a grave difficulty was presented due to the nature of the radiations from such an arrangement. The train of waves thus generated is not continuous, but consists of intermittent wave-trains separated by short periods of time during which no radiation takes place. These breaks in the continuity of the train are often of greater duration than the individual oscillations due to one complete discharge of the condenser; they consequently produce in the telephone receiver a continuous buzz which seriously interferes with the audibility of the received voice vibrations. As the timbre of the human voice depends upon overtones and upper harmonies of a frequency of from 5,000 to 8,000 or more, the pauses between oscillation trains also interfere with clear articulation whenever their frequency drops much below 10,000 per second. At frequencies of from 20,000 to 50,000, however, this feature ceases to be a hindrance. The success of the method of telephonically varying the energy emitted from a continuously operating source of radiation was seen, therefore, to depend upon the possibility of producing more perfectly sustained oscillations of high frequency. The means for creating oscillations that are undamped and practically continuous, may be considered the greatest problem of radiotelephony relative to transmission. At the present time there are two methods of accomplishing such persistent radiations, viz, by employing the high-frequency alternator, or by using some form of the oscillating arc. The last-named method has been developed, under the ministrations of Valdemar Poulsen, to a degree of efficiency that promises to place radiotelephony on a commercial basis. The alternator method has been persistently favored by Prof. R. A. Fessenden, who has accomplished some remarkable results. Both methods have their staunch advocates, each possessing its own peculiar advantages as well as limitations.

Nature of a High-Frequency Telephone Current. The foregoing paragraphs have indicated briefly the general theory upon which the

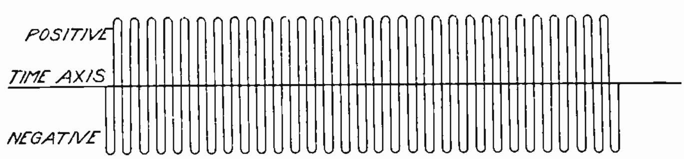


Fig. 3. Diagram Representing High-Frequency Current

most successful systems of radiotelephony have been developed. It remains to consider in more detail the nature of the action involved when a uniform flow of undamped oscillations is modified by the variations of a voice current.

It is convenient for a ready understanding of the matter to first consider the case of a high-frequency alternator supplying a constant alternating current of a periodicity somewhat above human audibility—say 50,000 cycles per second. Supposing such a current to be flowing through a variable resistance such as a telephone transmitter, the effect of an increase of the resistance thereof manifests itself by a lessening of the amplitude of each individual half-wave of current; while, conversely, a decrease of the resistance manifests itself by an amplification of the current half-waves. When, therefore, the resistance is made to vary with great rapidity, as when the diaphragm of the transmitter is thrown into vibration by sound, the effect upon the alternating current flowing therein is to produce a corresponding change in the maxi um value of each half-wave.

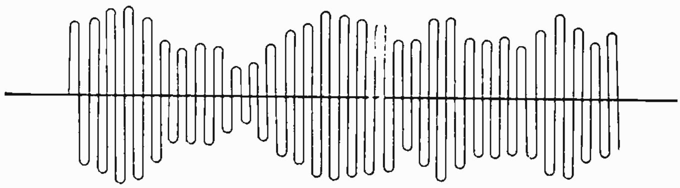


Fig. 4. Diagram Representing Variations of Amplitude

As the energy of each half-wave may be represented by its amplitude, it is evident that an alternating current varying in this manner exhibits a wave-form of energy equivalent in many respects to a direct current similarly modified. Figs. 3 and 4 illustrate this idea, Fig. 3 representing the steady alternating current permitted by the normal resistance of a transmitter; and Fig. 4 showing the alterations of amplitude thereof occasioned by the variations of resistance in the said transmitter. It will be noticed that the maximum instantaneous values may be greater than normal, as well as less, due to the fact that the resistance of a transmitter when spoken into varies between limits above and below its resistance when at rest. Some idea of the complexity of the action taking place under the conditions of actual practice may be had by referring to the wave-form shown in Fig. 5, which represents the current curve, or oscillagram, of a

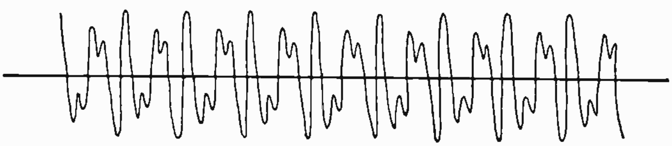


Fig. 5. Oscillagram of a Telephone Current

telephone current produced by the vowel, long ō, spoken into the transmitter. In forming a mental conception of the wave-form resulting from the superimposing of a telephonic voice current upon a high-frequency oscillating current, the enormous difference in their respective periodicities must be borne in mind.

In the case of an oscillation generating arrangement which does not produce a perfectly sustained train of electric waves but a series of partially damped wave-trains separated by slight breaks of continuity, the essential condition for success in connection with radiotelephonic work is that the interruptions shall not take place at an audible frequency. It is highly probable that the direct-current arc method of creating oscillations does not produce an absolutely continuous train of waves, as is the case with a high-frequency alternator, but, on the contrary, is made up of a great number of groups of almost undamped oscillations separated by an interval of time, very small even in comparison with the duration of each group.

Oscillation Generators. An account has already been given, in the pages devoted to Radiotelegraphy, of the attempts which have been made to construct high-frequency alternators for use in the production of continuous, undamped oscillations, and some description given of such machines. Reference has also been made to the development of the direct-current arc method of producing a similar result. In the present instance it is not deemed necessary to dwell on these subjects further than to give some notion of the particular devices constructed for use in connection with the most successful systems of radiotelephony, and to mention those modifications of the arc method which have been found to give the best results in this field of use.

Undoubtedly the most successful high-frequency alternators have been those constructed by Prof. Fessenden for use in his extensive experiments in radiotelephony carried on at the Brant Rock (Mass.) Station of the National Electric Signaling Company. This inventor has devised several such machines, one of them having an output of 2 kilowatts operating at 80,000 cycles, and a voltage of 225 volts. This machine was of the double armature type with 300 teeth on each, direct-coupled to a DeLeval turbine. A similar generator designed for use on shipboard and run by a turbine is capable of developing 3 kilowatts at a frequency of about 100,000 cycles. Fessenden has also designed a 10-kilowatt machine of a periodicity of 100,000 per second. The problem of properly designing such generating units and constructing them on a commercial basis cannot as yet be said to be satisfactorily solved; it is generally felt, however, that the solution of the problem will be effected at no distant date, at which time this method of producing the requisite oscillations for electric-wave communication will supersede in many instances the more complicated and less constant methods now in use.

There are in use at the present time various arrangements of the direct-current arc employed as a means of creating alternating currents of great frequency, all of which depend for their operation upon the principle of the Duddell arc but differing in the details of application. One of the earliest and most successful of these is due to Poulsen, who achieves extremely high-frequency oscillations of great energy by causing the arc to take place between copper and carbon electrodes enclosed in a chamber containing hydrocarbon gas. In order to increase the energy of radiation, Poulsen later employed several arcs in series. This is known as the multiple-arc system, and has been developed to a high degree by die Gesellschaft fur Drahtlose Telegraphie of Berlin.

Telephonic Control of Oscillations. Radiotelephony figuratively substitutes in place of the metallic line of ordinary telephone practice a continuous stream of electric waves of approximately uniform strength. By varying from instant to instant the energy of this stream of waves in accordance with the variations of air-pressure acting against a transmitting diaphragm, a transference of such energy-variations is effected between two stations. By the employment of suitable translating devices, the energy-vibrations of the wave-stream may be made to undergo a transformation resulting in the movement of a second diaphragm which exactly duplicates the vibrations of the first, and the variations of air-pressure occasioned thereby complete the cycle of energy-transformations from sound to sound.

It is to be noted in connection with the foregoing analysis that it is not the entire amount of energy of the flow of waves between stations that is available for transformation into sound at the receiving end, but only the energy represented by the *variations* of this flow of waves. Thus the problem of telephonically controlling a large amount of energy for efficient radiotelephonic transmission is to effect, by means of the energy of the voice vibrations, a maximum percentage of variation in the energy radiated. With the methods employed at the present time there are reasons for believing that this percentage does not greatly exceed 5 to 8 per cent of the total energy.

In this respect radiotelephony differs very widely from radiotelegraphy, for with the latter the entire energy of radiation is available to the limit of our ability to detect it. Some of the inventors claim a greater percentage of efficiency for their respective systems of radiotelephony. Fessenden has devised an improved form of transmitter which he states produces much better results.

There are several ways of modifying the electric oscillations set up in a transmitting arrangement for the purposes of radiotelephony. The method generally employed involves the use of some form of carbon transmitter whereby the variations of its resistance under the influence of the energy of the voice are made to vary the oscillatory current directly, or a local-battery circuit similarly affected is inductively associated with the oscillatory circuit. Variations in the emitted wave-train may also be accomplished by the use of a condenser transmitter formed by a thin metallic diaphragm separated from a metallic plate by a thin layer of air acting as dielectric, the vibrations of said diaphragm producing variations of capacity between the two surfaces. This variable capacity is used to throw the aërial in and out of tune. The inductance of an oscillatory circuit may also be made to vary by means of the voice and produce a like result. One of the earliest suggestions relating to the telephonic control of the energy of oscillations was made by an Italian, Lonardi, who, in 1897, proposed that the spark balls of a Righi oscillator connected to a source of constant potential be made to vibrate by the voice, thereby altering the length of the spark gap and causing the oscillator to be charged to greater or lesser potentials, and thus varying the energy of the emitted waves.

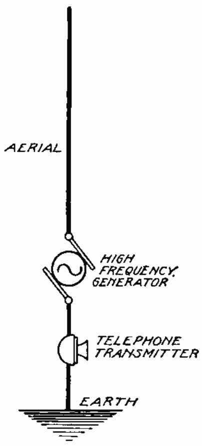


Fig. 6. A Form of Fessenden Circuit

Transmitting Circuits. One of the simplest and earliest circuits patented for use in connection with radiotelephony is shown in Fig. 6. It is due to Fessenden, and consists of a high-frequency alternator connected in series with an aërial, a telephone transmitter, and the ground. The time-period of the radiating circuit thus formed is adjusted to the periodicity of the dynamo.

The patent application on this arrangement was filed in 1901 at a time when it is generally believed that the creation of electric waves necessitated an abrupt release of energy, as exhibited by the discharge of a condenser. In experiments carried on with this arrangement in 1906, a distance of about ten miles was covered, the generator running at 10,000 revolutions per minute and developing 50 watts at 80,000 cycles per second. The resistance of the armature was about 6 ohms. An electrolytic cell was used for a detector.

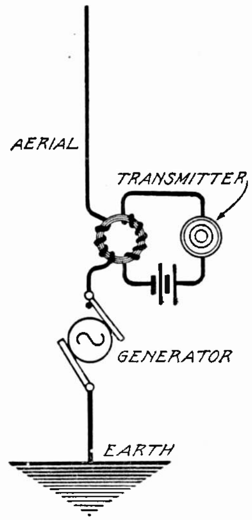


Fig. 7. Transmitter Inductively Associated with Aërial

Another method of effecting the telephonic variation of an oscillatory system is shown in Fig. 7. The aërial is connected to the secondary of a small transformer, the primary winding of the same being included in a local-battery transmitter circuit.

An arrangement for use with the arc form of oscillation generator is shown in Fig. 8. Direct current for the arc is supplied to the terminals of the closed oscillating circuit through the secondary of

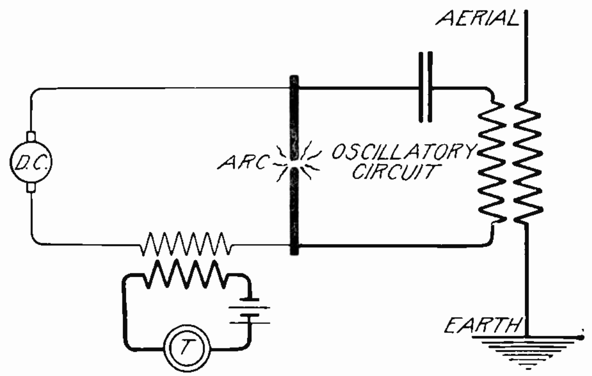


Fig. 8. Transmitter Associated with the Supply Circuit

a transformer, the primary circuit of which contains a carbon transmitter and local battery. The fluctuations of intensity of the oscillations may be effected in a manner diagrammatically shown in

Fig. 9, where the inductive method of superimposing the telephone current from a local circuit is applied directly to the closed oscillatory circuit. Inductances *I* and *I′* inserted in the supply mains

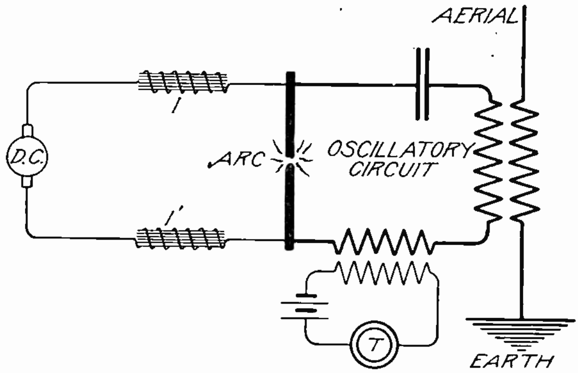


Fig. 9. Transmitter Inductively Associated with the Closed Oscillatory Circuit

prevent the voice current from passing around through the source of supply.

In Fig. 10 is shown still another method of locating the variable-resistance member, viz, by shunting the secondary of the oscillation

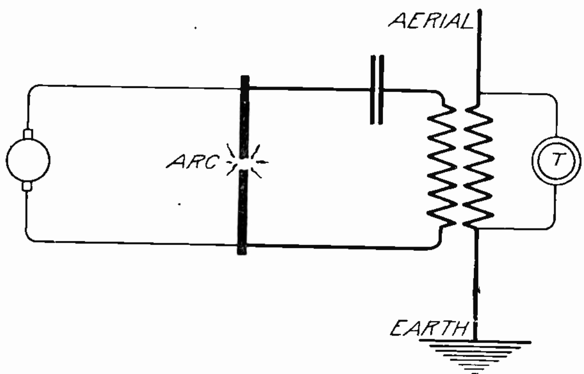


Fig. 10. Transmitter Shunted across the Aërial Inductance

transformer employed in connection with an inductively coupled aërial. The telephone transmitter may also be used with a directly coupled aërial by causing it to vary the effective turns of a portion of the inductance included in the open radiating circuit, as in Fig. 11.

From the circuits here given, it is evident that the conditions essential to telephony are fulfilled when the transmitter is so placed as to produce by its action a change of the electrical properties of the radiating aërial; and experience has shown that this may be accomplished with the microphonic, or carbon, transmitter in a variety of ways, many of which seem to operate with equally good effect. The condenser, or variable-capacity, transmitter is effectively operative only in conjunction with the oscillatory portions of the sending circuit, usually as a shunt. One method of placing this form

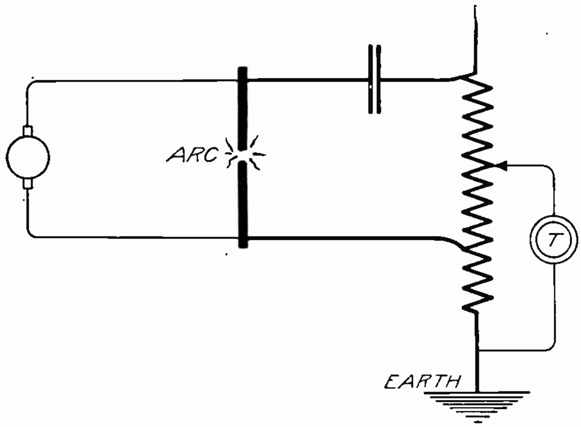


Fig. 11. Transmitter Shunted across a Portion of the Aërial Inductance

of transmitter is shown in Fig. 12, which arrangement has been employed by Fessenden.

