boilers, their function being to warm the feed-water by means of the waste furnace gases. The boiler room should be designed with a special view to the expeditious handling of coal and ashes with a minimum of labor. To accomplish this, it is well to deliver the coal from a railroad car and unload directly into bunkers beneath the track, extending through into the boiler room immediately opposite the fire-doors. These cellars should have storage capacity for at least fifteen days, unless there is another large supply easily accessible. A subway may be built beneath the ash pits, and these may be fitted with doors to open downwards, through which the ashes can be swept into a small car running on a track beneath. This is a refinement of practice, perhaps only justifiable in the case of very large plants, but may be used when it is necessary to clean out the ash pits rapidly, if the owners of the plant are willing to incur the extra expense.

Provision must be made for an unlimited supply of water. It is not always well to trust entirely to the city mains for this purpose, although such a source is usually reliable. When the station is not located near running water, it may be found advisable to sink a well, from which water may be pumped into a tank, and the water from the mains used only in cases of emergency.

ENGINES AND DYNAMOS.

2579. The type of engine which is most suitable for a railway power station depends entirely upon the size of the road—that is, on the number of cars in regular operation. The closest speed regulation under widely varying loads is obtained with high-speed, automatic cut-off engines, and this class is, therefore, particularly suitable for very small roads. A little consideration will show that such a road may furnish extremes of load at very short intervals; for if there were only one car in service, the station load would be zero (or, simply, the friction of the moving machinery) when the car was at rest, and a maximum when it was

starting on a heavy grade. When a second car is added, it is not likely that the same conditions will occur so often, and the more cars that are operated, the nearer will the load approach a constant normal value, until, with a very large number, the load will be a maximum at certain times of the day, and will fall gradually to the lowest point in the early hours in the morning. For such an installation, it is best to use low-speed Corliss engines, and run them with condensers, if water for this purpose is readily available.

2580. Power is usually transmitted from engines to dynamos by means of a light double belting, countershafts being largely employed, as already explained; but a very general practice, especially in large stations, is to install direct-connected units, the dynamo frame being bolted to the engine base plate. By this arrangement, the loss due to belt slipping is eliminated, and a great saving is made in the required engine-room area. The question of the proper proportion of engine to dynamo power is, in this case, already determined, but for belt-connected plants, it should be a matter of careful consideration. A dynamo may be run under a light load, and still be efficient, whereas an engine, under the same circumstances, is decidedly inefficient; therefore, the latter should, as a rule, be worked up to nearly its full load—that is, the engine should not be too large, while the dynamo may be of greater capacity. Such proportioning will give a good working economy, the normal rating of the dynamo being from 15 to 20% greater than that of the engine.

2581. The **size of units** to be used in any given plant is a subject which has aroused much discussion, some favoring a number of small machines, others a few larger ones. The best practice is, probably, to provide two small generators, adding as many others, of three times their capacity, as are necessary to obtain the required total horsepower. By this arrangement the running machinery can always be suited to the load and worked efficiently.

When a very large road is under consideration, the small units may themselves be quite large, comparatively, and be able to deliver 200 horsepower to the line. The largest generators, of say 1,500 kilowatts or 2,000 horsepower, are frequently connected directly to the shaft of large triple-expansion vertical marine engines, which afford a considerable saving in ground space, although their first cost is somewhat above that of the horizontal type. It is not well to have too many different sizes of dynamos in one station, as this necessitates keeping so many extra armatures and other fittings in stock; this is one reason advanced by those who favor the use of a number of small units, in preference to a few of larger size, or an indiscriminate collection; but economy in operation will always be best attained with the arrangement of units already recommended.

Since the engines are called upon for sudden, and, often, extreme variations in output, heavy fly-wheels are of the greatest importance as speed regulators, and, in the case of medium-speed engines, of 200 or 300 horsepower and over, their weight is generally from one-quarter to one-third that of the engine itself.

CAR HOUSE AND REPAIR SHOP.

2582. The **car house** is a building in which the cars are stored during those hours of the night when the line is out of operation, and should contain all facilities for inspection and repair. It is not necessary that it should be near the station, for it may be located wherever convenient, even at the other end of the line. Telephonic communication should, however, be provided with the power house, so that current for the cars may be available when required. Space should be allowed for somewhat more than the number of cars in use, to provide for additional rolling stock, as the extension of the system may warrant. The general plan of the building should be long, and traversed by as many parallel tracks as the required accommodation calls for, all entering at one end, and each track closed by a large folding

door. The rails should be laid on brickwork piers or walls provided with substantial foundation, with a clear space between, forming a pit four or five feet deep, by means of which ready access may be had to the motors and other fittings under the car body. The floor of the pit should be laid with concrete, as small trucks may then be easily moved along it, carrying armatures or other parts for the cars. With the increasing weights of motors, the old practice of raising them into place by main force is becoming more evidently inadequate. It is, at best, a very inefficient means, wasting both time and energy, and the most satisfactory method of handling is by the use of hydraulic jacks, which may be bought on the market, adapted to this particular purpose, and mounted on trucks to run on rails laid in the pit.

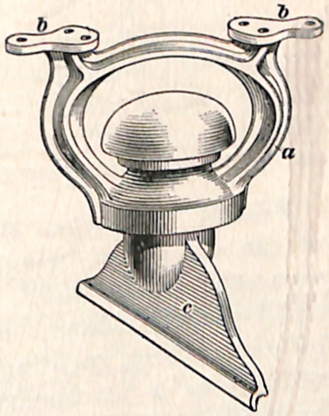

Fig. 1043.

2583. The wiring of the car house is a simple matter, one overhead wire being brought in over each track and connected at the door by a switch, so that it may be cut out of circuit for the sake of greater safety in handling the motors. These wires may be supported on insulators, as shown in Fig. 1043, and are intended to be fastened to overhead wooden beams by the lugs *b*, *b*. The clamp *c* holds the wire in the groove at the bottom, and is screwed to an insulated bolt passing through the frame *a*.

2584. It is well to make some provision for running cars out in case of fire. This is sometimes accomplished by making the track inclined, so that the cars will run down and out by gravity, when the brakes are released; another suggestion is to set the controllers of all cars on the first notch when they are left for the night, but cut off the current from the overhead sections. In case of fire the switches at the doors, may be thrown over one by one, and all the cars would then slowly move out. Probably the best plan is to make the building of brick, with concrete floor and iron roof, so that the danger of fire will be reduced to a minimum.

2585. When the car house is situated near the street line, the several tracks running into it should not start from the main line, but a siding *s*, Fig. 1044, should be laid out so that through cars need not go over so many switches. Those from the left pass over the switch *a* only, those from the right over *b* only, saving some amount of wear and tear on car wheels and greatly prolonging the life of the switches.

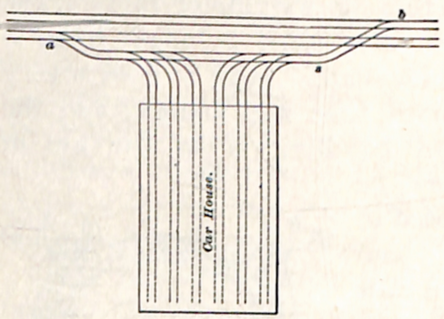

FIG. 1044.

