ELECTRIC RAILWAYS.

(PART 2.)

RAILWAY SWITCHBOARD APPLIANCES.

1. The Recording Wattmeter.—The recording wattmeter is used to measure the total amount of energy delivered from the station. The power, or the rate at which work is done by the generators, is found by multiplying the current by the E. M. F. This gives the watts delivered at the instant at which the readings are taken. The watts multiplied by the number of hours during which they are delivered give the total work done in watt-hours. Since 1 kilowatt = 1,000 watts, the watt-hours divided by 1,000 will give the kilowatt-hours delivered, and, also, since 1 horsepower = 746 watts, the watt-hours divided by 746 will give the horsepower-hours delivered by the station. It would be an easy matter to obtain the output in horsepower-hours or kilowatt-hours for any station if the load remained constant, because all that would then be necessary would be to multiply the ammeter and voltmeter readings together and then multiply the product so obtained by the number of hours the station is in operation. This would give the total watt-hours, which divided by 746 would give the horsepower-hours. This method is, however, seldom practicable, especially in railway stations. If the load is a variable one, it is necessary to take readings at frequent intervals throughout the time during which the amount of energy absorbed is sought; then, adding the voltmeter readings together and dividing by the number of readings gives the average voltage during the time, and adding the current readings together and dividing by the number of readings gives the average current during the time under test. These two average values for the current and for the voltage, multiplied together, give the average watts, and this multiplied by the number of hours gives the watt-hours output. Where, however, the variations in load are very violent and sudden, the energy consumption for any given period of time obtained in this way is not always to be relied on, so it is necessary to use an instrument that will average up the energy delivered to the lines, and for this purpose a recording wattmeter is used on the switchboard in the best equipped stations. The Thomson meter is generally used for this purpose. The instrument used on railway switchboards is the same in principle as that previously described, though, of course, the design is considerably modified to suit it to the heavy currents that it has to handle.

2. A Thomson recording wattmeter as designed for switchboard work is shown in Fig. 1. The series coils of the ordinary meter are here replaced by the heavy copper bar *a*, through which the whole current output of the station passes, connection being made on the back of the board to the lugs *b*, *b*. Above and below this bar are the two small armatures *c*, *c*, which are connected in series with a resistance across the line, so that the current in them is proportional to the voltage. Current is led into the armatures through a small silver commutator *d*, as in the ordinary recording meter, and the reading is registered on a dial *e* in the usual way. The damping magnets used to control the speed are contained in the case *f*. The main current flowing through the crosspiece *a* sets up a field surrounding it, and this field acts on the two armatures *c*, *c*. The current in these instruments is so large that a sufficiently strong magnetic field is produced by passing the current through what is practically a portion of one turn only, whereas in the small meters several turns are required. The reading (watt-hours) is obtained in the same way as for the ordinary style of meter, and by keeping a record of the readings, the output of the station for any given interval of time may be readily obtained. This instrument is constructed so that outside magnetic fields have little or no influence on it. On some of the older styles of meters, the magnetic field

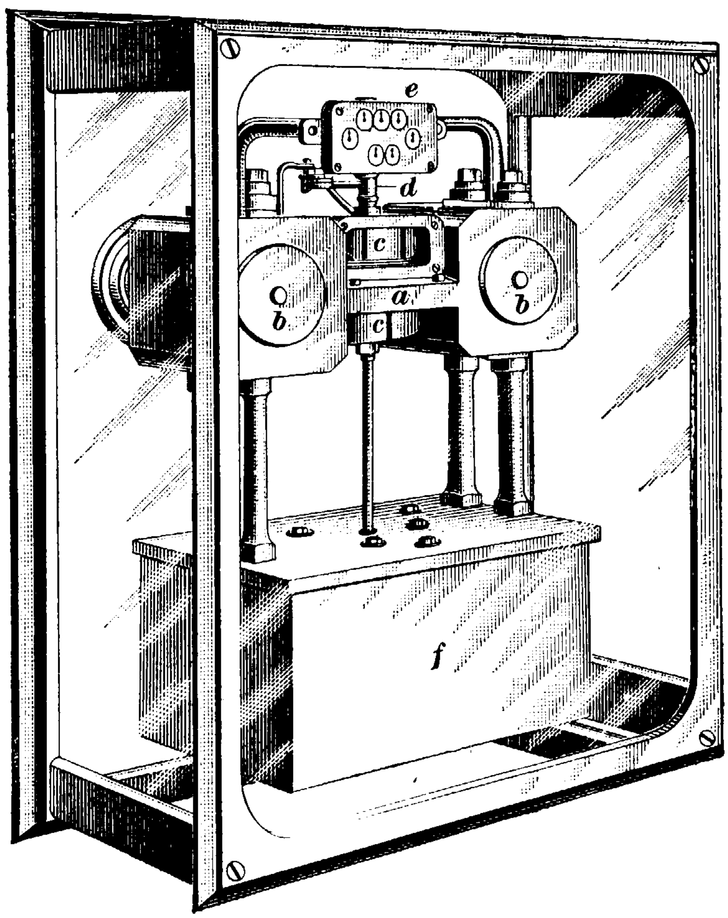

FIG. 1.

surrounding the heavy conductors on the back of the board affected the meter. In this meter any stray field affects both the armatures *c*, *c*, which are so connected that an outside field tends to turn them in opposite directions, and the disturbing effect is thus neutralized. The field set up by the instrument itself is in opposite directions on the upper and lower sides of *a*, so that these two fields propel the armatures in the same direction.

3. Car Wattmeter.—Recording wattmeters are also made in portable form for use in connection with railway work. They are very useful for making tests on the power consumption of cars. Fig. 2 shows a Thomson recording wattmeter as adapted for use on street cars. It is made so that it can stand considerable jarring without injury. It differs from the stationary types of Thomson meters in that an iron core *A* is used in the field. This gives a much

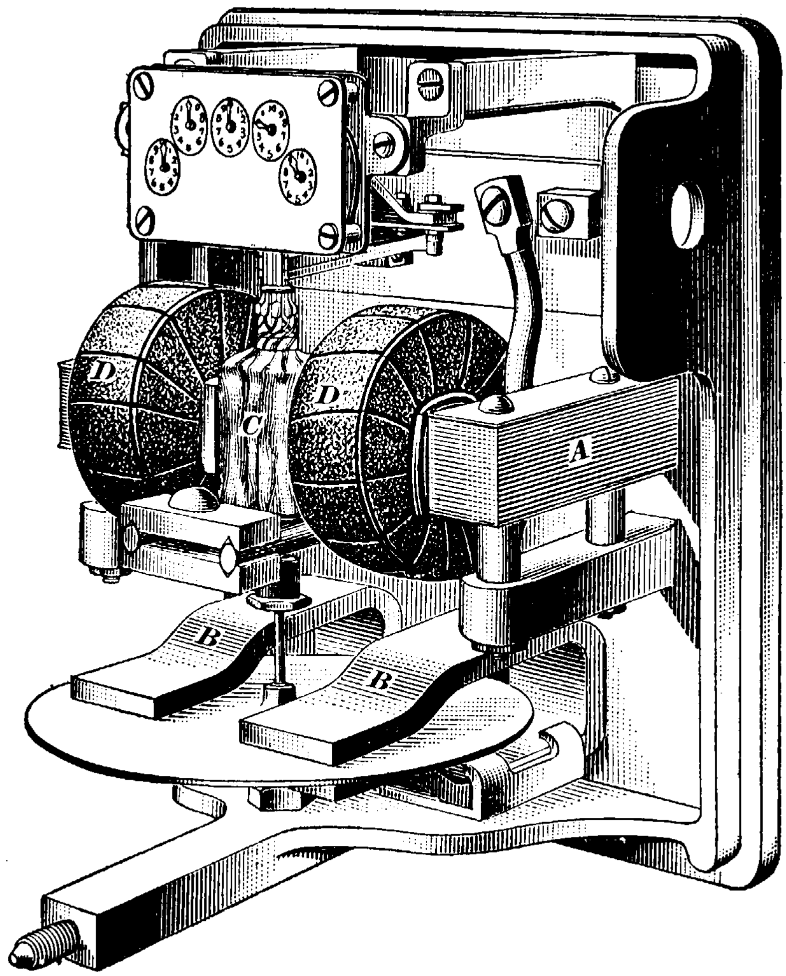

FIG. 2.

stronger field than where no iron is used, thus giving a larger twisting action on the armature, so that jarring is not so liable to interfere with the accuracy of the meter. *B*, *B* are the damping magnets used to control the speed and *C* is the armature. The current coils *D*, *D* are connected between the trolley and the motors so that the current used by the car passes through them. The armature *C*, in series with its resistance, is connected across the line between the trolley and ground so that the current in it will be proportional to the voltage supplied to the car. The ordinary style of stationary wattmeter is not suitable for car testing, as the shocks and jars would soon knock it out of adjustment.

4. Bus-Bars.—Railway switchboards are always provided with at least two bus-bars, and in case the equalizer connections are run to the board, an additional bar is necessary. One of the bus-bars (the positive) is run across to the feeder panels and there connected to the various feeders through the necessary circuit-breakers. The positive leads from all the dynamos are connected, through the main switches, to this bar. The negative bus-bar is usually much shorter than the positive, and is connected to the cables running to the rails or other ground-return connections. In many cases the negative bus-bar is not as large as the positive, because connection is made to ground between the panels, and hence the bar does not have to carry the combined current from all the machines. The positive bar, on the other hand, has to carry all the current across to the feeder panels. The bus-bars are generally of flat copper bar and are supported a few inches from the back of the board by means of heavy brass castings, which also serve to carry the current into them. Fig. 3 shows one of the common methods of mounting the bars. Too much stress cannot be laid on the fact that bus-bars should have ample cross-section. It is very poor economy to install small bus-bars on any board. If the loss due to the resistance of the bus-bars were to be considered for a few hours or days only, it would be small enough to neglect, but when it is remembered that this loss is taking place year in and year out, it is no small matter. The cost of the power wasted in a small pair of bars will more than offset any slight saving in first cost that may be effected by the comparatively small weight of copper.

From 1,000 to 1,200 amperes per square inch of cross-section is a safe allowance. Bolted connections between bars will, if carefully made, carry from 180 to 200 amperes per square inch of contact surface. If, for example, a bus-bar has to carry 6,000 amperes, its cross-section should be at least $\frac{6000}{1200} = 5$ square inches. The bar may be made of any dimensions that will give a cross-section of 5 square inches; generally, however, the bars are of flat, rectangular cross-section. In this case, for example, 5 in. × 1 in. would answer. When very large bars are needed, they are usually made of a number of comparatively thin bars with air spaces between. In any event, the dimensions should be so selected that connections may

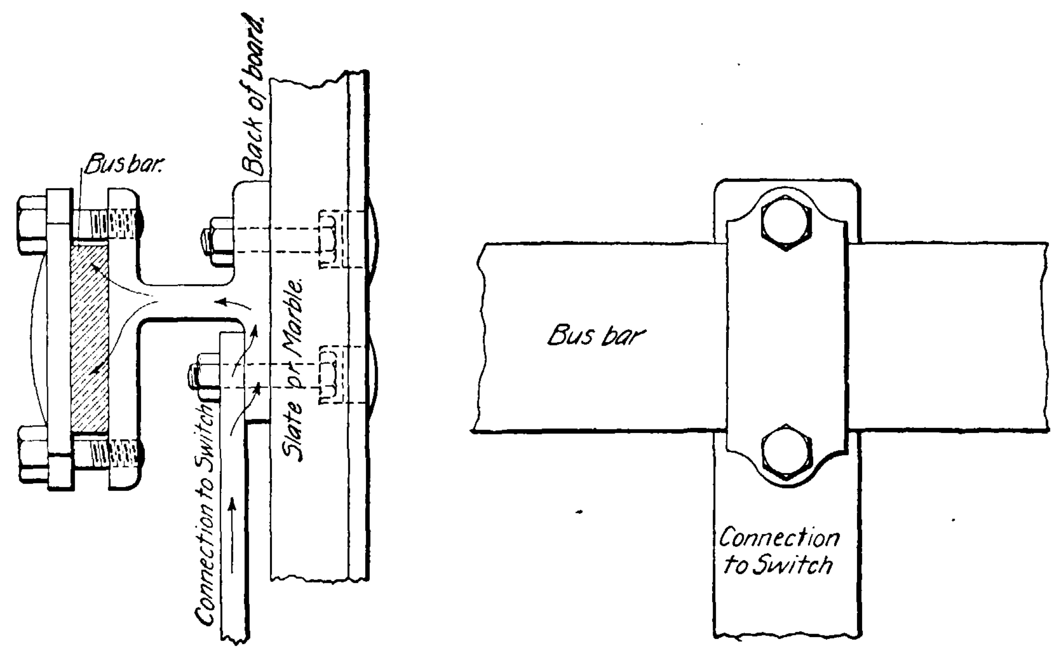

FIG. 3.

be made conveniently and give the required contact at the joints without lapping the bars too much. In the above case, a joint in the bar should have at least $\frac{6000}{200} = 30$ square inches surface, and the 5-inch bar should be lapped 6 inches. Great care should be taken to see that all joints on bus-bars or between the bus-bars and switches are well made and bolted tight. The current to be handled is large, and a poor contact, having what would, under ordinary circumstances, be called a very low resistance, may give rise to considerable local heating. If an equalizer bar is used, it is very essential that all its connections should be well made. A slight resistance at this point may interfere with the proper working of the machines in multiple. If at any time the machines fail to work together as they should, examine all the connections through which the equalizing current has to flow, to see that none of them has become loose.