As before remarked, the small current-carrying capacity of the microphonic transmitter has proved to be a great obstacle to the rapid development of the art of radiotelephony as a commercial proposition; and it may be said that until an efficient means is devised for overcoming this difficulty, and thereby greatly increasing the percentage of variation in the intensity of the oscillations, or the equivalent thereof, the sphere of usefulness for this form of wireless communication will be much restricted. Many attempts have been made to effect this improvement by connecting several transmitters in multiple to be acted on by a common mouthpiece. Various so-called telephonic repeaters have also been devised purporting to accomplish an increase in the amplitude of the telephonic current Such devices, however, have not proved to be a satisfactory solution of the problem, although Fessenden claims to be able to effect a decided amplification with an instrument of the latter character designed by himself. This ingenious investigator has undoubtedly constructed an instrument more nearly fulfilling the requirements of a transmitter adapted to this class of work than any heretofore presented. It is called by him a "trough" transmitter, and is said to be able to carry continuously more than 10 amperes. The electrodes are water-jacketed The amount of variation in a current of this magnitude, produced by the action of the voice, is of course the important factor. The results accomplished by the "trough" transmitter indicate a decided gain over the form commonly employed. Further radical improvements in transmitter design may be confidently expected from the numerous experimenters whose inventive ability is now being brought to bear on the problem.

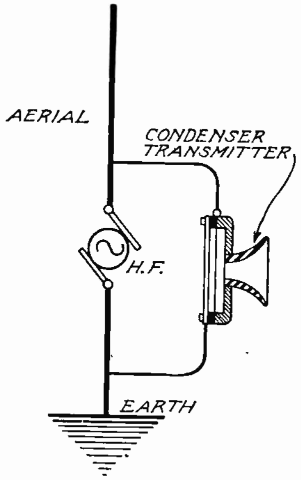


Fig. 12. Condenser Transmitter

Receiving Arrangements. For purposes of radiotelephony the detectors depending upon mere potential for their operation, such as the early forms of coherer, are practically useless. The essential characteristic which a detector suitable for this class of work must possess is that it shall not only respond to the received oscillations, but that it shall be affected to a certain extent in proportion to the amplitude of such oscillations. In short, radiotelephony requires a form of detector which is quantitative, that is, one which will respond to the varying integral value of the oscillating current. Such devices as the thermo-electric, electrolytic, ionized gas, and crystal-valve detectors are all of this type, and may be used for the reception of speech when properly connected with a telephone receiver. This quantitative function may be elucidated by considering the action of a thermo-electric detector properly associated with a tuned receiving circuit. If a continuous train of undamped waves falls upon the aërial, their effect on the detector is to increase its resistance by raising its temperature, and thereby decrease the amount of current flowing through the telephone receiver. As long as the flow of such waves remains constant, their heating effect upon the fine platinum wire of the detector, and consequently its resistance, remains constant, and no sound is heard in the receiver. If, however, the wave-train which strikes the aërial be of a fluctuating nature, due to the vibrations of the distant telephone transmitter, the variations of amplitude of the received oscillations will cause a corresponding variation in their heating effect on the platinum wire, accompanied by like variations in its resistance, whereupon the current flowing through the telephone receiver will be similarly varied, with the result that the diaphragm is thrown into vibrations exactly imitating the movement of the transmitting diaphragm.

There have been previously described under the head of radiotelegraphic detectors almost all the devices used for a similar purpose in connection with radiotelephony. In view thereof it is not thought necessary to devote more space to the subject here, further than to call attention to a form of telephone receiver invented by Fessenden and called by him a "heterodyne" receiver, a most ingenious application of the Bell instrument to the purposes of space telephony. The device consists of two small coils of wire, one of which is wound upon a stationary laminated core composed of very fine soft-iron wires; the second coil, held in close proximity to, and co-axial with, the first, is attached to the center of a thin mica diaphragm. A high-frequency current from a local source is maintained through the stationary coil. The other coil, arranged to vibrate with the diaphragm, is connected in the receiving oscillation circuit, as shown in Fig. 13. The periodicity of the local alternating current is adjusted to approximately the same frequency as the received waves, thereby creating a mechanical force exerted be-

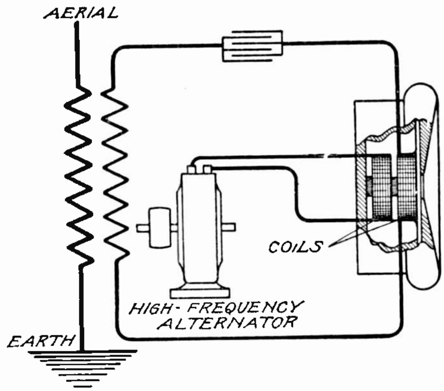


Fig. 13. Heterodyne Receiver Circuit

tween the two coils—a force which varies with every fluctuation of the intensity of the received oscillations, and results in vibrations of the mica diaphragm corresponding to those of the distant transmitter. When this device is used as a detector in connection with radio-telegraphy, the frequency of the local source of current is purposely made to be slightly different from the frequency of the received oscillations; under which condition the physical phenomenon known as "beats" is engendered. This is due to the fact that at certain equal intervals the two wave-form currents agree in phase and reinforce each other, while at times midway between two such successive agreements they are opposite in phase and tend to neutralize each other. These intervals of maximum reinforcement occurring at an audible frequency produce in the receiver a musical note of a duration depending upon the length of the Morse dot or dash. By means of this simple process, it is, therefore, possible to produce audible tones by the interaction of two alternating currents whose respective frequencies are far above audibility. The heterodyne receiver is almost entirely unaffected by atmospheric disturbances, and seems to offer exceptional possibilities in connection with multiplex transmission, as well as selective communication.

Two-Way Transmission. In wire telephony simultaneous talking and listening is possible by reason of the simple nature of the circuits and because of the comparatively small amount of energy involved in telephonic transmission. Radiotelephony presents in this regard difficulties which tax to the utmost present inventive ability. Without special appliances it is of course necessary after talking to throw over a listening key or switch in order to receive the reply. The introduction of this manual operation, while not of a nature to greatly detract from the usefulness of this method of communication, interferes to an appreciable extent with that ease of operation we are accustomed to associate with the telephone, and destroys the illusion of the actual presence of the person spoken to. It cannot well be expected in an art so young that minor details of this nature should have been thoroughly perfected. Arrangements for simultaneous talking and listening have already been put forward, and some have met with more or less practical success. Fessenden has patented several such devices—one involves the use of a commutator which connects the transmitter and receiver to the aërial in very rapid alternation; another and a more practicable method is called by him the "balance" method, and consists in the application of the "bridge" together with a "differential" arrangement often employed in duplex telegraphy, the complete circuit requiring a "phantom," or artificial, aërial. The detector is unresponsive to the powerful oscillations emanating from the same station, but sensitive to the oscillations from the distant station. This "balance" method materially cuts down the loudness of the received sounds.

Radiotelephonic "calling" is accomplished by radiotelegraphic methods. A coherer associated with a local battery and relay is sometimes employed to ring an electric call bell. In such cases it is necessary to provide means for cutting out the coherer and relay during conversation. Under conditions where it is impractical to achieve the operation of a relay, it becomes necessary to keep an operator on duty "listening in."

Systems of Radiotelephony. Radiotelephony undoubtedly possesses many advantages over radiotelegraphy, not the least of which is the fact that a skilled operator is not required to translate the dot-and-dash signals. The transmission of intelligence is more direct and expeditious, and in times of emergency this might become an advantage of great importance. No form of communication is so satisfying as that of speech. It is due to this fact, perhaps, that ordinary wire telephony stands today superior to the older art of telegraphy in point of development. The future may record a similarly greater development of radiotelephony than will be accorded to its companion art; but at the present time it cannot be said to compare with radiotelegraphy as regards efficiency and simplicity of apparatus. Its weak points are known and understood, however, and every effort is being made to remove the obstacles that stand in the way of a more efficient utilization of the means employed.

While still susceptible of great improvement, and in many cases requiring a multiplicity of complicated apparatus, there are a number of radiotelephonic systems which have been exploited in the various countries, many of which are in regular service. Nearly all of the large navies of the world are supplied with equipment for intercommunication between the different vessels of a fleet. Among the most successful systems may be mentioned the Telefunken and Ruhmer systems in Germany, the Poulsen system in Denmark, the Marjorana system in Italy, and in America the systems developed by Fessenden, DeForest, and Collins. Many other systems are known, but they exist in a more or less imperfect state of development.

Telefunken System. Die Gesellschaft fur Drahtlose Telegraphie of Berlin has put forward one of the most thoroughly developed systems of radiotelephony in commercial operation at the present time. It is generally known as the *Telefunken system,* which is the name applied to the radiotelegraphic system operated by the same company.

The Telefunken radiotelephonic system is of the oscillating-arc type. The arrangement of circuits is shown in Fig. 14. Six or

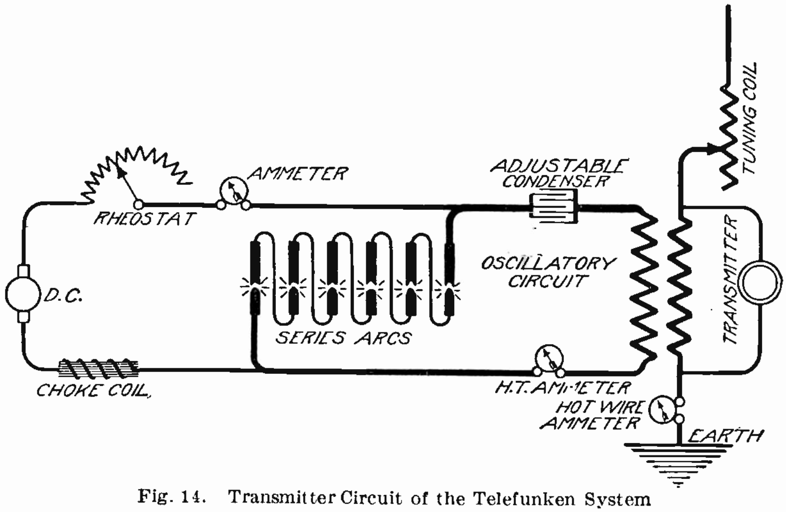


Fig. 14. Transmitter Circuit of the Telefunken System

twelve electric arcs, connected in series and shunted by an inductance and capacity, form the source of the high-frequency oscillations. The energy supplied to this portion of the circuit is derived from a direct-current source of 220 or 440 volts (if the latter, 12 arcs in series are used) connected through a rheostat, an ammeter, and a choke coil. The choke coil is used to prevent the oscillatory current from passing through the dynamo. A hot-wire ammeter is included in the oscillatory circuit, and another between the aërial and the ground, used for tuning purposes. When the circuits are in exact resonance, these instruments give a maximum reading, thus affording a very convenient means of ascertaining if the system is in proper adjustment at any time. An adjustable condenser is provided in the oscillatory circuit, and a variable inductance in the aërial, to facilitate tuning. It will be noted that the carbon transmitter is associated with the aërial as a shunt around the secondary of the oscillation transformer. An ordinary transmitter is used and, in practice, means are provided for opening the transmitter circuit while calling, and at other times when it is desired to protect the transmitter from the detrimental effects of continued exposure to the heavy current.

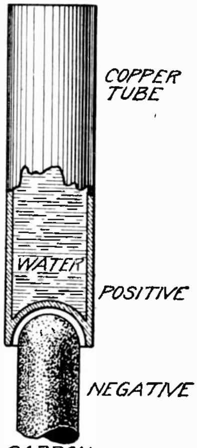


Fig. 15. Telefunken Electrodes

The electrodes employed for the arcs in this system possess features of interest. The positive member is formed by a copper tube about 2½ inches in diameter and 8 inches long closed at the bottom by a concave piece of the same material. The internal cavity is filled with water, thus serving to keep the metal cool. Fig. 15, which shows the Telefunken electrodes, represents the positive member as partially cut away in order to make clear the construction. The negative electrode is of carbon 1½ inches in diameter, set well up in the concave portion of the positive electrode, but separated therefrom by a gap of about ⅛ inch. The arc formed between these two members tends to maintain the uniformity of the gap. It is claimed that the consumption of carbon is only about 1 inch in nearly 300 hours, and that the copper electrode is not appreciably affected by the arc. The water is changed as often as required, according to the time it is subjected to the heat of the arc, or by reason of evaporation. Means are provided for the adjustment of each individual arc, and for the simultaneous striking of all. The frequency usually achieved by this method is approximately 375,000 cycles per second. The equipments are rated something under one kilowatt for connection with 220 volts.

The receiving arrangement used with this system is of the simplest kind, consisting of a detector (electrolytic or thermo-electric) and telephone directly coupled to the aërial, such as are commonly employed with radiotelegraphy. The entire apparatus is very compact, requiring but little space, and may be conveniently placed on a small table. A distance of 25 to 45 miles may be very well covered with the Telefunken sets such as are supplied for use on shipboard, and equipments of greater power may be had. Simultaneous talking and receiving is not provided for in this system.