2586. The repair shop may be built directly at the end of the car house, being, in fact, a continuation of it, but separated by the wall. Here a few tools, such as lathes, a small planer, shaper, milling machines, boring machines, hydraulic press, grinding machine, etc., should be available, as well as a blacksmith shop, so that repairs may be promptly attended to. Of especial importance is the grinding of wheels to remove any flats which may and do occur, owing to ill usage on the part of careless motormen, or to soft spots on the wheel. The question as to whether it is well to regrind wheels depends upon the cost involved, and also upon the likelihood of continued service. If a wheel has run about 40,000 or 50,000 miles, it will, perhaps, not pay to regrind, because so much of the surface is worn away that there is no depth of chilled iron left, and the tread of the wheel is soft. Then, again, if the wheel has to be removed from the axle after running 35,000 miles, the expense of so doing may not pay for the increased mileage obtained. Special grinding attachments may, however,

be had, which may be fitted to the axle while the car is blocked up from the rails, and the wheels trued up without removing them and with little delay. The motors on the car are used to revolve the wheels, resistance being inserted at some suitable point until the speed is about 100 revolutions per minute. When the other pair of wheels is resting on the track, that motor must be cut out. If flats on the wheels are allowed to develop, they will tend to destroy the track, since they cause heavy blows to be delivered at every revolution. Frequent inspection should be made of all cars, that no loose connections be allowed, and that commutators, brushes, gears, etc., are kept in good condition.

Another division of the repair department is the paint shop. Cracks develop in the car sides frequently, owing to the constant vibration due to running, and these should be filled and painted as soon as they appear, to prevent the access of water to the interior. All cars need revarnishing about once a year.

SWITCHBOARDS.

2587. Switchboards are insulating supports for cable terminals, measuring instruments, and switches, and have been mentioned in Arts. **2389-2407**. They are usually made of a number of vertical slabs of marble or slate, frequently six or seven feet in height, and each from eighteen inches to two feet or more in width. These divisions are called **panels**, and each is provided with switches and other instruments necessary for the regulation of one generator or of one feeder circuit, the feeders being those wires which carry the current from the station to the centers of distribution. The switchboard must be set a little distance away from the wall, and supported by brackets fastened into the brickwork, sufficient space being allowed for ready access and convenient handling of the wires. There are many different styles of arrangement of switchboard appliances, but a representative method is shown in

Fig. 1045. There are generally two main divisions, one of which contains the panels for the generator instruments, and the other those for the several feeders. In the illustration we have shown a switchboard for two generators and four feeders, to which extra panels might be added as the business extended. The generator panels are on the left, those for the feeders on the right. All connections are made behind the board, and the wires are shown dotted in the diagram. The bar running all the way across, marked $+B$, is the positive bus-bar; the negative bus-bar is $-B$, and is much smaller, both in cross-section and length, as it is only required to carry the current from one

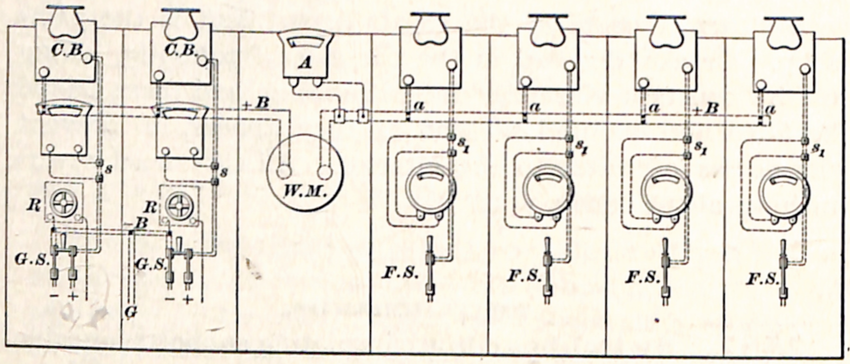

FIG. 1045.

generator, there being a connection to ground at *G*. On the generator panels at the bottom are the double pole switches *G. S.*, from which leads are run to the generator terminals, as indicated. The current passes from the positive side of the machine through the right-hand blade of the switch to the ammeter shunt *s*, then through the circuit-breaker *C. B.* to the positive bus-bar. The wattmeter *W. M.* is interposed in the circuit, being located, as shown, on the central panel; above it is the load ammeter *A*, connected across the shunt, which indicates the current output at any moment; the wattmeter sums up the total power which is delivered to the whole feeder system. At each of the feeder panels, connection is made to the bus-bar at *a*, and current is taken for the outside circuits, passing through

the circuit-breakers at the top of the board, then down to the ammeter shunts s_1 and the single pole feeder switches *F. S.* It may here be remarked that intersecting leads, as shown in the figure, do not touch each other unless they are marked with a dot at the point of junction; considerable clearance space should be given between any bare wires or bars crossing each other, and they must be firmly secured so that at no time will there be any danger of their coming into contact.

At the back of the generator panels there are rheostats *R*, the handles of which project through to the front. These resistances are in series with the shunt-field windings of the generators, to regulate the field strength. Circuit-breakers are used instead of fuses, as they are much quicker in action, and more easily adjusted to any current. They are simply automatic spring switches, which are released by an electromagnet when the current exceeds a certain strength, and are reset by pulling down the switch handle. Frequently, a bell is used as a signal to show the attendant that one of the feeder lines is broken, in case he did not hear the sound of the falling switch.

2588. The **ammeter shunt** is used to avoid the necessity of sending a very heavy current through the instru-

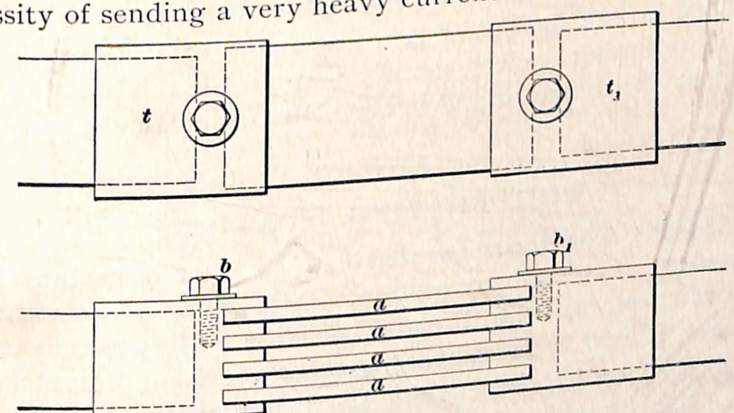

FIG. 1046.

ment. Its use was referred to in Art. **2400**; its construction is shown in Fig. 1046. Two heavy copper terminals t, t_1

are soldered to the ends of the cables c, c_1, the recesses being shaped to fit. Connection between the terminals is made by strips of metal alloy a soldered in place, thus forming a path of higher resistance than the main line. The ammeter leads are brought to these terminals and firmly clamped in place by the bolts b, b_1. The instrument thus becomes virtually a voltmeter, indicating the drop of potential between those two points; but, since this is proportional to the current flowing, the resulting readings are correct.

