ELECTRIC RAILWAYS.

(PART 1.)

INTRODUCTORY.

1. Electricity is now generally conceded to be the most economical agent for the transmission of power for the operation of street railways. It has shown itself superior to horses, compressed air, or cable, both as regards flexibility and cheapness of operation. Cable roads are advantageous in some very hilly localities, but for ordinary traffic even those cable roads already in use are being gradually converted into electric lines. Compressed air has been used in a few cases, notably in mining work, but for general purposes electricity now has the field practically to itself.

METHODS OF SUPPLYING CURRENT.

2. Several different methods may be used for supplying electrical energy to the cars, and the one to be used in any given case is generally fixed by local conditions. The methods that may be used for supplying current to the motors may be classed as follows:

a. By means of an overhead conductor or pair of conductors connected to the car by an under-running contact. This is known as the **overhead-trolley system.**

b. By means of underground conductors run in a conduit and connected with the car by means of a contact plow passing up through a slot. This is usually called the **open-conduit system,** or **slot system.**

c. By means of electromagnetic switching devices that make connection between the car and a conductor situated underground. This is often called the **electromagnetic system.** The conduit in which the conductor is run is, in this case, closed; hence, the name **closed-conduit system** is sometimes applied to this method of operation.

d. By means of a third rail run alongside of, or between, the car rails, contact being made with the third rail by means of a sliding shoe attached to the car. This is known as the **third-rail system.**

e. By means of storage batteries carried on the car. In this case no conductors between the power station and cars are necessary.

3. The overhead-trolley system is the method of operation used in the greatest number of cases, because it is the cheapest to install.

The slot system is used in a number of large cities where overhead wires are not allowed and where the traffic is heavy enough to warrant the expense. It is used, for example, in New York, Washington, Paris, etc., but it is altogether too expensive for the ordinary run of electric railroads.

The closed-conduit system has not yet come into commercial use to any extent. It is expensive to install and is comparatively complicated.

The third-rail method is extensively used for cross-country or suburban lines where the traffic is heavy and where a more substantial construction than the overhead trolley is necessary. It is also used for elevated roads, but is not permissible for surface roads in cities because of the liability of persons coming into contact with the third rail.

Cars operated by storage batteries have never been used very extensively, although they are used in special cases where overhead wires will not be permitted and where the traffic is not heavy enough to warrant the expense of putting down a conduit system. Each car is provided with storage cells, arranged so that they may be easily replaced by fresh ones when they become discharged.

The above methods cover those that, at present, are available for the supply of electrical energy to the motors. We will at this point take up very briefly each of these methods in turn in order to see how the current is supplied in each case. The details by which the methods are carried out will be treated more fully later on, when the subjects of track and line construction are taken up.

4. Overhead-Trolley System.—The general arrangement of the overhead-trolley system is shown in Fig. 1. The positive terminal of the dynamo connects, through the switchboard, to the overhead-trolley wire. The negative terminal connects to the rail. The path of the current is indicated by the arrows. The current is carried to the moving car by means of the under-running trolley wheel, and all the cars on a given system are operated in parallel.

This arrangement, simple as it may seem, was not arrived at before considerable experimenting had been done. In the early electric roads two trolley wires were used, and the track was not employed as one side of the circuit. This scheme is still used in a few places, notably in Cincinnati. Also, on the first roads installed, the trolley wheel ran on top of the wire; but this method of collecting the current was soon superseded by the under-running trolley.

It should also be noted that the cars are operated in parallel. This is true of all systems of distribution where current is supplied to the cars from a central station. All street-railway systems are, therefore, operated at approximately constant potential, i. e., constant or nearly constant pressure is maintained between the trolley wire and the track by means of the dynamos in the station. Whenever connection is made from the trolley to the track through the motors, a current flows and the car is propelled. Each car is independent of the others and takes an amount of current proportional to the power required to drive it.

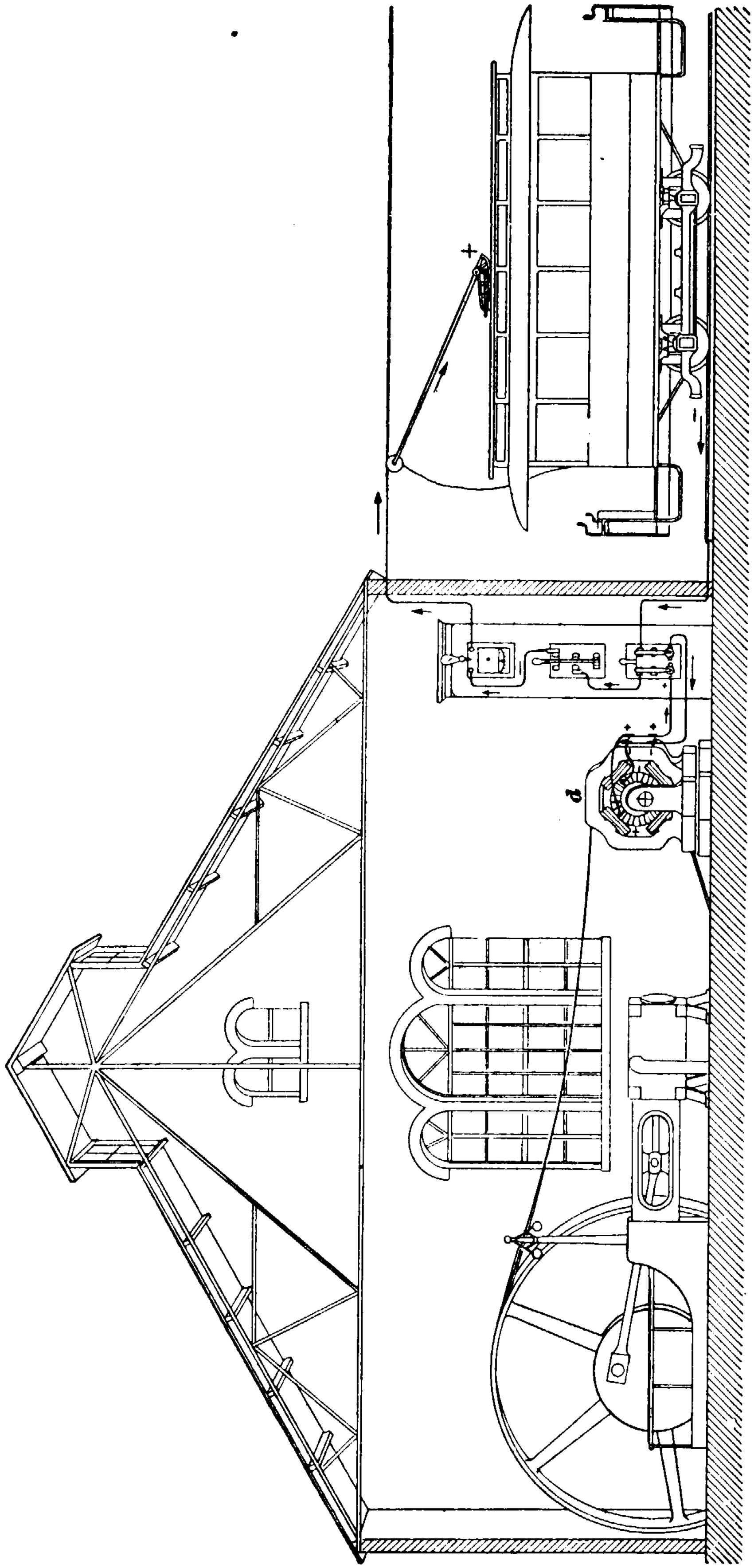

FIG. 1.

