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

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the **dynamos,** or **generators,** as the dynamos are commonly termed when used for railway work. The second part includes the **switchboard,** with all its devices for controlling and measuring the current sent out on the line.

DYNAMOS FOR RAILWAY WORK.

35. The dynamos used for railway work are in general the same as those used for lighting or power distribution.

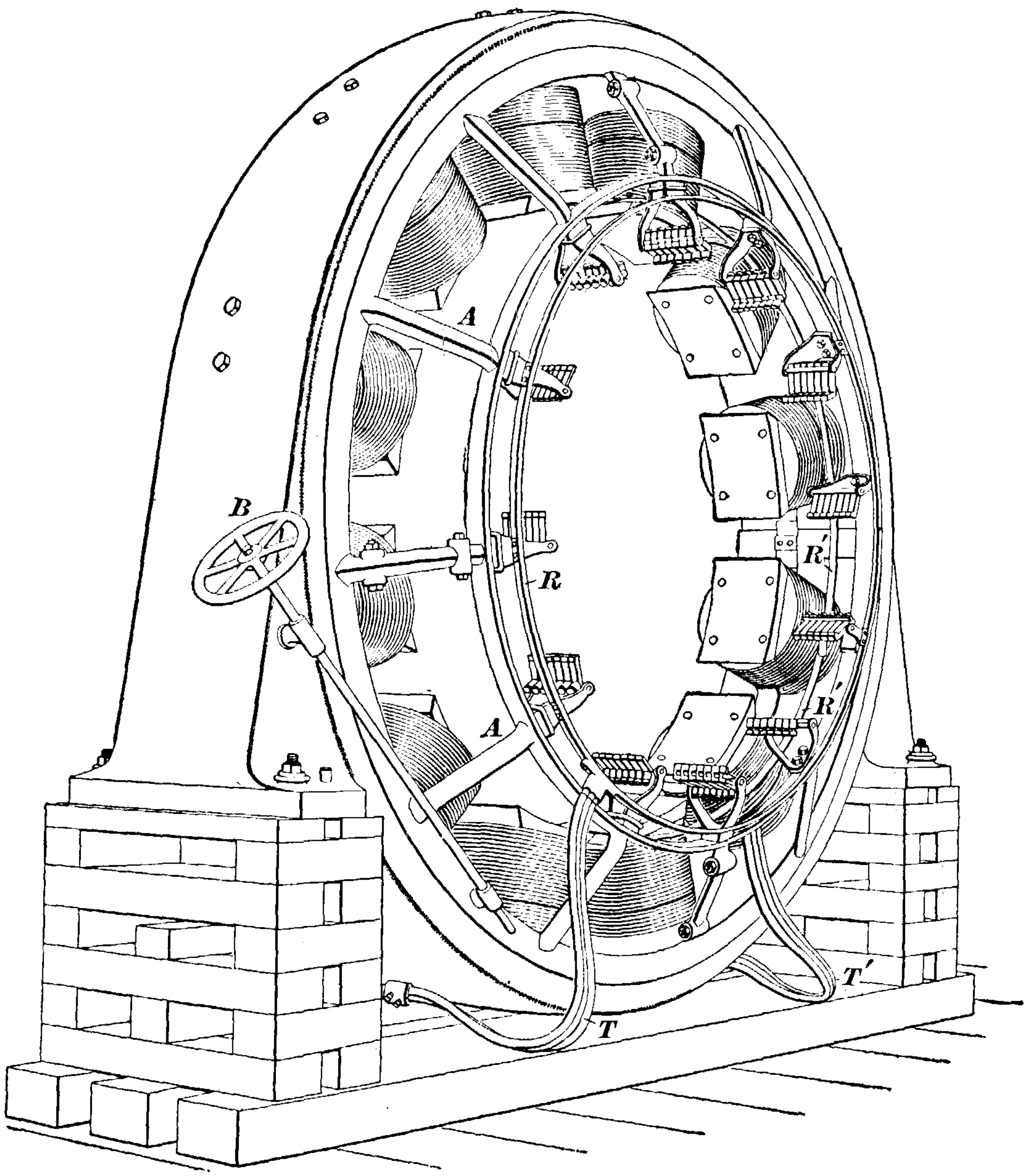

FIG. 12.

They should be exceptionally well built, so as to withstand the sudden strains thrown on them, and should be capable

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of handling a considerable overload for short periods without excessive sparking or heating. Whether direct- or alternating-current generators are used will depend on the system of distribution adopted. When the power must be carried for long distances, the best plan is to install high-pressure alternating-current generators to supply current to substations located at various points on the system. In these substations the alternating current is changed to direct current by passing it through rotary converters.

In the great majority of cases, however, direct-current generators are used, and these supply current at a pressure of from 500 to 600 volts directly to the feeding system.

36. Direct-Current Generators.—These machines may be either direct-connected or belt-driven. The former type is now installed in most new stations, especially where the units are fairly large. Fig. 12 shows the field frame, with the field coils in place, for a typical 650-kilowatt direct-connected generator. Compound-wound dynamos are used almost exclusively for railway work, and the reasons for their use will be seen later. Each of the field spools is provided with two windings, a series and a shunt, as indicated in the figure. The brush holders, of which there are as many sets as there are poles, are carried by the frame *A A*, which is fitted into the field casting so that it may be revolved through a small arc by turning the wheel *B*, thus allowing the brushes to be adjusted to the point on the commutator that gives the least amount of sparking. Alternate sets of brushes connect to the rings *R*, *R'*, and to these rings the main armature cables *T*, *T'* are attached.

37. Fig. 13 (*a*) and (*b*) gives two views of a typical armature for a direct-driven railway generator. It will be noticed that the construction is very substantial and that the commutator *A* is of ample proportions. The conductors on the armature are in the shape of rectangular copper bars, which are sunk into slots in the periphery of the iron core. The ends of these bars, seen projecting at *a*, *a* on the commutator end, are connected to the commutator bars by the

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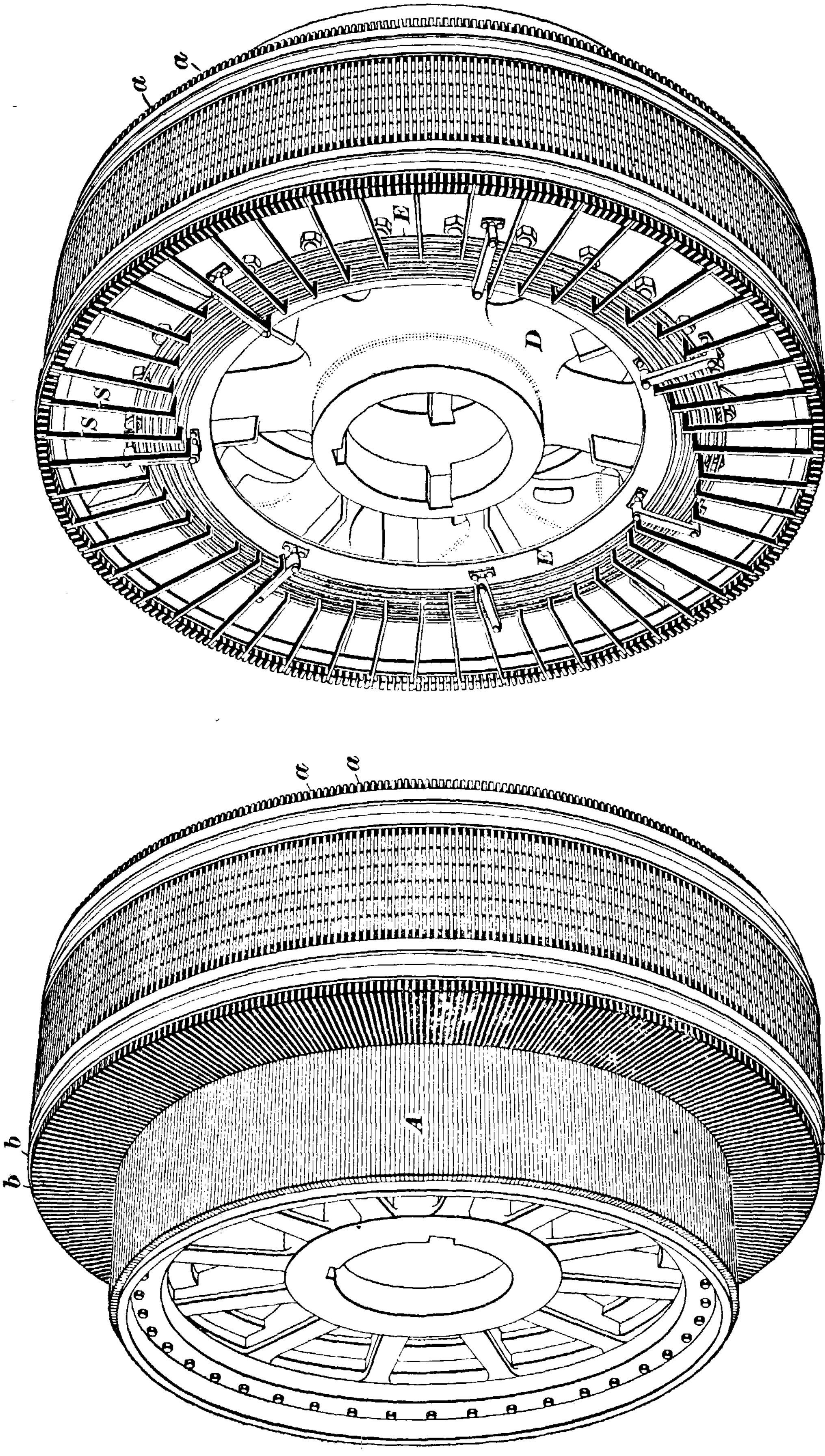

(b)

(a)

FIG. 13.

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strips *b*, *b*. The laminated iron core on which the conductors are carried is mounted on the heavy spider *D*, which is keyed to the engine shaft. In these large multipolar armatures there are a number of paths in parallel; i. e., when the current enters at one side, it has the choice of several parallel paths through the armature. If the E. M. F.'s generated in these armature sections, as they might be called, were all exactly equal, the currents flowing in the different parts of the armature would also be equal. It is very difficult to have the magnetic field exactly equal all around the armature, because some of the poles may be slightly closer to the armature than are others, due to wear in the bearings or other causes. This causes the E. M. F.'s in some parts of the armature to overbalance those in other parts, giving rise to local currents that may cause the armature to heat considerably.