5. Lightning Arresters.—A lightning arrester designed for use on a railway circuit has to operate under especially severe conditions, because one side of the system is grounded, and whenever a discharge passes through the arrester a short circuit results; besides, the pressure on railway systems (500 to 600 volts) is comparatively high. A great many different types of air-gap arresters have been used and are in all cases provided with some device to extinguish the arc following the discharge. In the General Electric Company's arresters the arc is extinguished by a magnetic blow-out arrangement, very similar to that used on their circuit-breakers. In the Garton arresters the arc is formed in a confined space and drawn out until it is broken, the action being almost instantaneous. In one type of Westinghouse arrester the discharge leaps across charred grooves in a confined space between two lignum-vitæ blocks and is practically smothered out. All these arresters are used for railway work. Of course, no matter what type is used, it is liable to fail at times, and arresters should be used liberally out on the lines instead of depending altogether on the station arresters.

6. Westinghouse Tank Arrester.—Fig. 4 (*a*) and (*b*) shows a style of arrester that has been used extensively for railway stations. This device, which is known as the **tank arrester,** differs materially from the ordinary air-gap arresters. The object and action of the tank arrester is to ground through a water resistance that part of the circuit that is to be protected. The arrester is used only when there is danger from lightning, and during this time the line to be protected is in actual connection with the ground, so that a lightning discharge does not have to jump an air gap in order to get to the earth. An air-gap arrester requires an abnormal potential to force the

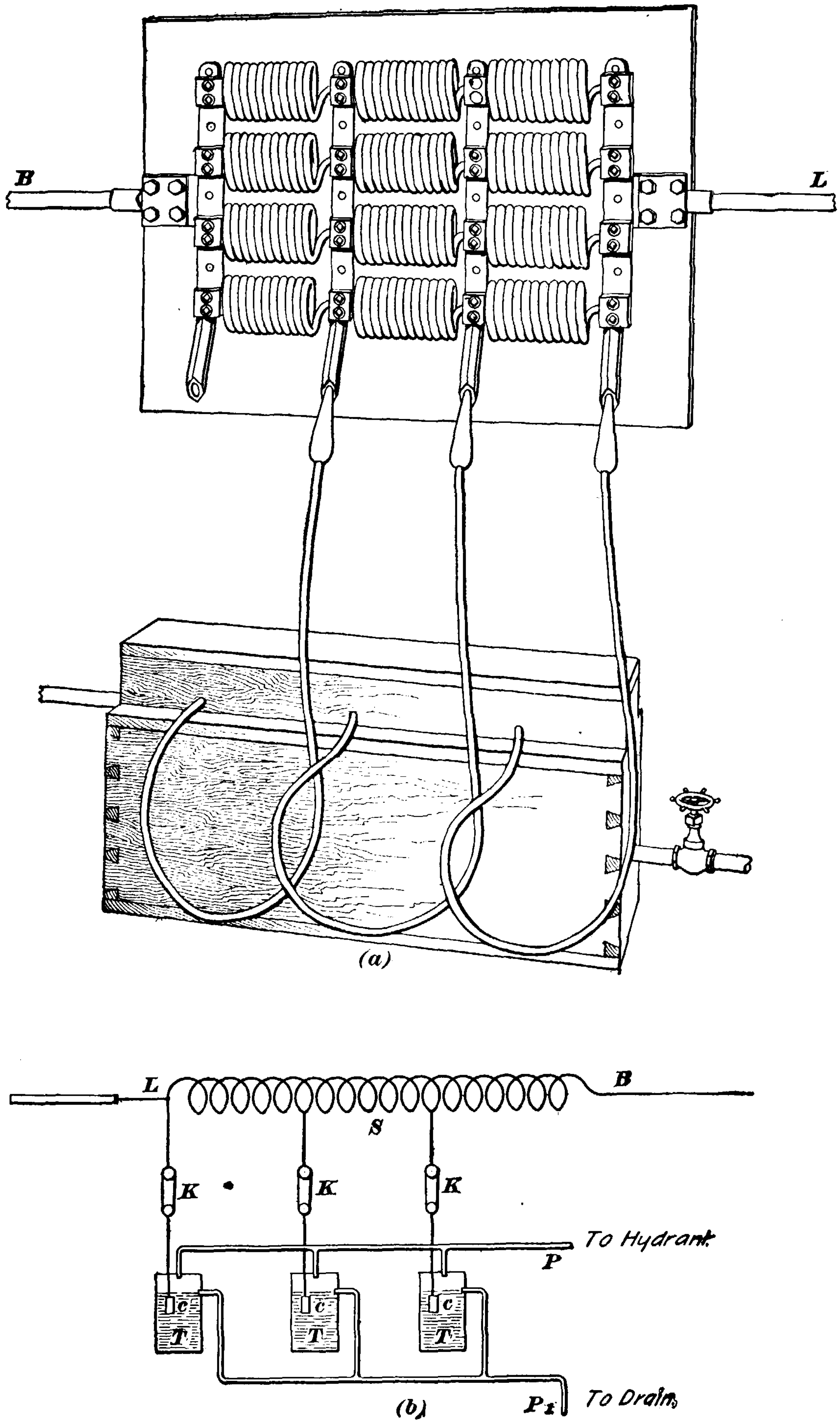

FIG. 4.

discharge across the gap; but the tank arrester works all the time and equalizes the line potential before it has a chance to reach a dangerous value. The strong point in favor of a tank arrester is that it passes off the induced charges due to overhanging clouds before they give rise to a line pressure high enough to cause a strike. The tank consists of three chambers *T*, *T*, *T* (*b*), each of which is kept filled with water by means of a stream that flows in at the same rate as it is allowed to flow out through an iron pipe to earth. Plunged into the water of each tank is a block of carbon *c* that connects directly to the device to be protected. The coil *S* shown in the figure constitutes a choke, or reactance, coil that makes the lightning pass through the arrester to ground in preference to going through the machine to ground. In Fig. 4 (*b*), the end *B* of the choke coil is connected to the + bus-bar and all on the station side of the choke coil is protected. *L* is the line or feeder over which the discharge of lightning is apt to come in. Plugs *K* connect the several sections of the choke coil to the several tanks in such a way that the choke-coil sections are all in series, and the tanks offer successively three different paths to earth, so that if a discharge misses the first tank, it still has the second and third tanks through which to reach the earth. The carbon plates are the positive pole of the arrester, the tanks and water the negative pole. It is thus seen that when the plugs are in place there is a direct connection from the line through the water to the ground. Current, therefore, flows through the arrester all the time it is connected, and for this reason it is only used when there is danger from storms. Of course, this arrester wastes a certain amount of current (about 3 amperes for each carbon in use), but it gives efficient protection, and the waste of current is a small item compared with the damage that might be done if the lightning discharges were not carried off.

7. Where ordinary air-gap arresters are used, each feeder should be equipped with one. Sometimes these feeder arresters are placed on the back of the board, but more often they are placed at a point near where the feeders enter the station and may be either inside or outside of the station. In addition, each generator is usually equipped with its own arrester, which is mounted on the back of the generator panel.

SWITCHBOARD CONNECTIONS.

8. The various devices that go to make up a railway switchboard have been considered, and we will now look at the connections necessary for an ordinary board. Of course, switchboards may differ considerably in their connections and yet accomplish the same purpose, so that it is not possible to lay down any fixed rules regarding them. Fig. 5 shows connections suitable for a board similar to the one shown in *Electric Railways*, Part 1. The various devices have been numbered to correspond in the two figures, and a number of minor fittings and connections have been omitted in order not to confuse the drawing; for example, connections are not shown for the switchboard or instrument lamps or for the exciting circuit of the Thomson ammeters; if Weston instruments were used, these latter connections would not be required. Only two feeder panels are shown, as the connections for all of them are alike. In this diagram the equalizer switch *E* is shown mounted on a stand near its machine, as this is the practice followed in the more recent plants. The + and — leads from the generators lead directly to the lower posts of the main switches. The upper posts of the + switches connect directly to the + bus-bar *A*. The upper posts of the — switches connect, through the ammeter shunt *B* and circuit-breaker *C*, to the — or rail bus-bar *D*. Note that the ammeter and circuit-breaker are not connected in the + side. This is because the equalizer is connected to the + side and the machine might be sending current through the equalizer, in which case the current in the + side on the switchboard