5. Schemes have been brought forward from time to time for operating street cars in series, but none of these have ever been put into everyday operation, and it is not worth while devoting space to them.

The arrangement shown in Fig. 1 may of course be modified. For example, except on very small roads, the trolley wire is not sufficiently large to carry the current necessary; so **feeders,** or heavy cables, are run to the station instead of carrying back the trolley wire itself. Also, return cables are sometimes used in connection with the track.

6. The Open-Conduit System.—The open-conduit system has not been put into very extensive use, because the expense of construction is very high compared to the overhead-trolley system. Where it has been installed, it has been a matter of compulsion, the city authorities refusing to allow the stringing of trolley wires and feeders above the surface. Two bare conductors are used, and these are held

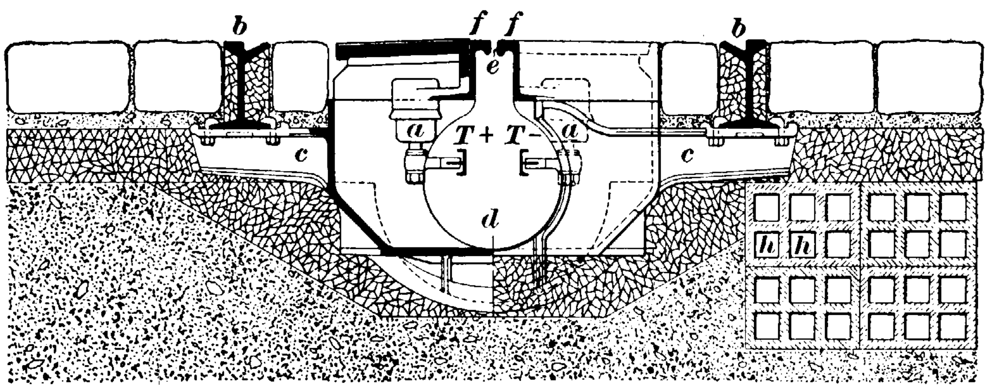

FIG. 2.

on insulating supports in the upper part of a channel or conduit, built in the roadway between the car rails, in the same way as a conduit for a cable road. In fact, in several instances the old cable conduit has been fitted up for use as a conduit for railway conductors.

The general method of construction, illustrated in Fig. 2, shows the style of conduit used by the Metropolitan Street Railway Company, New York. The rails are supported on cast-iron yokes in place of the ordinary ties, and the conduit extending between these yokes is made of concrete. Concrete is filled in around a sheet-iron form, which is afterwards removed, thus leaving a continuous tube or duct of concrete between the yokes.

In Fig. 2, $T+$ and $T-$ are the conductor rails, which connect through feeders run in the underground ducts *h*, *h*. The track is not used for one side of the circuit, as in the overhead-trolley system. The **T**-shaped conductor rails are attached to insulators *a*, which are, in turn, suspended from the slot rails *f*. Handhole covers are provided at the insulators in order to give access to the insulators and conductor rails.

Fig. 3 shows an enlarged view of a portion of a yoke, showing the method of mounting the conductor rail. The feeders that supply the conductors are buried along the side of the track in terra-cotta or cement-lined tubes. To obviate the necessity of having to raise the paving, more tubes than are necessary to fill the requirements of the present service are put down, so that in the future, when it may be necessary to lay more feeders, there is a place ready for them. To facilitate the installation of new feeders or the repair of old ones, manholes are provided every 400 feet.

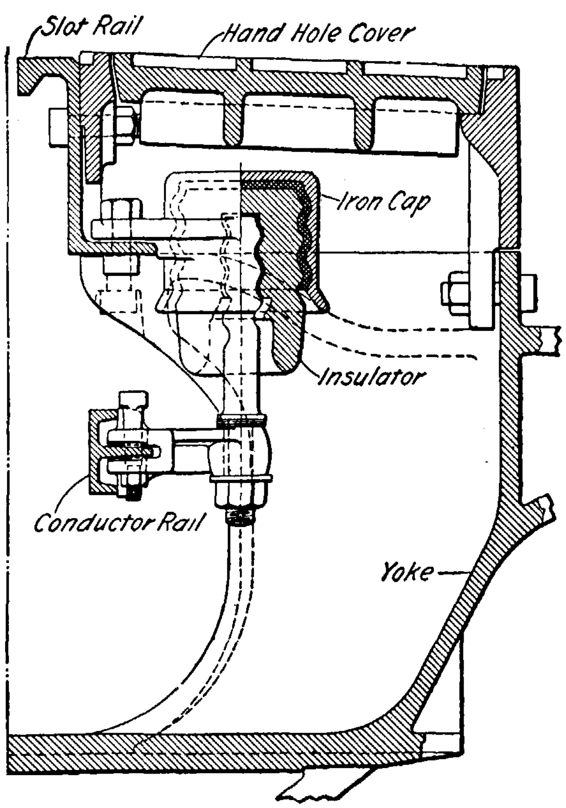

FIG. 3.

Mud accumulates in the main conduit very fast, and if not promptly removed gives trouble. At intervals of 200 feet there are manholes in the main conduit; at the bottom of the manhole is a 6-inch drain pipe leading to the sewer. The main conduit must be cleaned about once a month in the summer time, and perhaps oftener than this during the winter. By means of special scrapers, the mud is drawn into the manhole and is then lifted out and carted away.

7. The conductor rails are not continuous, but are divided into sections about a mile long, and each section is fed by its own feeder from the power house. There is no electrical connection between these feeders, so that the road is cut up into insulated sections, and trouble on one section is not so liable to interfere with the traffic on the others. Each feeder has its own switch and circuit-breaker. In case a ground occurs on one section, the circuit-breaker in the feeder that feeds that section flies out; the attendant in charge at the power house can tell exactly on what stretch of track the trouble is, and notifies the emergency crew to that effect, if it is necessary. Splitting the road into sections supplied by individual feeders has also the advantage that in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause heavy overloads in the power house, because the switchboard attendant has every section of the road under his control and can compel the cars to start up, one section at a time.