Ruhmer System. The system due to Ernst Ruhmer, the German investigator, well known for his extensive work in connection with the development of "light telephony" and for his researches

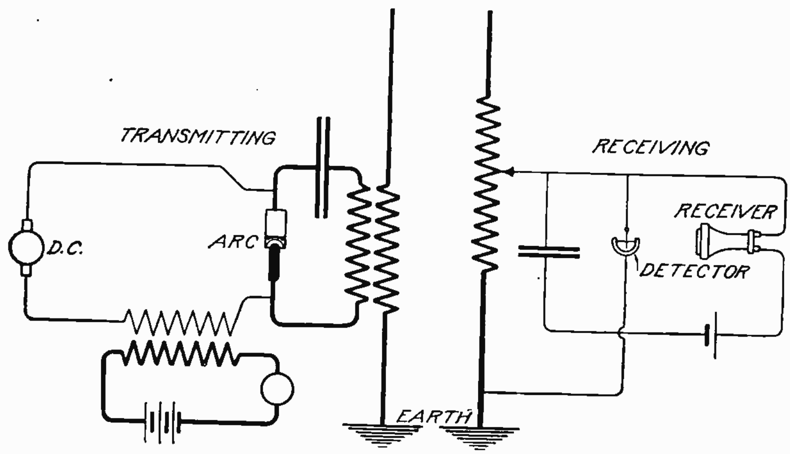
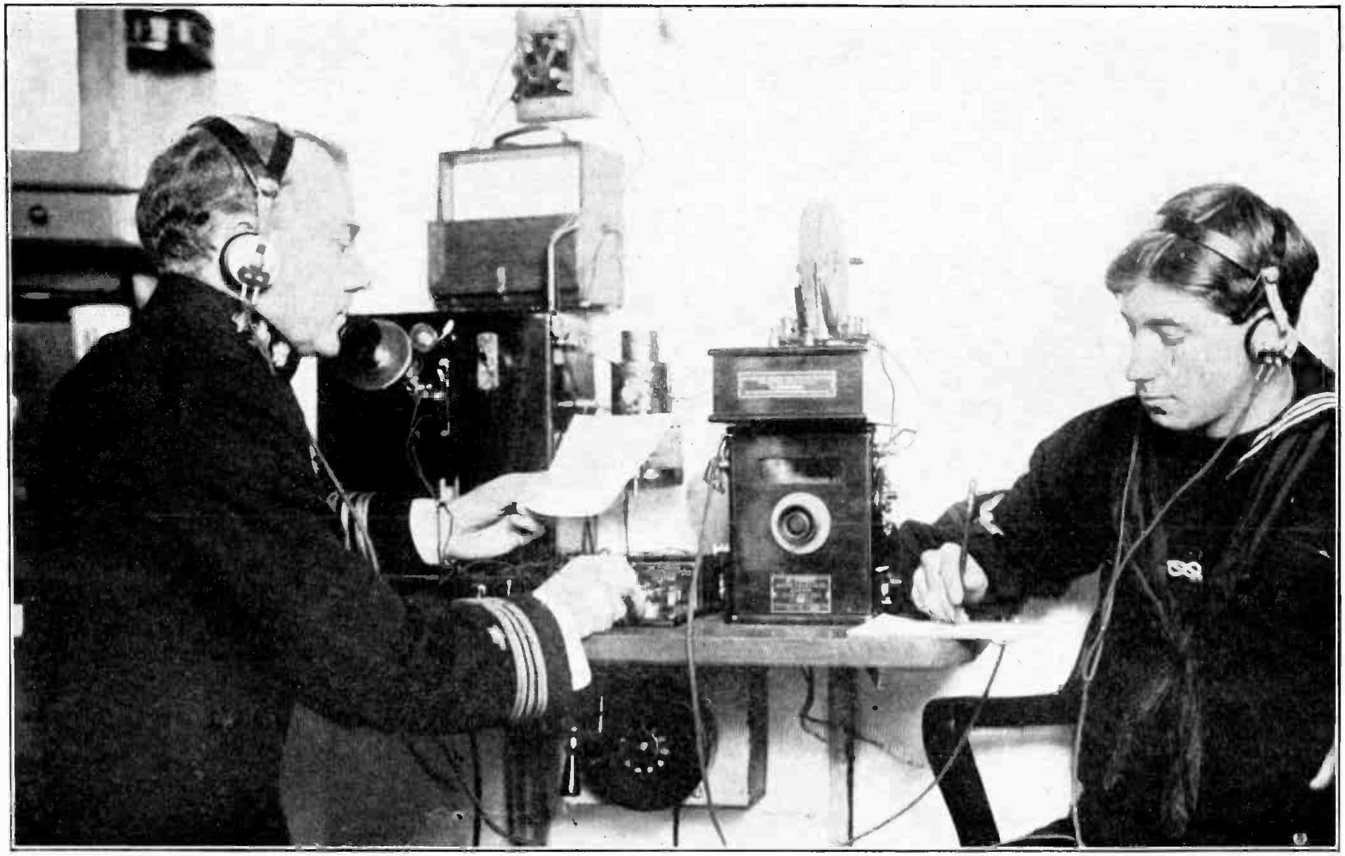


Fig. 16. Circuits of Ruhmer System

into the properties of selenium, is characterized by the use of an oscillatory arc burning in hydrogen or other suitable gas. The Ruhmer circuits are shown in Fig. 16. A local-battery transmitter circuit is employed to superimpose, by means of an induction coil, the voice current upon the supply terminals of the oscillatory portion of the arrangement. A direct-current dynamo of 440-volt pressure is used. The transmitting aërial is inductively coupled to the closed oscillation circuit. Many different forms of arc have been experimented with by this inventor, some with a magnetic blow-out. Simplicity of apparatus has been aimed at. The receiving arrangement consists of an electrolytic detector, battery, and telephone receiver



SENDING A FIVE-MILE WIRELESS TELEPHONE MESSAGE ON THE FLAGSHIP "CONNECTICUT"
Staff Officer Sending and Assistant Receiving a Distant Message.

connected with the aërial and its associated capacity and inductance. By using fairly low antennae, the Ruhmer system has operated very successfully over comparatively short distances.

Poulsen System. Special interest attaches to the Poulsen system by reason of the fact that the development of the arc method of producing sustained high-frequency oscillations was largely due to the initiative of this investigator. Mention was made of the Poulsen modification of the singing arc in its application to radiotelegraphy. Fig. 17 represents diagrammatically its application to a system of radiotelephony. A direct current from a suitable source is applied to the terminals of the arc through the secondary of a small trans-

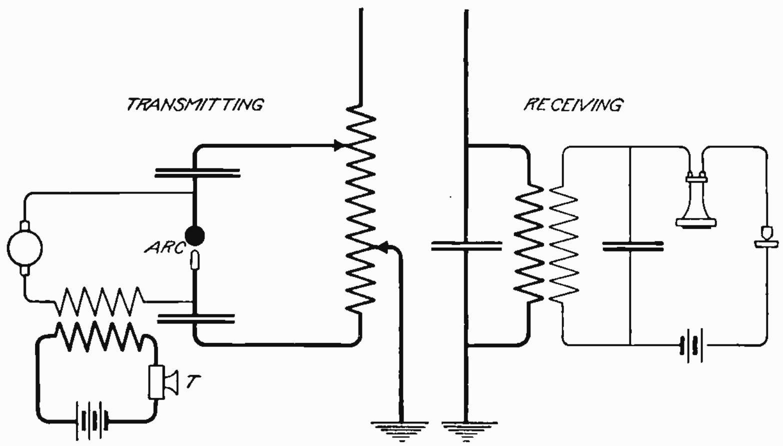


Fig. 17. Circuits of Poulsen System

former, in the primary of which is placed a local battery and telephone transmitter. The aërial is directly coupled, and two oil-condensers are so located as to prevent the direct current from reaching the aërial or ground. The magnetic blow-out devices are not shown in the cut. At the receiving station the aërial is inductively coupled with a closed oscillatory circuit which is connected with a local-battery circuit containing the detector and a telephone receiver.

Poulsen has constructed many forms of the copper-carbon arc burning in a magnetic field in an atmosphere of gas. In order to meet the difficulties caused by the irregularity of action due to the unequal burning of the carbon, he employs in connection with one form of his arc a cylindrical carbon electrode of large diameter which is slowly rotated, thus presenting constantly a new surface for the arc. In another modification, the same result is accomplished by means of a rotary magnetic field which acts directly on the arc, causing the latter to constantly change its position on the surface of the electrodes. He has also employed various gases through which the arc is maintained. In the commercial equipments more recently put out, the gas is supplied by alcohol allowed to drip slowly into the arc chamber, at a rate of about one drop every half second.

The transmitter employed by Poulsen is essentially the common carbon-granule device; he has, however, effected the variation of his oscillations by means of a multiple transmitter consisting of seven or eight such instruments connected in multiple and arranged to be acted upon by one mouthpiece.

Successful telephonic communication has been accomplished over distances varying from a few miles up to three hundred. Poulsen long-distance stations are located at Lyngby, Denmark; at Berlin, Germany; and at Cullercoats near Newcastle, England; and smaller stations are located in Denmark and elsewhere. The aërial used at Lyngby for long-distance transmission is about 225 feet high, and is of the umbrella type composed of 24 strands of phosphor-bronze wire. A 20-horse-power gasoline engine operates a 10-kilowatt, 500-volt, direct-current dynamo for the arc. A phonograph record has been transmitted from this station to Berlin and distinctly heard there—a distance of 325 miles.

The Marjorana System. In Italy radiotelephonic experiments have been carried on by Prof. Quirino Marjorana, resulting in the successful transmission of the voice from Rome to Messina, a distance of about 312 miles. As a means of creating the required oscillations, the Marjorana system employs an arc essentially identical with that used by Poulsen. The transmitting arrangement, however, is characterized by a peculiar manner of accomplishing the variations of intensity of the radiated waves. The complete circuit, including diagrammatic representation of the Marjorana liquid microphone, or transmitter, is shown in Fig. 18. The aërial is inductively coupled with the source of oscillations. The arc is fed through the blow-out magnets, which thus serve as choke coils to prevent the high-frequency current from flowing through the direct-current dynamo, which acts as supply. The receiving portion of the system possesses no points of novelty, as it is of the simple inductively coupled type and employs any of the well-known detectors suitable for this class of work.

It is the transmitter which, as suggested above, forms the distinguishing feature of this system. Its action is based upon the fact observed by Marjorana that a steady stream of water falling from an elevated containing vessel through a small orifice may have its uniformity modified by extremely minute mechanical jars imparted

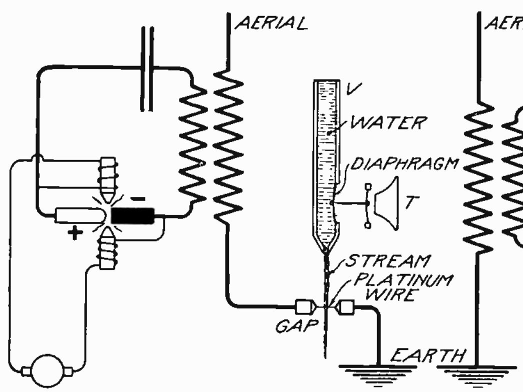


Fig. 18. Circuits of Marjorana System

to the containing vessel. The liquid transmitter is designed to take advantage of this property, and is shown partially in section in the illustration. A stationary rigid containing vessel *V* terminates at its lower end in a small hole through which the water, constantly supplied to said vessel, is allowed to flow continually in the form of a minute stream. Interposed in the path of this stream is a small gap in the aërial formed by two platinum points separated a short distance. The stream completes the connection across this gap. Means, in the form of a thin diaphragm introduced as a portion of the wall of the containing vessel, are provided to affect the diameter and contour of the stream in accordance with the vibrations of the voice. The center of this diaphragm is connected by a light rod to the center of another diaphragm which is acted upon by the voice through suitable mouthpiece. The action is as follows: The vibrations of the double diaphragm are communicated to the volume of the liquid in the form of variations of pressure manifested at the orifice and resulting in similar variations in the volume of water constituting the stream. Such modifications of the stream produce, at its juncture with the platinum electrodes of the aërial, corresponding variations in the resistance of the gap. It is of course obvious that this action produces corresponding variations in the intensity of the radiations. Numerous fluids and electrolytes have been employed by Marjorana in place of water. A form of ionized gas detector has been used in connection with this system with excellent results.

Fessenden System. In reviewing the development of radiotelephony it has been necessary to refer so often to the work of Fessenden relative to the many innovations introduced into the art by him that little remains to be said in this place in regard to the complete system which bears his name. The bibliography of radiotelephony includes many papers and articles by Fessenden of the greatest interest to the student of wireless communication. A remarkably clear and concise paper on the subject of wireless telephony, replete with much valuable data on transmission, etc., was presented by Prof. Fessenden at the 25th annual convention of the American Institute of Electrical Engineers at Atlantic City in June, 1908. Many illustrations and descriptions of the apparatus employed by him were given.

Among the many interesting facts determined by Fessenden in his very exhaustive tests dealing with the atmospheric absorption of electric waves, may be mentioned the fact that waves of a comparatively low frequency suffer less absorption than those of a much higher frequency, both being of equal power. Messages were successfully transmitted in daylight with a wave-frequency of 80,000 per second from Brant Rock, Massachusetts, to a radiotelegraphic station in the West Indies—a distance of 1,700 miles—with comparatively little absorption; while at the higher frequency of 200,000 per second communication was impossible.

The power required for radiotelephony, Fessenden states to be about five to fifteen times that required for radiotelegraphy. Fessenden has employed at various times all the well-known methods of generating a sustained train of waves but has met with greater success, particularly in radiotelephony, by the use of some form of the high-frequency alternator method, shown in Figs. 6, 7, and 12, used in connection with the heterodyne receiver illustrated in Fig. 13.

The Fessenden system has transmitted speech from Brant Rock to New York City with an expenditure of about 200 watts. Longer distances have also been covered with higher power apparatus. Fessenden's patents are controlled by the National Electric Signaling Company.

DeForest System. This system is exploited by the Radiotelephone Company and is due to Dr. Lee DeForest. It is an oscil-

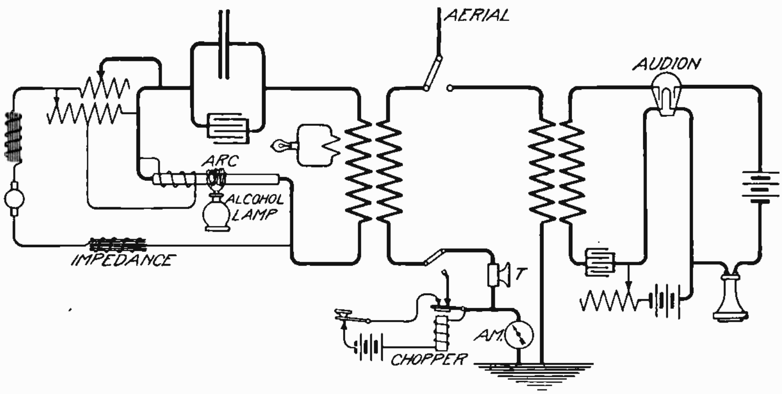


Fig. 19. Operating Circuits of the DeForest System

lating arc system presenting nothing of special novelty. Fig. 19 shows the essential features of the operating circuits, though in practice a more convenient means is provided for facilitating the change from the transmitter to receiver. The arc is of the Poulsen type, taking place between a copper positive electrode, water cooled, and a carbon negative. An electromagnetic means is provided for automatically adjusting the length of the arc by a movement of the carbon through the agency of a solenoid, which is represented in the drawing by the turns of wire around the left-hand electrode. A variable resistance is employed to effect the proper regulation of this feature. The arc is made to burn in the flame of a small alcohol lamp. The aërial is inductively coupled to the closed oscillation circuit, the latter containing two condensers connected in multiple, one of which is adjustable for tuning purposes. A small incandescent lamp, connected to a closed circuit, is placed in inductive relation with the primary of the oscillation transformer in order to give a visual indication of the proper working of the oscillation arc. The transformer used for inductive coupling with the aërial is of compact flat spiral design, the primary and secondary being placed side by side in a loose inductive couple. For telegraphic and "calling" purposes, a device for rapidly interrupting the steady flow of waves, called a "chopper," is thrown in by the movement of a switch; whereupon it becomes possible, by the operation of the Morse key, to cut up the wave-train into any desired combination of dots and

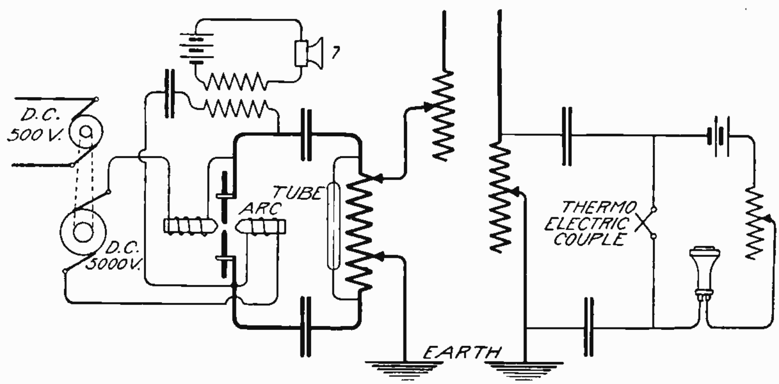


Fig. 20. Circuits of the Collins System

dashes. The telephone transmitter, which is introduced between the aërial and the ground, is out of circuit during such a performance. A hot-wire ammeter is placed in the aërial circuit to indicate when the latter is in tune. For the detector, a form of the DeForest audion receptor is used, connected in the circuit as shown.