In order to balance the currents in the various parts of the armature, **equalizing rings,** shown at *E*, *E*, Fig. 13 (*b*), are sometimes used. These rings, to some extent, are similar to the equalizing connection used between dynamos running in parallel. They are mounted on the back of the armature and connect points in the winding that are normally at equal potential. If one section becomes overloaded, current flows through the equalizing rings to the other sections and the load is thus equalized. All armatures are not provided with these rings, and if the armature is correctly centered in the field, it works very well without them. The winding of the armature is the same in either case, the rings being simply connected by pieces *S*, *S* to the projecting ends of the bars at the back.

38. Fig. 14 shows a Westinghouse six-pole street-railway generator arranged for belt driving. The smaller units are, as a rule, belt-connected, and this is especially the case where there are no particular restrictions in regard to floor space. The dynamo shown in Fig. 14 has a substantial bearing on both sides of the pulley, so that there is none of the hang-over effect that is to be found on some generators

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of the belted type. It is true that a belted generator is not as efficient commercially as a direct-connected generator of the same type and output, but for units up to 300 horsepower the difference can as a rule be neglected. The amount of power lost in friction on a belted generator depends to a great extent on the judgment of the man that

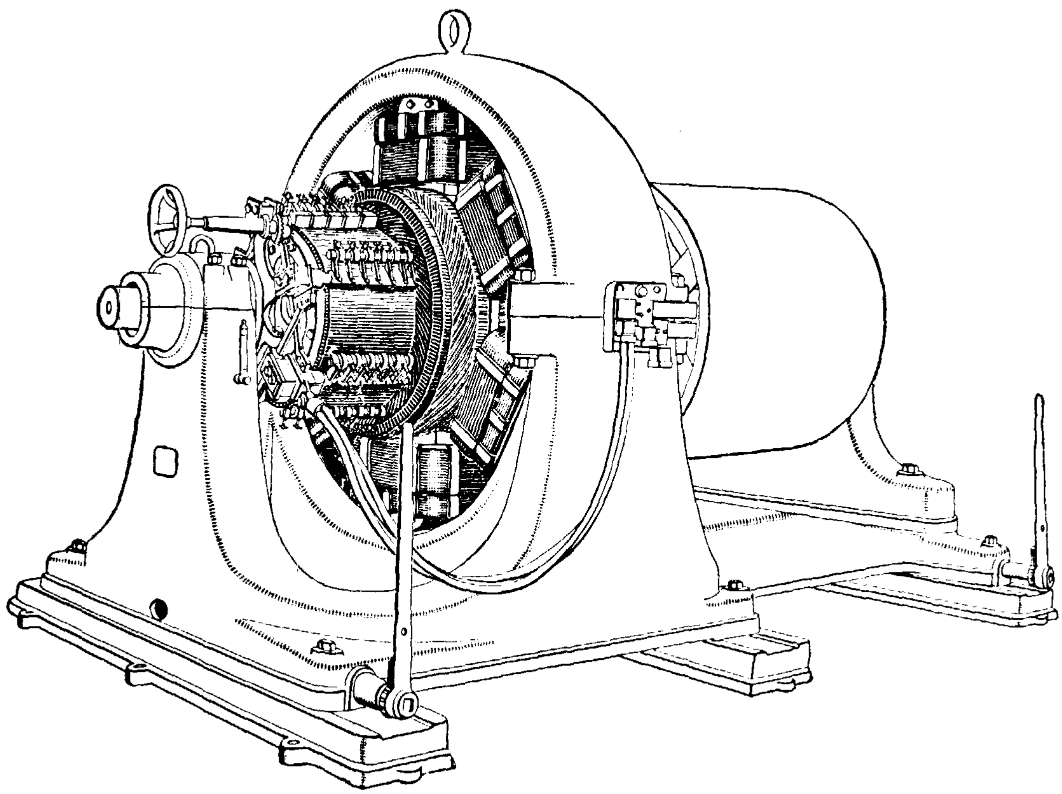

FIG. 14.

sets up the machine. If there is not room in the engine room to set the dynamo far enough from the engine, so that there shall be a slight sag in the tight side of the belt, even when the dynamo is running under full load, one may expect to have high bearing losses and, in extreme cases, hot boxes.

39. The **size of the generators** to be used in any plant is a subject that has aroused a great deal of discussion, some favoring a number of small machines and others a few large ones. It is not good practice to have a number of different types and sizes of dynamos in a station, because it multiplies to a great extent the number of repair parts,

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brushes, and general stock that must be kept on hand. For example, suppose a station to be equipped with dynamos all of the same make and size. This will mean that even if there are a number of dynamos in the station, one armature and one field, as extra parts, will do for the whole station. Whereas, if the dynamos were all of different sizes or types, one field and one armature must be kept on hand for each. Dynamos of good modern construction seldom lose a field or an armature unless struck by lightning, but they always seem much more apt to do so if the station is not prepared for such an accident. Also, different dynamos call for different brushes, bearings, brush holders, commutators, and wire. These facts are advanced as arguments against the use of a number of small dynamos to take up the required load.

On the other hand, the following points must be kept in mind: A dynamo runs at its greatest efficiency when it runs at or near full load, because, under this condition, most of the work put into it by the steam engine is given out again as useful work; but if the dynamo runs with a light load, it may be that as much work is used in overcoming the internal and frictional losses as is sent out on the line, in which hypothetical case the machine runs at an efficiency of only 50 per cent. If the dynamo is up to speed and its field is excited, but its line switch open, all the work given to the dynamo is wasted; none goes out on the line, so that the machine runs at an efficiency of zero. This goes to prove that any given dynamo or dynamos should be run at as nearly full load as possible, so that the losses may become a small percentage of the total power supplied by the steam engine. This means, in actual practice, that when the load on the station falls off, so that the single dynamo carrying it is only half loaded, it should be cut out and replaced by one of smaller capacity.

Again, for several reasons, a large dynamo at full load is more efficient than a small dynamo at full load; but a large dynamo at half load is not, as a rule, more efficient than one of half the capacity at full load. Also, one large dynamo at full load is much more efficient than a number

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of small dynamos whose aggregate capacity is the same as the large one; because in the large dynamo not only are the frictional and internal losses smaller proportionately than those on any one of the small dynamos, but in the case of the large dynamo these losses occur but once, whereas, in the case of a number of small machines, each machine has its own losses and their sum is much greater than the single loss on the large machines. The general conclusion to be drawn, then, is that in the actual operation of dynamos it is best to have the whole station load carried by one generator at full load, or at least to keep those generators that are in operation running as nearly at full load as possible.

40. Use of Compound-Wound Dynamos.—The fact has already been mentioned that compound-wound dynamos are used for operating street-railway systems. In the early days of electric railroading shunt dynamos were used, but they have since been displaced by the compound-wound machines. The reasons for the use of the latter are twofold. In the first place, compound-wound dynamos will operate well in parallel if they are properly installed. In the second place, they have the valuable property of holding the voltage constant or even increasing it as the load is applied; whereas, with the shunt machine, under similar conditions, the voltage will fall off unless field resistance is cut out. Compound-wound dynamos used for operating railways are the same, as regards their construction and connections, as those used for lighting or other kinds of work; hence, what has already been said in regard to compound-wound machines in general applies equally well to railway generators.

41. Overcompounding.—If a power station is equipped with ordinary shunt dynamos, the distribution of load among the several machines must be regulated either by means of shifting the brushes or by the field rheostats; but compound-wound dynamos are not supposed to require any such hand regulation. Once adjusted, under the proper conditions, they will not only share the load proportionately

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among themselves, but they will keep the voltage, at a specified point, up to normal value, without any further adjustment of the rheostats, because any increase in the load that would cause the terminal voltage on an ordinary shunt dynamo to drop must pass through the series coils and strengthen the field, thereby restoring the voltage to normal value. Nearly all railway generators are **overcompounded,** i. e., the voltage rises as the load increases. This increase in voltage at the machine terminals is usually from 10 to 20 per cent.; that is, if the normal voltage on an open circuit is 500 and the dynamo at full load gives a terminal voltage of 550, the machine is said to be 10 per cent. overcompounded; if the full-load terminal voltage is 600, the machine is 20 per cent. overcompounded. A compound-wound dynamo will hold the voltage constant at only one point, so that if the machine is overcompounded to hold the voltage constant at some point out on the line, the voltage in the station will move up and down; and if it is compounded to keep the station voltage constant, the voltage at points out on the line will vary.

In spite of the fact that a railway system may be supplied by a good machine heavily overcompounded, it is quite common to see the voltage on removed parts of the system vary between wide limits; in some cases the car lamps almost go out every time a car is started or the speed of a car increased. That such a state of affairs exists is in no way due to a fault in the dynamo. If the dynamo is compounded to look after a 10- or 20-per-cent. loss in the line, it cannot be expected to look after a 40- or 50-per-cent. loss due to a poor rail-return circuit, nor can it be expected to compound at some point 4 or 5 miles farther out on the line than it was originally adjusted for. As a rule, compound-wound dynamos have a shunt in multiple with their series field, as already explained. If this shunt works loose, the greater part of the current will flow through the series field and the dynamo will overcompound more than it should. On the other hand, if a series-field connection becomes loose or the shunt short-circuited, the series field will be weakened and

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the dynamo will fail to overcompound as much as it should. How much the dynamo will overcompound depends on the relative resistances of the series-field coils and the series-field shunt with which they are in multiple. Any change in this relation also changes the degree to which the dynamo will overcompound.