8. Fig. 4 shows the style of plow used by the Metropolitan Company. The plow is provided with two iron contact shoes *s*, *s* that press sidewise against the conductor rails *a*, *a* under the action of the flat springs *b*, *b'*. Connection is made to the car by means of cables *c*, *c'*, which connect to the shoes by means of flat insulated strips passing through the flat part of the plow and connecting to the shoes by means of flexible cables *d*. The plow passes between the slot rails *e*, *e* and is securely fastened to a crosshead underneath the car. This crosshead is mounted so that it can move from one side of the car to the

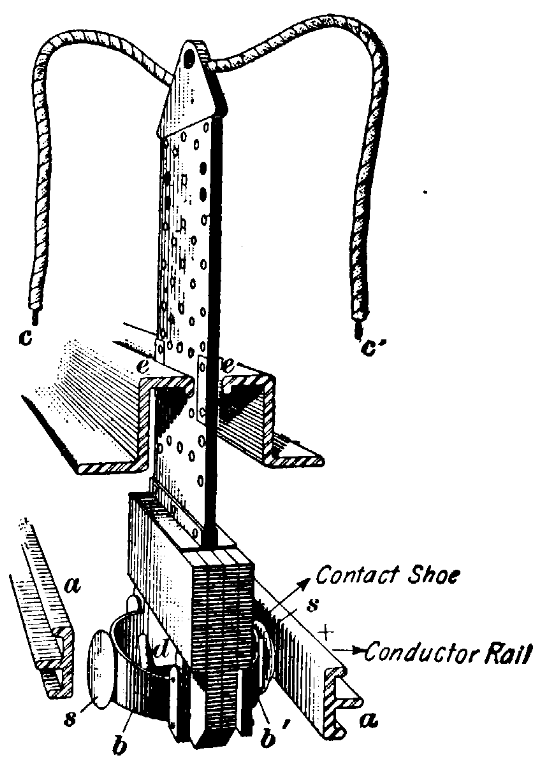

FIG. 4.

other, in order that the plow can change its position relative to the car when necessary.

9. As stated above, the open-conduit construction is very expensive. It is necessary that the yokes be well designed to resist the pressure of the earth (which is packed down by the heavy traffic) and the very heavy pressure in cold climates, due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been used for this purpose, the latter, perhaps, being the most used. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates or it may be constructed on the sides of concrete alone; in some cases the metal yokes have been replaced by concrete, but the best practice is to use heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of the conduit and the character of the wagon traffic expected.

10. Electromagnetic System.—In this system the regular rails constitute one side of the circuit, and the other side, by means of which the circuit through the car is completed, consists of an insulated third rail split into a number of short sections. These rail sections are supplied with current by successively connecting them to a line conductor run alongside the track.

Fig. 5 will give an idea as to the method of operation. G is the dynamo in the power house. The negative pole of G is connected to the rails t, t_1, as in the ordinary overhead-trolley system. The main conductor m, which is well insulated, is connected to the + side of the generator, and connection is made from it to the sectional rail r r r through switches s, s. The switch is enclosed in a rectangular box located between the middle rail and one of the track rails and is provided with a non-magnetic cover hermetically sealed to prevent water from entering. Directly under this cover and connected to the switch lever are two armatures that are alternately attracted by magnets on the car, one at the front and the other at the rear end, so that any section has current in it only so long as the car is passing over it. For collecting the current a sliding shoe is used.

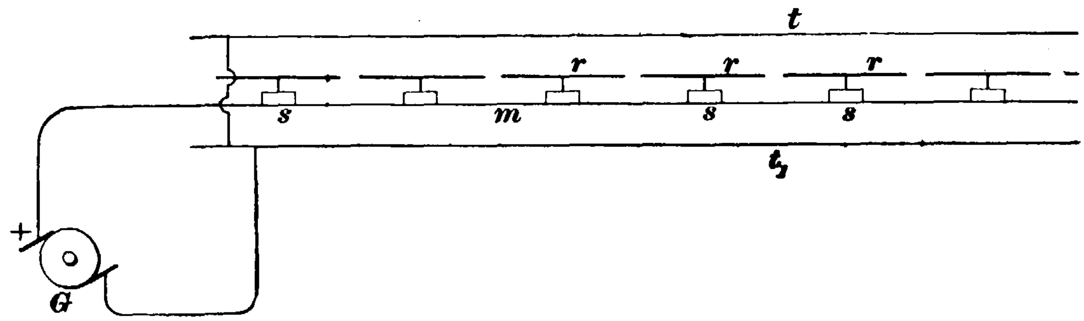

FIG. 5.

A number of other electromagnetic systems have been invented, but so far they have not been adopted very extensively. They have some good points, but these are outweighed considerably by the number of automatic switching arrangements necessary.

11. Third-Rail System.—It is common to hear the third-rail system spoken of as being something comparatively new in the electric-railway line. As a matter of fact, it was one of the very earliest methods used for supplying current to electric cars. One of the first electric roads put into practical operation was at Portrush, Ireland, and was operated on the third-rail system. Of late years the third rail is coming into favor, especially for heavy work. For interurban and elevated-railroad work something more substantial than a trolley wire is required, because the speeds are high and the current to be handled is large. In this system a third rail is mounted, usually at one side of the track, and contact is made with it by means of a sliding shoe carried on the car. The rail is mounted on special insulators and is generally raised somewhat above the other rails. The regular track rails constitute the return circuit. At grade crossings the third rail is omitted, as the momentum of the car is sufficient to carry it over. Of course, the third rail can only be used where there will be no liability of persons coming into contact with it, but for the class of work mentioned above it gives very satisfactory service and its use is rapidly extending. For example, elevated trains in New York, Chicago, and Boston are operated by means of the third rail.

12. Fig. 6 shows a third-rail construction used on the Nantasket Beach and East Weymouth Road. The third rail *r* is, in this case, of special shape, though ordinary **T** rails are often used. The rail shown is made in 30-foot lengths and weighs 93 pounds to the yard. It is shown supported on posts *a*, which are treated with creosote.