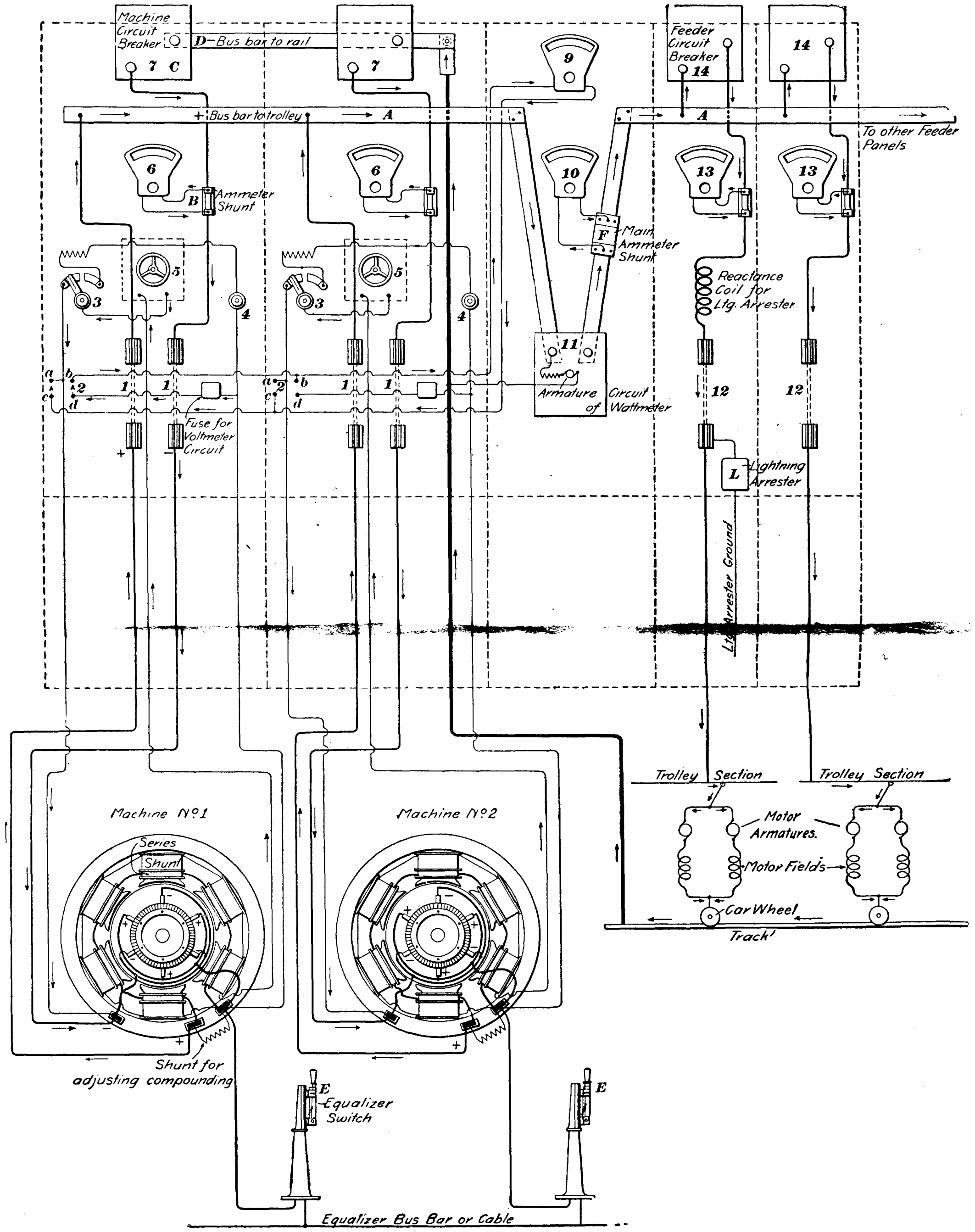
Machine Circuit Breaker
D–Bus bar to rail
+Bus bar to trolley
A
Feeder Circuit Breaker
To other Feeder Panels
Ammeter Shunt
B
Main Ammeter Shunt
F
Reactance Coil for Ltg. Arrester
Armature of Circuit Wattmeter
Fuse for Voltmeter Circuit
Lightning Arrester
L
Ltg. Arrester Ground
Trolley Section
Motor Armatures.
Motor Fields
Car Wheel
Track
Machine No. 1
Machine No. 2
Series
Shunt
Shunt for adjusting compounding
Equalizer Switch
E
Equalizer Bus Bar or Cable

FIG. 5.

would not be the total current delivered by the machine. Under such circumstances, an ammeter connected in the + side would not give true indications. Of course, the equalizer will work all right no matter whether the pole it is connected to is + or −, the only condition being that it must connect together the points where the brushes are connected to the series winding.

The + bus-bar *A A* is carried through the wattmeter as indicated at *11*, so that the whole current passes through *11* on its way to the feeder panels. The shunt *F* for the total-output ammeter *10* is also connected in series with *A* between the generator and feeder panels, so that *10* indicates the total current.

The voltmeter is connected to either machine by means of the plug receptacles *a*, *b*, *c*, *d*; *a* and *d* are in each case connected to their respective dynamo terminals, while *c* and *b* are connected to the voltmeter. When the plug is inserted, *a* is connected to *c* and *b* to *d*, thus giving a reading. Note that a voltmeter reading may be obtained even if the main switches are open; this is essential, because the voltage of a machine must be adjusted before it is thrown in parallel with another.

On the feeder panels, the circuit-breaker, ammeter shunt, and feeder switch are simply connected in series. If a lightning arrester is used, as indicated on one panel at *L*, the connection between the ammeter shunt and the feeder switch is usually coiled up, as shown, in order to form a reactance, or choke, coil to help keep the lightning discharge out of the machines.

SPECIAL ELECTRICAL APPLIANCES.

9. In describing the foregoing apparatus required for the power station, we have considered only that to be found in the ordinary station operating at 500 volts and supplying the current direct from the machines to the various parts of the system. On some roads, however, special conditions arise where one or more of the feeders have to run to points much farther distant from the station than others. Almost every power station has several feeders running from the bus-bars out to different sections of the trolley wire. Some of these feeders will be short and there will not be very much drop in them ; others will be long and the line loss in them may be so great as to seriously interfere with the operation of the cars on the distant sections of the road. Of course, the voltage of the bus-bars in the power station could be raised by raising the voltage of all the dynamos that feed into them, but this would also raise the voltage on the short feeders that do not require a high voltage. In order to supply a high voltage to those feeders that require it, a number of different schemes are used.

10. Use of Auxiliary Bus-Bar. — Fig. 6 shows one method that is available when one of the machines in the station can be set apart for the supply of these high-voltage feeders. It consists simply in supplying the feeder boards

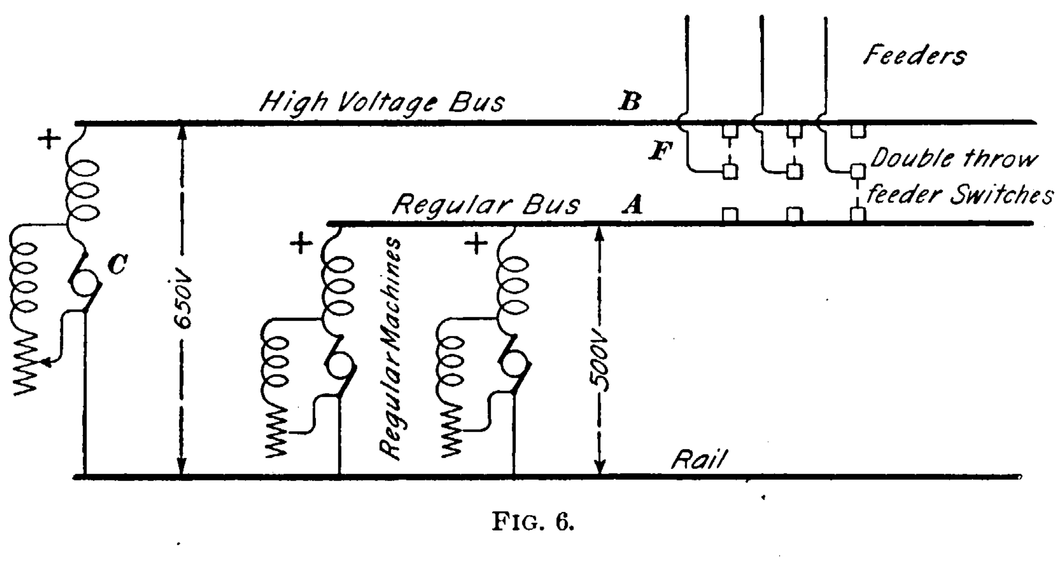

FIG. 6.

with an additional bus-bar *B*, which is connected to machine *C*. This machine, for example, might generate 650 volts, while the regular machines feeding into + bus-bar *A* generate the usual 500 volts. The feeders are connected to double-throw switches *F*, so that they may be run on either the high or low bus ; hence, if any feeder is heavily loaded or if it runs to an outlying point, it may be connected to the high-voltage machine *C* by throwing its switch up; at the same time the other feeders would be supplied from *A* at the usual voltage.

USE OF BOOSTERS.

11. A separate machine is not always available for use, as described in the last article, in which case a **booster** is generally employed to raise the voltage for those feeders that require it. The term booster is used in railway work for a number of different appliances. It is used to designate a machine to raise the voltage on outgoing feeders, and it is also used in reference to the machine for regulating the charge and discharge of storage batteries. In all cases, however, the term booster carries with it the idea of a machine for changing voltage, and we shall now consider only the type of machine used to increase the voltage supplied to outgoing feeders; the storage-battery booster will be taken up later.

12. Let us take the case of a single large dynamo feeding into a pair of street-railway bus-bars from which run out a long feeder and a short one, as shown in Fig. 7. In this figure, *A* represents the power-house dynamo feeding into the two bus-bars *a b* and *c d*. Running out from the positive bus-bar *a b* are two feeders *e* and *f* that supply the two sections of trolley wire *C* and *D*, respectively. *M* is a car somewhere out on the line. Feeder *e* is so short that no excessive drop in voltage takes place through it, so that it does not require an increased voltage; but feeder *f*, being much longer, does. In order to supply the additional voltage, the armature of a dynamo *B* is connected in series with the feeder *f*. Any kind of dynamo can be used as a booster, but some dynamos are much better adapted to this service than others. The series dynamo is used most largely for this work in railway plants, because, between certain limits of load, its ability to add voltage to the circuit increases directly as the demand made upon it. In other words, all the current that goes through the feeder passes also through the series field of the booster and enables it to generate voltage in proportion. It is easy to see, then, that since the booster must carry the entire load of the feeder or feeders with which it is in series, its current capacity must be equal to the entire current required by the cars that run on the trolley sections fed by the feeder or feeders connected to the booster. Although the current capacity thus has to be large, the voltage generated by the booster is usually only a fraction of that generated by the main dynamo, so that the *watts* output of the booster may be considerably less than that of the main dynamo. In many instances, special switches have been provided, so that one of the regular 500-volt dynamos, running ordinarily as a dynamo in multiple

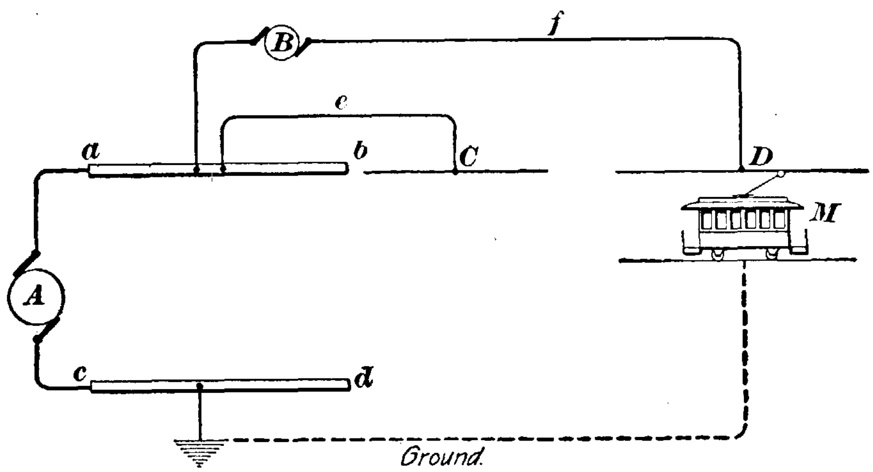

FIG. 7.

on the bus-bars with the other dynamos in the station, can be cut out of the regular dynamo service and cut into series with one of the feeders as a booster. Where a dynamo can always be spared for such service, such an arrangement saves the expense of buying a special machine for the work. It is rarely the case, though, that a feeder requires to be boosted as much as 500 volts. The number of cars supplied by the feeder may call for the full current-carrying capacity of the available 500-volt compound-wound dynamo, but need not call for its full voltage. In such a case, it is the custom either to cut out the shunt field on the dynamo and resort to the series field alone or to use some special method of separately exciting the shunt field to any desired degree and supplement its field with that due to the series coils. It is easily seen that a dynamo that is run at normal current, but under the normal voltage, is not running at full load, and is not, therefore, running with the greatest attainable economy. The question of connections for a *convertible booster and dynamo* will be taken up later.