42. Connections for Compound-Wound Generator. Fig. 15 is a sketch of the connections of an ordinary four-pole railway generator. The machine indicated in Fig. 15 has four poles and four brush holders, but it has only two armature terminals, because alternate brush holders are

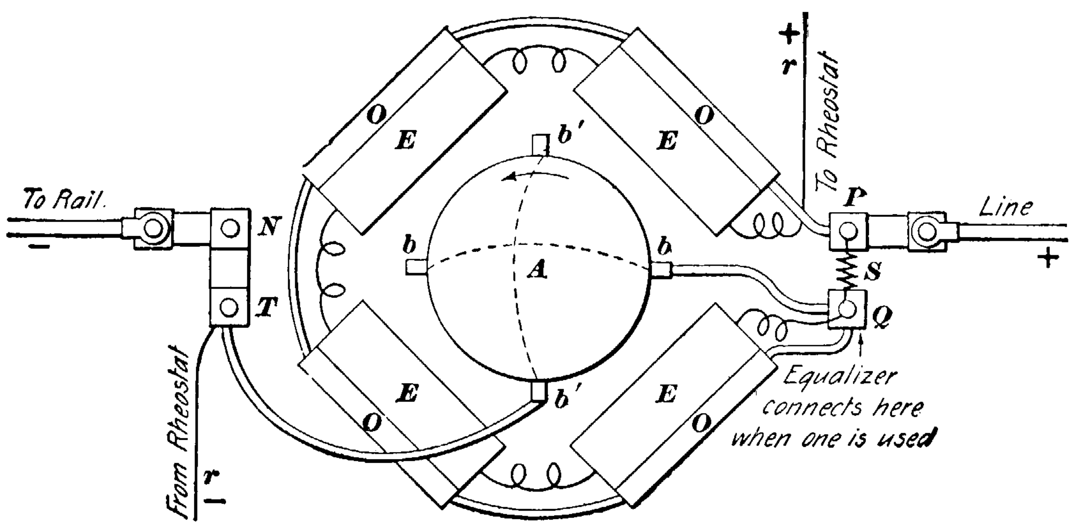

FIG. 15.

connected together by means of a half circle copper strip. If the machine had eight or ten poles and eight or ten brush holders, it would still have only two armature terminals, because all brushes of the same polarity would be joined together.

It will be noticed that each field coil is divided into two sections—a thin section next to the frame and a thick section next to the armature. One section is the fine-wire shunt field and the other section is the series field, which is usually wound with copper strip. The two sections are not only carefully insulated from the frame of the dynamo, but are insulated from each other. They are put on the spool

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alongside of each other, so that in case of trouble in one section, it can be taken off without disturbing the other section. Sometimes the shunt coils are placed next the yoke and the series coils next the armature, but it makes no difference, as far as the operation of the machine is concerned, in what relation they are placed.

43. In Fig. 15, *A* represents the commutator; *O*, the series field; *S*, the shunt to the series field; *E*, the shunt field, and *r*, *r* the lines leading to the rheostat for varying the strength of the shunt field. *P* and *N* are the terminals; one goes to the trolley wire and the other to the rail. The actual arrangement of the connections will of course vary somewhat with different makes of machines, but this sketch will serve to illustrate the general arrangement. One end of the fine-wire field connects to block *Q* by means of a small connecting screw, and the other end passes to the field rheostat and comes back to the negative side of the dynamo at block *T*. The cable on the right, marked "Line," leads from the positive side of the dynamo to the trolley wire; the line cable on the left comes from the rail. The current, therefore, goes out of the dynamo on the right-hand side and goes into it on the left-hand side. Coming out of the armature by way of the *b–Q* armature terminal, it splits into three parts as soon as it gets to block *Q*. One part takes the path *Q–E–E–E–E–r*+, through the field rheostat and back to the negative side of the dynamo by way of the rheostat wire *r*—, to block *T*. Another part takes the short path *Q–S–P* through the series-field shunt *S* to block *P*, while the third part reaches block *P* by way of the path *Q–O–O–O–O–P*, thus flowing through the series coils.

44. Connecting Field Coils of Compound-Wound Generators.—One very necessary point to look after in connecting the fields of any dynamo is to see that the shunt field is so connected that the machine will pick up and hold its voltage on open circuit; also, that the series and shunt fields are connected so that they will be of the same polarity

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and therefore help each other; i. e., so that they will both tend to magnetize the field the same way. If, in Fig. 15, the top shunt-field wire is made to exchange places with the bottom shunt-field wire—that is, if the *E–Q* fine wire is run to the field rheostat and the *E–r+* fine wire is made to take its place at *Q*—the effect will be to reverse the polarity of the shunt field, and the machine will refuse to generate on open circuit, unless the direction of rotation of the armature is reversed.

45. The Series-Field Shunt.—The use of a shunt across the series field to regulate the effect of the series coils has already been mentioned, and railway generators are usually provided with such shunts. This shunt is generally made of German-silver ribbon. German silver is used because not only is its resistance high, but this resistance remains comparatively constant throughout wide variations in temperature. The strips are folded back and forth, as shown in Fig. 16, well wrapped with heavy tape, and painted with insulating paint. The shunt is also provided with

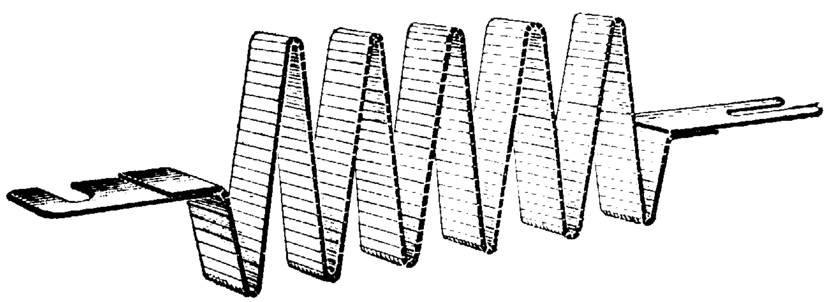

FIG. 16.

terminals on the ends. The shunt should always receive its final adjustment after the dynamo is heated. A dynamo adjusted for a certain amount of compounding while it is cold will fall short of this amount after it is hot. This is due to two main causes. In the first place, the shunt field loses strength as it gets hot. When a machine is compounded properly, its voltage is adjusted to normal value on open circuit; the shunt coils supply a field to generate this voltage, which should, without further regulation, remain the same for any length of time. If the open-circuit

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adjustment is made while the fields are cold, their resistance increases as they become heated and this cuts down the field current, thus decreasing the magnetizing power. This can be proved by adjusting the open-circuit voltage to 500 while the dynamo is cold, letting it run an hour or so on open circuit, and again trying the voltage; it will be found to be much lower. Again, when the series coils are cold, they have a certain resistance, and the shunt across the series coils is adjusted accordingly to bring the full-load voltage to the desired value. Let us assume, for example, that the German-silver shunt and the series coils with which it is in multiple have the same resistance, so that each takes the same amount of current. Now, the shunt is outside, exposed to a free circulation of air, and if it is properly proportioned, its temperature will change very little from no load to full load, and even if the temperature changes considerably, the change in resistance will be so small that it can almost be neglected. On the other hand, the series coils are buried inside the field spool, where the facilities for radiation are poor, and their resistance increases materially; the result is that the hotter the machine gets, the greater becomes the disparity in resistance between the series field and its shunt.

46. A dynamo tender should know in what position to place the field-rheostat handle bar, in order that the machine will generate normal voltage on open circuit after it has become heated. It is true that a dynamo adjusted to compound to a given degree hot will overcompound when cold, but this condition does not last long enough to do any harm. Besides, the tender should not, when the machine is cold, advance the rheostat handle bar at once to the position that will give the normal voltage when hot. The bar can be gradually worked around to that position as the fields become heated. In a great many cases, the full benefit of a dynamo's compounding property is never made use of. Especially is this so where there are several compound-wound dynamos to be run in multiple on the same load. An

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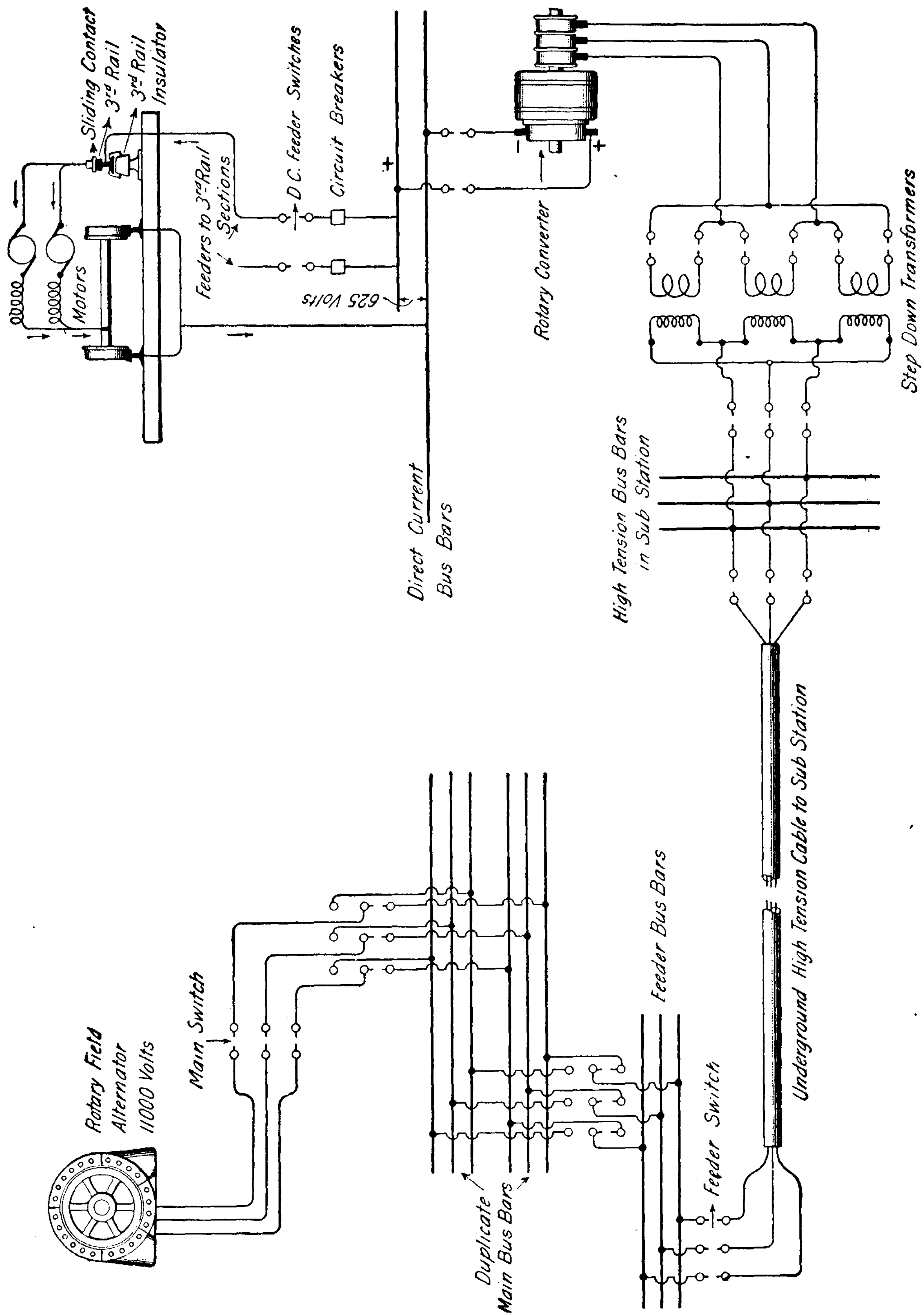

FIG. 17.