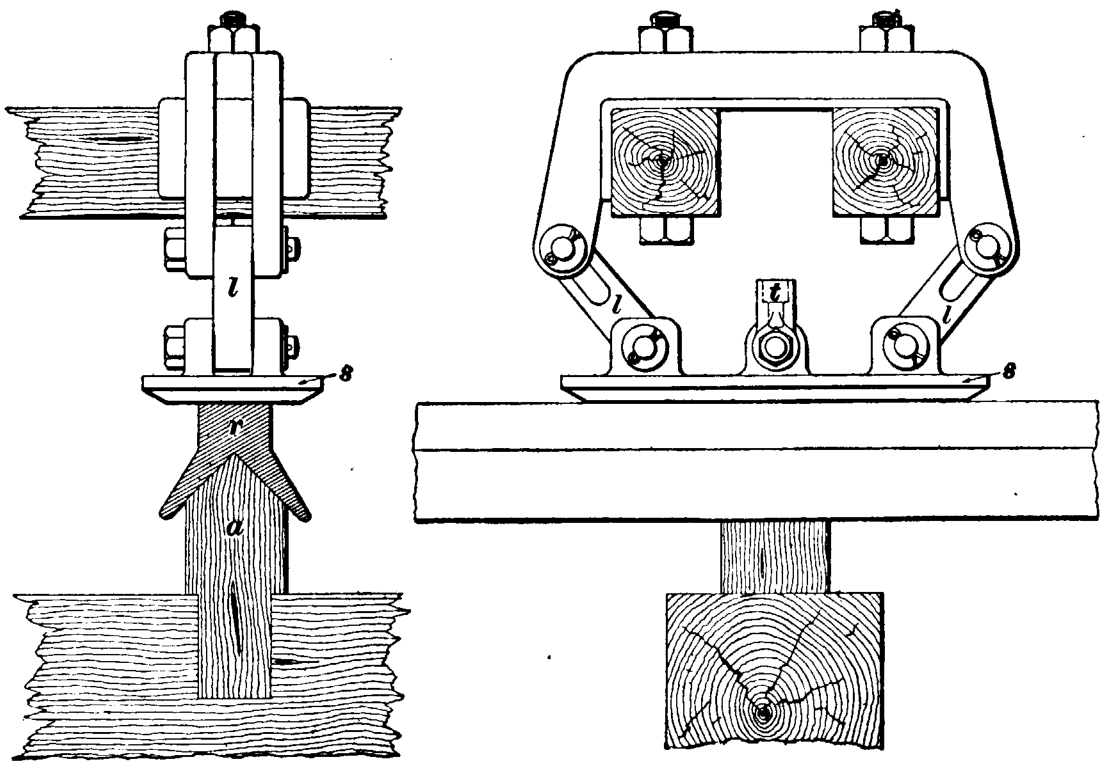

FIG. 6.

Electrical continuity between the rails is secured by fastening them together by copper **bonds.** In the later styles of third-rail equipment, which will be described more fully when track construction is taken up, porcelain or granite insulators are used for supporting the rail.

The shoe *s*, Fig. 6, slides on the rail and conveys the current to the car by means of a cable fastened to the terminal *t*. The slotted links *l* allow the shoe to play vertically, so as to follow inequalities in the track. There are two contact shoes and frames to each car on this particular road and they are placed 33 feet apart, so that at road crossings the third rail may be omitted and the momentum of the moving car depended on to carry it over. When the width of the road is less than 33 feet, there is no break.

CURRENT SUPPLY.

13. Direct Current vs. Alternating.—Electric street cars are operated almost wholly by means of direct current. This means that the current actually supplied to the motors is direct, although the current generated in the central power station may be alternating. The reason for this is that the alternating-current motor has not as yet proved as reliable for this class of work as has the direct-current motor. It must be remembered, however, that alternating-current induction motors have been making rapid advances, and some railroads in Europe are at present operated by them. It is not at all improbable that in the future alternating-current motors will be more used on electric cars, but the practice so far in the United States has been to convert the alternating current into direct current by means of rotary transformers and to use direct-current motors on the cars rather than to supply the alternating current directly to induction motors.

Induction motors, if properly designed, can be made to give a strong starting effort, which is one thing very necessary in a street-car motor. Three-phase motors have been used on what few roads have been equipped with alternating-current apparatus. The three-phase system requires three wires, and as the track answers for one of them, two overhead wires are needed. This complicates the overhead construction and has been brought forward as one argument against alternating-current motors for street-railway work.

While alternating-current motors themselves have not made very great headway in street-railway work, the use of alternating current at high pressure as a means of transmitting the power has come into much favor, because it allows the cars to be operated from a central station situated some distance from the point where the power is used.

14. Voltage.—The pressure at which current is supplied to the cars is limited by considerations of safety. It would, of course, be desirable to use a high pressure, because this would mean a small current for a given amount of power, and small feeders would be sufficient. However, a pressure is soon reached where it would be decidedly dangerous to life, and for this reason the working voltage on street railways has been fixed at about 500 volts. On some suburban lines the pressure runs over 600 volts, and again in other places it will be found much lower than 500 volts, on account of an excessive drop in the line. Railway motors and other apparatus are designed for 500 volts, and the pressure on the line should be maintained at or near this point. Low voltage requires a correspondingly large current to supply enough power to operate the cars at the required speed; hence, if the pressure is lower than normal, heating of the motors is liable to result.

THE POWER HOUSE.

15. In considering electric railways in detail, it will be convenient to divide the subject into three parts, as follows: (*a*) the *power house;* (*b*) the *line and track;* (*c*) the *car equipment.*

We will take these up in their order, beginning with the power house and the apparatus with which it should be equipped.

LOCATION OF POWER HOUSE.

16. General Considerations.—The **power house,** or **power station,** as the name implies, is the place or source of supply of power for running the cars, and it should be situated as near the center of the system as possible. By the center of the system is meant the center of the load or traffic. In other words, since wires must be used to convey the power from the power house out to the point where it is to be used, a part of the power generated will be lost in these wires, because they always have some resistance. If the line wires are not of sufficient size, they will cause a loss of power that will make itself very strongly felt in its effect on the speed that the cars make and also upon the amount of heat that the motors develop. Laying other things aside for the present, the amount of loss in one of these supply wires depends on its length and on the amount of current that it may be called on to carry. Hence, it follows that the center of the load may not be the geographical center of the system. As a matter of fact, these two centers very seldom fall in the same place. The true load center is located in the same way that the center of gravity of any system of bodies is located. The geographical center, as we have called it, depends on the number of miles of track and how these are disposed; the other depends on how the load is distributed.

In Fig. 7, *A B* represents 10 miles of track free from grades and sharp curves, and on this track a certain number of cars *1*, *2*, *3*, *4*, etc., of about the same weight and equipped with motors of the same size, run at regular intervals. It is easily seen that the geographical center, or center of mileage, is in this case located at *P*, a point midway between the two ends, so that there are 5 miles of track on each side of it. It can also be shown that the load center in this particular case is also at *P*; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power, and since the loads are evenly distributed throughout the length of track, they can be represented by circles of the same size, as shown in Fig. 7. Here, there are seven loads on each side of the center line passing through *P*, and if each circle is supposed to represent a weight of a certain number of pounds, and the center of gravity of the system of weights is to be determined, it will be found to fall on the center line *c l*. So also, if all cars, except the two end ones, are supposed to stand still or to coast along with the power off, and the two end ones start at the same time, the same load will be drawn to both ends of the line, and point *P* will still be the center of load and will therefore mark the spot where the power house should stand.