2589. Every panel should have a distinguishing number or letter, repeated, in the case of the generator panels, on the machines which they control, so that no mistake may be made in switch manipulation and any trouble set right without delay.

An extra panel may be provided to carry one or more station voltmeters, or they may be mounted on the central panel. A ground detector, similar in principle to those already familiar to the student, may also be added. This will take the form of two series of five lamps, connecting between each bus-bar and the ground.

The dynamos are always compound-wound, and an equalizing bar may be added to the switchboard, as already explained in Art. **2402.** Lightning arresters are to be placed on all outgoing feeders, usually just outside the building, to protect the dynamos and instruments from damage.

THE TESTING STATION.

2590. The **testing station** is a most important department of the railway system. It is not at all necessary, or even desirable, that it should be close to the power house; in fact, it will be found that greater precision of measurement can be obtained when the instruments are removed from the influence of the strong currents in that neighborhood, which may affect the galvanometers and prevent accuracy in testing. The apparatus required will include a

reflecting galvanometer, as described in Art. **2167,** capable of being connected differentially or not, as desired; a battery of 150 Leclanche cells, and a Wheatstone bridge (capacity about .1 to 10,000 ohms). In addition to these, it will be well to provide a ballistic galvanometer, a standard condenser of about $\frac{1}{2}$ microfarad, and one of $\frac{1}{50}$ microfarad.

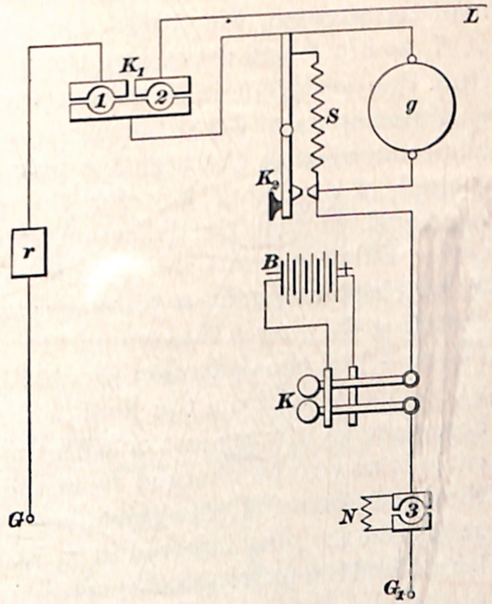

FIG. 1047.

The reflecting galvanometer is used in testing the insulation resistance of the cables when there are no disturbing currents in neighboring conductors, the arrangement of instruments being shown in Fig. 1047. The galvanometer and shunt are represented by g and S, respectively, and may be short-circuited by means of the key K_2. One block of the plug commutator K_1 is connected to the cable core, or line L, another to the ground G through a high resistance r, and the larger block to the galvanometer. The battery B is connected by a reversing key K to the galvanometer on one side; on the other side, it is connected, through a resistance N equal to that of the battery, to the earth at G_1.

CABLE TESTING.

2591. By Direct Deflection.—The following method is used in making insulation tests: The far end of the cable is freed, so that there is no complete metallic circuit through the core, and the near end is grounded for a sufficient length of time to dissipate any charge due to previous electrification. All leading wires between cable and instruments must show infinite insulation resistance to ensure accurate testing. The first operation, when all is in readiness, is to find the galvanometer constant, which consists in obtaining the deflection through a known resistance, using the galvanometer shunt S, Fig. 1047. On inserting plugs in hole *1* of K_1 and in *3*, and depressing the upper key of K, a current from the positive pole of the battery will flow through the galvanometer g and resistance r; the same deflection should be produced with the negative pole of the battery, and, if desired, a reversing key for the galvanometer may be employed, so that the deflection will be in the same direction. Earth currents should now be observed, if any exist, by cutting out the shunt S, removing the plug in hole *3*, and changing the plug in the commutator K_1 from *1* to *2*. The sign (+ or −) of the deflection should also be noted and added to or subtracted from the final deflection obtained later on, according as it is against or with the battery current. The cable is now to be charged from the battery by depressing the upper key of K, the galvanometer being short-circuited at K_2 and the plug inserted in *3*; after 30 seconds, K_2 is released and the galvanometer readings noted every 15 seconds of the time required, which may be 3, 4, or 5 minutes. The mean of the deflections at 45 seconds, 60 seconds, and 15 seconds gives the true deflection for each minute. Immediately after the last reading taken in this manner, with the battery to the line, the galvanometer is again short-circuited, the battery key K released, and plug *3* removed. Thirty seconds after thus disconnecting the battery, return readings are taken from the cable at 15-second intervals, the galvanometer key being opened. The mean return deflection for the first minute, added to the mean deflection for the last minute's charge, gives the true deflection for the first minute's electrification. The cable is then grounded for a time sufficient to thoroughly discharge it, and the electrification tests are repeated with the negative pole to line, using the lower key of K.

2592. This whole process may be simplified by presenting it in algebraic form. Let

B = resistance of battery in ohms;
G = resistance of galvanometer in ohms;
s = resistance of galvanometer shunt in ohms;
r = high resistance in ohms;
R = total resistance in megohms* of galvanometer with shunt, battery, and high resistance;
d_1 = deflection for galvanometer constant;
d_2 = deflection for cable, corrected for earth currents;
I = insulation resistance of cable in megohms.

According to the rule given in Art. **2202**, relative to derived circuits, the joint resistance in ohms of galvanometer and shunt $= \frac{G s}{G + s}$, and the multiplying power of the shunt will be $\frac{G + s}{s}$. Then, $R = \left(r + \frac{G s}{G + s} + B\right) \div 10^6 =$ resistance in megohms of circuit when obtaining deflection d_1. The deflection without a shunt through this resistance will be $d_1 \frac{G + s}{s}$, which multiplied by R gives the galvanometer constant $= R\, d_1 \frac{G + s}{s}$. The insulation resistance of the cable in megohms is then,

$$I = \frac{\text{constant}}{d_2} = \frac{R\, d_1 \frac{G + s}{s}}{d_2}. \qquad \textbf{(368.)}$$

To find the insulation resistance of a cable by the direct deflection method, obtain first the galvanometer constant as described. This number divided by the deflection obtained from the cable will give the insulation resistance in megohms.

Example.—It is required to find the insulation resistance of a cable, and the following apparatus is provided: A battery having a resistance of 450 ohms; a galvanometer of 8,100 ohms; a galvanometer shunt of 900 ohms; a high resistance box of 1,000,000 ohms. The deflection

*Note.—A megohm is one million ohms.

through the resistance R is 240 divisions, and the deflection from the cable, corrected for earth currents, is 193 divisions.

SOLUTION.—

Resistance of battery	$B =$	450 ohms.
Resistance of galvanometer and shunt	$\frac{Gs}{G+s} =$	810 ohms.
Resistance of box	$r =$	1,000,000 ohms.
		1,001,260 ohms = 1.0013 megohms.