13. Boosters for use in railway service can be bought specially wound to handle any current at any voltage to suit the conditions of the particular service to which they are to be put. Such machines are usually designed to run from a steam engine direct-connected or from a motor whose armature is coupled to the same shaft and whose bedplate supports the frame of both machines. The booster plant can be installed in the power station itself or it can be put out on the line. On account of the cost of attendance, the power station is the best place for it, unless there are conditions that prohibit its being placed there. Where each feeder supplies its own section of trolley wire, as shown in Fig. 7, it makes no difference where the booster is located so long as it is in series with the feeder, because the booster can never be called on to carry any current except what goes to section *D*. But on such feeder construction as that shown in Fig. 8, it makes a great difference, especially to the

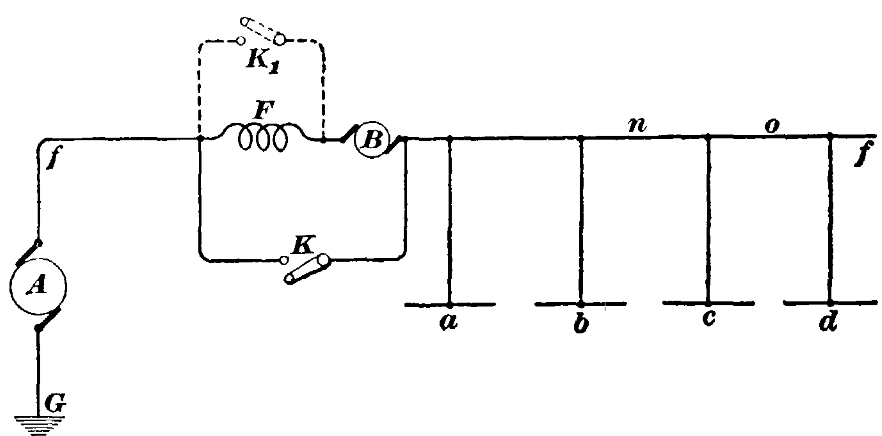

FIG. 8.

booster itself, where it is placed. In Fig. 8, several sections of trolley wire *a*, *b*, *c*, *d* are connected to the same feeder *f f*. If the booster is cut in at *B*, it must carry the current called for on all four sections; if it is cut in at *n*, it will carry the current for the *c* and *d* sections only; while if it is cut in at *o*, it will have to carry only the current that goes to section *d*; so that a booster put into a feeder at *B* would have to have four times the current-carrying capacity of one put in at *o*. Most feeder work at the present time is laid out after the plan shown in Fig. 7, so that the booster can be placed in the power station as well as not.

14. Operation of an Engine-Driven Booster.—The same rules that are observed in the care and operation of a dynamo of any other kind hold good in the case of the booster; but on account of its unusual relationship (being in series) to the rest of the circuit, it has some peculiar points not found where dynamos are run in multiple. In the first place, great care must be taken to connect the machine properly, so that it will add its voltage to that of the power house. The polarity of the booster may be determined by means of a voltmeter, as this is the most convenient method. We will suppose that the booster, which is a series machine, is not connected in circuit, but is running at about half speed. Short-circuit its terminals with a piece of light fuse wire, so that it may be able to generate and at the same time note the direction in which the needle of a voltmeter attached to the terminals deflects. The negative terminal of the booster must connect to the power-house end of the feeder and its positive terminal to the line side of the feeder; for it must be borne in mind that connecting the booster in series with the feeder is really connecting it in series with the dynamos that supply the power-house busbars, from which the feeder draws its current, so the positive side of the generator must go to the negative side of the booster. After the circuit is once closed by connecting in the booster, the line current dictates the polarity of the booster voltage, so this polarity cannot be wrong, unless the machine itself is incorrectly connected. Since for given connections, the booster, like any other dynamo, can generate only for one direction of rotation, it follows that if the direction of rotation proves to be such that the machine cannot be made to generate even on short circuit through the light fuse wire, either the field or armature terminals must be reversed or the booster must be turned end for end so that the direction of rotation of the armature may be reversed. If the booster is direct-connected to the engine, turning it end for end is of course impracticable, so that it is best to reverse the connections of the field or armature. If the booster is direct-connected to a motor, the best plan is to reverse the shunt field on the motor.

Reverting to the engine-driven booster: since the booster is a series machine and since series machines run in the opposite direction as motors from what they do as dynamos, the connections remaining the same in both cases, the effect of throwing the booster into service with either its field or armature leads crossed would cause it to keep on running in the same direction as a motor, with the result that, instead of boosting the voltage of the feeder, it would insert in the circuit a counter E. M. F., the amount of which would depend on the value of the current in the feeder; in this case, the voltage in the feeder would be made less instead of greater. The next mistake possible is, after getting the fields and armature of the machine properly connected, so that the machine can act as a dynamo, to get the dynamo as a whole cut into the feeder electrically wrong end to, so that its polarity opposes that of the dynamo supplying the feeder.

15. Cutting the Booster In and Out.—The principle involved in cutting a booster in and out of service is very much the same as that used to cut in and out arc-light dynamos that run in series on the same load. As a matter of fact, the feeder, or the dynamo that supplies it, and the booster are just as much in series as are two arc-light dynamos on a lamp load. In Fig. 8, *B* and *F* are the armature and field, respectively, of the booster connected in series with the feeder at the power house and driven by a steam engine not shown. *K* is a switch across the outside terminals of the booster and K_1 is a switch across the terminals of its field. There are several ways of rendering a booster electrically inactive. One way is to short-circuit its field by means of a switch connected across it, as shown at K_1. In this case, the armature continues to carry the same amount of current as the feeder, but even if the booster engine is kept turning at full speed, the pressure of the feeder current is not raised any, because, since the field is cut out, no voltage is generated within the armature itself.

Another way to cut the booster out of active service is to simply short-circuit the field and shut the steam engine down; in this case, the feeder current continues to pass through the armature of the booster, and to avoid unnecessary drop and heating, it is well to provide a switch such as K, so that the whole machine can be cut out *after* it is shut

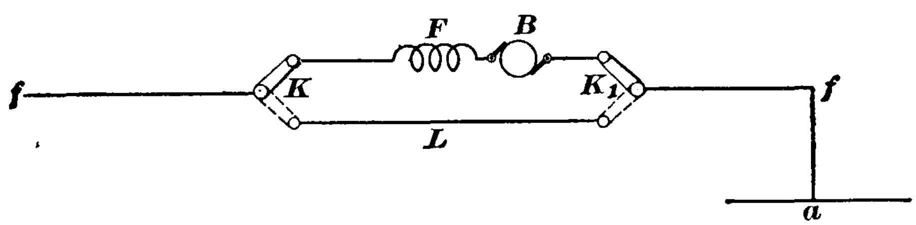

FIG. 9.

down. Under no circumstances should the switch K be closed while the booster is up to speed, for, since the machine is connected to generate, the effect would be to have it act as a dynamo on short circuit through the local path K–F–B–K. Nor should the engine be started up with K closed unless K_1 is closed also, because the same thing will happen.

The safest arrangement of all is to install a combination switch that will open the booster circuit at both ends and put a bar of copper in its place to close the circuit. Such a switch is shown in the sketch in Fig. 9, where f f is the feeder; a, the trolley section that it feeds; $F B$ is the booster; and L is the bar of copper. K and K_1 are two double-throw switches, shown at opposite ends of the booster in the diagram, but in practice they are mounted on the same base plate and operated by the same handle. When the switch blades are in the full line position, as shown in the figure, the booster is in service; but when the switch blades are thrown down to the dotted position, the booster is cut out at both ends and the copper bar *L* takes its place. This method has the advantage that the machine is entirely cut out and *dead*, as it is termed.

16. Motor-Driven Booster.—When a motor is used to drive the booster, the shunt-wound type of motor is invariably selected, because it runs at practically constant speed no matter what the load on it may be. As far as the booster itself is concerned, it does not matter whether it is driven by a motor, a waterwheel, or an engine as long as the speed is kept up so that it can provide an E. M. F. proportional to the current demand on the feeder. On the other hand, the use of a motor for driving widens the field for electrical troubles in so far as the motor takes the place of the steam engine. Especially is this the case where the booster unit must be placed out on the line. In either case,

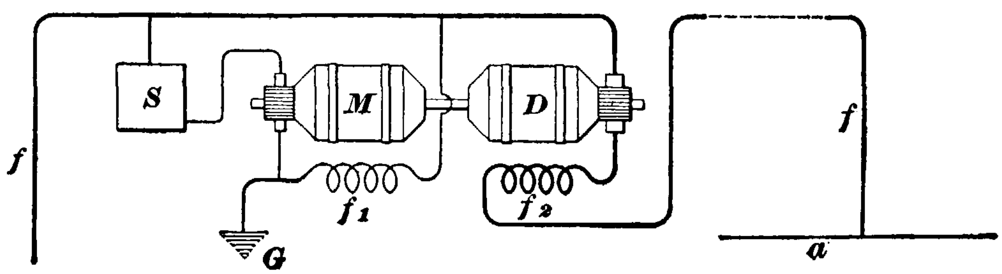

FIG. 10.

whether the booster is in the power house or out on the line, the motor is connected in the same way as any other shunt motor; that is, there must be facilities for starting and stopping it and also for protecting it in case there is trouble on the line. As shown in Fig. 10, the booster as a whole is put in series with the feeder, and the motor as a whole is put across the line, i. e., between the trolley and ground. In this figure, *M* is the motor armature, which has the starting box *S* in series with it; f_1 is the shunt field of the motor; *f f* is the feeder supplying trolley section *a*; *D* is the booster armature; f_2 is the series field, and *G* is the ground or rail return. If the booster unit is out on the line, it is not difficult to see

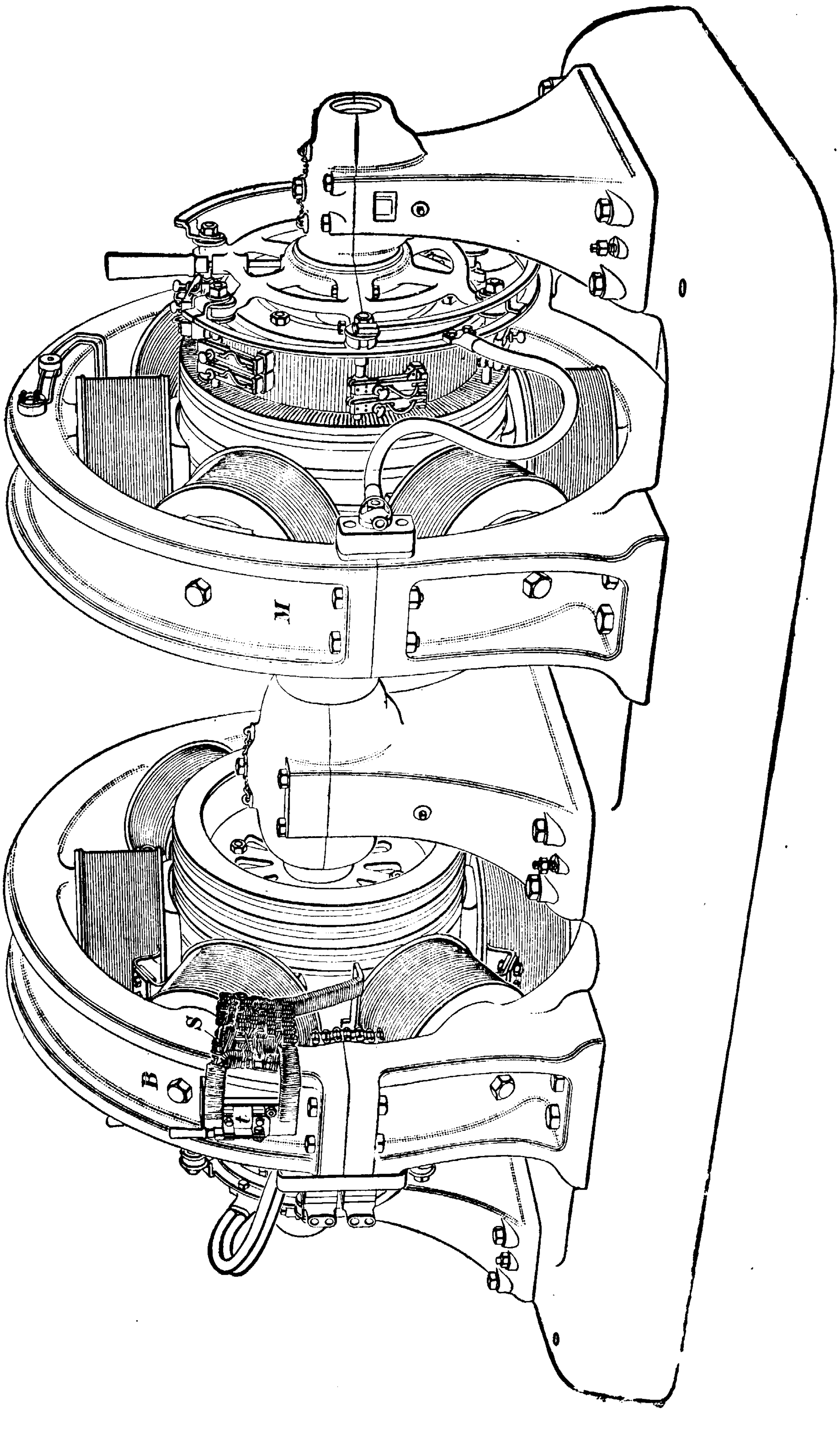

FIG. 11.

that trouble might be brought on some time by the power going off the line, in which case the motor would stop, as there would be no power to run it. Then, when the power comes on again, the motor being across the line, produces a prolonged short circuit. There would be an abnormal flow of current through the armature because the motor would be standing still and generating no counter E. M. F. On this account, when the booster is put in a place removed from the power house, it must either have attendance all the time or it must be provided with very refined devices for starting and stopping it in time of trouble.