It is not intended to convey the idea that the load, even on such a simple layout, will always be as evenly distributed as has been supposed in this ideal case, for, as a matter of fact, such a condition will be the exception rather than the rule. Suppose *A* to be in the outskirts of a large city and

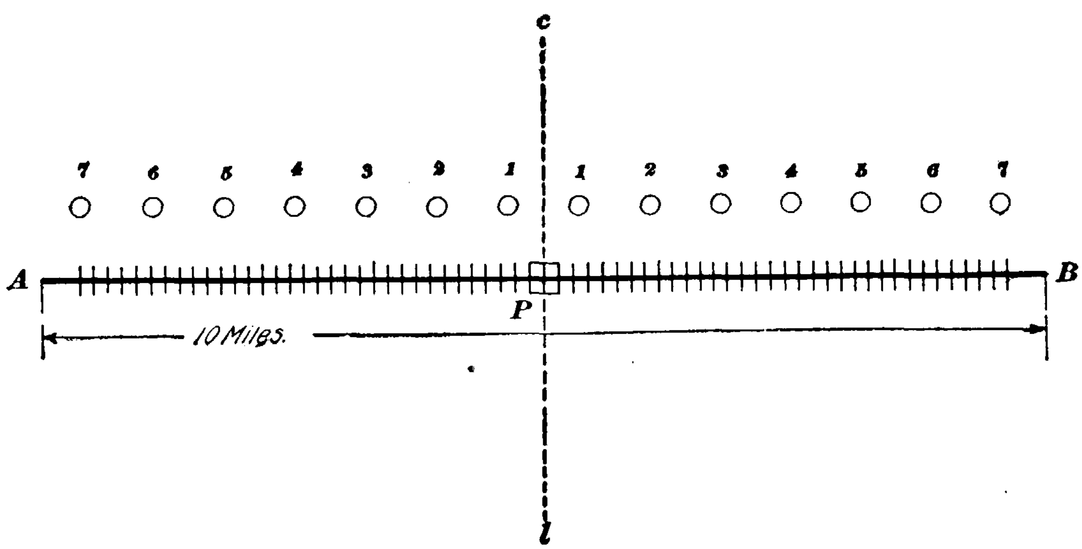

FIG. 7.

suppose *B* to be down-town, where the people must all go to business; then, in the mornings and evenings, when the crowd is going to and coming from work, the load leans a little towards the *B* end of the line, but during the rest of the day it is uniformly distributed. To alter conditions, suppose that from the middle of the line to *B* there is an up grade. It is easily seen that those cars that are ascending the grade will be called on to do more work than those on the level and on the down grade, so that the final effect will be to shift the ideal site for the station towards *B*. In this case, the mileage center remains the same, but the load center is changed.

17. Influence of Future Extensions. — In locating the site for the power house, future extension and increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly. Long experience and computation have proved that it is not profitable, with the ordinary direct-current, 500-volt transmission, to operate cars at points more than 7 miles from the house, because, in order to keep the line loss down to a reasonable amount, the feeders must be so large that their cost becomes excessive.

Suppose, for example, as shown in Fig. 8, that the full-line section *A B* represents the stretch of track put down at the first building of the road and that, in accordance with the demand at that time, the power house was put at *P*, the center of load for *A B*, which is supposed to be level.

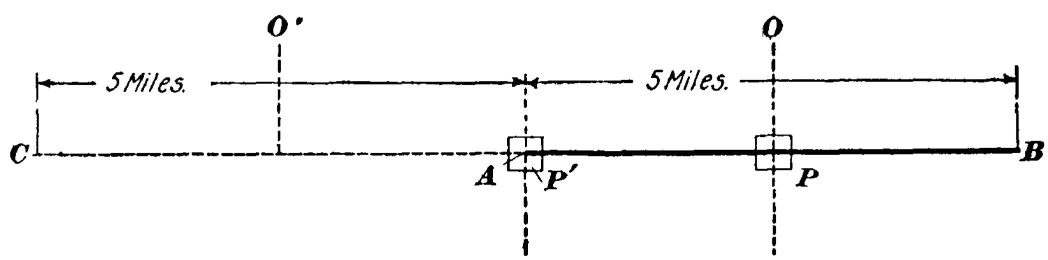

FIG. 8.

Now, suppose that the road has been extended out to a point *C*, so that $A\,B = A\,C$. If we further assume that the district through which *A C* runs becomes built up, it will be only a matter of time when the travel density will be as great on the new stretch of track as it is on the old, in which case, assuming the different load units to be fairly evenly distributed throughout the distance *B C*, the proper place for the power house would be at point *P'*, midway between *B* and *C*, the two ends of the road.

For, suppose $B\,C = 10$ miles; then will $A\,C = A\,B = 5$ miles, and $P\,A = P\,B = 2\frac{1}{2}$ miles. As long as *A B* constituted this whole road, the power house situated at *P* was at the center of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other.

As soon, however, as the extension $A\ C$ is started, it is not a difficult matter to see that a power house at P would be $2\frac{1}{2}$ miles from the B end of the road and $C\ A + A\ P$ or $7\frac{1}{2}$ miles from the C end of the road. Under such a condition, should all the cars, through trouble of some sort, become congested at the far end of the line, the line loss incidental to the great distance and to the large current caused by trying to start all the cars at once would seriously delay getting the cars on their time again. By moving the station to A, matters will be righted.

If the station were put at A in the first place, it would, of course, be at one end of the line as long as $A\ B$ were the whole road, and would not therefore be at the center of load; but if the extension $A\ C$ is only a matter of time, it will be far the better plan to put up with the line loss due to want of balance on the shorter line, locate the station at A, and be prepared to get the best results when the extension is in operation and the number of cars, therefore, greater.

18. If, in deciding the best location for the power house, it were only a matter of fixing the probable center of load, the problem would be a comparatively easy one. In many cases, as we shall see later, the problem is an easy one; but in other cases it is made very hard and almost impossible to solve, except approximately, by the fact that several other considerations have a great influence on the location. The prospective center of the load might be located under conditions that point with absolute certainty, from a purely electrical point of view, to the desirability of a certain place as a site for the power house; at the same time, this place might prove to be so situated that every pound of coal to be burned under the boilers would have to be hauled to the power house. Again, the center of load might fall at a place where it would be difficult to get water for the boilers and the condensers; such a place would, of course, be out of the question. Finally, the question of land comes in. It would be a very poor move to build a power house in a part of a city where a city building would probably pay as good dividends as many well-managed roads. In such a case, then, there must be a careful comparison made between what an improved building on the proposed site would pay and what the annual power loss would be as a result of selecting some other power-house site electrically not as good as the center of load. It can be seen, then, that the final selection of a site for the power house must, in some cases, be a compromise between conflicting conditions. Load conditions will point to one site; good, cheap water and plenty of it will point to another site; the coal bunkers should be arranged so that the coal may be passed directly to them from the boat, or at least from a coal car that can be run alongside of them by means of a siding or a spur from the main line. Very often a point can be selected to fulfil all these conditions; but just as often it is necessary to select a compromise that will be fair to all of them. It is not hard to see, therefore, that the proper solution of the problem may require a great deal of study, work, and experience.