The DeForest system has met with considerable success, and has been installed on several United States battleships. Tests have been made with the DeForest equipment by the British Admiralty, and the greatest distance over which it was possible to transmit satisfactorily was about 57 miles, a distance which has since been extended with improved apparatus. The sound from phonographic records transmitted by this system when temporarily installed at the Eiffel Tower in Paris, was said to be audible 400 miles away. This station permitted of the use of an exceedingly tall aërial, the tower being nearly 1,000 feet high.

Collins System. This system has been developed by A. F. Collins, who for several years has carried on experiments in the field of radiotelephony. The circuits employed are shown in Fig. 20, the arrangement including some unusual features, though nothing in the nature of a radical departure. The oscillations are created by an arc of a higher potential than is generally used, 5,000 volts being supplied through the agency of a direct-current dynamo directly coupled to a 500-volt motor. The electrodes of the arc are both in the form of carbon disks, which are made to revolve by means of a small motor, as shown in Fig. 21. A magnetic blowout is also provided, the coils of which serve the purpose of choke-coils, thus preventing the oscillatory current from entering the generator. The aërial is of the direct-coupled type in both the transmitting and receiving stations. A visual indication of the correct working of the arc takes place in the form of a glow within an exhausted glass tube. This tube is supplied with platinum terminal wires sealed into the ends, and projecting inwardly to within a short distance from each other. This device is shunted across the inductance in the closed oscillatory circuit. The transmitter is located in a local-battery circuit and acts inductively on a shunt connected across the terminals of the arc. This shunt includes the secondary of the induction coil and a condenser. Collins has recently employed several transmitters connected in multiple and operable through a common mouthpiece. The detector employed in this system is the invention of Collins, and is in effect a sensitive thermo-electric couple composed of two dissimilar metals, the juncture of which is heated by the received oscillations. The variation of this thermal effect produces a corresponding variation in the effective resistance of the detector, and consequent vibrations of the receiver diaphragm.

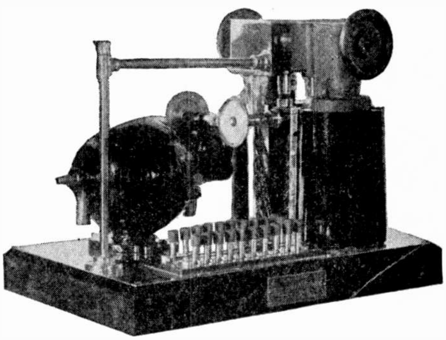


Fig. 21. Collins Revolving Electrodes

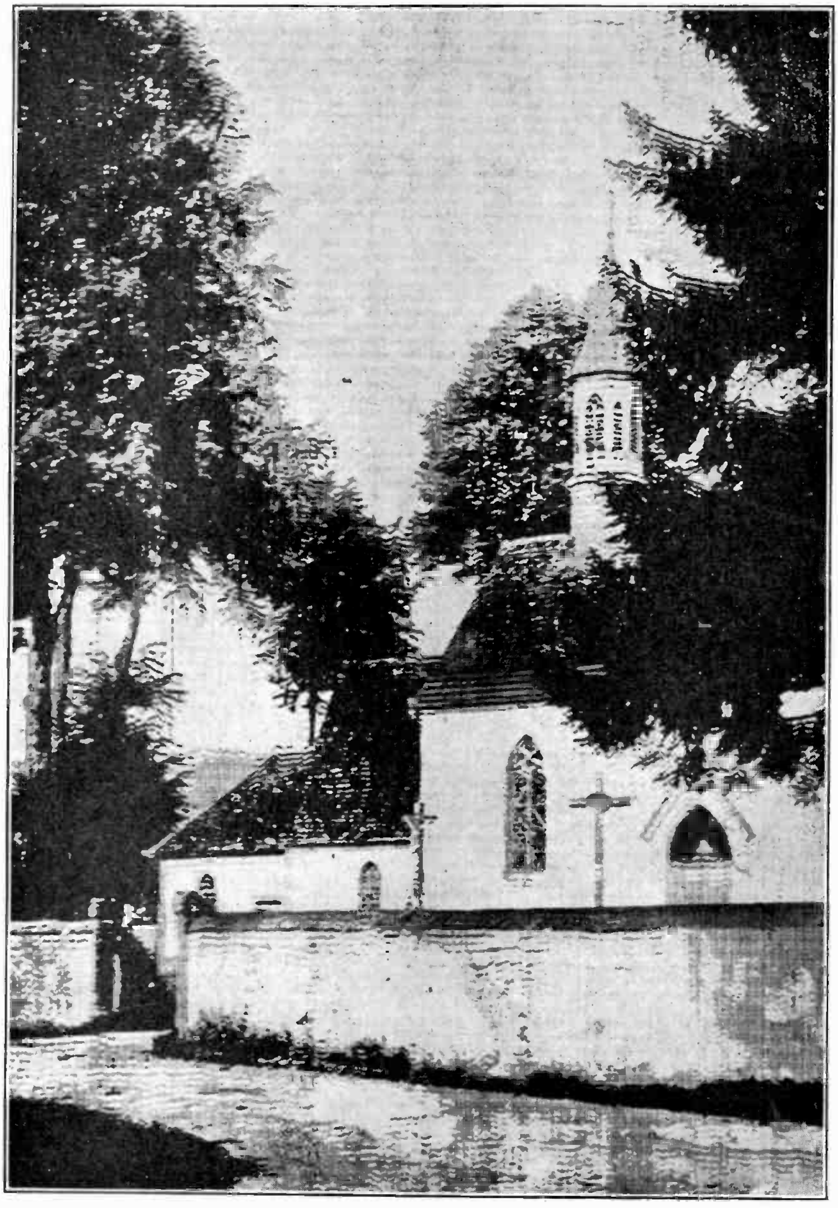
The Collins system is exploited by the Collins Wireless Telephone Company of Newark, New Jersey.

Conclusion. In conclusion attention is called to an important characteristic of radiotelephonic communication which has been observed in practice, namely, the exceptional clearness of articulation, due to an absence of wave-form distortion which is always present in wire telephony by reason of the deleterious effect of the electrostatic capacity of metallic lines and cables. This fact alone bespeaks wonderful promise for this form of telephony, particularly in view of the very limited distance over which it is at present possible to telephone when the medium is a submarine cable.

Experience has thus far shown that great advantage is to be gained by the very accurate tuning of the various circuits in connection with radiotelephony as well as with radiotelegraphy. The employment of sustained oscillations greatly facilitates the accomplishment of more perfect resonance; which, in turn, tends to eliminate interference and aids selective communication. Experience has also shown that in systems using an inductively coupled aërial, a decided gain in the clearness of articulation is noticeable when such coupling is "loose." In practice, therefore, the primary and secondary helices are often separated several inches.

In the foregoing discussion of radiotelephony it has been impossible to do more than very briefly present the subject. Many interesting questions of a theoretical nature and a description of several other systems, it has been found necessary to omit. If, however, the present short survey awakens a greater interest in space-communication, the reader may avail himself of the extensive literature dealing with the subject, and delve as deeply into the theory and problems involved as he desires.

SENDING AND RECEIVING A MESSAGE. COLLINS' SYSTEM.



PICTURE SENT BY TELEGRAPH

This View was Transmitted by Means of the Belin Telestereograph. Notice the Wavy Effect Produced by Telegraphic Reproduction.

THE TELAUTOGRAPH.*

Electrical transmission of handwriting has engaged a certain amount of attention ever since telegraphic transmission of printed characters was successfully carried out.

As early as 1886, Cowper and Robertson brought the writing telegraph[1] into a fairly operative form. This instrument was adapted to operate several receivers in series in "reporting" service, where the regular news ticker service was unobtainable or too expensive. The system was put to some use, chiefly in Pittsburg and vicinity.

The writing was received on a paper tape, advanced at constant speed by clockwork. No pen-lifting device was provided and the words were connected together by a mark of the pen, making figure work poor. As the characters were formed by the combination of the pen motion and the tape motion, a certain amount of practice and skill was required to produce a legible message.

The electrical features were as follows : two independent variable currents were obtained from the transmitter; these passed over lines to the receiver where they traversed two electromagnets set at right angles to each other, and so influenced their effect upon a common armature as to cause the receiver-pen rod to reproduce the motion of the transmitter pencil.

It will be noted that this principle is nearly identical with that of Grühn's Telechirograph,[2] recently described in the technical press, the main differences being that the telechirograph writes upon a larger field and uses a beam of light, and photographic record instead of a pen with ink record.

Following the writing telegraph, Professor Elisha Gray constructed, at his Chicago laboratory, an instrument which wrote upon stationary paper, and which he called a telautograph. It

1. Wm. Maver, Jr., *American Telegraphy.*
2. *Scientific American*, August, 1903.

*Prepared by James Dixon, E.E., and read by him before the American Institute of Electrical Engineers. October 28th. 1904. Reprinted by special permission.

required four line wires and operated as follows: by means of cords and drums the motions of the transmitting stylus were resolved into two component rotary motions which were used to operate two mechanical interrupters in the primary circuits of two induction coils. The relations of the parts were such that a motion of the transmitting stylus amounting to one-fortieth of an inch caused a complete make-and-break at one or both of the interrupters.

The line currents were the impulses produced in the secondary circuits of the induction coils. These impulses passed over lines to two electromechanical escapements in the receiver. By means of cords and drums, their motions were combined and caused to act upon the receiver pen. By the use of relays and condensers and a local battery at each receiver, the paper was advanced when necessary and the pen lifted from and lowered to the paper. The mechanical difficulties met with in perfecting this instrument were very great, and in the apparatus exhibited at the World's Fair in Chicago in 1893 the escapement mechanism was brought to a perfection thought impossible of attainment only a short time before. The writing showed a saw-tooth or step-by-step character due to the action of the escapements. The instrument was abandoned on account of the number of line wires required, limited speed, numerous fine adjustments, and cost and difficulty of manufacture.

In 1893, while still working at the escapement device, Professor Gray patented a variable-current instrument,[1] using two line wires, which worked, in a general way, like the present telautograph. The motions of the transmitter pencil were resolved into two components which were used to vary two line currents, the variable resistances being carbon rods dipping into tubes of mercury. The receiver contained two D'Arsonval movements, to the moving elements of which the pen-arms were attached. Professor Gray never developed this instrument much beyond the laboratory stage, probably on account of his firm belief in the escapement type.

Foster Ritchie, at that time an assistant to Professor Gray, gave considerable attention to this patent and perfected an instru-

1. U. S. Patent 494,962, April 4, 1893.

ment based on it. He obtained a patent for improvements[1] and has produced an instrument that operates in a fairly satisfactory manner[2] under certain favorable conditions.

The telautograph has been brought to its present state chiefly through experimental work done by, or under the personal direction of, Mr. George S. Tiffany, to whom several patents[3] for improvements have been granted. Mr. Tiffany's instrument operates upon the variable-current principle and includes a number of interesting features, among them what may be called a straight-line D'Arsonval movement, which is used to operate the receiver.

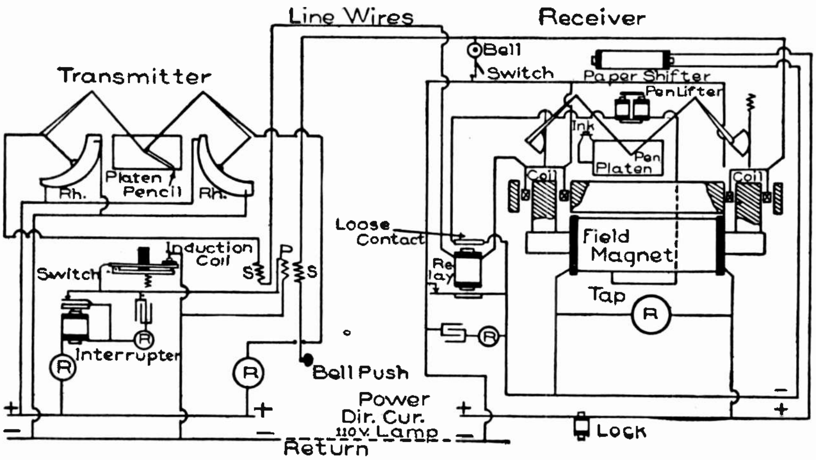


Fig. 1.

The operation may be briefly described thus: at the transmitter a pencil is attached by rods to two lever-arms which carry contact-rollers at their ends. These rollers bear against the surfaces of two current-carrying rheostats, connected to a constant-pressure source of direct current. The writing currents pass from the rheostats to the rollers and from them to the line wires. When the pencil is moved, as in writing, the positions of the rollers upon the rheostats are changed, and currents of varying strength go out upon the line wires. At the receiver these currents pass through two vertically movable coils, suspended by springs in magnetic

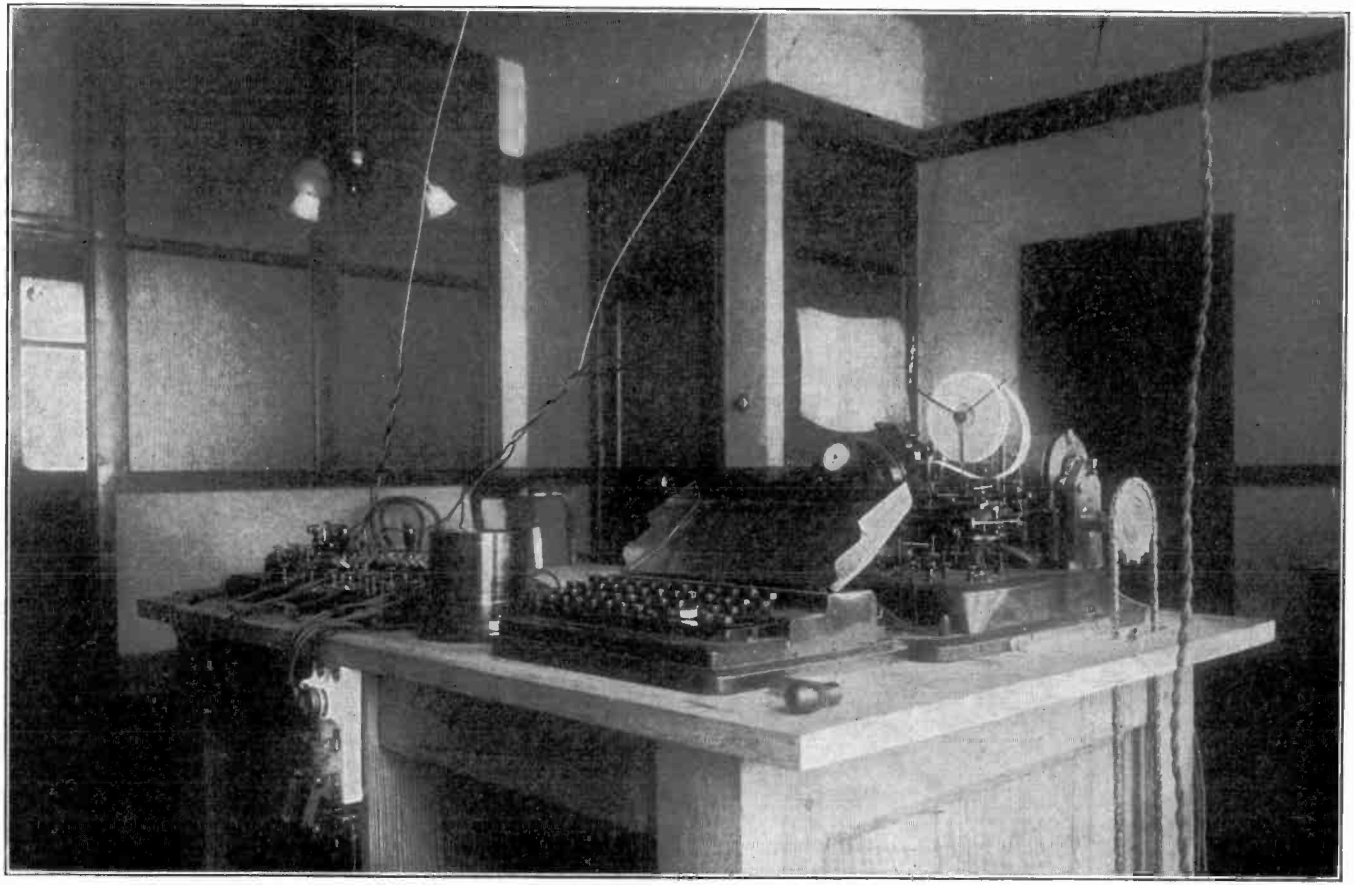
1. U. S. Pat. 656,828, Aug. 28, 1900.
2. *Elec. World and Engineer*, Dec. 8, 1900, Vol. XXXVI., No. 23.
3. U. S. Patents 668,889 to 668,895 inclusive, Feb. 26, 1901.

fields, and the coils move up or down according to the strengths of the line currents. The motions of the coils are communicated to levers similar to those at the transmitter, and on these levers is mounted the receiver pen, which, by the motions of the coils, is caused to duplicate the motions of the sending pencil. Fig. 1 shows the circuits of the instrument.