As a rule, though, in present practice, if a single feeder is to be boosted and the additional E. M. F. required is not too great, the boosting is done by putting one of the regular dynamos, compounded to a high degree, on the feeder. It is sometimes the custom to put the booster in series with several feeders which run out about the same distance from the power house or whose load demands are, for other reasons, about the same, in which case the booster cannot be put out on the line, but must be put in the power house, where it can be cut in at a point common to all the feeders to be boosted. When the booster is installed in the power house, the fields of the motor are excited from the station bus-bars, and, as a rule, the motor armature is operated from that source. The booster field and armature are, as usual, put in series with the feeder or feeders to be boosted. Fig. 11 shows a type of motor-driven booster made by the General Electric Company. There are two separate armatures, each of which has its own frame and pole piece, but the two frames are mounted on the same bedplate. *M* is the shunt-wound motor driving the series booster *B*; *S* is a shunt across the field of the booster, which can be cut in or out of service by means of switch *t*.

17. Convertible Booster.—As previously mentioned, it sometimes becomes desirable to adapt one of the regular station dynamos to booster use. In such a case, provision is made so that the machine can be used either as a dynamo in the regular service or as a booster to raise the voltage on a feeder or group of feeders.

In Fig. 12, *L* is the power-station dynamo; its positive terminal goes to the positive bus-bar, marked + in the figure. The negative terminal of the dynamo connects to the negative bus-bar; and the junction of the dynamo series field and brush holder is connected to the equalizer bus-bar, used only when more than one dynamo is carrying

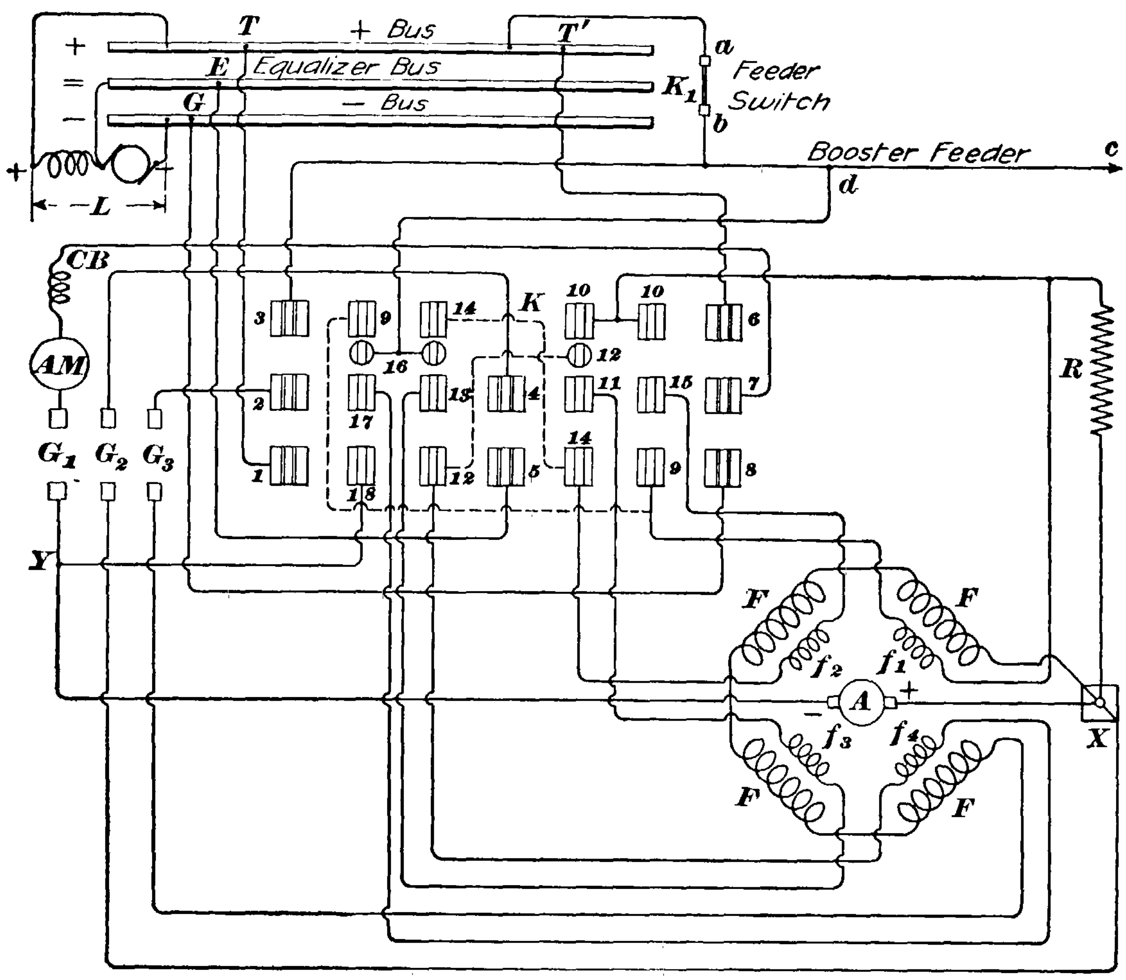

FIG. 12.

the load. In the lower right-hand corner of the figure the booster is shown. *F*, *F*, *F*, *F* are the series coils of the booster and f_1, f_2, f_3, f_4 are the shunt-field coils. The circle *A* in the center is the booster armature. G_1 G_2 G_3 is the generator switch. The switch *K*, with the numbered blocks, is used for connecting the machine either as a booster in series with the booster feeder or as a dynamo in multiple with dynamo *L* or whatever other dynamos may be carrying the load. When the switch *K* is thrown up, the machine acts as a booster, but before it can do so the feeder switch K_1, which short-circuits it, must be opened. When switch *K* is thrown up, block *2* connects to block *3*; block *7* to *6*; blocks *9*, *14*, *16*, *17*, and *13* connect together; blocks *10*, *11*, *12*, and *15* connect together. It will be noticed that the series coils of the machine are all connected in series, the same as on any dynamo or motor; each shunt coil, however, has a pair of leads of its own, because when the machine is used as a booster, all the shunt coils must be in multiple, and when the machine is used as an ordinary dynamo, all the shunt coils must be in series as usual. The two ends of the booster circuit are *T'* and *b*; the two ends of the switch K_1 are *a* and *b*; points *T'* and *a* are practically the same point, being connected by a few feet of stout copper bus-bar. It is easily seen, then, that if switch K_1 is closed, the two ends of the booster circuit are brought directly together; in other words, the machine is short-circuited. When the switch K_1 is open, however, the only way that current from the positive bus-bar can get out on the line to the cars by way of feeder *b c* is to go through the booster, which, if its polarity is right, adds its voltage to that of the line dynamos. Neglecting for the present the shunt field of the booster and assuming that switch K_1 is open, the path of the current through the power-station dynamo, the booster, and the booster feeder is $L+$ $-T-T'-6-7-C\ B$ (circuit-breaker) $-A\ M$ (ammeter) $-G_1-A-$ $-A+$ $-X-F-F-F-F-G_3-$ $2-3-c$ through the cars, back to the station by way of the rail to the negative side of *L*. When the switch K_1 is closed, the path of the current is $L+$ $-T-T'-a-K_1-b-c$, and so on, the booster being cut out. The booster field is excited not only by the series coils, but also by the shunt coils, which are all in multiple, thereby greatly decreasing the resistance of the shunt-field circuit, so that it may be excited by being connected in parallel with a certain length of the feeder, and thereby subjected to the voltage drop in that length. One end of the f_1 shunt-field coil goes to block *9* and the other to block *10*. The ends of field coil f_2 go to blocks *14* and *15*; the ends of f_3 to blocks *11* and *13*; the ends of f_4 to blocks *17* and *12*. The result of this arrangement is that when the booster switch is thrown up, the positive ends of all the shunt coils go to one set of blocks that are connected together and the negative ends to another set of blocks that are also connected together. The positive ends go to blocks *10*, *11*, *12*, and *15*, which are all connected together by the switch blade when the switch is thrown up. The negative ends go to blocks *9*, *13*, *14*, and *17*. Double block *16* connects to the feeder at some point *d*, determined by the amount of feeder required to give the drop necessary to excite the fields sufficiently. Double block *16* connects to the negative ends of the fields when *K* is thrown up. Double block *10* connects to the positive ends of the fields when *K* is thrown up. The connecting wire from double block *10* leads through the field rheostat *R* and the block *X* to the positive side of the booster armature.

18. When the booster switch *K* is thrown down, blocks *2* and *1* are connected together; block *17* is connected to block *18*; block *13* to block *12*; *4* to *5*; *11* to *14*; *15* to *9*; *7* to *8*. In both positions of the switch, the large blocks are connected with the main booster circuit and the small blocks with the shunt-field coils. The two ends of the booster, which is now connected across the trolley and ground bus-bars as a regular generator, are *T* and *G*; the path of the booster current is $A+ - X - F - F - F - F - G_3 - 2 - 1 - T$, out on the line by way of the switch K_1 and the feeder *c* to the cars, through the motors to the rail, along the rail back to the ground bus-bar *G* in the power house, through $8 - 7 - C\,B - A\,M - G_1 - A -$. The current contributed by the booster joins the current contributed by the station dynamo *L* at point *T*. One end of the shunt-field circuit is at block *X*; the other end is spliced to the negative armature wire $A - - G_1$ at *Y*, and the path of the current through the shunt field is $A+ - X - R - f_1 - 9 - 15 - f_2 - 14 - 11 - f_3 - 13 - 12 - f_4 - 17 - 18 - Y$. The shunt coils are now all in series and the current flows through them in the same direction that it flows through the series-field coils.

19. Economy of the Booster.—The booster may be regarded as an electrical economizer, not in the same sense of the term that holds good when applied to such devices as a condenser for exhaust steam or the heater for feed-water used in a steam plant, because these devices effect a still further economy under conditions that are already comparatively good, but in the sense that at times it may relieve a hopeless condition that nothing else will without great cost.

Suppose, for example, that a certain section of a road is a long distance from the power house and operating with a large drop. The voltage at the cars will be low and they will run slowly. If a booster is installed, the voltage at the cars will be raised and they will run faster. The result will be that, while the current they draw from the power house may be nearly as large as it was before, because the series motor such as used on street cars takes a certain current for a given effort no matter what the speed may be, the cars will not require the current for so long a time; hence, more cars may be operated. The booster, therefore, actually increases the working efficiency of the system and improves a condition that could not be otherwise bettered without a very large expenditure for copper in the overhead feeders.