DETERMINING THE LOAD CENTER.

19. In illustrating the method used for obtaining the load center, we do not intend to deal with roads that require the equalization of the advantages incidental to the above limiting conditions. Such a consideration involves details that are beyond the scope of this Course; also, the conditions vary so widely that it is almost impossible to lay down any rules that can be applied with safety in particular cases. We shall assume, therefore, that in all cases the layout of the road is along the lines shown in the diagrams, and that, as there are no limitations imposed by coal, water, and property requirements, the selection of a site for the power house resolves itself to the determination of the load center. To find the load center, the engineer must have a knowledge of the traversed district. With this knowledge in hand, the problem can be treated graphically, and it amounts to the same thing as finding the center of gravity of a system of bodies. As an example, in Fig. 9, W and W' are two bodies whose centers are 11 feet apart, and each of which, for example, weighs 20 pounds. Since, in this case,

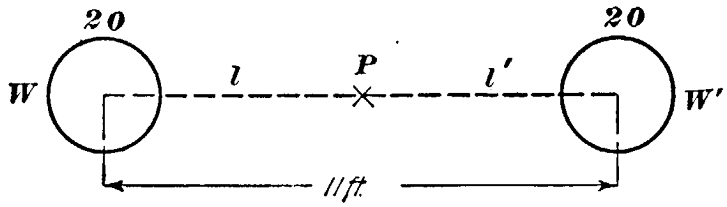

FIG. 9.

the two weights are equal, the distance of their centers from the center of gravity P must also be equal, in order that $W \times l$ shall equal $W' \times l'$. The center of gravity is, therefore, midway between the two bodies, and the system, as a unit, acts the same as if a weight of 40 pounds were fixed at P.

20. Finding the center of gravity of W and W', in Fig. 9, amounts to about the same thing as finding the center of load or the location of the power house in Figs. 7 and 8. Take Fig. 8, for example. The load is supposed to be uniform over the two sections $A\,B$ and $A\,C$. Let $A\,B = A\,C = 5$ miles. Suppose that there are 10 cars on each section and that each car averages a load of 20 horsepower. Each section will, then, carry a load of 200 horsepower, and all this load can, in each case, be supposed to be concentrated at points O and O' in the center of the respective sections. These centers, will, therefore, be $\frac{1}{2}\,A\,B + \frac{1}{2}\,A\,C$ miles apart; that is, 5 miles apart. The two loads of 200 horsepower concentrated at points O and O' in Fig. 8 correspond to the two weights of 20 pounds in Fig. 9, and if we treat the 200 horsepower as weights and find their center of gravity, that center of gravity will be the center of load or the correct location for the power house. Since the two loads or weights are equal, the center of gravity or load must, as in Fig. 8, be at point A, midway between O and O'

21. Take another case. Suppose that there are three weights (Fig. 10): $W = 40$ pounds; $W' = 50$ pounds; and $W'' = 10$ pounds; further, suppose that the distance from W to W' is 6 miles; from W to W'', 7 miles; and from W' to W'', 4 miles. Where is the center of gravity situated? The way to ascertain this is to first find the center of gravity between any two of the weights, and then, supposing the sum of the two weights to be situated at this point, to find the center of gravity between this and the third weight. Let us first find the center of gravity between weights $W = 40$ and $W'' = 10$, where the distance

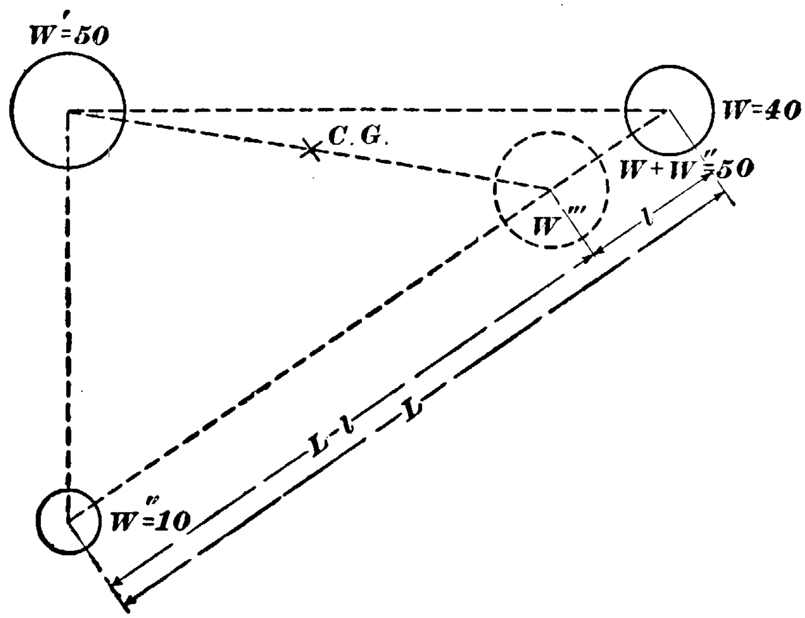

FIG. 10.

between centers is 7 miles. This distance of 7 miles must be divided into 2 parts, such that $W \times l = W'' \times l''$, where l and l'' are the distances of W and W'', respectively, from the center of gravity for these two bodies. To solve the problem graphically, lay out the plan to scale on paper; that is, represent the 7 miles by 7 inches, and so on, and let a difference in the sizes of the circles represent the difference in weights, as shown in the diagram. Call L the distance from W to W'', and let the distance from W to the center of gravity, to be found, be represented by l; then the distance of W'' from the center of gravity will be represented by the difference, or $L - l$; and since $W \times l = W'' \times (L - l)$, we have $W l = W'' L - W'' l$, or $W'' L$

$= Wl + W''l$, and $l = \frac{W''L}{W + W''}$. Substituting for the weights and for L the numerical values given, we have $l = \frac{10 \times 7}{50}$ $= 1\frac{2}{5}$ miles, or inches on the paper, as the distance of the weight W from the required center of gravity. Since the total distance $L = 7$, the distance from the center of gravity to the center of W'' must be $L - l$, or $5\frac{3}{5}$ miles. Now take a pair of dividers and a scale and on the line joining the centers of W and W'' locate a point that is $1\frac{2}{5}$ inches from the center of W; this is the center of gravity sought, and it will be $5\frac{3}{5}$ inches from the center of W''.

It is now in order to find the center of gravity between the large dotted circle, representing the combined weights (50 pounds) of W and W'', situated at their center of gravity, and W', which is also 50 pounds. Call the dotted circle W'''; since the weights W''' and W' are the same, it is evident that their center of gravity is midway between them on the line joining their centers, so that it is only necessary to take a pair of dividers and bisect this line in order to find the center of gravity of W' and W''', and hence of the whole system.