Many of the principles and devices in the instruments are of considerable interest. The method by which the variable currents are obtained is the laboratory arrangement for securing a variable pressure from a direct-current, constant-pressure circuit; that is, the line circuit (of constant resistance) is connected as a shunt around that part of the rheostat between the moving roller and the ground or return. Motion of the roller varies the amount of resistance in series with the line and also the amount in parallel with it and fine gradations are easily obtained, giving smooth motion of the receiver pen. In this way a variable pressure is impressed on the line circuit, giving a variable current. In all the other variable-current instruments, a constant pressure was impressed on the line and a resistance in series with the line varied to give the desired variations in current. One result of the shunting method is a better form of rheostat, more easy of construction and handling, in which, also, the heating is better distributed.

The rheostats are wound upon castings of I cross-section, with the turns of wire lying close together on the inner or contact-face. After winding, the insulation on this face is saturated with glue, which is allowed to harden and is then scraped off, taking the insulation with it, and giving a surface where contact is possible on every turn of the wire. This gives a rheostat of a large number of small steps, of good mechanical construction, and of low cost.

The receiver operates with what may be called a straight-line d'Arsonval movement. The moving element or coil is wound upon a copper shell for damping effect. The magnetic circuit is so arranged that one pole surrounds the other, forming an annular air-gap of short length and large cross-section in which the direction of the flux is radial. The field is electromagnetic and is highly excited, to secure uniformity. The coil, suspended in the annular space, moves up or down with little friction, as it touches the



THE TELAUTOPRINT

At the Left is Located the Controlling Device and at the Right is the Electrically-Operated Printing Bar.

sides of the space or the core very lightly if at all. The principle is the well-known one that a current-carrying coil, in a magnetic field, tends to place itself with respect to the field so that the flux enclosed by the coil shall be a maximum.

The current for operating is taken from the ordinary lighting mains, preferably at about 115 volts. Satisfactory operation has resulted with pressures from 80 up to 250. At 115 volts, receiver and transmitter each require about one ampere while in operation. Fairly steady pressure is necessary as the receiver, being in effect a voltmeter, is rather sensitive to sudden changes, the effect being slight distortion of the message.

A master-switch at the transmitter is provided to do all necessary switching of line and power circuits, to make needed changes in connections and to cut off current when not writing. A relay in one of the lines closes the power circuit of the receiver whenever the transmitter at the distant station is switched on, and serves to prevent waste of current when not in operation.

Attached to the master-switch is a mechanical device which shifts the transmitter paper the space of one line of ordinary writing for each stroke of the switch. The relay mentioned controls the electrical receiver paper shifter and, as each stroke of the switch causes a stroke of the relay, the receiver paper is shifted an amount equal to that at the transmitter. The writing space is about two inches long and five inches wide, allowing for three or four lines of writing. When filled by messages, a few strokes of the switch serve to bring fresh paper into position at both receiver and transmitter.

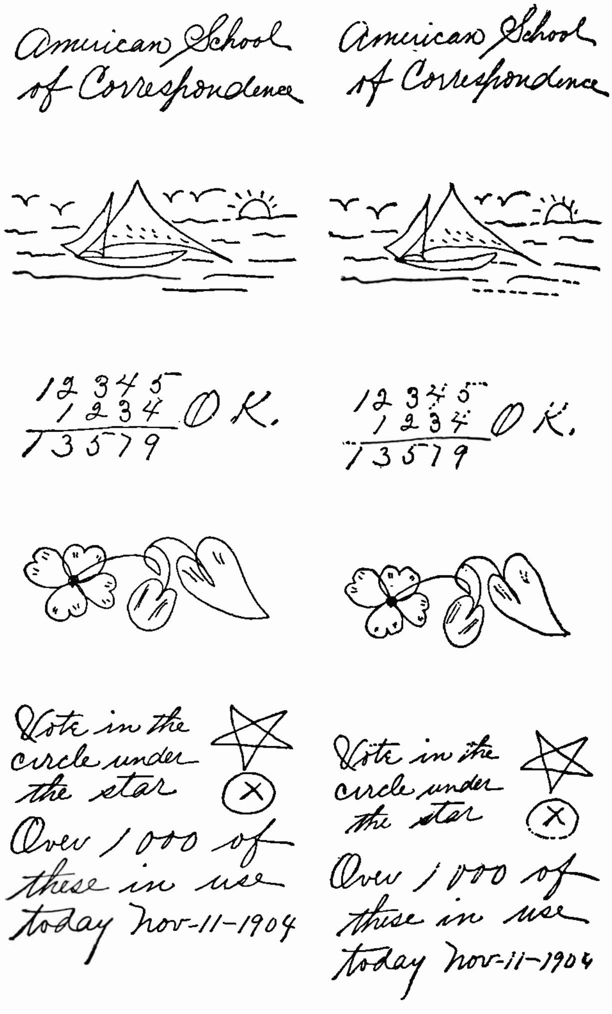
To prevent switching on of the transmitter while its home receiver is receiving a message from the distant station, an electromagnet lock is connected in the receiver power circuit, controlled by the relay, which locks the home transmitter in the "off" position until the distant transmitter is switched off. If both transmitters were switched on at once, neither station would receive any message; the lock is provided to render this condition impossible.

The ink supply is most important, and is arranged for as follows: at the left of the receiver platen is a bottle with a hole in the front near the bottom. When filled with ink and tightly corked the ink does not run out of this hole because of the pressure of the atmosphere. The ink is accessible for the pen at the hole and the surface of ink exposed to evaporation is small.

The pen is made of a piece of German silver bent double, after the manner of a ruling pen, and makes a uniform line in any direction over the paper. It takes up its supply by capillary attraction, from the hole in the front of the bottle. When the receiver is switched off, retractile springs draw the pen-arms to stops so arranged as to bring the pen exactly in front of the hole in the bottle, and when the pen-lifter armature is released the pen is caused to insert its tip in the opening. Thus a fresh filling of ink is obtained each time the paper is shifted. When not in use the pen rests in the ink, always ready to write.

For the prevention of mechanical shocks to the necessarily light moving system of the receiver, it has been necessary to supply means to prevent the switching on or off of the transmitter, and by that action of the receiver, when the transmitter pencil is "out in the field"; that is, at a position other than that corresponding to the opening in the receiver ink-bottle; as in that case the receiver pen would instantly jump to a similar position. This position is called the "unison point," a term having its origin in the days of the "self-propellor" escapement telautograph. By placing a catch, released only by pressure of the pencil-point upon it, at the transmitter unison point, the desired result is accomplished and the transmitter master-switch can not be switched either "off" or "on" unless the pencil be placed at the unison point and held there until the stroke of the switch is completed. In this case, as everywhere, the apparatus is made strong enough to stand any possible shocks, although every precaution is taken to prevent their occurrence. Aside from the shock to the moving system these jumps might shake the ink supply out of the pen and prevent the recording of the message.

The pen-lifter is a magnet placed back of the receiver writing platen, and carrying upon its armature a rod adapted to engage with the pen-arm rods and raise the pen clear of the paper when the magnet is energized. This magnet is controlled from the transmitter as follows: beneath the transmitter platen is a spring-contact, opened by pressure of the pencil upon the paper, and closed by a spring when the pencil is raised. An induction coil having an interrupter in its primary circuit is so connected to this spring-contact that when the pencil is raised the primary winding is short-circuited. The induction coil has two independent sec-



SAMPLE OF WRITING

Made especially for the American School of Correspondence over a distance of about 20 miles. At the left is shown the original, at the right the reproduction.

ondary windings through which the two variable line currents pass before leaving the transmitter. The effect of the induction coil and its interrupted primary current is to induce, in the two line currents, superimposed vibrations or "ripples" when the pencil is pressed down on the paper and the spring-contact is open. When the contact is closed, by its spring, and the primary winding is cut out, no vibrations are produced in the line currents. In one of the line wires, at the receiver, is placed a relay upon whose sheet-iron diaphragm armature is mounted a loose contact, consisting of two platinum-silver contacts in series, sealed in a glass tube, to prevent oxidation. A local circuit contains the winding of the pen-lifter magnet and this loose contact.

When the vibrations are present in the line current, due to the pressure of the pencil upon the paper and consequent opening of short circuit of the primary of the induction coil, the diaphragm of the relay is shaken, the loose contact opened, and the pen-lifter de-energized, its armature being drawn back by a spring and the pen being allowed to rest against the paper. When there are no vibrations in the line currents due to the raising of the pencil from the paper, the relay diaphragm is at rest, the pen-lifter is energized, and the pen is lifted clear of the paper.

The superimposed vibrations used for operating the pen-lifter nave another minor effect. The suspended coils, and through them the entire moving system of the receiver, are kept in a state of very slight mechanical vibration while the pen is on the paper. This aids the flow of ink from the pen-point, assists the pen in passing over any roughness or irregularity in the surface of the paper, and materially reduces friction in the joints and pivots of the moving system, and results in better writing. In some of the later instruments, the two relays, that for pen-lifting and that for paper-shifting and power-switching, are combined in a single piece of apparatus.

For signaling, a push-button is placed upon the transmitter and a call-bell or buzzer is mounted on the receiver. This circuit is disconnected by the master-switch while a message is being written. Spring reels are attached when needed to roll up the received messages for preservation and future reference.

The ordinary arrangements for operation are as follows: the instruments may be operated singly, upon a private line having an instrument at each end, or on an exchange system where a switchboard provides for connection. Working in this way, satisfactory writing has been obtained with a resistance in each line wire of 1,600 ohms and an operating pressure of 110 volts. Multiple operation can be carried out to a limited extent, three receivers being at present the maximum number that can be operated at once, in multiple, using 110 volts. This allows of placing a supervisory machine upon a line.

When no response to messages beyond a bell signal is required, and the same message is to be sent to a number of stations, a series

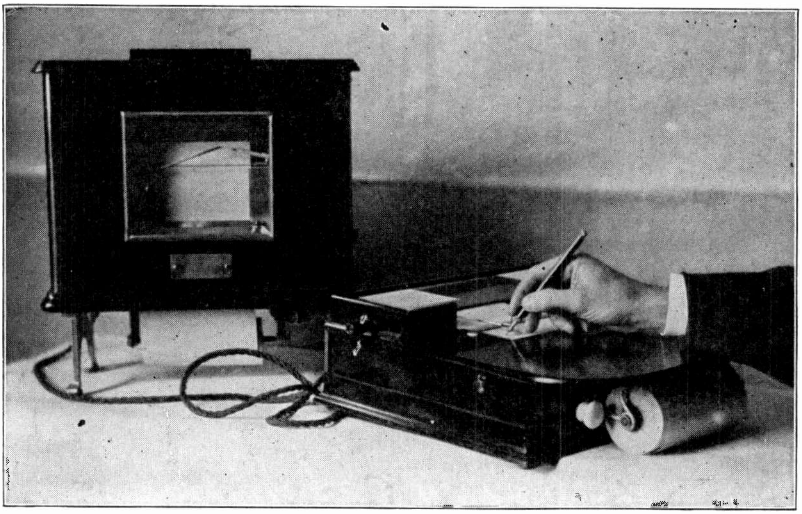


Fig. 2.

arrangement of receivers is used. With a transmitting pressure of 110 volts a maximum of seven receivers can be operated from a single pair of transmitting rheostats and rollers. This number may be increased by increasing the pressure or by adding additional rheostats and rollers, operated by the same pencil. Using both these methods a maximum of 50 or more receivers may be operated at once.

Instances in actual commercial use of the arrangements of instruments mentioned are: private lines; the transmission of mail and other orders from office to factory or yards; investigation of checks over lines between paying tellers and bookkeepers in banking concerns, and transmission of messages, usually in cipher, between brokerage firms and cable or telegraph offices. A few moments' thought will bring to mind many places where a telautograph private line could be used to save time and trouble, especially where accurate transmission of figures is essential.

Multiple operation may be resorted to when a third station upon a line desires a record, accessible at any time, of what is being sent, as, for instance, when one of the officers of a bank desires to know what passes between his bookkeepers and paying tellers. On such a line the third station receives all messages and can write to either or both of the other stations, should the necessity arise.

Series operation may be used when several stations are to receive the same message and no response except a bell signal is required, as in sending orders in a hotel or club from dining room to kitchen, pantry and wine room; in "reporting" or news service, or for bulletin work, such as the announcement of arrival and departure of trains to a number of stations in a large railway station or freight depot. Fig. 2 shows the standard commercial instrument.

One of the most important uses for series systems has been found in the U. S. Coast Defense Service, in sending ballistic data, such as range and azimuth of target, or character of projectile, from position-finding stations to the gunners. This is called "fire-control communication" and is installed in the forts by the U. S. Signal Corps. In a paper presented by Col. Samuel Reber on "Electricity in the Signal Corps,"[1] will be found a description of the position-finding systems. The desired characteristics of a system of communication for sending this data to the guns are stated as follows:

> "The system that will successfully solve this problem must be simple in construction, mechanically strong so as not to be affected by the blast, as the receivers are placed close to the guns, rapid in operation, and give a character of record that can be read without liability of error."