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attendant will look at the ammeters, see that one dynamo is taking more or less load than it should, and immediately proceed to give its rheostat bar a twist to even up the load. In a little while it will be necessary to give that same bar or some other one another twist, and so on. It is very often the case that the existing conditions are such that to make the dynamos share the load properly, this practice must be resorted to. If such conditions exist, they should be changed. The station should be compounded as a unit. After a rheostat is once adjusted to make its machine give normal voltage on open circuit when hot, it should not be necessary to disturb it afterwards.

ALTERNATING-CURRENT MACHINERY FOR RAILWAY WORK.

47. Alternators.—The use of alternating current for the operation of electric railways has already been referred to. Some very large systems are now operated by alternating current, among which may be mentioned the Metropolitan Railway and Manhattan Elevated systems in New York and the Central London Underground. Most of the large systems that spread over a wide area are now being operated by distributing the power from one main central station to a number of substations, where the alternating current is changed to direct current, which is supplied to the cars. To carry out such a scheme of transmission, two-phase or three-phase alternating current is used, the latter being the more common. The current at the main station is usually generated by large revolving field alternators, because this type admits of a high pressure being generated in the machine and avoids the use of step-up transformers at the station. Where water-power is available, the alternators are direct-connected to turbines.

48. Fig. 17 shows the general scheme of distributing current for the Manhattan Elevated Railway, New York, and will serve to illustrate the general method of distribution referred to above. Current is generated in one large

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central station by revolving-field, three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine enables the current to be generated at 11,000 volts in the machine. It is distributed to a number of substations by means of heavily insulated lead-covered cables run in underground conduits. At the substations it is passed through stationary transformers that step down the voltage. The rotary converters

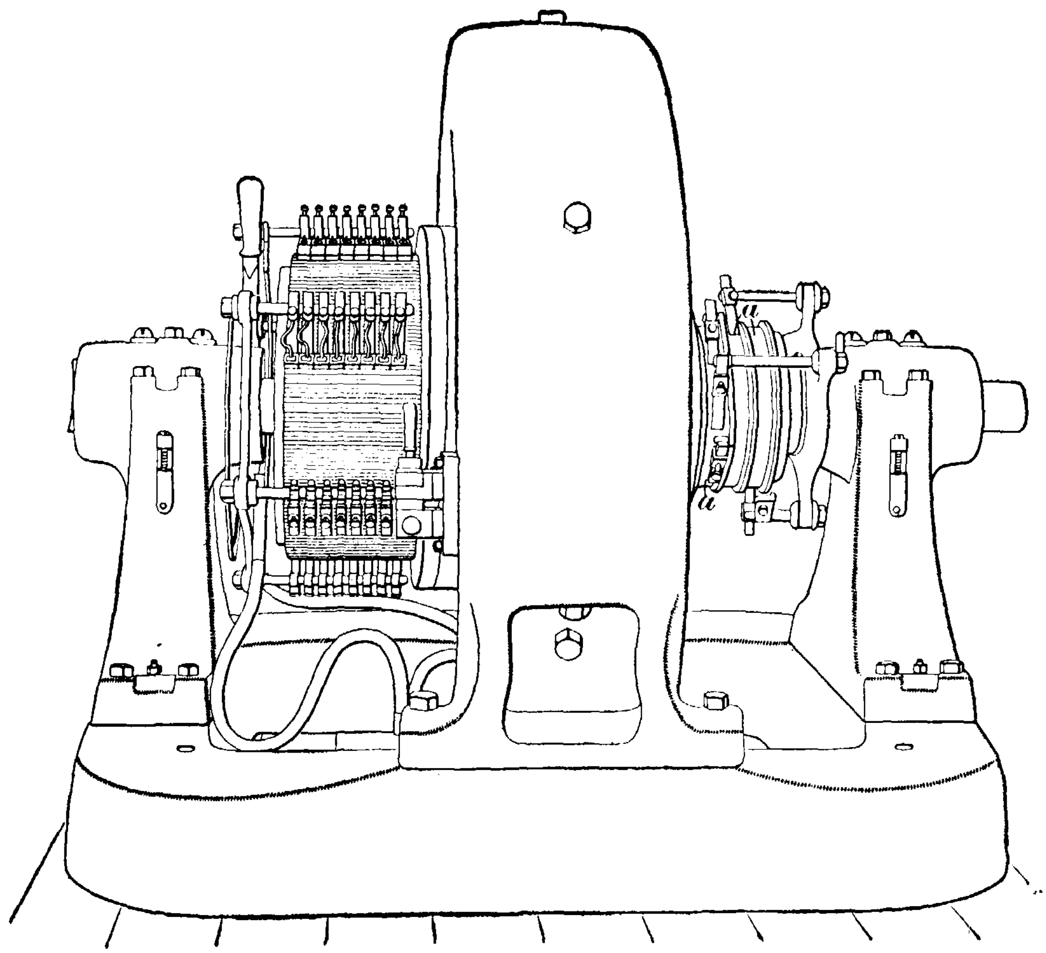

FIG. 18.

change the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of a third rail and the ordinary track. The systems of distribution used by the Metropolitan Railway Company, of New York, and the London Underground are almost exactly the same as this one, except that the distributing pressures are somewhat lower. In the case of the Metropolitan road the distributing pressure is 6,600 volts.

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49. Rotary Converters.—As before mentioned, alternating current is used comparatively little to propel the cars themselves, but is first changed to direct current by means of rotary converters. Fig. 18 shows a three-phase rotary converter designed for railway work; it is a six-pole machine of 300 kilowatts capacity. The high-pressure alternating current from the line is first run through step-down transformers and then supplied to the rotary through the collecting rings *a*, *a*; the direct current is supplied to the cars from the commutator side. Rotary transformers are not provided with a pulley, because no outside source of mechanical power is required to drive them.

50. Double-current generators are machines that generate both alternating and direct current. In appearance they look almost exactly like a rotary converter, except, of course, that they are provided with a pulley or are direct-connected, so as to be driven from an outside source of power. Their whole output may be utilized as direct current, as alternating current, or as a combination of the two. These machines have been used to some extent in stations where a part of the power must be used close at hand and a part transmitted for a considerable distance. The part of the railway near the station is supplied from the direct-current side and the distant part is supplied through step-up transformers from the alternating-current side. These machines generate between 500 and 600 volts direct current, so that the alternating-current voltage is comparatively low and step-up transformers must be used to obtain the high pressure necessary for transmitting the power over long distances.

51. Alternating-Current Motors for Railway Work. Polyphase induction motors are in successful use on a few European electric railways, and it is not improbable that these motors will be more used in the future. Those that have been used are the same in their essential parts as the ordinary stationary induction motor, but are cased in and

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have about the same general appearance as ordinary direct current motors, which are to be described later. They give a good starting effort, but take considerable current from the line in so doing. Their speed is usually controlled by having an adjustable resistance in the armature circuit. Those that have been used are of the three-phase type, and hence require three wires for their operation; the track answers for one of these, so that two trolley wires are necessary. In some installations three trolley wires have been used. Induction motors would be well suited for suburban lines where the overhead work would not be complicated and where it might be allowable to use a high pressure between the trolley and the rail. Induction motors could be wound for higher pressures than direct-current motors, because they have no commutator to give trouble. It is quite possible that they may come into use for suburban, elevated, and underground work, in which case the necessity of rotary converters would be done away with, and in some cases even step-down transformers would not be needed.

RAILWAY SWITCHBOARDS.

52. Switchboards are used for centralizing the many circuits used to distribute the power, and in this capacity are called on to hold the switches used in making the various connections and combinations, the instruments used for controlling and measuring the loads on these circuits, and the various protective devices necessary to insure that the expensive apparatus shall not be injured by abnormal conditions arising either in the station or out on the lines. In the earlier railway days it was the practice to string incoming and outgoing wires along the walls of the station and to mount the various devices, bus-bars, etc. upon the face of a wooden switchboard placed right up against a wall, in a position selected with no particular end in view of having the switchboard with its measuring and indicating devices

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anywhere near the engines and dynamos. The tendency of today is to spare nothing in the effort to have the switchboard well constructed and convenient in every way, and many of the boards now built are models in this respect. It has taken time, however, for this change to be brought about. Dynamos in their present state of perfection do not give nearly as much trouble as the older types, and on account of the state of perfection reached by the various protective and safety devices, no trouble can do the damage and cause the shut-downs that were once so common.

The switchboard, if properly arranged, is a great time and labor saver; it enables each dynamo and each circuit to be used as a separate unit; where occasion demands such practice, one dynamo can be thrown on to several circuits, and any or all of the dynamos can be cut out of circuit. All these combinations may be effected, if necessary, without the man that does it going near the dynamos.

53. Location of Switchboard.—It generally falls to the lot of the road engineer to decide where the board shall be placed in the station, and this is no easy matter, as so many different requirements must be reconciled. The tendency of the day in large stations is to have one man give all his time to the operation of the switchboard and do absolutely nothing else. In very large stations, where large currents are handled and large units must be used, it keeps one man busy watching the total station load and the individual dynamo loads, to see that just enough and not too many dynamos are in operation to care for the load, and that no dynamo is taking more than its share. On the smaller roads, however, it is, as a rule, the duty of one of the engineers to operate the switchboard.