The multiplying power of the shunt is $\frac{G+s}{s} = \frac{8,100+900}{900} = 10.$

Then, the galvanometer constant $R\,d_1 \frac{G+s}{s} = 1.0013 \times 240 \times 10 =$ 2,403. The deflection d_2 from the cable is 193 divisions, and the insulation resistance will be, by formula **368**,

$$I = \frac{2,403}{193} = 12.45 \text{ megohms. Ans.}$$

When r is very large, compared with the resistance of galvanometer and battery, and only approximate results are desired, sufficient accuracy is obtained by making $R = r$ in calculating the insulation resistance.

2593. Testing by Ballistic Galvanometer.—The direct-deflection method can not be used when adjoining cables carry heavy variable currents, as the readings are affected thereby, and it is therefore not suitable for testing one cable of a railway system when others in the same conduit are supplying current for cars. In such a case the **ballistic** galvanometer is employed to measure a charge held by the cable, the amount of leakage in a given time being dependent upon the insulating qualities of the covering.

2594. In the ballistic galvanometer, the suspended magnetic system is so constructed as to be of considerable weight, and to give the least possible damping effect. If a momentary current passes through the coils of the instrument, the impulse given to the needle does not cause appreciable movement of the magnetic system until after the current has ceased, owing to the inertia of the heavy moving parts, resulting in a slow swing after the impulse has ceased. The maximum angle of swing may be read by

watching a spot of light, reflected from a mirror secured to the moving parts, move across a suitably divided scale (as used in the Thomson reflecting galvanometer); the point at which the spot of light ceases to move forwards, and begins to swing back, is the angle of deflection used in the calculation.

2595. The battery required for these tests should consist of about 150 Leclanche cells, charged with a solution only about one-fifth the usual strength, which will prevent the salts creeping, and, since the current used is so small, the solution will be sufficiently active to produce it. It is necessary to highly insulate the battery, as well as all wires and switches, in all insulation tests; the cells may be arranged on glass plates supported on porcelain oil insulators. At various points, flexible leads are connected and brought to a convenient part of the instrument table, or made fast to studs on a suspended insulated frame, where connections may be made to their ends by means of metal clips attached to flexible cords.

2596. The method employed in testing insulation by the ballistic galvanometer involves the determination of the capacity of the cable, which is found by comparing it with a standard condenser. Before any tests can be made, it is necessary to neutralize the charge in the cable due to its having been subjected for a long time to the effect of the 500-volt potential, which causes the dielectric to retain considerable electrification, which leaks out slowly and continuously into the cable after it is disconnected from the source of supply. This, if not removed before commencing tests, would indicate a much higher apparent resistance than the cable really possesses. Neutralization may be effected by grounding the core of the cable for, perhaps, a couple of hours, but it is not always possible or desirable to wait so long, and other means must be employed. If the cable is charged positively by the generators at 500 volts, then it may be brought to a neutral state by applying 500 volts negative, the time of application varying from one to thirty seconds. A peculiarity to be noted is that the cable may return charges alternating in sign, in reverse order to that in which they were applied. A test for complete neutralization is to insulate the core for one minute, and see that no deflection is produced on connecting to earth through the galvanometer.

2597. In determining the capacity of the cable, the far end is disconnected from the trolley line and insulated. A deflection d_1 is then obtained on the galvanometer with a standard condenser of, perhaps, half a microfarad, and (the same battery being used) a deflection d_2 on the cable. The capacity of the cable may be determined by the following formula:

If K_1 = capacity of the condenser;
K_2 = capacity of the cable;
d_1 = deflection from condenser;
d_2 = deflection from cable,

$$K_2 = K_1 \frac{d_2}{d_1}. \qquad (369.)$$

When comparative galvanometer deflections are obtained with a cable and a condenser, the capacity of the condenser being known, then the capacity of the cable is found by dividing the deflection from the cable by that from the condenser, and multiplying the quotient by the capacity of the condenser.

The capacity may also be given by the manufacturer who supplies the cable.

2598. A simple arrangement for testing the insulation resistance of a cable is shown in Fig. 1048. A condenser c of very small capacity (say $\frac{1}{50}$ microfarad) is connected to ground at G through the ballistic galvanometer g, also to the cable, or line L, by means of the key k, so that both may be charged at once by the battery B. The method of operation is as follows: All leading wires, instruments, and switches being thoroughly insulated, and the cable freed at the far end, it is connected by the key k with the condenser c. Key k_1 is then depressed, and a charge given both condenser

and cable, the condenser taking a proportionate part. At a moment when the current through the galvanometer is zero, indicating that the charge in the cable is steady, the key k is released, and the condenser discharges through the galvanometer, giving a deflection d_1 representing the full charge of the cable. The key k is then again depressed, and the battery again charges the cable and condenser for, say 30 seconds, after which the battery is disconnected at k_1, and leakage is allowed to take place for, perhaps, five minutes. If the galvanometer shows a steady charge, the key k is then raised, discharging the condenser through the galvanometer and giving a deflection d_2, which is smaller than the first on account of the loss by leakage.

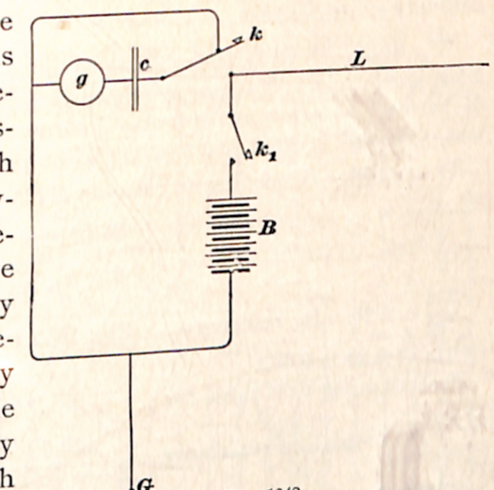

FIG. 1048.

2599. The formula used in the determination of resistance is

$$I = \frac{26.06\,t}{K \log \frac{d_1}{d_2}}, \qquad (370.)$$

where I = insulation resistance of cable in megohms, t = time in minutes during which the charge is allowed to leak, K = capacity of cable in microfarads, d_1 = initial discharge deflection, d_2 = final discharge deflection after t minutes.

Rule.—*To find the insulation resistance of a cable by the ballistic galvanometer method, multiply the time in minutes during which the charge is allowed to leak by 26.06, and divide the product by a number obtained by multiplying together the capacity of the cable in microfarads and the* *logarithm* of the quotient given by dividing the initial discharge deflection (representing full charge) by the final discharge deflection.*

EXAMPLE.—A railway feeder is $3\frac{1}{2}$ miles long, and has a capacity of 2.5 microfarads. The galvanometer deflection for full charge was 234 divisions, and after five minutes' leakage a deflection of 104 divisions was observed. What was the insulation resistance?

SOLUTION.—According to formula **370**,

$$I = \frac{26.06 \times 5}{2.5 \times \log \frac{234}{104}}.$$

$\frac{234}{104} = 2.25$. By reference to Fig. 1055 it will be seen that the logarithm of 2.25 is 0.352.