Since that paper was prepared, it has been decided that the receivers must be mounted directly on the gun-carriage and can have no shelter other than that afforded by their own cases. Add to these requirements the facts that the instruments must be cared for by post electricians, and operated by enlisted artillerymen; that messages must be visible at night; and the operation must be

1. TRANSACTIONS, A. I. E. E., Vol. XIX., pp. 723 and 724.

independent of rain, salt mists, cold, heat, or tropical insects, and it is apparent that no easy problem is presented.

A special type of telautograph has been designed for this service and has been adopted by the U. S. Signal Corps[1] for fire-control communication.

In this "service telautograph," the pen-lifter controlling

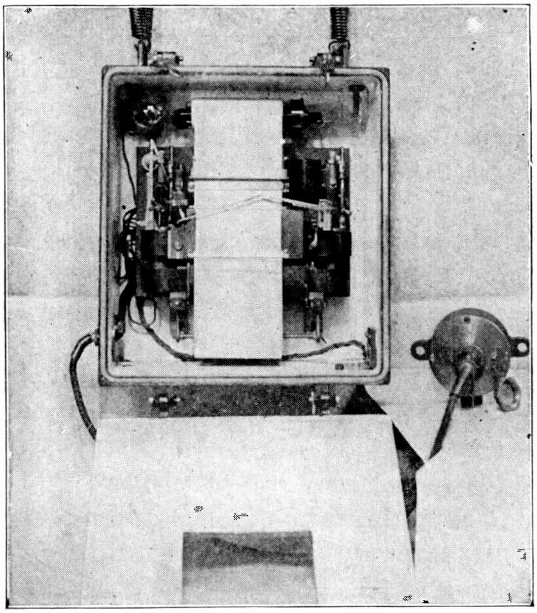


Fig. 3.

relay is eliminated and the receiver pen-lifters are operated over a third line wire by the transmitter platen switch directly.

Each gun receiver is enclosed in a water-tight brass case, suspended by springs from the gun carriage directly in front of the gunner. The parts are as far as possible made "brutally strong," and the construction is as simple as possible.

The desired rapidity of operation is inherent to the telautograph, and accuracy of record is ensured by careful writing and by the use of a "home" receiver, mounted at the transmitter where the operator can see it plainly, which is connected in series with

1. TRANSACTIONS, A. I. E. E., Vol. XIX., p. 673.

the gun receivers and records the messages as actually sent over the line.

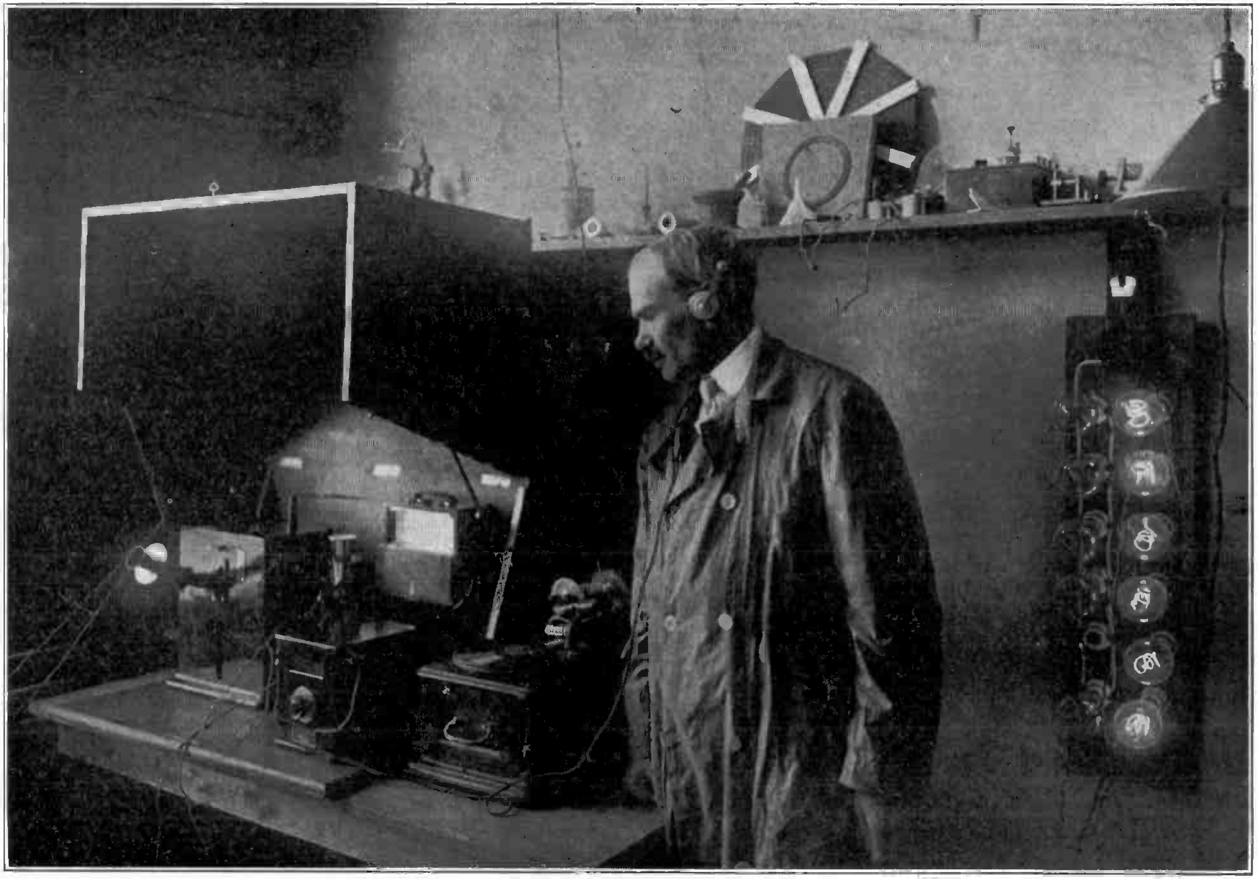
Freezing of ink is prevented by the addition of alcohol; and rain, mists, and insects, as well as the effects of the blast, are shut out by the metal case. A heavy glass window is placed in the case so that messages can be read without opening the case.

A small incandescent lamp inside the case lights automatically when the receiver is writing and may be lighted by pressing a button at other times, thus providing for visibility at night. Fig. 3 shows the army type of receiver mounting.

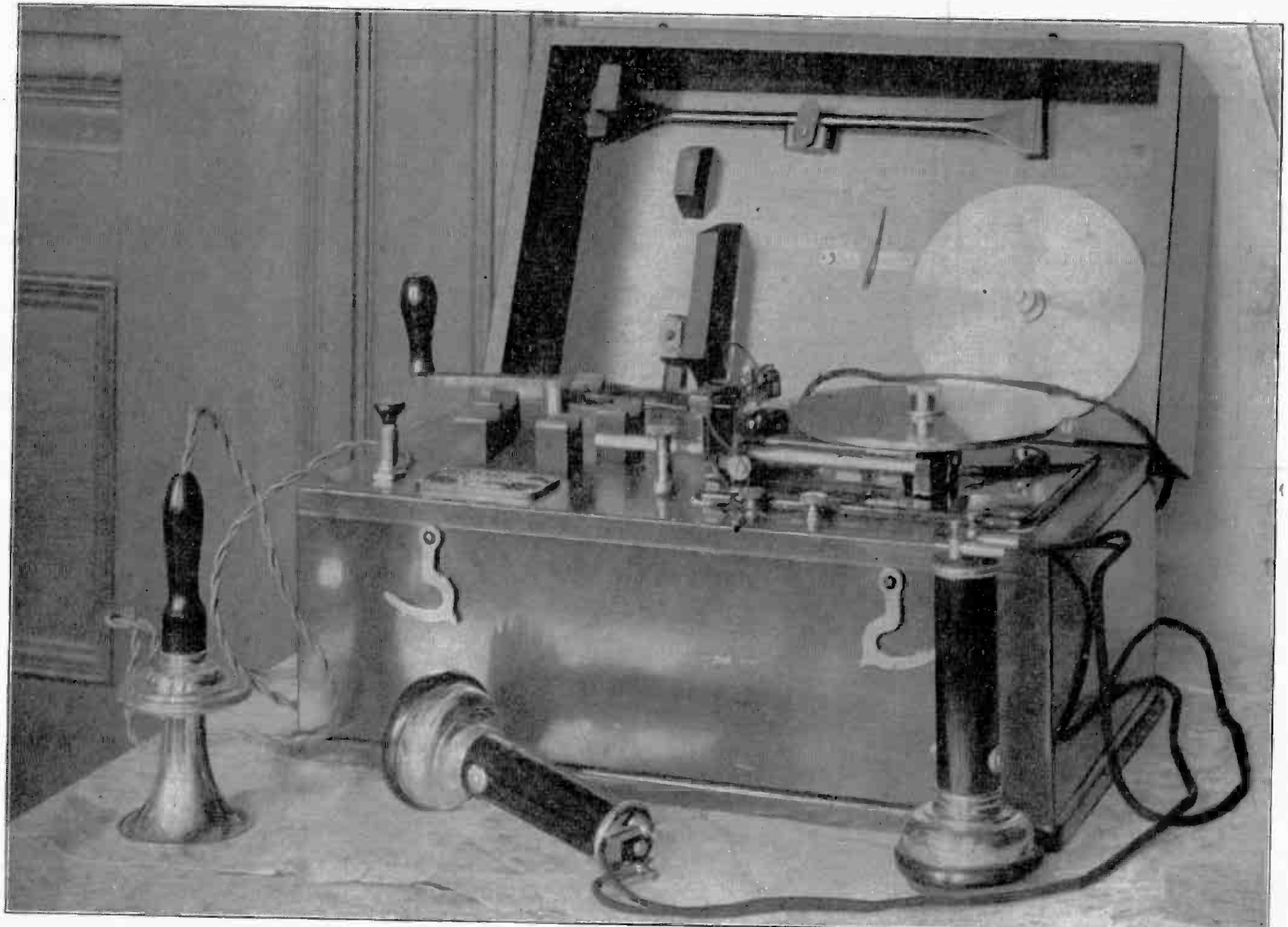
On warships there is a somewhat similar service to be rendered and the performance of this should fall to the army type of telautograph.

Commercial service has given opportunity for the installation of a considerable number of private line telautographs in actual use, and at least three of each of the other typical installations are in operation at the present time.

Much of the improvement in details of construction and reliability in operation has resulted from experience gained in efforts to perfect the service of these commercial plants. The experience leading up to the special army type of telautograph has extended over a period of about five years and in the present instrument all the requirements, unusually severe as they are, have been successfully fulfilled.



DR. LEE DeFORREST AND HIS WIRELESS TELEPHONE



TELEGRAPHONE OF DISC TYPE, WITH CASE

THE TELEGRAPHONE

The telegraphone is an electro-mechanical device which records the human voice, music, or other sounds on a thin steel disc or on a fine steel wire, and then reproduces these as perfectly as a telephone—a result that is impossible with the phonograph or graphophone.

The invention of this new instrument is due to the researches of Vladimir Poulsen of Copenhagen, Denmark, who, while experimenting with a telephone about 1900, discovered a new principle in electromagnetism which seemed to offer a complete solution of the difficult problem of reproducing sound.

This principle is the *localization of magnetism*; and its action, as well as the apparatus employed, will be readily understood by referring to Fig. 1, in which *E* is an electromagnet of small dimensions

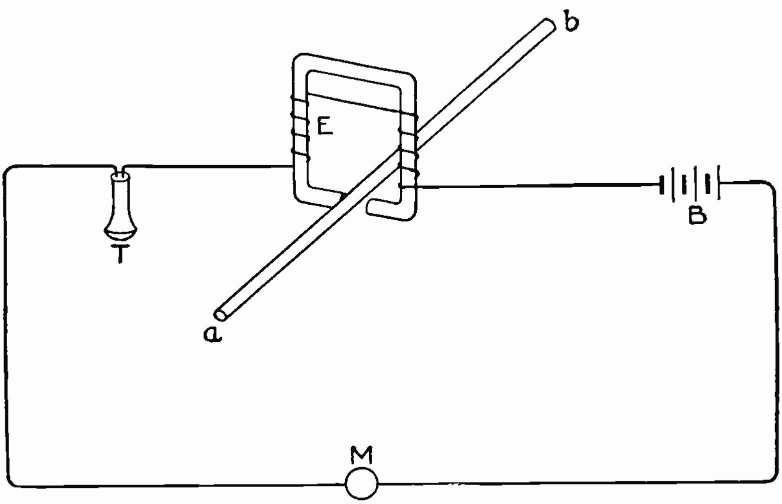


Fig. 1. Illustrating the Principle of the Telegraphone.

inserted in a telephone circuit including a battery *B*, telephone transmitter *M*, and receiver *T*. The poles of the electromagnet are separated by a space large enough to permit the steel wire *a b* to pass.

Steel piano-wire is employed, having a diameter of $\frac{1}{50}$ to $\frac{1}{100}$ inch; and this is drawn forward between the poles of the magnet so that the successive portions of the wire advance at the rate of 7 or 8 feet per second. The early type of apparatus resembled an ordinary phonograph in which the wire *a b* replaced the wax cylinder, and the magnet between the poles, the stylus.

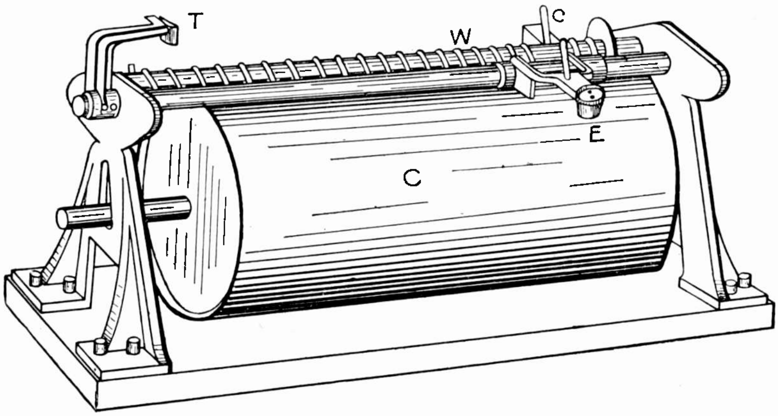


Fig. 2. Early Model of Telegraphone, Wire Type.

The sound is recorded by speaking into a transmitter either near at hand or located at any distance over which the telephone is capable of working. The electric impulses thus set up in the circuit cause the current in the coils surrounding the core of the electromagnet to vary in strength; and consequently the magnetic flux between the poles undergoes a series of variations corresponding to the original sound waves.

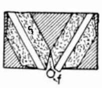


Fig. 3. Section of Electromagnet and Wire.

These magnetic forces act in turn upon the steel wire as it travels in front of the poles, and magnetize it transversely. Each part of the steel wire retains its magnetization, the strength of which depends upon the force developed at a given instant. The magnetic record upon the wire corresponds, therefore, exactly to the original sound waves.