Among other things, the location of the switchboard is fixed by the relative position of the dynamos and engines. The switchboard should be so placed that there will be no necessity for the engineer, in case trouble occurs at any point or in case he must get to the throttle of an engine, to go through a belt or down a flight of stairs. The life risk

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should be kept in mind above all other considerations. After this, perhaps, comes a consideration of the economy side of the question. If the board is very far from the dynamos, the drop in the connecting wires will be considerable, and the machines are apt to equalize badly unless the

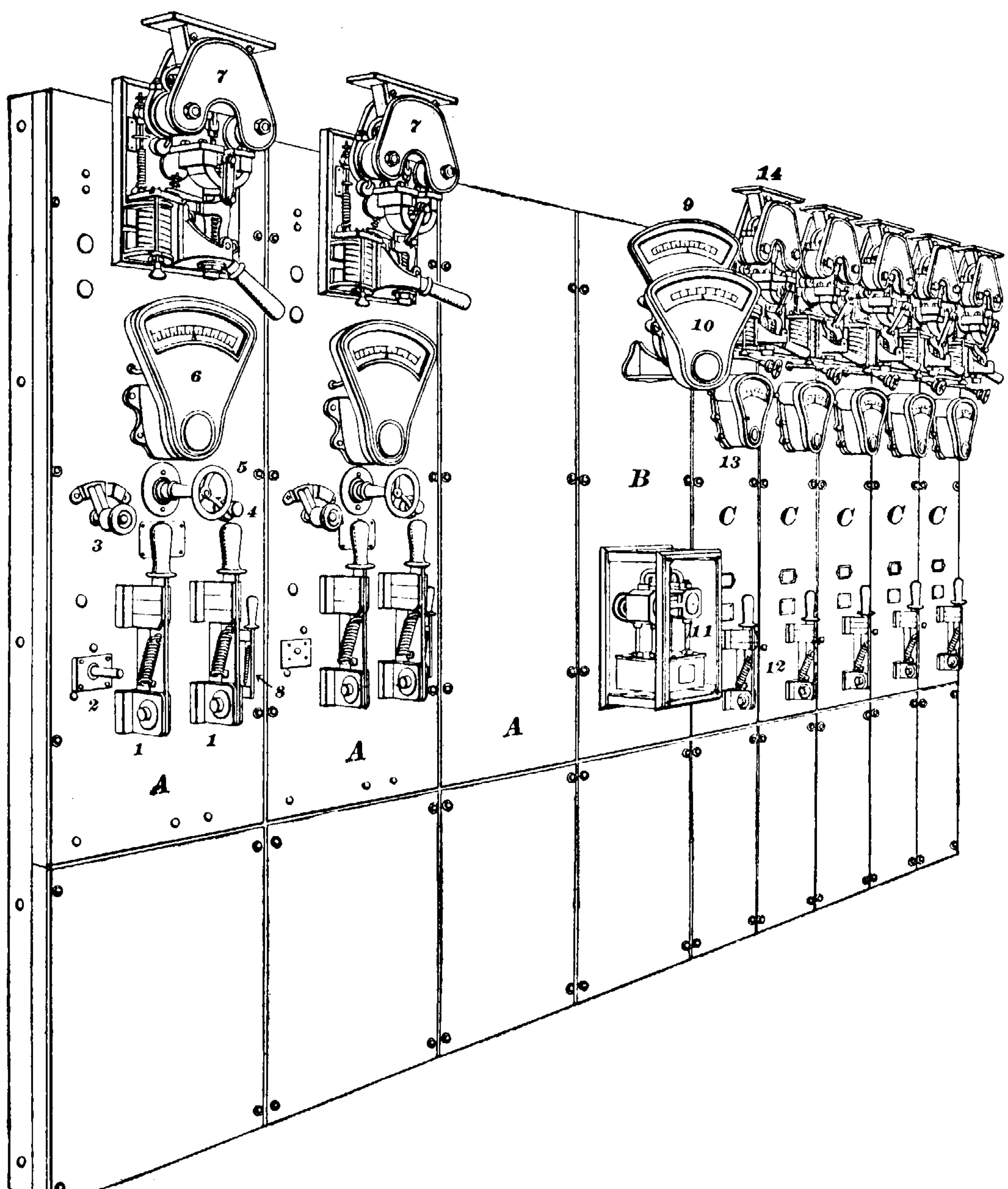

FIG. 19.

equalizing wire is run directly between the machines and not carried to the switchboard at all. When dealing with small currents, the question of drop in a large wire almost escapes notice, but when we deal with currents of several

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thousand amperes, such losses become an important item and care must be taken to reduce them to a minimum.

54. Materials Used for Railway Switchboards.—Railway switchboards, like all other modern boards, are made of fireproof material throughout. The board itself is usually made of slate or marble about 2 inches thick, and is bolted to vertical angle irons. The instruments are mounted on the face of the panel, and all connections between them are made on the back. The board is stood out from the wall or mounted in such a way that the back shall be easily accessible in case it is necessary to do work on any of the connections. Fig. 19 shows a typical railway switchboard for handling 500-volt direct current. This board is made of three *generator panels A*, *A*, *A*, one *total output panel B*, and five *feeder panels C*, *C*, etc. Only two of the generator panels are equipped with instruments, the third being left blank to accommodate a third machine when it is installed. Generator panels are usually about 24 to 30 inches wide and feeder panels 16 inches; the total height of the board is 90 inches.

55. Equipment of Generator Panels.—Each generator panel carries the switches and instruments necessary for the generator to which it is connected. These are as follows: *main switches 1*, *1*, *voltmeter plug 2*, *field switch 3*, *pilot-lamp receptacle 4*, *field rheostat 5* (the rheostat itself is mounted on the back of the board with the operating handle in front), *ammeter 6*, and *circuit-breaker 7*. The small switch *8* is used for controlling any station lights or motors that may be operated from the machine.

56. Equipment of Total-Output Panel.—This panel is not always provided, but it is generally installed in the best plants. It generally carries the *voltmeter 9* and a *total-output ammeter 10*, which is connected so that it indicates the total combined current delivered by all the generators. This panel is also equipped with a *recording wattmeter 11*, which measures the total number of watt-hours delivered by

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the station, so that an accurate account may be kept of just what work the station is doing.

57. Equipment of Feeder Panels.—The feeder panels are supplied with the equipment necessary for the control and measurement of the current on the different feeders going out from the station. Each panel is equipped with a *feeder switch 12*, a *feeder ammeter 13*, and a *circuit-breaker 14*. On some boards the feeder panels are not equipped with ammeters.

58. General Remarks.—The advantages of the panel type of construction are that it groups the apparatus belonging to each individual part of the plant by itself; also, it allows the board to be extended easily in case the plant is enlarged either by adding more feeders or more generating apparatus. As a rule, only one voltmeter is necessary, because by means of the plug *2* the instrument may be connected to any machine in case a reading is desired. Some boards, however, have two voltmeters, one of which is permanently connected across the bus-bars and the other arranged so that it may be connected to any machine. This is a convenient arrangement where a machine is being thrown in multiple on the bus-bars, but it is not essential that the board should be equipped in this way. The voltmeter is often mounted on a swinging bracket, as in Fig. 19, so that it may be readily seen by the operator. In case a total-output panel is not provided, the voltmeter is often mounted on a swinging arm at one end of the board. In addition to the apparatus shown in Fig. 19, each generator panel, and in some cases the feeder panels also, is equipped with lightning arresters mounted behind the board.

RAILWAY SWITCHBOARD APPLIANCES.

59. Main Switches.—Before considering the connections necessary for a railway switchboard, we will take up the various appliances used on the board. The *main*

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switches shown at *1*, *1* are, of course, intended to disconnect their generator from the bus-bars. These switches should be of substantial construction, as they are called on to carry a heavy current. They are usually made so as to give a quick break and thus prevent arcing. In general, however, the main switches are not used to open the circuit when the machine is carrying a load. If it is necessary to do this, the circuit-breaker should be used, because it is constructed so that it will break the circuit without any injurious arcing. Single-pole switches are generally used on railway boards. In Fig. 19, two main switches are shown on each generator panel, though it is quite common to find three switches. If the equalizer wire is run to the switchboard, then three switches are used, but if it is run between the machines, as is done in the more recent installations, only two switches are necessary on the board, and the equalizer switch is mounted on a stand near its dynamo.

60. Voltmeter Plugs and Switches.—These are used to enable the voltmeter to be connected to any one of the generators. For railway boards, a plugging arrangement is generally preferred to a switch, as it is less complicated and more substantial. The plug is arranged so that when it is inserted as shown at *2* on the first panel, Fig. 19, it connects the voltmeter *9* across the dynamo connected to the first panel. The way in which this is carried out will be apparent when we come to take up the switchboard connections.

61. Field Switch.—The field switch is used to open the shunt-field circuit of the generator; it is, therefore, of comparatively small current-carrying capacity. The shunt-field winding of a railway generator consists of a great many turns of wire, and it must not be forgotten that if the shunt-field circuit is suddenly broken, an exceedingly high E. M. F. will be induced in the winding, due to the sudden decrease in the magnetization threading through the field coils. The field switch must, therefore, be arranged to take up any discharge from the field, otherwise the high induced voltage may puncture the insulation on the field spools.

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Fig. 20 shows the arrangement of the field switch and pilot lamp used on the board in Fig. 19. The switch *S* has two contact segments *a*, *a'*, and the tongue *t* is wide enough to bridge over the gap between them. The switch is shown in the position that it occupies when the generator is in operation. The current then passes through the field rheostat *r* and the switch *S* as indicated by the arrowheads. When the switch is moved to the position indicated by the dotted line, connection between the field and the negative side of the armature is broken, but before the break takes place, tongue *t* comes into contact with *a'*, so that the shunt field, the rheostat *r*, discharge resistance *r'*, and pilot lamp *l* all form a closed circuit. The shunt field is thus able to discharge through this closed circuit, and danger of puncturing the insulation is avoided. When the machine is being started, the tongue *t* is placed in its mid-position, so that current can flow through *r'* and *l* as well as through the shunt field and rheostat *r*. As the machine builds up, the pilot lamp becomes brighter, thus giving the attendant an indication as to whether the machine is "picking up" properly or not. After the machine has come up to voltage, the switch is moved to the position shown in the figure and the pilot lamp is cut out. On some boards, five or six lamps in series are used in place of the resistance *r'* and the single lamp *l*. The pilot lamp *l* is inserted in the receptacle *4*, shown in Fig. 19.