Substituting this value for the ratio of the deflections, we have

$$I = \text{insulation resistance} = \frac{130.3}{2.5 \times 0.352} = 148 \text{ megohms. Ans.}$$

2600. The insulation of all cables should be periodically tested, in order to avoid breakdowns. A fault will usually develop quite slowly, and, being constantly watched, the cable may be put out of service before trouble is caused or a dangerous point reached. It will be found convenient to provide a section-lined chart, upon which the insulation of each cable may be graphically noted at every test, the line obtained by joining these readings showing at a glance the condition of the cable. Such a chart is shown in Fig. 1049, the vertical divisions representing weeks and months, each chart constituting a record for six months. Several cables may be grouped together on one sheet by using different colored inks or lines of different formation. Three cables are shown in the figure; the heavy line represents the action of a cable in which a fault is developing. It will be seen that there is a decided droop in the curve in the tests made after March 18, and that one month later the insulation is still lower, its resistance steadily decreasing during another month, until it has a decided fall in May; the last test on the 27th of that month shows such a low

*See Art. **2618** for explanation of the use of logarithms.

value that the cable is put out of service, the fault located and repaired; and on June 10th the service is resumed, the insulation resistance being 350 megohms. These records are very valuable, showing the degree of insulation of the

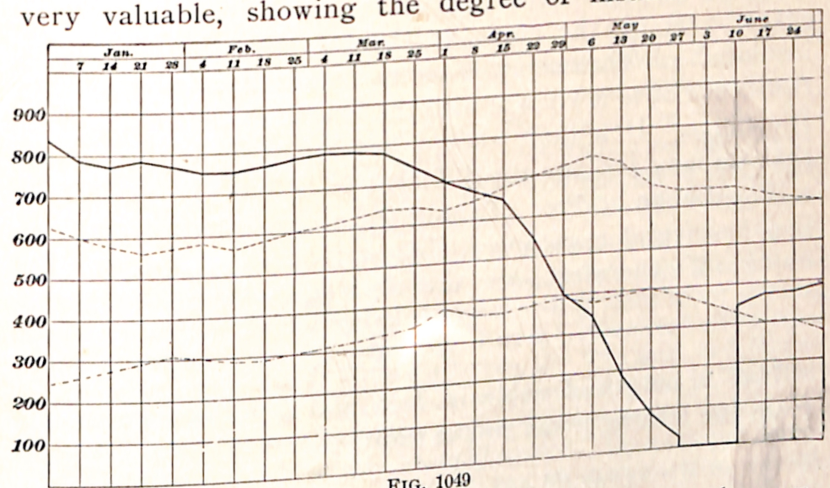

FIG. 1049

various cables and affording a means of judging the comparative merits of different makes.

2601. Ordinary methods of testing for faults are not applicable to railway feeders, owing to their low resistance,

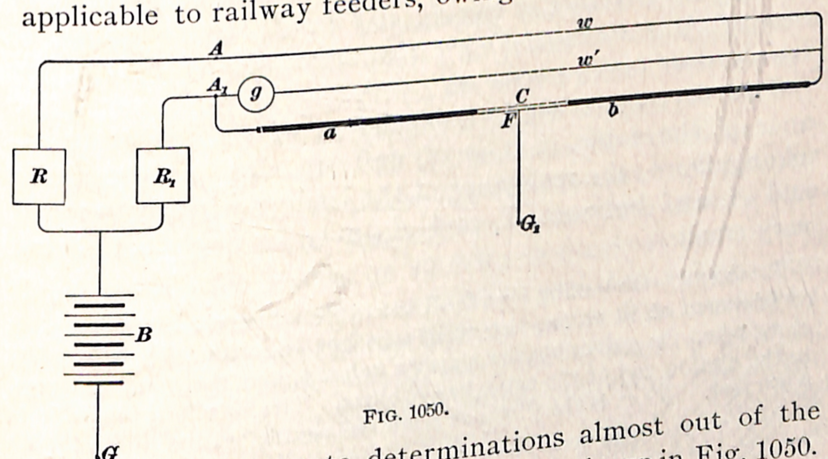

FIG. 1050.

which renders accurate determinations almost out of the question. A means of locating a fault is shown in Fig. 1050. This requires that two well insulated wires w, w' be run the length of the cable. At the testing station, located at one end of the line, are two resistance boxes R, R_1, connected on one side through the battery B to the ground at G, and on the other to A, A_1, respectively, these points being the terminals of the extra line wires, which are connected together and to the cable at the far end, this end being insulated. A Thomson galvanometer g is inserted at w'; the resistance of w is known, also the length of the cable, or its resistance. If a fault should develop at F, it will be seen that we may arrange the different resistances in the form of a Wheatstone bridge. Taking the above letters as indicating the several resistances, then $a : b :: R_1 : R + w$. But $a + b = C$; therefore, $a : C :: R_1 : R_1 + R + w$, and

$$a = C\frac{R_1}{R_1 + R + w}.$$

If $C' =$ length of cable in feet, and $D =$ distance in feet from the testing point to the fault, then

$$D = C'\frac{R_1}{R_1 + R + w}. \qquad \textbf{(371.)}$$

To find the distance in feet to a fault from the end of a cable, obtain a balance on the galvanometer with the arrangement shown in Fig. 1050, then multiply the length of cable in feet by the resistance in box R_1, and divide the product by the sum of the resistances in the two boxes R and R_1 and the resistance of the line wire w.

This determination is independent of the copper resistance of the cable, if it is of uniform size. In the above arrangement, the resistance of the leading wires between R and A, and between R_1 and A_1, may be neglected, being very small.

EXAMPLE.—On testing for a fault in a cable, a line wire is used having a resistance of 12 ohms; the resistance box in series with it has 230 ohms when the galvanometer shows a balance, and the box connected to the station end of the cable has 93 ohms. The length of the cable is 8,000 feet. What is the distance from the testing station to the fault?

SOLUTION.—The quantities given are: $R = 230$; $R_1 = 93$; $w = 12$ $C' = 8{,}000$. (Compare Fig. 1050.) By formula **371**,

$$D = \frac{8{,}000 \times 93}{93 + 230 + 12} = 2{,}221 \text{ feet. Ans.}$$

EXAMPLES FOR PRACTICE.

1. The testing arrangements, when determining the insulation resistance of a certain cable, are as follows: A Thomson reflecting galvanometer of 10,000 ohms resistance; shunt, 1,480 ohms; resistance box, 1,000,560 ohms; battery, 500 ohms. The deflection for galvanometer constant was 306 divisions, and the corrected deflection from cable was 95 divisions. What was the insulation resistance?
Ans. 23.24 megohms.

2. The capacity of a cable is 2.14 microfarads. On testing for insulation by the loss of charge method, the deflection for full charge was 287 divisions, and the deflection after four minutes' leakage was 194 divisions. Find the insulation resistance. Ans. 286.4 megohms.

3. In testing a cable for a fault, the ends were freed from ground and joined by a wire, a galvanometer being included in the circuit. Another wire from the far end of the cable was brought to the testing station at the near end, its resistance being 5.8 ohms, and there connected to one terminal of a resistance box A. The near end of the cable was connected to one terminal of a resistance box B, and the remaining terminals of the two boxes were joined together and to one pole of a battery, the other pole being grounded. On a balance being obtained with the galvanometer, there was in A a resistance of 340 ohms, and in B 860 ohms. What was the distance to the fault from the station, the cable being 11,000 feet long? Ans. 7,845 feet.