After the record has been made, it can be reproduced at any time. To do this, it is only necessary to connect the receiver to the terminals of the electromagnet, and to cause the wire to pass again between the poles of the electromagnet in the same direction and at approximately the same speed as before. As the magnetic strength varies from point to point, the movement of the wire between the poles causes a variation in the magnetic flux and sets up a series of undulating currents in the circuit, the wave-form being precisely

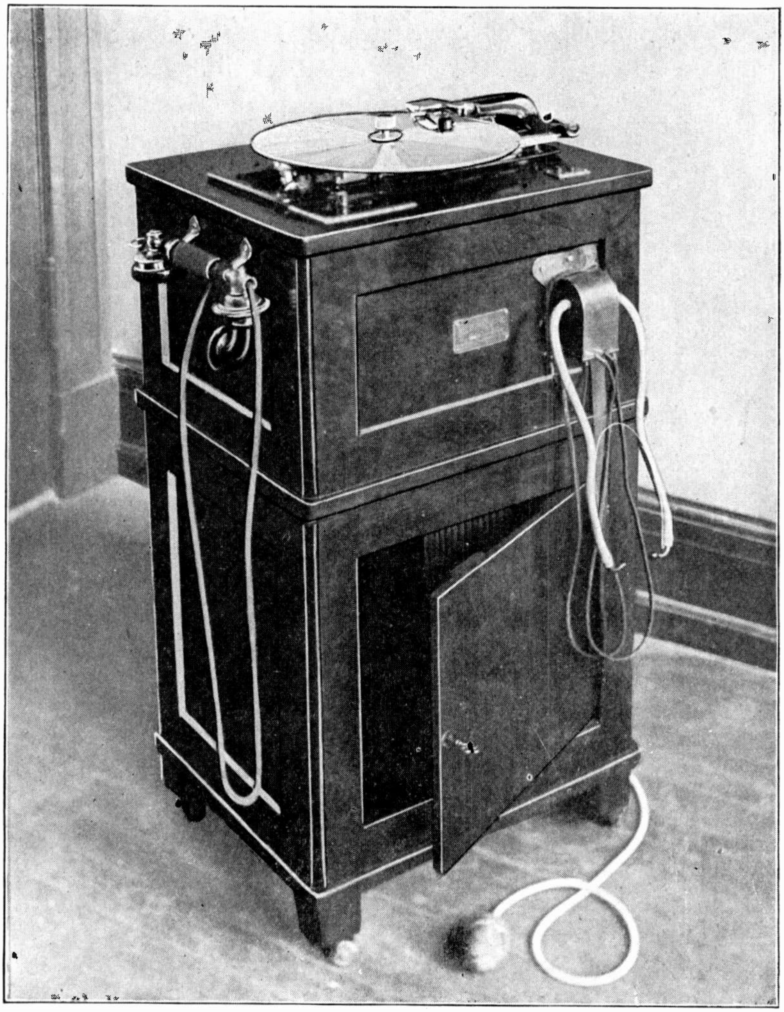


Fig. 4. Disc Type of Telegraphone, with Cabinet.

the same as in the first instance, and the sound reproduced in the telephone receiver exactly like the original.

The magnetic inscription will remain intact for many months if desired; or it may be effaced in an instant by passing a stronger magnet over the disc or the wire, whereupon the inequalities of the remanent magnetism are, as it were, planed off. This process may be accomplished while the disc or wire is being used for another record, and it causes no inconvenience or delay.

Wire and Disc Types of Machines. The first type of telegraphone completed for commercial use was exhibited in the Danish section at the Paris Exposition of 1900. In the model illustrated in Fig. 2, a steel wire .01 inch in diameter was wound spirally with 380 turns around a cylinder 15 inches in length and 5 inches in diameter. Fig. 3 represents a small electromagnet, full size, the axes of the two coils forming an acute angle so as to embrace the wire *f* at right angles to its length.

In Fig. 2, it will be observed, the electromagnet *E* is supported by a small carriage *c* which, at the end of its normal travel, will be arrested by a stop *T*; at this moment a screw *W* engages it and brings it back to its starting point. The normal duration of the travel of the carriage is 50 seconds; the electromagnet and the cylinder are set in motion by means of a 0.6 horse-power motor.

The range of this type was so limited that the inventor devised a modified form using a disc instead of the spirally wound wire. This is shown complete in Fig. 4. The principles of this telegraphone, however, remain unchanged, for in this instrument, as well as in those which preceded and have since followed it, each molecule of the steel surface is locally magnetized to an extent corresponding with the current variations set up by the voice in the speaking circuit.

In its mode of operation this instrument resembled the ordinary gramophone in appearance. The reproduction lacks the full loudness of the latter; but, on the other hand, the articulation is perfectly distinct, and entirely free from the nasal and scratching sounds emitted by the ordinary phonograph—which result is explained by the fact that there are no accessory vibrations set up by the friction of a stylus upon the wax as in the last-named instrument.

The steel disc which receives the message is about 5 inches in diameter, and is secured to a rotating plate by a milled nut. As the disc rotates, the magnet and coil, which are held in a carrier, are gradually moved toward the center of the disc, by a micrometer screw, the speed of rotation being increased as the magnet approaches the center of the disc, so that the latter rotates beneath the magnet with a constant linear velocity of about 1.5 feet per second. In place of the pair of magnets with two coils, which characterized the earlier machines, a straight magnet brought to a sharp point is employed; this can be lifted out and renewed, the coil being imbedded in an insulating composition and held in a small ebonite cylinder. The record can easily be erased by passing a bar magnet over the disc.

Still another type of instrument has been designed, in which a steel piano-wire is used. In this type, which is illustrated in Fig. 5,

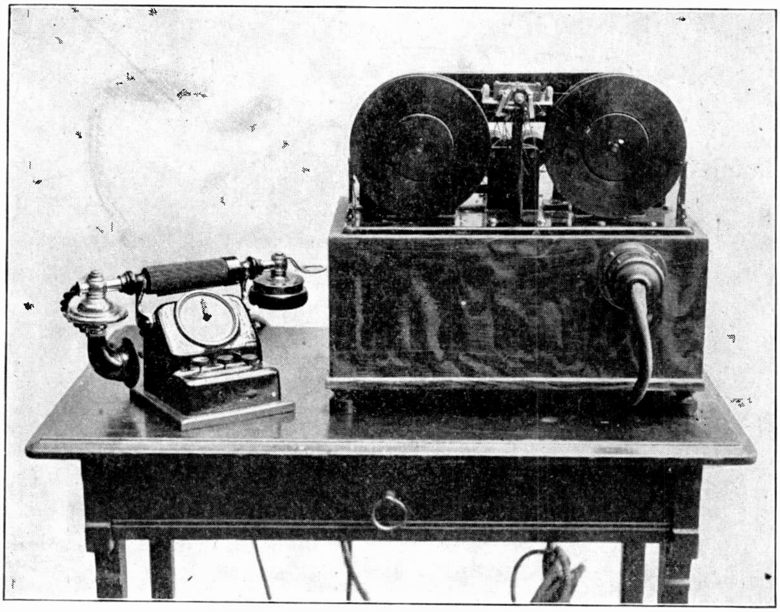


Fig. 5. Wire Type of Telegraphone. Indicator at left.

the wire is wound off one reel onto another between two magnet-poles, by means of an electric motor contained in the base of the instrument. The speed is about 10 feet per second, and enough wire is carried on the reels to make a record 7,000 words in length. Should only a part of the record be used at a time, the location of the used portion is noted by an indicator finger which rotates at a speed equal to that of the reels.

In this instrument three pairs of magnets and coils are employed, these being similar to the straight magnets used in the disc machine. Two of the pairs of magnets are placed horizontally, one on each side of the wire, which serve for erasing records and demagnetizing the wire, while the sounds are recorded by the middle pair of magnets. As the wire is reeled off, the magnet carrier travels forth and back, holding and guiding it on and off the reels.

By means of a push-button switch on the indicator, the motor can be reversed and one of the pairs of erasing magnets energized; if the wire is passing from right to left, the right-hand pair of magnets receives the current, and any previous record that may have been imposed on the wire is completely removed. A new record can then be made, and this can be heard by removing the transmitter and using in its stead the telephone receiver. The wire can be run back to any point, so that the instrument can be made to repeat any part of the record. The second pair of magnets serve the purpose of enabling the wire to record a message while it is being reeled off from right to left, or *vice versâ*; and the erasing magnets on the right or left are connected up—when the transmitter and the receiver are not in use—according to the position of the reversing switch for the motor. It is a singular fact that, although the turns of wire are packed closely together on the reels, no demagnetizing effect is to be observed, nor is the record in any way impaired. The new wire instrument leaves nothing to be desired, for the articulation is perfect.

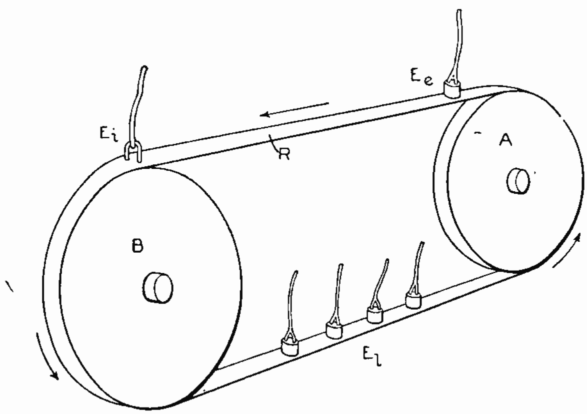
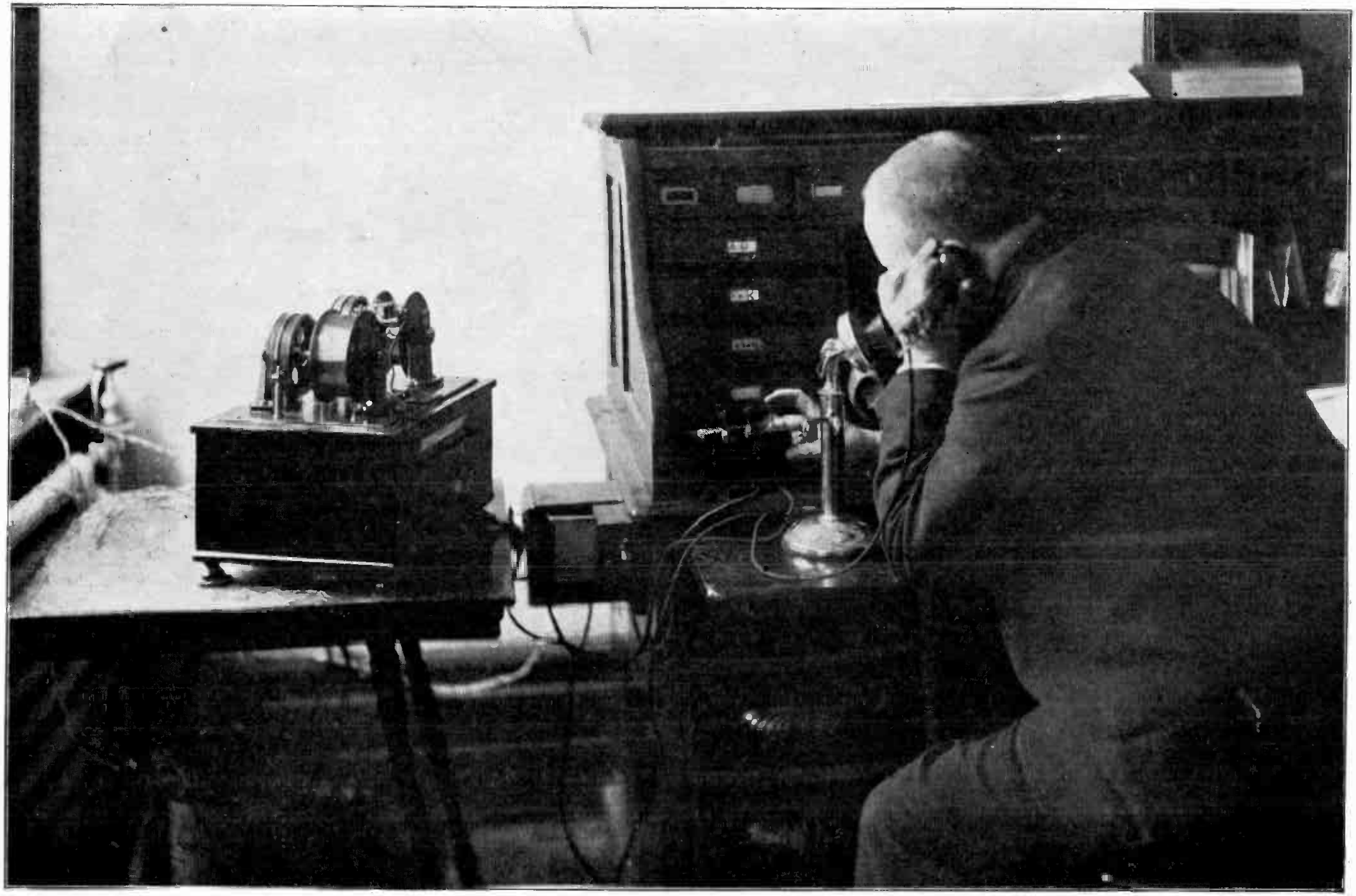


Fig. 6. Arrangement for Multiplex Transmission of Telegraphonic Messages.

Applications. The telegraphone has some very interesting applications. A most striking one is the simultaneous transmission by telephone of a speech, lecture, music, news of the day, etc., to any number of subscribers, up to as many as a thousand if desired. The arrangement for this purpose is shown in Fig. 6, where A and B are two parallel horizontal pulleys in alignment, over which runs an endless steel ribbon R; Ei and Ee are two electromagnets oppositely



TELEGRAPHONE USED IN COMBINATION WITH TELEPHONE
Connection with the telegraphone is made or broken by means of a push-button, as indicated, the instrument accurately recording all impulses passing over the telephone wire in either direction.

TYPIST TAKING DICTATION FROM TELEGRAPHONE disposed in symmetrical positions. The first of these magnets inscribes and the latter effaces the recorded sounds. Between the two are interposed any number of electromagnets E_1 connected with independent telephone circuits.

Another practical application of the telegraphone is found in its combination with the telephone. In this case it will record verbal communications even when the subscriber is absent, which can be repeated when he arrives. The apparatus employed for this purpose comprises a spring motor mechanism for rotating the revolving parts. An inverted U-shaped frame (Fig. 7) made of tubing, has its ends connected by an arm *e'* mounted to turn on a sprindle *c*. The upper end of the U has a bearing at the middle of the frame, by means of a short stud, which passes through the U and enters the frame *b*. The rotary motion is imparted to the U by the motor mechanism. A fixed ring 48, carrying two annular electrical contacts 49 on its upper surface, is arranged immediately below the arm *e'*; and the arm is provided with a spring pin adapted to be forced into connection with both of the electrical contacts for the purpose of electrically connecting them together.

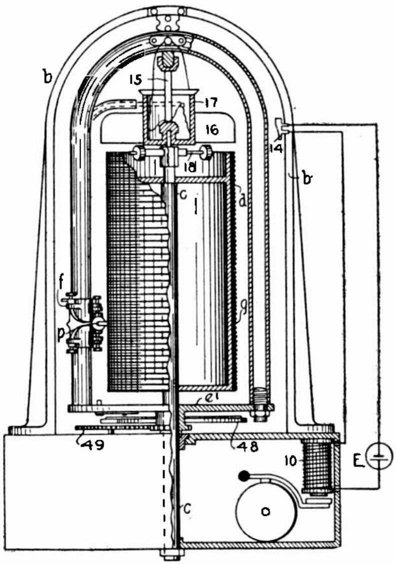


Fig. 7. Telephone Message Recorder.