The booster, of course, requires power for its operation. This fact becomes more apparent when the booster is put out on the line and a motor used to run it; in this case, there is not only a loss within the booster itself, but there is an additional loss in transmission, because the booster motor draws current from the line at low pressure and gives it back to the feeder at high pressure, but the generator end of the booster can never give back to the line as much energy as the motor end takes out of it. The service rendered by the booster, however, cannot always be estimated by the amount of energy that it consumes. There are conditions under which no other means outside of a substation or a new power house will make the car service practicable. The feeder to be boosted may be so long as to render the addition of enough copper out of the question. On account of low voltage, and hence low car speed and unsatisfactory service in general, the public will refrain from riding on that part of the line except when they cannot help themselves. The addition of a booster will enable the cars to run on time and draw the travel. It is a well-known fact among street-railway men that for a given time table, low voltage on the line is much harder on the motors and controllers than high voltage, because, in the first place, the motorman must get his quick start by throwing the controller far around before the car has run any distance; and, in the second place, each car, instead of coasting, has to take current in order to make its time.

STORAGE BATTERIES IN CONNECTION WITH ELECTRIC RAILWAYS.

20. Storage Batteries on Cars.—The storage battery as applied directly to the running of cars and stationed on the cars themselves has not, for several reasons, scored the degree of success that it has attained in other lines of work, the main feature militating against the direct application of storage batteries being their excessive weight. One of the storage-battery traction systems that has most nearly approached success in America is that installed on the system now known as the Chicago Electric Traction Company. It is a fact beyond dispute that the overhead-trolley system is far more economical than the storage-battery system, and the Chicago advocates of the latter system do not claim otherwise, but they state that on their own line, where the erection of overhead work was not allowed by the city, the storage system has been operated on a profitable basis. They operate about 25 cars over a line 30 miles long, and for these 25 cars 40 batteries are provided. Each battery is composed of 72 cells and weighs, with its tray, about 3 tons. The motors are mounted on the outside of the axles, leaving the space between the axles for the tray of batteries. The weight of the batteries renders their handling a problem that has been very successfully and economically worked out by providing an automatic shifter, which does away with manual labor entirely in effecting a change of batteries. All connections are made automatically by means of spring contacts.

Each storage cell when fully charged gives an E. M. F. of 2.18 volts, so that 72 cells would furnish a voltage of $72 \times 2.18 = 157$ volts. Each car is provided with a single 50-horsepower motor wound for 135 volts, so the motor is subjected to an excess pressure of 22 volts, but seems to be in no way harmed by it. It is a well-known fact that the E. M. F. of a storage battery becomes less as the charge is paid out. In the case in question, the batteries are charged until their E. M. F. is 2.18 volts per cell and are allowed to run until the E. M. F. falls to 2 volts. During this drop in E. M. F., the car makes from 10 to 12 miles. The batteries would run the car farther than this, but experience has shown that this is the most economical run to get out of the car before recharging. As far as the actual running life of the batteries is concerned, this is limited only by the disintegration of the positive plates. The old-time weakness of buckling does not give any trouble on this road, but it is found to be a great advantage to thoroughly wash and clean the plates after the completion of each 4,000 miles. If the car averages 100 miles a day, this would mean a cleaning of the plates every 40 days, or, say, every month and a half.

In charging the batteries, a current of 160 volts pressure is first applied; as the charge increases and the E. M. F. of the battery rises, the charging voltage is raised to 170, and finally to 180 volts. The motors used on such a system as this must, of course, be especially designed for the lower voltage and the larger current. A 50-horsepower motor to be run on a 135-volt line calls for a current of $\frac{50 \times 746}{135} = 276$ amperes

—a current which, if it had to be transmitted to a distance for any number of cars, would cause a prohibitive line loss. In this case there is no line, and therefore no line loss, and on account of the low voltage, insulation breakdowns are very rare.

21. One of the most valuable features of the storage battery is its ability to deliver heavy currents for short intervals. It is therefore very valuable as an auxiliary in power plants or substations to steady the load carried by the dynamos or rotary converters. In almost all power houses there are certain times of the day when the dynamos are called upon to run at their full capacity in order to carry the load. At other times of the day, when the traffic is light, there may be very little demand on the dynamos and perhaps only half of them may be in use. The average load on the power house has a certain value, but the maximum load may be easily twice this value. It is easily seen, then, that while the machine capacity of the power house should be adequate to meet only the requirements of the average load in order to fulfil the best possible conditions of economy, yet, in order to meet the actual requirements of the service, it is necessary that the machine capacity of the power house should be able to cope with the maximum load; otherwise, just when it is most urgent that the cars should run on schedule time, the station will not be able to supply enough power.

In a small power house it is usually necessary that the machine capacity should be adequate to meet the demands of the maximum load. But in such a case, the actual amount of machine capacity represented by the difference between the maximum and average load is small compared to the difference between that of a large power house, and so does not amount to as much from a money point of view. In a large power house the difference between the maximum and average loads may amount to several thousand horsepower, and this represents a very heavy investment in the way of machinery that may be idle a great part of the time.

22. Methods of Using Storage Batteries.—One way of expressing the fact that the storage battery helps out the power-station dynamos during their period of heaviest load is to say that the battery takes the **peak** of the load. The method of carrying this out is about as follows: The storage battery as a whole is put in multiple with the dynamos, being connected to the same bus-bars; during the hours when the load is light, the dynamos not only supply the outside load, but they charge the battery as well. When the rush hours come on, the battery helps the dynamos on the outside load. In this way the engines and dynamos are kept more nearly at full load all the time.

Storage batteries may be installed either as an aid to the power-house dynamos, by taking the peak of the load and cushioning the violence of the fluctuations, or they may be placed at the end of a long line to keep up the voltage and obviate the heavy line loss incidental to supplying large currents from the power house through long feeders. In either case, the final effect is to relieve the power house of some of its load.

23. Battery Used to Take Peak of Load.—An example of this application is found in the storage-battery plant of the Buffalo Street Railway Company. The storage batteries are installed at the main power house for the purpose of cushioning the fluctuations and to carry the peak of the load. Now, the generators in such a station are heavily overcompounded, and their terminal voltage, therefore, varies according to the load; the battery is in multiple with the generators on the bus-bars. Also, since the E. M. F. of the generators increases as the load increases and since the E. M. F. of the battery decreases as the load increases, on account of its internal resistance, there must be some means provided for regulating the voltage of the battery to suit that of the bus-bars. This regulation is effected by means of a motor-driven booster connected in series with the battery.

This booster is designed to increase the effective voltage of the battery at the same rate as the load increases, thereby preserving the relationship between its E. M. F. and that of the generators. The positive end of the battery is connected to the positive bus-bar of the station; the negative end of the battery goes to one terminal of the booster armature, the other end of which goes to the ground. The motor end of the booster unit is a six-pole machine running at 500 revolutions per minute from the station bus-bars. The booster performs two duties: it regulates the voltage at which the battery discharges and it also helps to charge the battery. On this account, means must be provided for not only varying the voltage of the booster from zero to a maximum, but for reversing its polarity, because during a charge the current flows towards the battery, and during a discharge from it. This is done by means of a combination switch whose blade has three positions. In one of the positions, the polarity of the booster is such as to charge the battery; in a second position, the polarity is such as to discharge the battery; while in a third or neutral position, it is out of action.

The Buffalo road obtains its power from Niagara Falls as a three-phase alternating current, which is changed by means of rotary converters into a direct current for use on the railway. At night the rotary converters are used to charge the battery that is cut in on the line about 5.30 A. M. The battery itself is composed of 270 chloride cells, which at 2.18 volts each give a total of $270 \times 2.18 = 589$ volts. The battery has a capacity of 1,200 horsepower-hours, when discharged at the rate of 1,200 horsepower, in which case it would discharge in 1 hour. The cells are not full of plates, room being left for a future increase in the capacity to 2,000 horsepower at 1 hour's discharge. The containing tanks are made of wood, lined with lead, and are supported on porcelain insulators. The floor is made of concrete and slopes to one side to facilitate drainage. Insulating mats of wood are laid in the aisles between the rows of cells.

24. Battery Out on the Line.—An example of the second method of applying storage batteries to railway work is found on the South Side Elevated Road, of Chicago. The cars operated are quite heavy, and the power station is near the center of the road. There are two storage-battery plants, one near each end of the line. The trains are all equipped with the Sprague multiple-unit system. This system provides that each car in the train shall be a motor car and that all the motor cars can be operated simultaneously from either end of any car in the train. On starting, the train accelerates very rapidly, and in a few seconds is under full headway, so that during this time the flow of current is large and the strain on the feeders severe. The load units being large, the fluctuations in the load are of course violent. The storage batteries are connected directly across the line without the intervention of any booster, and they depend for automatic regulation on the variation in the drop that takes place in the feeders between them and the power house. The drop varies between 10 and 30 volts, according to the load. When the load is light, the drop is small, and the voltage of the feeder, being above that of the battery, sends a charging current through it. The battery consists of 248 cells, having a capacity of 1,000 horsepower at the 1-hour rate. When the load is heavy, the excessive drop brings the feeder voltage down below that of the battery, enabling the latter to send a current into the line, thereby aiding the power house. The automatic regulation of the charge and discharge of the battery requires that there be a certain amount of variation in drop. If it is found that a battery is called on to discharge more than it is charged, an extra feeder must be run between it and the power house to raise the feeder voltage in the neighborhood of the battery and thereby relieve the battery of some of the load. In the battery plants of the above-mentioned road, each battery is connected to the power house through two special feeders, so that by means of them the automatic regulation can be helped. If it is found that the battery does but little discharging, it means that its E. M. F. relative to that of the feeder must be raised. This can be done either by putting several more cells in series with the battery or by increasing the drop in the feeder itself. To do this, if there are extra feeders between the battery and the power house, as in the above case, one of them can be cut out. A battery used at the end of the line has the advantage of maintaining the voltage and enabling the cars to keep their schedule, besides relieving the generating apparatus and saving copper in the line. A drop of 10 per cent. in the lines is sufficient to allow the battery to operate automatically as above described. Of course, in all cases the line must be long enough and the load sufficiently heavy to justify the use of the battery ; otherwise, no economy will be effected by its use.

25. Differential Storage-Battery Booster.—The action and use of the differential battery booster has already been explained. In this style of booster the whole output of the plant is carried through the series-field winding, and the battery charges and discharges according as the load on the line is light or heavy. This style of booster is generally used when the load on the line is rapidly fluctuating.

26. Compound Booster.—In cases where the battery is intended to take the peak of the load, which may extend over a considerable period, the compound booster is frequently used. This differs from the differential booster in that only the battery current passes through the series coils of the booster, as indicated in Fig. 13. *A* is the armature of the booster and *F* its series-field winding. *G* is one of the regular compound-wound generators feeding into the bus-bars; *s*, *r*, *s'*, *r'* are the shunt fields and rheostats of the booster and generator. In this scheme of connections, it is seen that only the current furnished by the battery passes through *F*, and not the whole line current, as in the case of the differential booster. When the battery is carrying the peak of the load, the voltage across its terminals of course falls off as the current increases, on account of the internal resistance and also on account of the drop in voltage due to the cells becoming discharged. The booster voltage increases as the current delivered by the battery increases, and as this voltage is added to that of the battery, the result is that the voltage at the bus-bars is maintained and the battery takes its share of the load. When the battery is to be charged, the polarity of the booster may be reversed by means of field reversing switches and the booster made to generate a voltage of the opposite polarity, thus helping the generator to

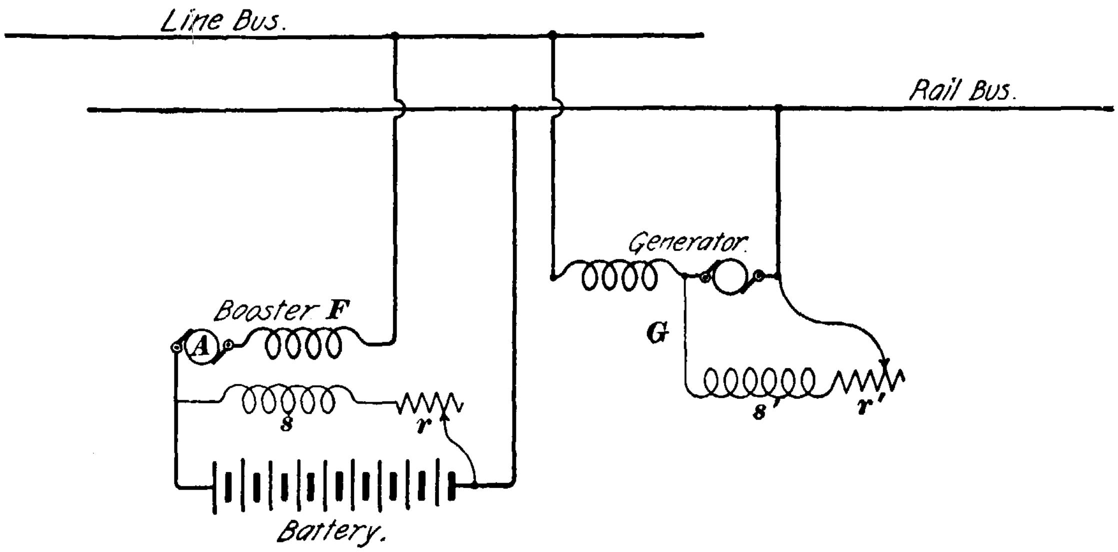

FIG. 13.

force current through the batteries. A booster of this type is used therefore when a battery is either to charge or discharge for a certain length of time, but where it has to discharge for short intervals and then charge for similar intervals, as it should on a load subject to sudden changes, the differential booster is used.