ALTERNATING CURRENTS IN RAILWAY WORK.

2602. The use of alternating currents is, in general, only advisable when the source of power is a long distance from the point of utilization or distribution, and in such cases the three-phase system of transmission has proved well adapted to the purpose. It is then usual to install generators supplying a three-phase high-tension current directly to the line; but, if the distance is so great as to make a very high tension (of 10,000 or 15,000 volts) necessary, step-up transformers are used in connection with low-voltage generators. At the sub-station this current is then lowered by means of a step-down transformer, and brought to a rotary transformer, or motor-dynamo, which supplies a direct current to the street railway system at the regular pressure of 500 volts. Rotary field motors are sometimes used on the cars, in which case the high-tension current is simply transformed to a lower pressure and so used, but such a system requires two trolleys on each car and double overhead construction, two wires running side by side and insulated from each other. The switches and crossings become more complicated in consequence, and the wear and tear is greater. On the other hand, the total weight of wire put up need not be much greater than would be the case with the direct current supply; the motors also are of very simple construction (see Art. **2357**), and not liable to get out of order, having no commutators. Speed regulation is effected by cutting out the starting resistances; the armature is designed to give a large starting torque, and any of the extra resistance in series with it becomes a reactive coil, full speed being attained when this is cut out entirely. A peculiarity of the motor is that the speed is nearly constant under varying load, which is due to the low resistance of the armature, as already explained in the article referred to above.

The chief field for polyphase railway systems is in long-distance or interurban traffic, where there is less danger to life from the high-tension current and few crossings of wires.

THE APPLICATION OF BATTERIES TO ELECTRIC TRACTION.

2603. Storage batteries may, in some cases, be used with advantage in connection with electric railways. When used in a station, the engines may always be run at full load, and, during the time that the output to the line is below the average, the batteries will be charged, and when there is a rise in the external load, the batteries will assist the engines. Such an arrangement is seldom put in practice, partly on account of the first cost of the battery, but more generally because there is sure to be deterioration, more or less rapid, according to the quality of the cells and the amount of attention they receive, and central station managers are skeptical as to their value. There is usually some period in the day's run when the station load rises to a point where it is double the regular amount, and, notwithstanding its short duration, engine power must be provided to take that load. It is here that the value of the storage battery is apparent, for its reserve power is then given out, and the engines do not require to furnish more than the normal load, and can be smaller and run more economically than would otherwise be possible. A separate engine might be provided for this extra load, but, since it would be standing idle most of the time, the interest on its cost would be a continual loss.

2604. There are some particular points to be noted in connection with regulation. It will be seen that, since railway generators are usually over-compounded (see Art. **2255**), if a battery were simply connected in parallel with them on the circuit, it would be charged when the external load was heavy, because the voltage of the generators would then be the highest, and would discharge when the external load was light, thus aggravating the faults which it should remedy. To overcome this action, it is necessary that the voltage of the battery should be raised as the load increases, so that at heavy loads it will feed into the line. This can be accomplished by switching in or out extra cells; but there is the disadvantage that these cells may be undercharged or reversed. Another method consists in using an electro-mechanical regulator, but this causes short-circuiting of the cells as the contact switch passes along, since it must cover two contacts at once in passing from one to the other, if the circuit is not to be broken; with the heavy currents used, the contacts would soon burn out if the circuit were frequently opened.

2605. The best way to regulate the action of the battery is by the method shown in Fig. 1051. The compound-wound dynamos are represented by d, d_1, their series windings by c, c_1, and shunt by s, s_1. An extra dynamo, or "booster," d_2 is put in series with the battery B, having shunt and series coils as shown, wound in opposition to each other. When the external load is light, the voltage of the dynamos d, d_1 is low, and very little current passes through the series coils; hence, the shunt winding s_2 of the booster acts to produce such polarity of its field magnets as to develop an E. M. F. opposing that of the battery, which, therefore, helps the dynamos d, d_1, to charge it. When the external load is heavy, the series coil c_2 will take its share of the main current, and overpower the shunt field s_2, reversing the polarity of the booster, and allowing the battery current to feed into the line, thereby taking some of the load off the main dynamos d, d_1. With a moderate load, the shunt and series windings of the booster balance each

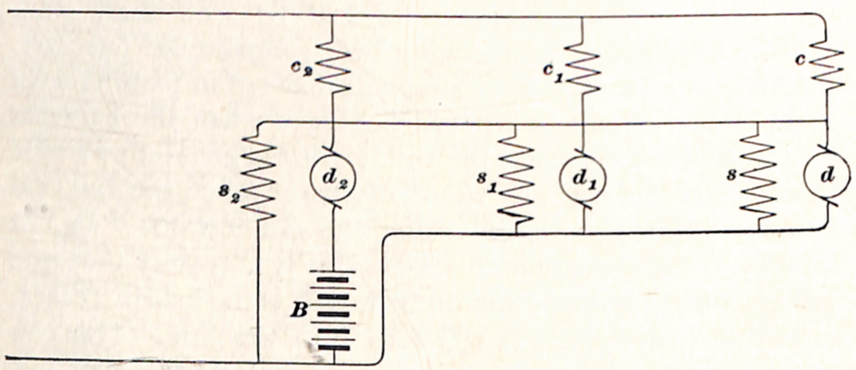

FIG. 1051.

other, and the machine is idle, but at this time the engines are working at an economical point.

There is still another matter to consider. The charging and discharging must be so adjusted that they preserve a balance, that is, the charging in 24 hours must equal the discharge plus the battery loss. This may be accomplished by regulating the booster shunt by hand, the effect of which is to change the point of reversal of the booster with respect to the load. If the battery tends to discharge, the shunt field must be strengthened, and *vice versa*. When one dynamo alone is running, and the battery is required to furnish extra power, the shunt is weakened.

When the booster is connected on at first, it will be necessary to increase the series field of the generators d, d_1 by cutting out some of the resistance forming the shunt across the series winding, in order to compensate for the extra coil c_2, but this is only substituting another path for

the current instead of allowing the energy to be wasted in heating the resistance.