On the surface of the cylinder *d* is wound the steel wire *g*. On one of the arms of the U is placed a sleeve *f* arranged to slide freely up and down on the U-frame; this sleeve has pivoted to it a magnet-holder, and this in turn is provided with a tail-piece, which is normally pressed upon by a spring tending to force the poles of the magnet out of contact with the wire *g*. When the U rotates, it carries the drum 17 with it; but, owing to the action of the brake 18 and the rings 16, there will be a certain amount of lagging on the part of the drum which will be permitted by the twisting of the wires 15. The brake is released by the electromagnet 10 in circuit with the battery *E* and a cut-out 14 attached to the frame *b*.

The operation of this apparatus in circuit with a telephone is as follows: Let it be assumed that speech or signals are being transmitted electrically over the circuit containing the magnet; that the sleeve is at the lower end of the U; and that the machine is started by closing the circuit of the magnet 10. Under these conditions, the U will immediately begin to rotate around the cylinder. When the speed is great enough, centrifugal force, acting on the weight *p*, will cause the core of the magnet to be thrown into contact with the wire *g*, when the sleeve will be caused to slide upward upon the U, because of the spiral winding of the wire on the cylinder. At the same time

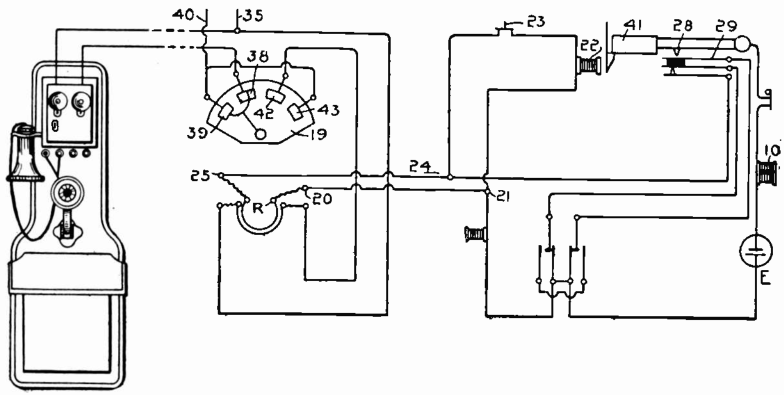


Fig. 8. Connections of the Telegraphone in a Telephone Circuit.

the undulations of current in the circuit of the magnet will vary the magnetic intensity of the latter, thus imparting to it a record.

The message may continue until the sleeve reaches the elevation of the cut-out, when the finger on the sleeve strikes the cut-out and swings it to one side, thus opening the circuit of the magnet 10.

To reproduce the message which has thus been recorded, it is only necessary to put a telephone receiver into circuit with the magnet, instead of the telephone transmitter, and start the machine again, when the sleeve will travel upon the U, and the poles of the magnet will traverse the wire *g*.

The connections of a telegraphone with a telephone are shown in Fig. 8. A switch 19 is provided, having four terminals 38, 39, 42, and 43. These terminals can be connected with each other in three different ways by means of a switch. In the position shown in the diagram, the two terminals 38 and 39 are connected together. This position establishes the circuit for the ordinary use of the telephone. The two conductors 35 and 40 constitute the outgoing and incoming lines.

If the switch lever is so adjusted as to connect the two terminals 38 and 42, the instrument can then be used as an ordinary telegraphone, and the transmitting telephone can then be used independently of it. This will be easily understood by following the course of the current when the terminals 38 and 42 are connected. When the subscriber lifts his receiver from the hook, a current will pass through the secondary of the induction coil *R*; the electromagnet 22 is thus excited, and the armature attracted, whereupon a weight 41 is released and falls. By this movement a connection is made between the contact block 28 and spring 29 whereby the local circuit of the battery *E* is closed through the electromagnet 10 and attracts an armature so that the spring motor is set in operation and the U (Fig. 7) rotated.

The sleeve, which has been resting upon the pin, begins to rise, and the connection between the contacts 49 (Fig. 7) is broken. The contact 23 consequently exists only for an instant, so that the circuit formed by 20, 21, 22, 23, 24, and 25 is open during the operation of the spring motor and mechanism.

Now, during the rise of the sleeve and while the electromagnet is in contact with the steel wire *g*, as previously described, the subscriber can speak into his transmitter, and the spirally-wound wire will accordingly be magnetized. The words thus recorded can now be transmitted over the line by using the third connection, that is, by throwing the switch 19 on the terminals 42 and 43.

As an illustration, if the message "The subscriber is not at home, but will return at 4 o'clock" is recorded on the steel wire, the subscriber at the opposite end of the line will hear this message through his receiver, and knows that in order to speak with the subscriber he must call up again at 4 o'clock. The advantages of such an arrangement are of course perfectly obvious.

Of equal value with the application above described, is the use of the telegraphone in recording telephonic conversations or contracts; and these can be made over commercial lines of any length by simply pressing a button, the operation in no way interfering with the use of the telephone. In this way the chief weakness of the telephone as a means of communication—in that it keeps no record—has been eliminated. Applications of this principle to telephonic train dispatching, so that the order of the dispatcher would be recorded at stations along the road, would be invaluable in checking errors and preventing catastrophes. Another feature that is likely to widen immensely the field of telephony, is the possibility of utilizing the telegraphone principle in a telephone repeater when trans-oceanic and trans-continental telephony shall have been realized.

The recording of Morse telegraphic signals has been easily and successfully accomplished; and the recording of signals peculiar to high-speed telegraph systems, such as the Delany, is not only possible but thoroughly practicable. Also, wireless signals and conversations can be recorded quite as easily as ordinary speech transmitted over a wire.

Next to its application in combination with the telephone, the most extensive use of the telegraphone will be for recording dictation. An instrument has been constructed which makes it possible for a person to dictate continuously for 30 minutes; and the typist is enabled afterward to hear and write the dictation without the slightest difficulty.

Compared with the commercial phonogragh now in use for this purpose, the telegraphone excels in that the person who is dictating and the typist who is writing can be isolated from the machine at telephonic distances; moreover, the record material can be used over and over again, as against repeatedly shaving the cylinders; and finally, the dictation may be long continued without having to stop to change cylinders.

The above are some of the obvious uses to which the telegraphone readily adapts itself. There are, however, many others, and when these have been fulfilled, this instrument will mean almost as much to the business man and to the world at large as does the telephone itself.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

POWER STATIONS.

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1. Why is it desirable to allow a reserve capacity when deciding upon the number of units to be installed?

2. Draw a diagram of the piping system for what you consider a first-class arrangement of the units.

3. Would you use a high or low-speed engine (*a*) in the case of a 200 K.W. generator; (*b*) in the case of a 300 K.W. generator; (*c*) in the case of a 1,000 K.W. generator?

4. When alternators are driven in parallel by gas engines, what arrangement is used to compensate for the variation in angular velocity?

5. Is it better to have a machine of very high efficiency at the expense of excessive cost, or to have it reasonable in price with lower efficiency?

6. What arrangement is now frequently used to avoid placing the different pieces of apparatus directly on the panels of a switchboard?

7. Explain the function of a substation and tell of what its equipment should consist.

8. What are the advantages of oil switches?

9. Explain why the capacity of a 6-phase rotary converter is greater than that of a single-phase, two-phase, or three-phase.

10. Which system of charging for power do you consider the fairest and best? Explain why.

11. Explain what is meant by a reverse-current relay, and give an example of its usefulness.

12. What factors must be taken into consideration when locating a rotary converter substation?

13. Discuss the requirements of boilers for central station operation.

14. What are the advantages and disadvantages of mechanical draft over natural draft?

15. Do you believe the gas engine will ever replace the steam engine as a prime mover? Give reasons.

16. Should an exciter be direct-connected to the shaft of an alternator or should it be belt-connected, and why?

17. How does the lightning arrester for alternating-current work differ from that for direct-current work?

18. If a dynamo is located immediately above the engine, show by sketch how you would arrange the belting.

19. Which type of circuit breaker do you consider better, the carbon break or the magnetic blow-out type?

20. Why is it desirable to keep careful station records and of what should such records consist?

21. In direct-current railway work what is the maximum distance over which power may be economically transmitted?

22. Draw a diagram of a system of piping in which provision may be easily made to allow for expansion of pipes, while on the other hand a damaged section may disable one boiler or one engine.

23. Describe the Curtis turbine and explain the method of governing the same.

24. What points should be taken into consideration when deciding upon the voltage to use for a given system?

25. Do you consider Niagara Falls a good location for the large power plants located there? Explain fully your reason for answer.

26. Upon what does the ratio of the voltage applied to the alternating-current side and that applied to the direct-current side of a rotary converter, depend?

27. In charging for power, why should a higher rate be demanded for that which is used during the peak hours?

28. In the case of a large lighting station, why is it desirable that there should also be a demand for power?

29. What are the advantages of cross connecting in the ring system of piping over the same system without cross connecting?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC TELEGRAPH.

PART I.

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1. Give examples of the different kinds of messages.

2. Wherein does the construction of the relay differ from that of the sounder? Why?

3. How many copies are made of train orders? Why?

4. How does the count of a government message differ from that of an ordinary message? Of a cable message?

5. How could signals be transmitted without a key?

6. (a) What is Code telegraphy? (b) Give a brief example.

7. In copying a message why is the destination placed on a line by itself?

8. (a) Give three points of difference between commercial and railway telegraphy. (b) What is the important feature of a railway operator's work?

9. In the switchboard, what is the only means of electrical connection between the bars and discs?

10. Name the apparatus used in a one-wire office.

11. What are the parts of the sounder?

12. (a) What are the six different classes in which the signals of the Morse code can be arranged? (b) Give examples.

13. What part of the relay does the work of a key for the local circuit?

14. (a) In the Auto-Alphabet instrument what determines the movement of the local points? (b) What care must be taken with regard to them?

15. (a) What are the elements of the Morse code? (b) Which is the time unit?

16. (a) How would you transform the local circuit into a learner's outfit?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC TELEGRAPH

PART II.

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1. What test can be applied to make sure that the armature of an electromagnet does not touch the core?

2. What is the essential feature of the Phonoplex? How are the signals produced?

3. What are the principal uses of the dynamo in telegraphy?

4. What two forms of apparatus are combined to form the quadruplex?

5. (*a*) What is static electricity? (*b*) How are the effects of the discharge on the duplex relay overcome?

6. If the transmitters are open in the Stearns duplex, admitting a small proportion of each battery to line, how can the effect on the relay be overcome?

7. What is the only means of electrical connection in the switchboard between the rows of discs and the strips?

8. How is the home relay in the Stearns duplex made unresponsive to the home battery?

9. What is the function of the transmitter in the quadruplex as compared with that of the pole changer?

10. What is the rule for determining the polarities in a core around which a current is passing?

11. What would be the resistance of six four-ohm sounders in series? In multiple?

12. What is a rheostat and what part does it play in the duplex?

13. How could a test of the short and long end of the quad battery be made without a meter?

14 What is meant by a differential relay?

15. In a polar duplex when like and equal poles are to the main line, how are the relays operated?

16. What feature of every form of magnet is illustrated by the action of the magnetic needle?

17. From which relay is the static eliminated in balancing the quadruplex?

18. Wherein does the movement of the armature of a polar differ from that of a common relay?

19. To set up an electric current in a closed conductor in a magnetic field what is necessary?

20. After the grounding at each terminal what is the next step in the balancing of a polar duplex? How is the ohmic balance obtained? How the static?

21. How is the dynamo made to suit the current supply to lines of different lengths?

22. Of what method of winding is the extra magnet in the Weiny-Phillips relay an illustration?

23. What is the common side of a quad? What is the function of the repeating sounder therein?

24. What are the advantages of the closed- over the open-circuit system?

25. What is the rule for the adjustment of the pole changer in either form?

26. What is the common aim in the construction of every form of automatic single line repeater?

REVIEW QUESTIONS

ON THE SUBJECT OF

WIRELESS TELEGRAPHY

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1. What is meant by *conduction systems* and *induction systems* of wireless telegraphy?

2. Draw a diagram showing how a river may be used in place of telegraph lines.

3. What is meant by *radiotelegraphy?*

4. What is meant by the ether? By radiant energy?

5. What is meant by an oscillatory discharge, and what kind of waves are produced by oscillatory discharges?

6. What is meant by resonance? Sympathetic vibration?

7. What is meant by two circuits being "in tune"? What two characteristics of a circuit determine its frequency?

8. What is the characteristic of a closed oscillatory circuit? An open one? Draw two types.

9. Which are the longer ether waves—light or Hertzian waves? What is their velocity?

10. What is meant by the Righi oscillator? By the Branley coherer?

11. What effect do electric waves have upon powders and metal filings?

12. Explain what is meant by *inductive receiving antennae.* Draw a diagram.

13. What is an oscillation transformer? Should the open oscillatory circuit of the antennae and the closed oscillatory circuit be "in tune"? Why?

14. What is meant by selective signaling?

15. Name two different pieces of apparatus which may be used to charge the aërial.

16. Why cannot an ordinary Morse telegraph key be used for long-distance work in radiotelegraphy?

17. Draw a diagram of the Thomson method of creating oscillations from a direct current.

18. Draw out three methods of constructing aërials. Why is it necessary to elevate an antennae?

19. Describe a coherer.

20. What is a cymometer?

21. How many telegraphic codes are there in general use today? Name them, and tell where, and for what class of business they are commonly used.

22. Describe briefly the Marconi "X stopper" and tell what form of detector has met with success in the Marconi system.

23. Describe briefly the Fessenden system.

24. Describe the characteristics of the Telefunken system.

25. What is meant by a continuous train of undamped oscillations?

26. Name and describe briefly three systems of radiotelegraphy.

27. In what field of operation has radiotelegraphy been the most useful?

REVIEW QUESTIONS

ON THE SUBJECT OF

WIRELESS TELEPHONY

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1. What is a Bell radiophone?

2. What is the effect of light on selenium? What is the photophone?

3. Describe the method of causing a direct-current arc to emit musical and other sounds.

4. What is the principal difficulty encountered in applying Hertzian waves to the problem of wireless telephony?

5. Why could not a common telephone transmitter be efficiently used as an interrupter for an induction coil in the production of high-frequency oscillations?

6. What is meant by intermittent wave trains?

7. Describe the method of superimposing a telephone current upon a constantly operating source of oscillations of high intermittency.

8. Name two different methods of creating sustained oscillations.

9. Draw a diagram of the Fessenden method of transmitting radiotelephonically by use of the high-frequency alternator.

10. Name the two most common methods of producing sustained oscillations.

11. Draw three different ways of connecting a telephone carbon transmitter to the oscillatory circuits in order to vary the energy of the radiation therefrom in accordance with the voice current.

12. What detectors may be used for radiotelephony? May a coherer be used?

13. Describe the action of the Fessenden "heterodyne" receiver.

14. Tell why two-way transmission in radiotelephony is not as simple of accomplishment as in ordinary wire telephony.

15. Name seven different radiotelephonic systems.

16. Describe the Telefunken system.

17. Describe briefly the Ruhmer system.

18. Describe the characteristics of the Poulsen system.

19. How does the Marjorana system differ from others?

20. What method of producing sustained oscillations does Fessenden employ?

21. Describe the DeForest system briefly.

22. What detector does DeForest use?

23. Give the general features of the Collins system.

24. Why is the clearness of articulation better in radiotelephony than in wire telephony over long lines and cables?

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