22. Conclusion.—The general rule, then, for locating the center of load or the best position for the power house is as follows: Divide the line of the proposed road into several sections; with a knowledge of the service to be rendered on the road, assign a certain load in horsepower, kilowatts, or amperes to each section. Lay out, to scale, a plan of the road on paper. Suppose that the load assigned to each section is concentrated at its middle point; there will then be as many of these points as there are sections, and each point will bear a number designating the load on the section of which that point is the center. The numbers can be considered as representing weights and the center of gravity of all of them determined as shown in the preceding articles. The center of gravity so found will be the load center that marks the best location for the power house.

STATION EQUIPMENT.

ENGINES AND BOILERS.

23. The type of engine most suitable for use in a railway power station depends on the size of road, that is, on the number of cars in regular operation. The closest speed regulation under widely varying loads is obtained with high-speed, automatic cut-off engines, and this class is, therefore, particularly suitable for very small roads. It is easily seen that such a road furnishes extremes of load at very short intervals of time, for if there is only one car in service, the station load, except for the friction losses, field exciting currents, and a few lamps, is zero when that one car is at rest or on a down grade, and is at a maximum when the car is starting on a steep up grade. When a second car is added to the service, the chances are less that such extreme variations will occur, and the more cars that there are in service, the nearer will the load approach something like a constant normal value. The more cars that there are, the less probable is it that all of them will be taking no power at the same time, so that the station is under a certain amount of load all the time. It does not matter how large the output of the station may be, the load fluctuations will be sudden and violent; but still, if the station is large, a given variation in the load is a smaller percentage of the total load and is, therefore, not felt as much on the generating and regulating devices. On stations of any size, the load, as a rule, has several high values during a day of 24 hours. The two greatest values occur in the morning, when the people are going to work, and at night, when they are coming from work. Around noon and on towards 2 o'clock, when the shoppers begin to move, the load is again above normal. The time of occurrence of maximum and minimum loads depends a great deal on local conditions; it is different on different roads, and sometimes on the same road it differs from day to day.

24. As stated above, high-speed, automatic cut-off engines are suitable for small roads where the load fluctuates rapidly. Mine-haulage plants, for example, are usually of this class. On most roads, however, it has become the practice to use slow-speed engines of the Corliss type, especially when the load is moderately large. In moderate sized stations, where space is not scarce, belted dynamos are used. These machines are usually driven directly from the flywheel of the engine. The station is made up of a number of units, each consisting of an engine belted to its dynamo. Countershafts are not now used to any extent in railway plants, the tendency being rather to split the station into a number of distinct units. When the units are very large, and also in case space is limited, direct-connected engines and dynamos are to be preferred. In some of the largest stations, vertical Corliss engines are used, and these are generally of the compound or triple-expansion type. The first cost of a direct-connected dynamo is greater than a belted one for the same output, but the saving in space and absence of belts go far to compensate for this and account for the rapidly increasing use of direct-connected units. When this class of machinery was first used, trouble was caused in some instances by magnetic leakage. This magnetized the shaft and bearings in such a way as to cause a lateral thrust on the shaft and give rise to hot bearings. In the later styles of machines, the design in this respect has been so improved that this trouble has been done away with to a large extent.

25. On most large direct-connected railway sets using slow-speed engines, a heavy flywheel is provided. The fact that the steam and electric units are rigidly connected and that the dynamo armature has great inertia complicate the conditions in case of an excessive overload due to a short circuit or other abnormal condition on the line, because, in the case of a short circuit, there is nothing to finally relieve the strain on the dynamo should the circuit-breaker fail to open the circuit at once. With a belted unit, an excessive load causes the belt to slip—a clutch will act in the same way—so that a belt or clutch acts as a kind of mechanical safety device to cushion the shock that the dynamo gets in case of a sudden overload. On the whole, however, everything is in favor of the direct connection, due precautions being taken to see that the circuit-breaker is set at a safe load and that it is in a condition to work at the load for which it is set. Generally speaking, very heavy flywheels should be used on engines for running street railways. The whole engine construction must be of a very substantial character, because it must be remembered that the load is much more liable to severe fluctuations than with electric lighting or ordinary power transmission work.

26. Size of Engines.—The size of engines and dynamos for different station units will, of course, depend largely on the total output of the plant. In general, it is not a good plan to have a large number of small units, but on the other hand, it is not economical to have only one or two large units, because under such circumstances, even if only one of these units were operated, it would be run on a load much below its capacity, and hence would operate at a low efficiency. The units should be arranged so that they may be kept loaded up to nearly their capacity. In most of the recent plants the units are of the same size and type, because a small stock of repair parts is then sufficient for the station. It is always an advantage to have the machinery in a station uniform, even if it is necessary to sacrifice a few advantages in other directions to attain this end.

27. Steam Piping.—What has been said with regard to steam piping for electric plants in general applies also to street-railway power houses. In some cases, duplicate steam piping is used to avoid shut-downs in case a break occurs, but in some of the largest and most modern power stations, duplicate piping is not used. The single piping is installed in a very substantial manner and with a large margin of safety, so that the chances of a breakdown in the piping system are very small. Duplicate piping is complicated and expensive, and for this reason there appears to be a tendency to revert to the single piping and to install this in such a way that it will be able to meet all demands made on it.

28. Condensers.—The engines should, when possible, be run in connection with condensers. These condense the exhaust steam, instead of allowing it to exhaust into the air, and thereby create a partial vacuum behind the piston of the engine. This increases the effective pressure on the piston and results in a saving in fuel. Jet condensers are most commonly used in power plants. In this type the exhaust steam is condensed by being brought into contact with a jet of cold water. This of course heats the water, and if provision is not made for a fresh supply of cold water, the warm water must be cooled before it can be used over again. The warm water is pumped out by means of the air pump, which also carries out any air that may be mixed with the water.

This air pump, in large stations, is usually independently driven by an engine of its own. For smaller stations, it is generally arranged like a direct-acting steam pump, or else it is operated from the steam engine itself. In some instances, the air pumps and boiler-feed pumps are driven by electric motors.

29. Cooling Towers.—In many places it is not possible to get sufficient water to operate condensers without going to great expense. This is usually the case where the plant cannot be situated on a water front and where all the water used must be bought. Where the water supply is limited, **cooling towers** are used to cool the condenser water and enable it to be used over again. These are made in a number of different ways, but in most cases the water is cooled by allowing it to drop from the top of a tower in a thin sheet so that it will be exposed to the air. Sometimes the water is allowed to fall through a current of air set up by fans; in other cases, requiring a longer tower than the former, no artificial draft is used. In either case, the comparatively rapid evaporation of the water results in its being cooled enough so that it can be used over again.

30. Boilers.—The boilers used in railway plants are generally either of the return-tubular or water-tube type. In the former, the hot gases pass through flues or tubes surrounded by water, while in the latter the water is in tubes and the gases pass around them. The ordinary return-tubular boiler is low in first cost, is easy to keep in repair, and has given excellent service in many places. The water-tube type is, however, very largely used, because of its safety and because it can make steam very rapidly if occasion demands it. Both types of boiler have their good and bad points, and both are extensively used. Where space is scarce, vertical boilers may be used to advantage.