2606. In Fig. 1052 the heavy line is a graphic representation of the variation of load during a certain day in a central station. It will be seen that the lowest point, about 85 amperes, is reached between 3 and 4 o'clock in the morning; that the load 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

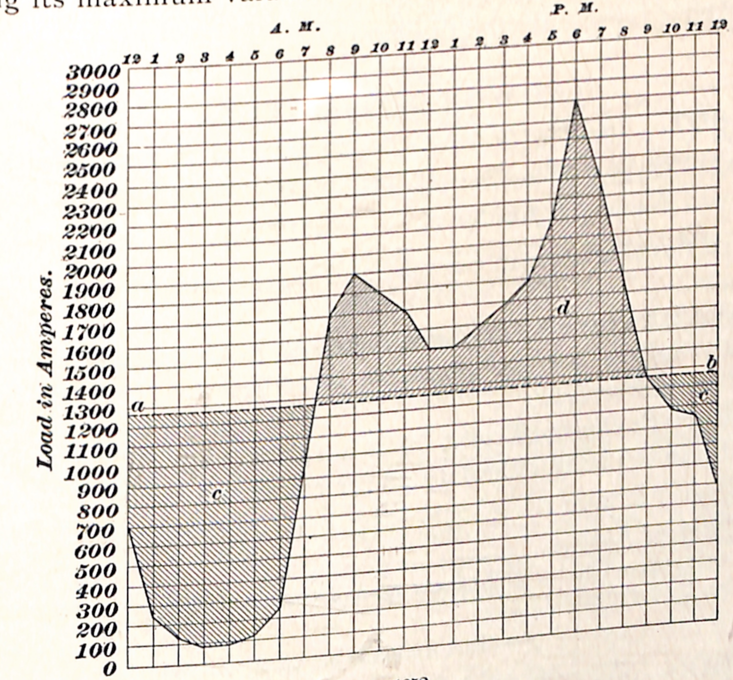

FIG. 1052.

rapidly and continuously. It is evident that to operate such a road, a plant would have to be provided capable of furnishing 2,700 amperes to the line, and probably more on some occasions; but this amount is only required during 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 to equalize the effect of the low parts, and the storage battery accomplishes this. If it were installed in such a station, the dynamos would only be called upon to deliver about half the current, 1,300, instead of 2,700 amperes, and would, therefore, be one-half the size; engines and boilers would also be correspondingly smaller. In the diagram, the shaded portion marked *c* represents the charge given to the accumulators, and that marked *d* represents the discharge.

POWER ESTIMATES.

2607. In determining the amount of power required for propelling a car, we may use the following formula:

$$f = 30\, w_t, \qquad \textbf{(372.)}$$

where f is the force in pounds, and w_t the weight of the car in tons.

That is to say: *The force required to drag a car over a level track in average condition is 30 pounds for every ton that the car weighs.*

Although the coefficient 30 is a rather high figure, it is a good one to use in calculations for estimated power.

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

Solution.—The weight of car $w_t = 9$ tons, and the force required will be, by formula **372,**

$$f = 30 \times 9 = 270 \text{ lb.} \quad \text{Ans.}$$

2608. When a grade has to be taken into account, the perpendicular distance in feet ascended in one 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 one 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 upon the efficiency of the apparatus. We may express these several operations in a single formula, as follows:

$$H = \frac{h\, w + D f}{33{,}000\, \mathsf{E}}, \qquad \textbf{(373.)}$$

where H is the total horsepower required for the motors, h is the perpendicular distance in feet ascended in 1 minute, w is the weight of the car in pounds, D is the horizontal distance in feet traveled in 1 minute, f is the force in pounds necessary to move the car, and E is the 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, their efficiency being 75 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 car expressed in pounds $= 8 \times 2{,}000 = 16{,}000$ pounds $= w$. The force required for propulsion is, by formula **372,** $f = 30 \times 8 = 240$ pounds, and the efficiency being 75 per cent., $\mathsf{E} = .75$.

Then, by formula **373,** we have

$$H = \frac{h\, w + D f}{33{,}000\, \mathsf{E}} = \frac{844{,}800 + 211{,}200}{24{,}750} = 42.67.$$

The power delivered to the motors must be 42.67 H. P. Ans.

2609. The *power* required in going around curves depends upon their radius, and upon the construction of the truck. The power required for starting may be taken as the same as that for rounding curves.

2610. 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 for every ton weight and for each 1 per cent. of grade.

Expressed as a formula, the force required will be

$$f' = (70 + 20\,x)\,w_t, \qquad \textbf{(374.)}$$

where f' is the force in pounds, x is the per cent. grade, and w_t the weight of the 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 **374,** the force will be

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

2611. The limit of adhesion may be $\frac{1}{8}$ of the weight; therefore, on a level track the maximum force which could be applied without slipping would be $\frac{2{,}000}{8} = 250$ 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 car is on the drivers, in which case the limiting grade for starting

$$G_s = \frac{2{,}000\,a\,w_t - 70\,w_t}{20\,w_t} = \frac{2{,}000\,a - 70}{20} \text{ per cent.} \qquad \textbf{(375.)}$$

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

$$G_s = \frac{\frac{2{,}000\,a}{x} - 70}{20} \text{ per cent.} \qquad \textbf{(376.)}$$

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 one-eighth 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 **375,**

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

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

2612. When the car is running, only 30 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,

$$G_r = \frac{\frac{2{,}000\,a}{x} - 30}{20} \text{ per cent.} \qquad \textbf{(377.)}$$

The limiting grade which 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 30, this difference being divided by 20.

EXAMPLE.—The limit of adhesion being one-sixth the weight on the drivers, how steep a grade could be surmounted by a car with one-quarter of its weight on the drivers, starting from the level?

SOLUTION.—According to formula **377**,

$$G_r = \frac{\frac{2,000\,a}{x} - 30}{20} = \frac{\left(\frac{2,000}{4} \times \frac{1}{6}\right) - 30}{20} = 2.67 \text{ per cent. Ans.}$$

2613. Maximum Load.—Before making the selection of the engines for a station, it is first necessary to decide, from the nature of the road and other circumstances, what the maximum load is likely to be, and to find the ratio between this and the average load throughout the day (of 24 hours). We have seen that in the case of a road having a single car, the maximum station load is reached every time that the car starts on a grade. If there were two cars, the chance of the maximum station load being double this amount would not be so great, because they would seldom both start at once on a heavy grade, and when the number is increased still further, the maximum load per car likely to come on the station is reduced in proportion. There are several factors to be taken into consideration before the maximum load can be determined, such as the condition of the track, the percentage of grades, the methods of car dispatching, the radius of the curves, the probable number of cars ascending and of those descending grades simultaneously, the weight of cars, the number of passengers, the frequency of stops, and the efficiency of the motors. With these points all known, some variation may still occur. By the following plan, a determination may be made, which will be found practically correct, representing the maximum load. The working schedule, average speed, and maximum number of cars in use being known, a map of the road is provided, upon which the cars may be marked and so distributed that, at regular distances apart, they may represent the condition of maximum load. We will suppose, as an example, the following case:

EXAMPLE.—A road employs 5 cars, each weighing, with the average number of passengers, 10 tons. The track is 4 miles long, and the cars are to remain at equal distances apart, making one round trip each

half hour. The condition of probable maximum load is found to be, when one is starting, two are on 5 per cent. grades, one rounding a curve, and one on the level; motor efficiency to be taken as 75 per cent. Determine the maximum load.

SOLUTION.—The average speed of the cars will be 4 miles in half an hour, then the distance traveled in 1 minute $= \frac{4 \times 5,280}{30} = 704$ feet. The force required to propel the car on the level is 30 pounds per ton; then $\frac{10 \times 30 \times 704}{33,000} = 6.4$ horsepower will be necessary. For rounding a curve we require a force of 70 pounds per ton, and the power required may be determined by the proportion $30 : 70 = 6.4 : x$; whence $x =$ 14.9 H. P. The power required for starting is the same, or 14.9 H. P. (See Art. **2609.**) The power to run up the grades will be that required for the level, added to that necessary for raising the weight the specified amount. For the level, we have $6.4 \times 2 = 12.8$ horsepower for the two cars, and for the vertical distance, $\frac{704 \times .05 \times 20,000}{33,000} \times 2 =$ 42.6 H. P.—a total for these cars of $12.8 + 42.6 = 55.4$ horsepower. The total mechanical horsepower, or power at the wheels, will be $6.4 +$ $14.9 + 14.9 + 55.4 = 91.6$ horsepower. The efficiency of the motors being 75 per cent., the maximum power supplied will be $91.6 \div .75 = 122$ horsepower. Ans.