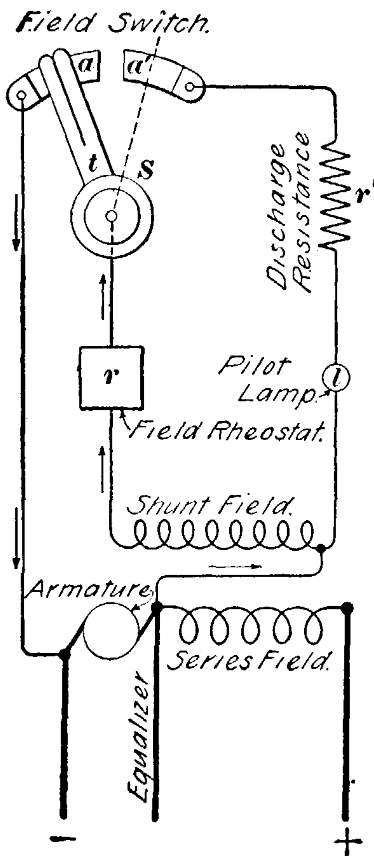

FIG. 20.

62. Field Rheostats.—Field rheostats, or resistance boxes, are used in connection with all railway generators, and are connected in series with the shunt-field winding, so that the field current, and hence the voltage of the generator,

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may be adjusted. The field resistance is not intended to be used for regulating the voltage to suit the variations in load, because the compound winding is supposed to take care of that. It is used to adjust the voltage when the machine is first started, and it is also necessary to cut out some of it as the field coils warm up.

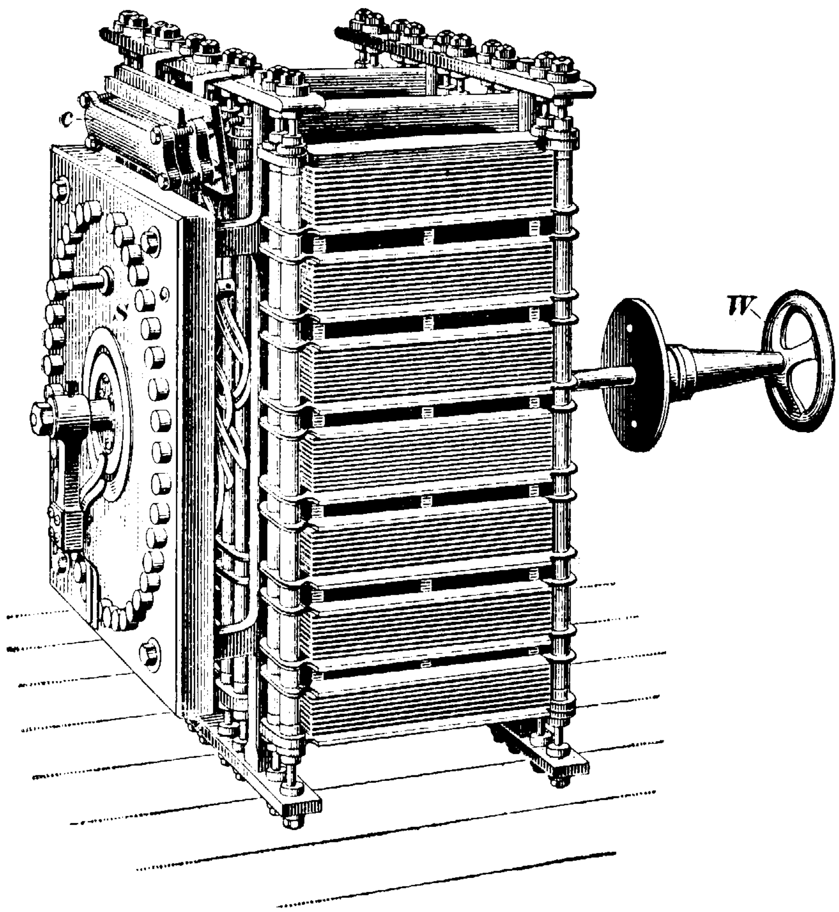

FIG. 21.

Field rheostats used on railway boards are made in a great variety of designs, but in all cases they consist of a resistance split up into a large number of sections that are connected to a multipoint switch, so that any amount of resistance may be cut in or out. In some styles the resistance is made up of German-silver or tinned-iron wire coiled into spirals and mounted in a well-ventilated iron box. In others, the wire is formed into zigzag shape and mounted in enamel on the back of cast-iron plates. In all cases, rheostats should be constructed so that they will be perfectly fireproof and at the same time allow easy radiation of the

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heat generated in them. If the latter point is not considered, burn-outs are apt to result. In some rheostats the resistance is in the form of cast-iron grids of zigzag form. This makes a substantial resistance that is well ventilated and is especially suited to rheostats of large capacity.

63. When rheostats are of comparatively small size, they are mounted on the back of the switchboard and operated from the front. Fig. 21 shows a type used by the General Electric Company on railway boards and arranged for mounting on the back. The switch is shown at *S* and is operated by the wheel *W* on the front of the board. In this particular rheostat, the resistance wire is wound on sheet-asbestos cylinders, which are afterwards flattened and clamped between pieces of sheet iron covered with asbestos. The wire is thus held firmly in place, and the pieces of iron nearest the wire serve to radiate the heat. To allow the voltage to be regulated by small steps, it is necessary to have a considerable number of points on the rheostat switch. Another method of accomplishing the same result is to have a small resistance connected to the switch arm, so that it will be put in multiple with each step as the arm is moved around. This scheme is used in the rheostat shown in Fig. 21, and will be understood by referring to Fig. 22. The regular rheostat contacts are arranged as usual and are shown at *1*, *2*, *3*, etc. Instead, however, of using a simple contact arm, the arm is provided with two contact tips *a*, *a'*, insulated from each other, and which press on the contact rings *b*, *b*; *c* is a small so-called multiplying resistance (see also *c*, Fig. 21), which is

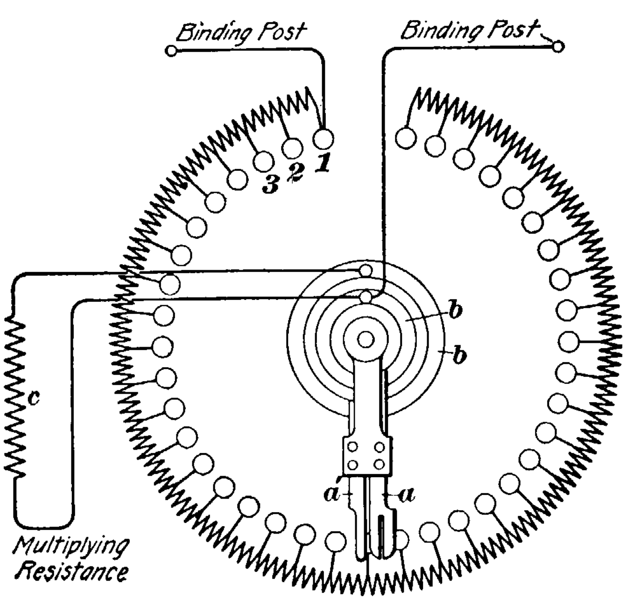

FIG. 22.

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approximately equal to one of the resistance sections on the rheostat. By tracing out the current, it will be seen that *c* is placed in parallel with the step on which the arm rests, and it has the effect of practically halving the resistance of each step as the arm is moved around; it, therefore, gives as fine an adjustment as though the rheostat were provided with a single arm and twice the number of steps.

When very large generators are used, the rheostat is generally mounted separately from the switchboard. In some cases, the switch is placed on the back of the board and is connected by wires running to the resistance, which may be mounted in any convenient location. In other cases, the rheostat and switch are both mounted away from the board and are controlled by a shaft fitted with bevel gears, or by a chain-and-sprocket arrangement. This arrangement is preferable to running wires from a rheostat switch on the board to the rheostat itself.

64. Ammeters.—Each generator should be provided with an ammeter that will indicate its current output. It is also advisable to have an ammeter in each feeder. The load on a railway generator fluctuates rapidly, and it is essential that the ammeters should be "dead-beat"; i. e., the hand should not swing back and forth, but should move to its place whenever there is a change in the current and it should stay there until another change takes place. The instrument should also be constructed so that it will require but a small amount of energy to operate it. This may seem a rather unimportant point, but where a station has a large number of instruments that are in circuit all the time, the amount of energy used in them in the course of a year may be considerable.

Weston ammeters are very largely used for railway boards. They are accurate, consume but little energy, and are dead-beat. The switchboard type used for railway work is exactly similar in principle to the portable type, but much larger. The main ammeters and voltmeters are

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provided with dials that are illuminated from the rear, so that they may be easily read. Feeder ammeters are not usually provided with illuminated dials.

65. Voltmeters.—At least one voltmeter is necessary on every railway switchboard, and it should be arranged so that it may be connected to any machine or to the bus-bars. The voltmeter is, of course, connected across the circuit, and it should therefore have a very high resistance, or else it will take considerable current. Voltmeters and ammeters are generally the same in appearance and the operating parts are the same, but the voltmeter has a very high resistance compared with that of the ammeter.

66. Westinghouse Railway Ammeters and Voltmeters.—On the earlier types of Westinghouse switchboards, ammeters and voltmeters of the plunger type were used. The current was led through a vertical coil or solenoid that was arranged so as to pull down an iron core hung from one side of a balance arm to which the pointer was attached. On their later boards, the Westinghouse Company use a round-style instrument, in which the current flowing in the coil acts on an iron vane placed within it, instead of on a plunger.

67. Thomson Astatic Ammeters and Voltmeters.—These instruments, invented by Professor Elihu Thomson, are used by the General Electric Company. The board shown in Fig. 19 is equipped with instruments of this type. In the Thomson astatic meters, electromagnets are used to set up the magnetic field instead of permanent magnets, as in the Weston instruments. Also, the moving coils are mounted on an aluminum disk instead of being made in rectangular shape. The retarding force acting on the armature is not supplied by spiral springs, but is provided for by the attraction of the field magnets for small iron vanes placed on the moving member. If, for any reason, the electromagnets become weaker, the force acting on the

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movable coils, for a given current flowing through them, also becomes weaker, but the retarding force decreases at the same time, so that the reading of the instrument is not affected. A Thomson astatic ammeter, as used on a generator panel, has six wires running to it; two of these run to the ammeter shunt, the same as for a Weston instrument; two others run to the bus-bars, so as to supply the field electromagnets with exciting current. These magnets are provided with a high-resistance winding, so that they may be connected directly across the line. The third pair is used to supply current to the lamps used for illuminating the dial. The ammeters used on the feeder panels do not have illuminated dials, hence these last two wires are not required.