31. Fuel Economizers.—In places where coal is comparatively expensive fuel economizers are used. These are intended to heat the feedwater before it passes into the boilers by making use of the heat contained in the hot gases which would otherwise pass up the stack. The feedwater is circulated through a large number of tubes, which are so arranged that the hot furnace gases pass around them on their way from the boilers to the stack. By this means, the feedwater may be heated to a temperature much higher than when an ordinary exhaust steam heater is used.

32. Conveyers.—For large stations, coal and ash conveyers should be provided. The coal conveyer is usually arranged to take coal directly from the car or barge and carry it to the coal bunkers above the boilers. The ash conveyer runs along under the ash-pits, so that, as the ashes are dumped down, they are carried out. In small plants, conveyers are not, as a rule, provided, at least not on an elaborate scale, because the amount of coal and ashes to be handled is comparatively small. In large stations, mechanical stokers are used for firing the boilers.

33. Example of Station.—Fig. 11 shows a cross-section of the power station of the South Side Elevated Railway Company, of Chicago, and will serve as a typical example of a modern power house of comparatively large capacity. The station, like nearly all power houses, consists of two large

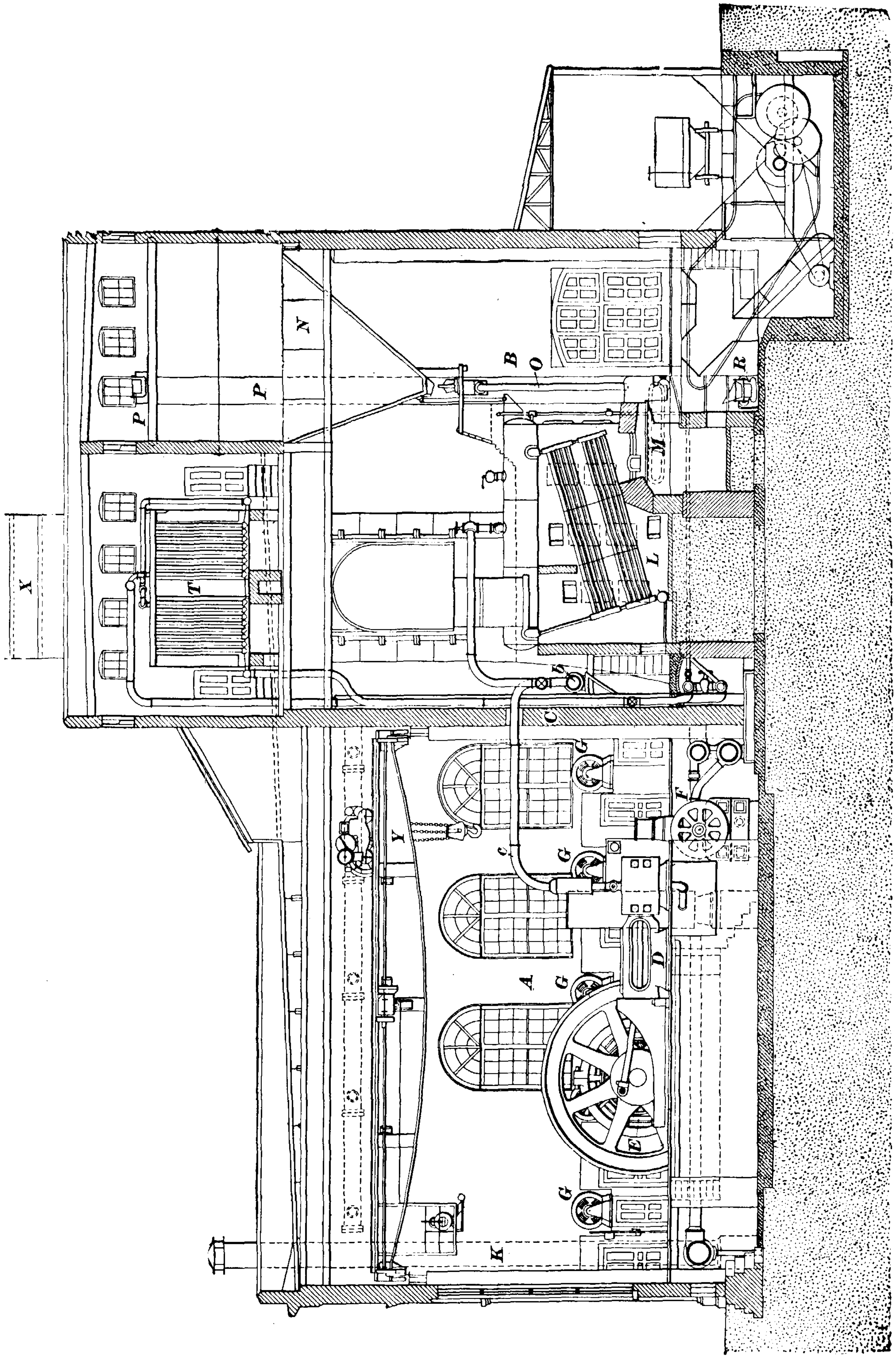

FIG. 11.

rooms—the engine room *A* and the boiler room *B*—separated by a brick fire-wall *C*. Each of the engines *D* is of the cross-compound Corliss type and is coupled directly to its dynamo *E*. These engines are especially heavy and are rated at 1,200 horsepower each; they can, however, develop 2,000 horsepower if necessary. The generators *E* are of 800 kilowatts capacity and have 12 poles. They also will stand a heavy overload without damage. The exhaust steam from the engines passes to an independently driven jet condenser *F*, and the condensing water is cooled by means of a cooling tower placed outside the building. The cooling tower is divided into sections, and each section is provided with fans driven by the motors *G*, which are inside the building. If necessary, the engines may be allowed to exhaust into the air through *K*. The boilers *L* are of the water-tube type and are fed by chain-grate stokers *M*. Coal is supplied to the boilers from the bunkers *N* through the chutes *O*. The bunkers have a storage capacity of 1,000 tons, and are filled by means of the conveyer *P*, which carries a continuous chain of buckets and passes up the side of the plant, across over the bunkers, along under the ash-pits, and up the other side of the plant, thus forming a continuous chain. The coal is delivered to this conveyer by a second conveyer *R*, which takes it from the car. A fuel economizer *T* is used, so that the hot gases on their way to the stack *X* may be used to heat the feedwater. All the steam pipes from the boilers run to the main pipe *b*, from which run the steam pipes *c* to the different engines. The dynamo room is provided with an overhead electric traveling crane *Y*, to be used in placing or repairing the engines and dynamos.

ELECTRICAL EQUIPMENT OF STATION.

34. The electrical equipment of a power house may be conveniently divided into two parts: the part that generates the power and the part that is used to control its distribution to the point where it is used. The first part includes