27. The effect of a battery in smoothing out the load line on a station is shown by Fig. 14. The heavy line indicates graphically the variation in the total current during a certain day. The lowest point, about 85 amperes, is reached between 3 and 4 o'clock in the morning; then it rises abruptly at 6 o'clock and continues to increase until 9, falling again towards noon, and attaining its maximum value at 6 in the evening, whence it falls rapidly and continuously. It is evident that to operate such a road, a plant would have to be provided with generators capable of furnishing 2,700 amperes to the line, and probably more on some occasions; but this amount is required during only a short period, and some of the plant must remain idle or work inefficiently for a greater part of the 24 hours. The average current is about 1,276 amperes, and a line drawn through this point indicates the current output if the load were steady all day and the same in total amount. It would obviously, then, be an advantage if the high parts of the load could be brought down and the low parts brought up, and

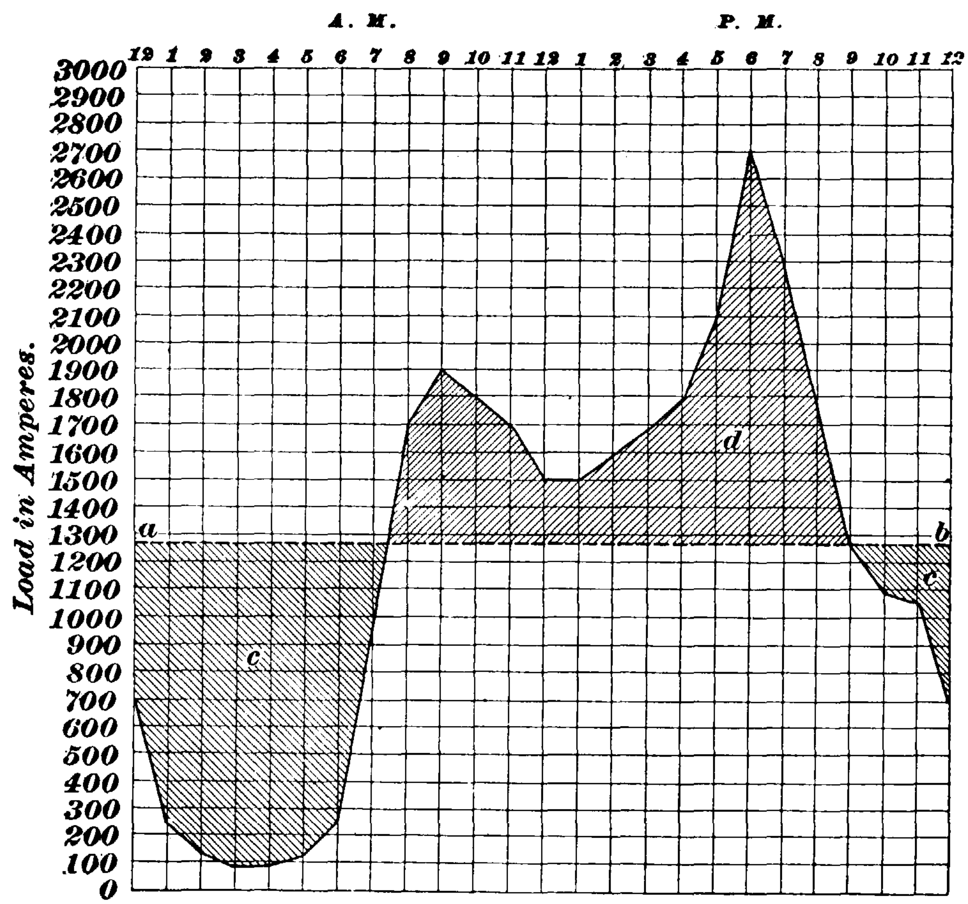

FIG. 14.

an equalization of the load thus effected. The storage battery can do this. If it were installed in such a station, the dynamos would be called on to deliver only about one-half of the current, 1,300 amperes instead of 2,700 amperes, and would therefore have to be but one-half the size; the engines and boilers could also be correspondingly smaller. In the diagram, the shaded portion marked *c* represents the charge given to the accumulators; *d* represents the discharge. Of course, in actual practice it would be almost impossible to bring the load on the generators down to a straight line like *a b*, but nevertheless it may be made so uniform that the variations put but little strain on the machinery.

On small roads the fluctuations in load are especially severe. The upper curve, Fig. 15, shows the load curve taken from a small station. It is at once apparent that the load fluctuations are rapid and violent, as the curve represents a period of only 5 minutes. The lower curve shows how the load on the generators was smoothed out when the batteries were installed. The battery consists of 262 chloride cells. Each cell consists of 9 plates about $10\frac{1}{2}$ inches square

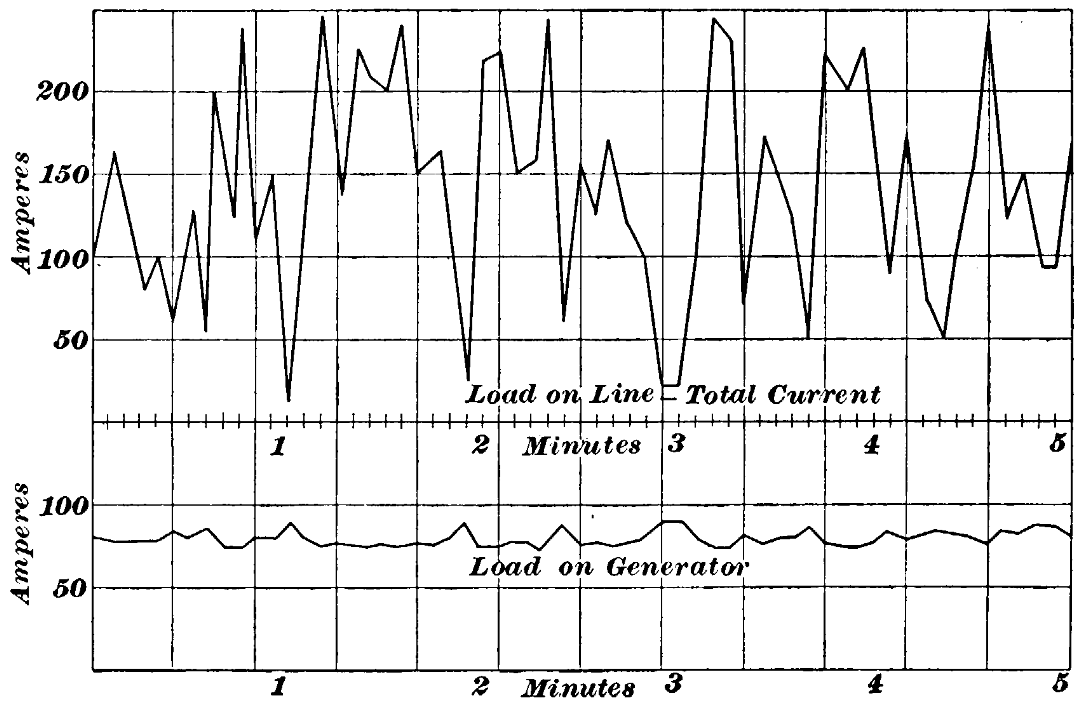

FIG. 15.

suspended in glass jars having outside dimensions of $10\frac{5}{8}$ in. $\times$ $12\frac{1}{2}$ in. $\times$ $15\frac{1}{2}$ in. These jars are of sufficient size to permit of the addition of 4 more plates to the elements, thus insuring a 50-per-cent. addition to the capacity, should it be needed in the future. Each cell is on a wooden tray filled with sand and supported by glass insulators. On full charge, the battery has a capacity of 40 amperes for 7 hours; or it can discharge at the rate of 160 amperes for a short time. As a matter of fact, the battery is often called on to discharge at a rate far in excess of this, sometimes 250 amperes being called for momentarily.

As a result of the heavy grades and the small number of cars operated, the fluctuations in the load are very violent. The power house is about $\frac{1}{2}$ mile from the lower end of the road, in the center of the heaviest but not the longest grade. The machinery for generating the 500-volt direct current consists of one 60-kilowatt generator and one differential booster, both belted to the same engine. To clearly see the great advantage obtained by the use of the storage battery in this particular case, it will be best to study the load diagram given in Fig. 15, which was plotted from readings taken on the line and generator. These readings were taken every 5 seconds for a period of 5 minutes at the time of heavy load. It will be noted that the load on the line varied from about 15 amperes to about 250 amperes, but the load on the generators varied comparatively little.

Many other instances could be cited to show the position that the storage battery now holds in the electric-railway field. The batteries of today are made of liberal size for a given rated output and are mechanically strong, so that they are free from the old-time trouble of buckling. The plates are carefully prepared and live their natural time without dropping all their active matter in the bottom of the containing vessel. It is not to be imagined, however, that storage cells give no trouble and require no care, for, like all other electrical apparatus, they must be looked after if they are to give satisfactory service.

POWER ESTIMATES.

28. The problem of deciding what capacity the station dynamos must have in order to operate a given number of cars on a given road is a complex one, in that it involves conditions peculiar to each case and calls for the use of quantities that must to a great degree be guessed at or assumed. Among the factors that must be considered in solving the problem are: Weight of equipment; number of cars; speed of cars; topography of the road (grades, curves, etc.); character of traffic; condition of line and rail return; manner of handling the equipment.

29. Weights of Cars.—The weight of an equipment, not including passengers, depends on the length and style of the car and on the weight of the motors. A modern open car just as it leaves the painter, with no equipment on it save the roof, wall, and light wiring, weighs about 320 pounds per foot, measured over all. A 20-foot body, then, would weigh in the neighborhood of 6,400 pounds; a 30-foot body, 9,600 pounds; a 35-foot body, 11,200 pounds, and so on. An open car equipped with motors of the proper size will weigh about 650 pounds per foot. This gives a 20-foot car a weight of 13,000 pounds; a 30-foot car, 19,500 pounds; a 35-foot car, 22,750 pounds. In designating the length of closed cars, it is customary to measure between the outsides of the bulkheads (end walls) and not between the bumpers. A modern closed car just as it comes from the painter, free of equipment, weighs about 395 pounds per foot of length between bulkheads. With the proper sized equipment, closed cars weigh about 880 pounds per linear foot. It will thus be seen that closed cars weigh more per foot than open cars. Up-to-date equipments complete weigh about 300 pounds per horsepower. This includes motors, trucks, hand-brake rigging, etc. The above figures may not exactly fit all cases, nor should they be expected to; but they have been averaged from observations made on standard equipments and will give a fair idea as to the value of these quantities. To the dead weight of the equipment must be added the weight of the passengers.