CIRCUIT-BREAKERS.

68. On the first railway boards that were brought out, fuses were used to protect the machines from overloads, but it was soon found that while these might be fairly well suited to lighting or other work where the machines were not subject to violent overloads, they were not reliable for railway work, and, moreover, the renewing of blown fuses was a nuisance. Fuses have, therefore, been replaced by automatic circuit-breakers, of which there are several different makes. Those that have been most widely used for this service are the General Electric, the Westinghouse, and the Cutter, or I. T. E., as it is sometimes called.

The circuit-breaker, as this name is now accepted, is automatic in action and is designed to open or break the main working circuit whenever, for any reason, the current reaches a value that is not safe for the dynamos to carry. It is not a difficult matter to get up a device that will break the current at a set value for the first few times that it is operated, but it took years of study and observation in actual practice to perfect a device that would not burn and blister itself into a worthless condition in a short

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while when used continuously. The circuit-breaker, to be effective, must be able to break heavy currents without damage from the burning effect and this means that the arc must be almost instantly extinguished as soon as the breaker opens.

69. General Electric Type M K Circuit-Breaker.—This is a type of breaker that has been very extensively used in railway work. In it the arc is extinguished by breaking the circuit in a magnetic field. It is a well-known fact that a wire carrying a current in a magnetic field tends to move across the field, this, in fact, being the principle of operation of the electric motor. An arc formed by the current between two terminals acts exactly like a wire carrying a current; hence, if the arc is made to take place in a magnetic field, it will be forced across the field and stretched out so that it is broken. This action is almost instantaneous, and if the magnetic field is fairly strong, the arc is blown out almost as soon as it is formed. This magnetic blow-out method of suppressing arcs is largely used in car controllers, lightning arresters, and other devices.

70. Fig. 23 shows the General Electric Company's M K breaker, which is the kind also shown on the board, Fig. 19. This type has been selected for illustration on account of its ready adaptability to almost any class of service and on account of its wide range of adjustment. M K breakers can be had of any capacity from 150 to 8,000 amperes, and are therefore equally suited to feeder or to individual generator duties. In Fig. 23, *B* is a heavy tripping coil of copper, through which passes the main current that operates the breaker. The main current enters the coil through the rear connecting post *A*; from the coil it passes to a connection on the back of the heavy copper contact block *C*. When the breaker is closed ready for service, as shown in the figure, the main current passes from *C* to the curved copper bridge *D D* and out to the line again through the heavy block *E*, which has a terminal like *A* in

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the rear. When the breaker is closed, the hinged iron armature F is held up by a spring G, the tension of which depends on the adjustment of a thumbscrew J. Attached to plate F is a trigger H, which has on the under side of its end a shoulder against which a projection on the main handle yoke K

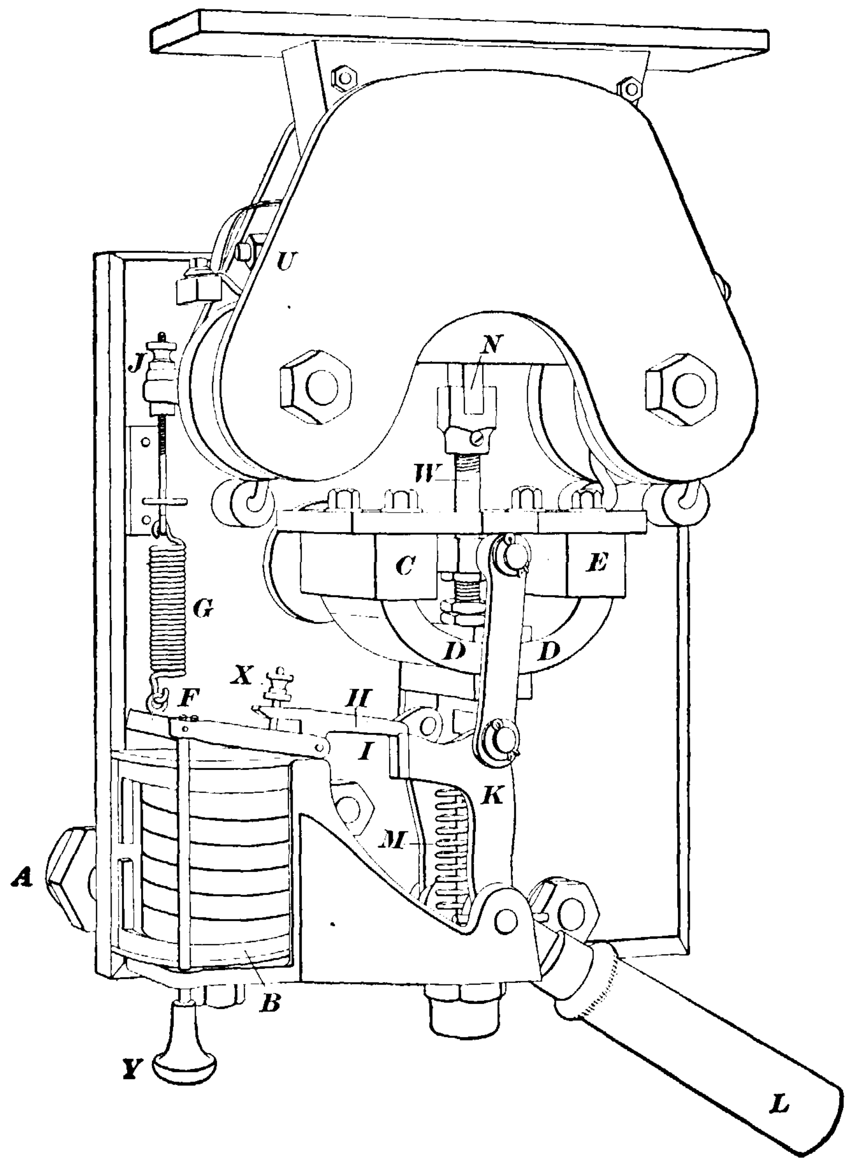

FIG. 23.

bears. To set the breaker, the main handle L is pulled down hard; this forces D D up against blocks C and E, and also causes the projection on K to engage trigger H, which holds the circuit-breaking parts in place. In setting the switch, spring M is extended. Now, suppose the current to go above the value for which the breaker is set to operate.

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The solenoid *B* draws down its armature plate *F*, and with it the trigger *H*, which liberates the switch yoke and allows the strong spring *M* to pull down *D D*, and hence open the circuit at *C* and *E*. It can thus be seen that this part of the device is a circuit-breaker within itself, but the arrangement as it stands would provide no means of suppressing the arc, and the blocks *C* and *E* and the bridge *D D* would burn badly. Fig. 24 is a diagrammatic sketch of the path of the main current through the breaker. The tripping coil *B*, the blocks *C* and *E*, and the bridge *D D* are all in series, forming part of the main

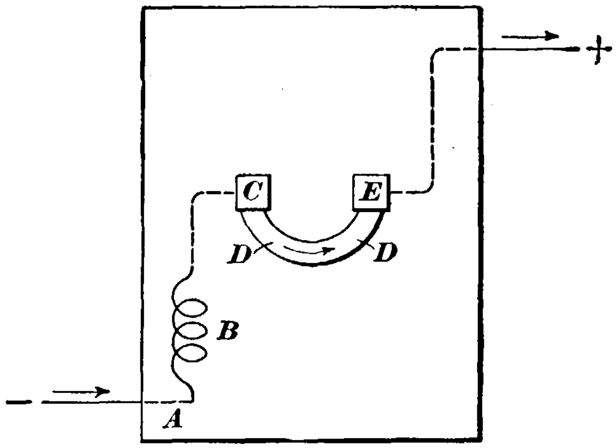

FIG. 24.

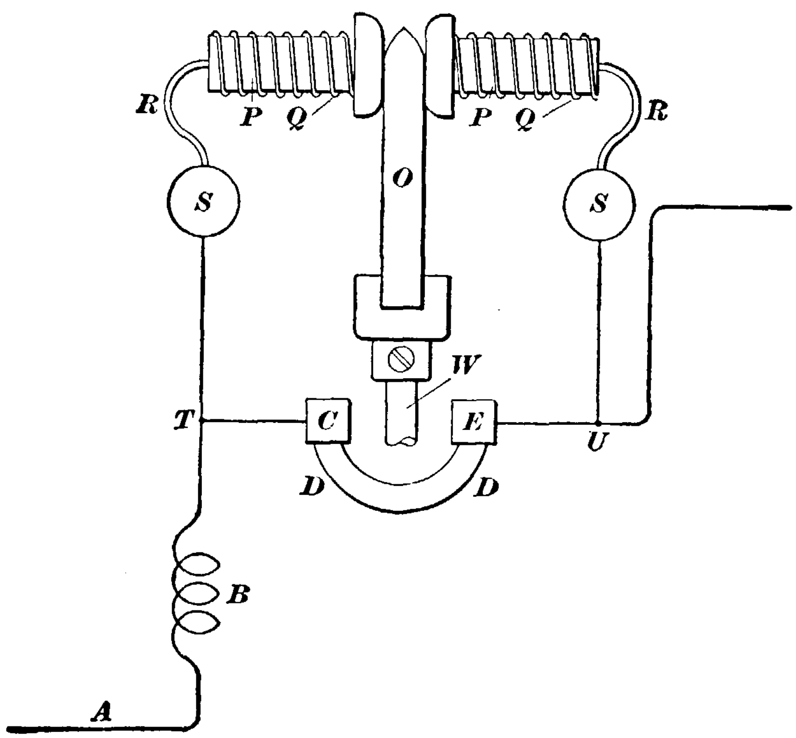

FIG. 25.

circuit. Let us now see how the arc is cared for. By taking the name plate off the breaker, a chamber is exposed that contains an arrangement similar to that shown in

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Fig. 25 and constituting what is called the *secondary break;* the break between *C* and *E* and the bridge is the primary break. *P*, *P* are two copper plunge contacts that are impelled towards each other by springs *Q*, *Q*, but which do not touch each other even if *O* is pulled out from between them; the switch tongue *O* is carried on a rod that is actuated by the movement of the main handle *L*, which also works the main bridge contact *D D*, but there is lost motion between contact *O* and contact *D D*, with the result that when the breaker works, *D D* leaves *C*, *E* before *O* leaves *P*, *P*. *S* and *S* are two coils that provide a powerful magnetic field across the place where the tongue *O* leaves the contacts *P*, *P*. By means of strips *R*, *R* each of the coils is connected to the *P* contact nearest to it. It can be seen, then, that the two coils *S*, *S*, the two contacts *P*, *P*, and the contact *O* are in series. When the breaker is set, *O* connects *P* and *P*, and *D D* connects *C* and *E*, so that when current entering the breaker at *A* gets to point *T*, it has a choice of two paths by means of which to reach point *U*; one path is straight across *T–C–D D–E–U*; and the other path is *T–S–R–P–O–P–R–S–U*. The primary and secondary paths, then, are in multiple. When the breaker is set, however, the resistance of the secondary path is comparatively so high that it takes little or no current. As soon as an overload causes the tripping coil *B* to trip the trigger *H*, *D D* leaves *C*, *E* at once, with very little arcing, because the current has still a good path through the secondary circuit. The same movement that pulls bridge *D D* from blocks *C*, *E* withdraws tongue *O* from between contacts *P*, *P*, a little later, however, so that although the circuit is open at *D D*, there is, nevertheless, an arc holding across *P*, *P*. The strong magnetic field across *P*, *P*, however, soon forces this arc upwards and breaks it, all smoke and gases being driven out through a draft hole in the top of the chamber that encloses the device. Frequent actions will, in course of time, deposit on the walls of this chamber a film of carbon, which, if not cleaned off, will cause a short circuit and will blow up the breaker. Contact blocks *P*, *P* have nuts by

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means of which the air gap between them can be adjusted. One of these nuts can be seen at *U*, Fig. 23. The stem *W*, Figs. 23 and 25, also has adjusting nuts, by means of which the amount of lost motion between *O* and *D D*, and hence the interval of time elapsing between the break at *P*, *P* and that at *D D*, can be regulated. As wear takes place in any of the connecting parts or as the contacts become burned, some of the lost motion must be taken up in order to preserve the right relationship between the time of breaking in the primary and secondary circuits. Contact bridge *D D* is made up of layers of leaf spring copper, so that it has more or less give to it. The result is that when the breaker is set, the surfaces of the bridge are forced apart a little, thus giving a certain amount of wipe instead of a plain butt contact. It is evident that the stronger the pull exerted on plate *F* by spring *G*, the more force must coil *B* exercise on it, and the greater current must there be in it to draw down the plate and to trip the trigger *H*. The tension on the spring can be regulated by means of the nut seen at *J*. Also, the amount of engagement between trigger *H* and the projection on the yoke *K* can be regulated by means of the thumbscrew seen at *X*, Fig. 23. The pull *Y* is a device used to trip the breaker by hand, whether it has any current going through it or not, and is very convenient when adjusting the time interval between the primary and secondary breaks. All the contacts on the breaker should be examined from time to time, and if any rough projections are present, they should be dressed down with a file.

71. Westinghouse Circuit-Breaker. — Fig. 26 shows the Westinghouse circuit-breaker, of which large numbers are in use, and which have given very good service. No magnetic blow-out is used, but the arc is taken care of by making the break take place at auxiliary carbon contacts, where the burning does no harm, since these contacts can be renewed at small expense. In Fig. 26, *a*, *b* are the main contacts, which are connected by the crosspiece *c*

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when the breaker is set. The current enters at *a*, flows across *c* to *b*, thence through the tripping coil *d* and out at *e*. Coil *d* has an iron core that pulls up an armature whenever the current exceeds that for which the breaker is set. This armature is weighted with an adjustable weight *w*, by means of which the tripping point may be adjusted. The auxiliary carbon contacts are in the form of plates *m*, *m* attached to the fixed contacts *a*, *b* and carbon wipers *n*, *n* attached to the breaker arm. The arm is pushed in against the action of a spring and is held in place by a catch. When the catch is released, by the current becoming excessive, the arm flies out. Contacts between *c* and *a*, *b* break first, and the current momentarily flows through the carbon contacts. When the wipers leave the carbon plates the break takes place, so that the burning action occurs on the carbon.

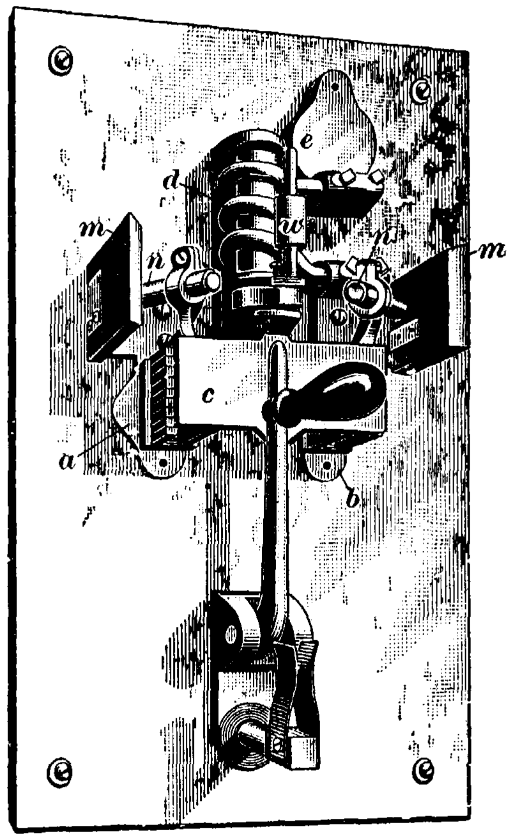

FIG. 26.

72. The Cutter Circuit-Breakers (I. T. E. Breakers). These circuit-breakers are somewhat similar in appearance and action to the Westinghouse breakers. The arcing is taken care of by using auxiliary carbon breaks, but the arrangement of the tripping device is different. In these breakers, the tripping coil or solenoid sucks up an iron core when the current becomes excessive. This core is mounted loosely in the solenoid and is not attached to the trigger, but operates the latter by striking it a blow when it is drawn up. One advantage of this breaker is that there is very little danger of the tripping device sticking and failing to work.

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COST OF POWER FOR ELECTRIC RAILWAYS.

Output Measured by Wattmeter in Each Case.

Station.	Month.	Monthly Output. Kilowatt-Hours.	Cost of Electrical Output per Kilowatt-Hour. Cents.						Gals. Cylinder Oil per 10,000 K. W. H.	Gals. Lubricating Oil per 10,000 K. W. H.	Lb. Water per Lb. Coal.	Lb. Fuel per K. W. H.	Price of Fuel per Ton of 2,000 Lb.	Kind of Fuel.
			Fuel.	Labor.	Supplies, Oil, Waste, Etc.	Water.	Repairs.	Total.						
1	Jan.	2,455,060	.322	.111	.029	.029	.044	.535	2.62	.848	10.83	2.45	$2.63	Bituminous
1	Feb.	2,511,280	.334	.114	.036	.027	.025	.536	2.64	.829	10.05	2.54	2.63	"
1	Mar.	2,097,160	.337	.123	.037	.030	.040	.567	2.84	.987	11.21	2.55	2.64	"
1	Apr.	2,158,660	.344	.129	.039	.032	.043	.587	2.98	.722	11.37	2.61	2.64	"
5	Jan.	2,445,161	.408	.110	.013	.011	.016	.558	2.18	1.31	5.51	4.10	1.99	"
5	Feb.	2,512,125	.389	.116	.014	.008	.011	.538	2.50	1.03	5.32	3.89	2.00	"
5	Mar.	2,352,698	.405	.126	.018	.011	.016	.576	2.52	1.70	5.15	4.33	1.87	"
5	Apr.	1,887,029	.347	.149	.020	.011	.036	.563	3.91	1.14	5.22	4.22	1.65	"
6	Nov.	827,008	.712	.198	.033	....	.067	1.010	....	.....	.....	2.35	.943*	Oil
6	Dec.	810,728	.709	.198	.024	....	.070	1.001	....	.....	.....	2.36	.937*	"
6	Jan.	643,482	.680	.251	.038	....	.185	1.154	....	.....	.....	2.24	.945*	"
6	Feb.	494,000	.655	.282	.037	....	.181	1.155	....	.....	.....	2.25	.905*	"
6	Mar.	562,574	.761	.266	.031	....	.059	1.117	....	.....	.....	2.42	.976*	"
6	Apr.	616,634	.638	.236	.030	....	.095	.989	....	.....	.....	2.31	.843*	"

* Price of oil per barrel.

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COST OF POWER.

73. The cost of generating power in electric-railway plants varies greatly, as one would naturally expect. The actual cost per kilowatt-hour at the switchboard includes so many items that are subject to such wide variation that it is difficult to give even approximate figures relating to cost. In fact in even the same station the cost will be higher during some months than others. The accompanying table, from the Street Railway Review, gives figures relating to the cost of generating power in some stations of considerable size. It should be noted that the total cost covers only the items of fuel, labor, supplies, water, and repairs. It does not allow for interest on the investment or depreciation of the plant. In a large number of plants the total cost, including interest, etc., will lie between 1 and 2 cents per kilowatt-hour, and in some of the largest plants it may be somewhat below 1 cent per kilowatt-hour.

74. The amount of power required to operate each car also varies greatly on different roads, and the cost per car mile is consequently subject to wide fluctuations. For the total operating expenses, including repairs of all kinds, office expenses, cost of labor, etc., per car mile is between 10 and 15 cents on a number of roads. The costs in individual cases might, however, vary widely from the above. The following shows the power consumption for a road operating about 400 cars, most of which were of the large double-truck type, and hence took a comparatively large current.

Average amperes used per car	75
Voltage	500
Kilowatts output per car	37.5
Cost of power per kilowatt-hour at power house	$.02
Cost of power per hour per car	$.75

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