30. Current Required for Operating Cars.—We will assume that the cars to be operated weigh, with their probable average load, 10 tons; that they are to average 14 miles per hour; and that 6 cars are to be operated. The road is assumed to be level and free from curves. Now, it is an experimentally determined fact that *to urge 1 ton along at the rate of 1 mile per hour on a level rail requires an expenditure of about .06 horsepower applied to the wheels of the car.*

The experiment, of course, was not made on a car weighing only 1 ton. It was actually determined from the power required to drive a car weighing several tons 1 mile per hour and the power per ton derived by dividing by the number of tons.

Allowing an efficiency of 70 per cent. between the trolley wire and the rail would mean that, in order to get .06 horsepower applied mechanically to the car wheel, it would be necessary to apply to the motors electrically $\frac{100 \times .06}{70} = .086$ horsepower. Now, .086 horsepower $= .086 \times 746 = 64.156$ watts, which at 500 volts means a current $= \frac{64.156}{500} = .128$ ampere. Then, to push 1 ton of weight along a level rail at the rate of 1 mile per hour requires the absorption of .128 ampere at 500 volts. Now, the amount of current required to run a car is proportional to its weight, and within certain limits it is almost proportional to its speed. To push a 10-ton car along at the rate of 1 mile per hour would require a current of $10 \times .128$ ampere $= 1.28$ amperes, and to push the 10 tons along at the rate of 14 miles per hour, the assumed average speed, would require a current of 14×1.28 amperes $= 17.92$ amperes. As there are 6 cars and each car averages 17.92, say 18 amperes, to run the 6 cars would require a current of 6×18 amperes $= 108$ amperes, and this would represent the theoretical capacity of the dynamo required to run the road. Practically, this would be figuring too close, as there are times when one car alone will take as much current as this, if the controller is handled poorly, with the result that if the circuit-breaker were set so as to be any protection to the dynamo, it would be constantly flying out and delaying traffic. A dynamo of twice this current capacity would be more in order; then there would be some margin to allow for extra cars and increased headway.

The larger a system is, the nearer together may the theoretical and practical values of the station output be made, for then the fluctuations of a single car are not as large a percentage of the total load. For example, one of the cars above averages 18 amperes, but if there were only one car on the road and the breaker were set to act at 18 amperes, it would be impossible to start that one car at all.

31. Current on Grades.—It is useful to know also that the current taken by a car is almost directly proportional to the steepness of the grade that it may be ascending. It is easily seen that it cannot be exactly proportional, because a 1-per-cent. grade is infinitely steeper than a 0-per-cent. grade, or level. The approximate relationship is this: *If it takes .128 ampere to push 1 ton along a level at the rate of 1 mile per hour, it will take approximately 10 × .128 ampere to push it up a 10-per-cent. grade at the same rate.* On the lower grades this relationship is not as true as it is on the higher ones.

32. Formulas for Power Estimates.—The figures just given will be found to give approximately close results. A number of formulas have been devised to calculate the power required by cars under certain conditions, but it is evident that any such formulas are at best only approximate, because several elements always modify the power taken. For example, the running gear may be in bad shape or the motors may be inefficient; the roadbed may be in bad condition or there may be excessive friction on some of the curves. Tests on different cars might therefore lead to results varying considerably from those given by the formulas that follow.

33. Force Required to Move Car on the Level.—The drawbar pull per ton weight required to move a trolley car on a level track at a uniform speed is somewhat higher than on steam roads. It will generally require a horizontal effort of about 25 pounds per ton to keep a car moving uniformly, and it will of course take a much greater effort than this to start the car, because the friction of rest is greater than the friction when the car has once started to move.

For obtaining the horizontal effort applied to the wheels, we may use the formula

$$f = 25\ w_t, \qquad \textbf{(1.)}$$

where f = force in pounds,

and w_t = weight of car in tons.

That is to say, *the force required to move a car over a level track in average condition is 25 pounds for every ton that the car weighs.*

EXAMPLE.—What force will be required to move a car, its weight being 9 tons?

SOLUTION.—The weight of car $w_t = 9$ tons, and the force required will be, by formula **1**,

$$f = 25 \times 9 = 225 \text{ lb.} \quad \text{Ans.}$$

34. When a grade has to be taken into account, the perpendicular distance in feet ascended in 1 minute multiplied by the weight of car will give the power in foot-pounds expended in raising the car; the horizontal distance in feet traveled in 1 minute multiplied by the force in pounds necessary to move the car will give the power in foot-pounds required for a level track. The sum of these values divided by 33,000 will be the total horsepower at the wheels. Loss of power in the transmitting mechanism will necessitate a larger figure for the power supplied to the motors, this depending on the efficiency of the apparatus. We may express these several operations in a single formula, as follows:

$$H = \frac{h\,w + D\,f}{33{,}000\ \mathsf{E}}, \qquad \textbf{(2.)}$$

where

H = total horsepower required for motors;
h = perpendicular distance in feet ascended in 1 minute;
w = weight of car in pounds;
D = horizontal distance in feet traveled in 1 minute;
f = force in pounds necessary to move the car;
E = motor efficiency expressed as a decimal part of 1.

The horsepower required to propel a car up a grade is equal to the product of the height in feet ascended and the weight of car in pounds plus the product of the horizontal distance in feet traveled per minute and the force in pounds necessary to move the car, this sum being divided by 33,000 times the motor efficiency expressed as a decimal part of 1.

EXAMPLE.—If a car with passengers weighs 8 tons and it is desired to take it up a 6-per-cent. grade at a speed of 10 miles per hour, what horsepower must be delivered to the motors, assuming that the efficiency between the trolley and wheels is 70 per cent.?

SOLUTION.—The car will cover in 1 minute $\frac{10 \times 5{,}280}{60} = 880$ feet $= D$, and on a 6-per-cent. grade this will correspond to a vertical distance of $880 \times .06 = 52.8$ feet $= h$. The weight of the car expressed in pounds $= 8 \times 2{,}000 = 16{,}000$ pounds $= w$. The force required for propulsion is, by formula **1**, $f = 25 \times 8 = 200$ pounds, and the efficiency being 70 per cent., $\mathbf{E} = .70$.

Then, by formula **2**, we have

$$H = \frac{h\,w + D\,f}{33{,}000\,\mathbf{E}} = \frac{844{,}800 + 176{,}000}{23{,}100} = 44 \text{ H. P. approximately. Ans.}$$

35. It will be of interest to work out this problem by using the data given in Arts. **30** and **31**. The efficiency has been taken as 70 per cent. in both cases; so we will take the current as $6 \times .128$ ampere per ton weight per mile per hour. The total current would then be $6 \times .128 \times 8 \times 10 = 61.44$ amperes. At 500 volts, this would be equivalent to $\frac{61.44 \times 500}{746} = 41.2$ horsepower. This comes out somewhat smaller, owing no doubt to the approximation introduced by taking the power as directly proportional to the grade. For approximate calculations, however, the agreement is sufficiently close.

36. The *power* required in going around curves depends on their radius and on the construction of the truck. The power required for starting may be taken as the same as that for rounding curves.

37. It has been found that a *force* of about 70 pounds per ton weight of car is required to start a car or to keep it in motion when rounding curves. When starting on a grade, the effort must be greater in proportion to the percentage of rise, and for this condition add 20 pounds to the 70 pounds for every ton weight for each 1 per cent. of grade.

Expressed as a formula, the force required will be

$$f' = (70 + 20\,x)\,w_t, \qquad \textbf{(3.)}$$

where f' = force in pounds;
x = per cent. grade;
w_t = weight of car in tons.

The force in pounds required to start a car on a grade is equal to the weight of the car in tons multiplied by 70 plus 20 times the per cent. grade.

On a 2-per-cent. grade the force required in starting will therefore be $f' = [70 + (20 \times 2)] \times 1 = 110$ pounds per ton.

EXAMPLE.—What force will be required to start an 8-ton car on a 5-per-cent. grade?

SOLUTION.—According to formula **3**, the force will be

$$f' = (70 + 20\,x)\,w_t = [70 + (20 \times 5)] \times 8 = 1{,}360 \text{ lb.} \quad \text{Ans.}$$

38. The limit of adhesion may be $\frac{1}{8}$ of the weight; therefore, on a level track the maximum force that could be applied without slipping would be $\frac{2000}{8} = 250$ pounds per ton. If the rails were muddy or greasy, much less than this force would be used, while very clean, dry rails might increase this amount. In ordinary street-railway service the rails are usually rather slippery, and often, in consequence, the adhesive force may be low. We may calculate the grade on which slipping will occur when starting the car and also when it is already in motion in the following manner:

Let a = ratio of adhesive force to weight on drivers;
w' = weight on drivers in pounds;
w_t = weight of car in tons of 2,000 pounds;
G_s = per cent. grade at which slipping occurs.

Then, slipping will occur at starting on a grade

$$G_s = \frac{a\,w' - 70\,w_t}{20\,w_t}.$$

But $w' = 2,000\ w_t$, when the whole weight of the car is on the drivers, in which case the limiting grade for starting

$$G_s = \frac{2,000\,a\,w_t - 70\,w_t}{20\,w_t} = \frac{2,000\,a - 70}{20} \text{ per cent.} \qquad \textbf{(4.)}$$

The limiting grade for starting a car, when the whole weight of the car is on the drivers, is equal to 2,000 times the ratio of adhesive force to weight on drivers minus 70, this difference being divided by 20.

When $\frac{1}{y}$ of the weight is on the drivers,

$$G_s = \frac{\frac{2,000\,a}{y} - 70}{20} \text{ per cent.} \qquad \textbf{(5.)}$$

The limiting grade for starting a car, when a fraction of its weight is on the drivers, is equal to that fractional part of 2,000 times the ratio of adhesive force to weight on drivers minus 70, this difference being divided by 20.

EXAMPLE.—If a car weighs 7 tons and all its weight is on the drivers, adhesion being $\frac{1}{8}$ of this weight, will it start on a 7-per-cent. grade?

SOLUTION.—The per-cent. grade at which slipping occurs at starting is, by formula **4**,

$$G_s = \frac{(2,000 \times \frac{1}{8}) - 70}{20} = \frac{180}{20} = 9 \text{ per cent.}$$

The car will therefore start on a 7-per-cent. grade, as 9 per cent. is the limit. Ans.

39. When the car is running, only 25 pounds per ton is necessary for propulsion, and the limit of grade which may be ascended is, when G_r = maximum grade which a running car will ascend,

$$G_r = \frac{\frac{2,000\,a}{y} - 25}{20} \text{ per cent.} \qquad \textbf{(6.)}$$

The limiting grade that a car will ascend, when a fraction of its weight is on the drivers, is equal to that fractional part of 2,000 times the ratio of adhesive force to weight on drivers minus 25, this difference being divided by 20.

EXAMPLE.—The limit of adhesion being $\frac{1}{6}$ the weight on the drivers, how steep a grade could be surmounted by a car with $\frac{1}{4}$ its weight on the drivers, starting from the level?

SOLUTION.—According to formula **6**,

$$G_r = \frac{\frac{2,000\ a}{y} - 25}{20} = \frac{\left(\frac{2,000}{4} \times \frac{1}{6}\right) - 25}{20} = 2.91 \text{ per cent. Ans.}$$

40. The foregoing data and formulas will enable approximate calculations to be made regarding the power required for a given number of cars. It is unsafe to give values of the power to be allowed per car, because there is such a wide variation in the size and weight of cars that such figures are not generally applicable. The safest method is to calculate the power required for any given case by taking into account the weight of the cars, speed, steepness of grades, etc., as indicated in the above formulas.

THE LINE.

41. The term **line,** when used in connection with a street railway, covers quite a large field of work; in the first place, the line may be an overhead-trolley system, a conduit system, a third-rail system, or a high-potential transmission line. Also, the name can include any of the several sectional surface systems, none of which, however, are in general enough use to warrant its consideration here. Whatever the system may be, its consideration calls for a study of the active trolley wire, its feeders, and their means of support.

OVERHEAD LINE CONSTRUCTION.

42. General Features.—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other