The steam engines and electrical generators can easily take a temporary overload of 20 per cent., and it would not be economical to employ machines rated at the full capacity as given above for the maximum load. Allowing, then, 20 per cent., we have $122 \div 1.20 = 102$ horsepower for the rated capacity.

2614. The average power per car will be about 9 horsepower, and the average load on the above station will be $5 \times 9 = 45$ horsepower. The ratio of the mean load to the maximum is here about $\frac{4}{9}$. Upon the value of this ratio depends the type of engine to be selected, and the following rule may be adopted:

Rule.—*The ratio between the maximum and average loads having been found, simple high-speed engines with a wide range of cut-off should be used when the maximum load is three or more times the mean load; and compound high-speed or Corliss engines when the maximum load is not more than twice the mean load.*

In all cases, very heavy fly-wheels must be used, as has already been pointed out; and in the larger stations condensers should be employed whenever water can be economically obtained.

POWER EQUIPMENT.

2615. In stations with heavy normal load, it is advisable to install compound or triple-expansion Corliss engines, directly connected to large low-speed generators. For the 5-car road we have been considering, a simple high-speed engine would prove most satisfactory, and, as we have shown, it should be able to develop about 100 horsepower at $\frac{1}{4}$ or $\frac{3}{8}$ cut-off. The dynamos may be two, of 50 kilowatts each, one of which would furnish service for a time if the other should be disabled. Two boilers should be provided, one of which should be capable of supplying all the steam needed while the other is being cleaned.

For more extensive roads, where a greater number of cars is in use, it is not necessary to go through the calculations respecting positions of various cars to determine the maximum load, for the mean load will approach this value more closely. For a 25-car road, the average station power to be allowed per car will be about 18 indicated horsepower, and the engines, if of the Corliss type, may be two, each of 225 horsepower; if the high-speed engine is used, with a greater range of cut-off, they may be each 200 horsepower. Three dynamos may be installed, each of 100 kilowatts, belted to a common countershaft to be driven by one or both engines.

For power stations to run 50 cars, the allowance is generally about 16 indicated horsepower per car, and two engines should be provided, each of about 400 horsepower, and four 150 K. W. dynamos. When a road has 100 cars, three engines should be used, in order to allow for the repair of one, and still be able to continue the service; by reckoning 15 horsepower per car, we have a total of 1,500 horsepower. Two compound or triple-expansion engines of 600 horsepower and one compound engine of 300 horsepower can here

be used, the larger ones belted each to two 250 kilowatt dynamos, and the smaller to one 250 kilowatt machine. In still larger installations, direct-connected units are very desirable, but the power available per car should not, in the largest plant, be below 15 H. P.

2616. When several circuits are run from one machine, or from two or more connected in parallel, it frequently happens that one circuit will be temporarily loaded more than the others, causing a local fall of potential. The E. M. F. of the generator can not be raised, so the expedient is now generally adopted of increasing the potential of that branch by adding in the circuit another generator of considerable current capacity and low E. M. F. This machine is a compensator, more commonly called a **booster**, and has already been mentioned in connection with battery regulation. It should be so arranged as to be easily transferred from any circuit to another requiring its aid, plug and socket connections being provided for this purpose on the switchboard. The armature, being in the main circuit, is of low resistance; the field magnets may be either series-wound or connected as a shunt across the station feeders. In the first case, the machine requires to be rather larger, and, therefore, more expensive, although it will be entirely self-regulating; in the second case, the field is controlled in the usual manner by a rheostat placed in its circuit.

INSPECTION.

2617. It is very necessary that proper inspection should be made of all parts of the equipment which are subject to wear. This includes not only the motors, but the gears, wheels, car bodies, track, and overhead wiring. The general operation must also be closely watched, to eliminate all possible source of unprofitable expense and to provide a reliable and efficient service. The motors should be periodically tested for insulation, that faults may be corrected before they assume dangerous proportions; the gears should be examined to see that they are wearing well and are free from grit. Particular attention should be devoted to the prevention of flats on wheels, which are caused by the motorman applying the brakes so forcibly as to hold the wheels and make them skid. As soon as a flat is discovered, the car must be brought to the shed and the wheels ground true, for the hammer blow on the track at every revolution of a flatted wheel is very severe.

The track needs constant attention to keep it in good condition. One of the most serious difficulties is the prevention of low joints; with the long fish-plates now coming into use, the joint can be held up better than formerly. The bonds must be tested to see that they make good contact with the rails on each side. One method is to provide a flat, wooden straight-edge, Fig. 1053, about 6 feet long, with a milli-

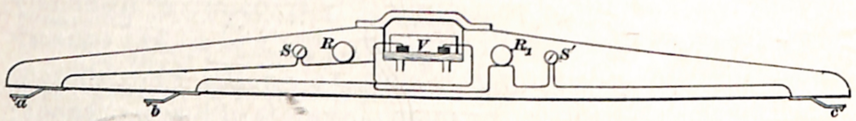

FIG. 1053.

voltmeter V mounted on a cross-board at the middle. At each end is a spring contact point on the lower edge, and a third about 12 inches from one end. These are connected to resistance coils R, R_1, of about 10 ohms each, and to the voltmeter terminals, as shown, small switches S, S' being placed in each circuit $a\ V\ b$ and $b\ V\ c$, so that separate readings may be taken. The voltmeter should have the zero point at the center of the scale, so that the readings will be on opposite sides for currents through the two circuits. This device may be placed upon the rails when they are carrying current, the joint being between the contacts a and b on the left, and the voltmeter will then indicate the ratio of the current in the rail to that passing through the joint. A certain deflection may be taken as the limit beyond which rebonding is required. Imperfect joints are to be marked with chalk in order to distinguish them, and they should be put in good condition without delay.

LOGARITHMS.

2618. The term "log," which occurs in formula **370**, means that the logarithm of the number indicated is to be used in the calculation, instead of the number itself. The logarithm of a number is that exponent by which some fixed number, called the *base*, must be affected in order to equal the number. In common logarithms the base used is 10. In Fig. 1054 are indicated graphically the logarithms of numbers from 1 to 30, which will amply cover the range of possible examples in which formula **370** may occur. Fig. 1055 gives the logarithms of smaller numbers, from 1 to 2.4, being simply the lower part of curve A, in Fig. 1054, laid out to a larger scale.

If it is desired to find the logarithm, for example of 10, the student will follow the line indicated by that number in the horizontal row of figures marked "Numbers," to the point where it crosses the curve (Fig. 1054), and from this point he will continue at a right angle to the former direction until the vertical row of values is reached, and the logarithm is read there. In this case, the logarithm would be 1.0. If the logarithm of 1.8 is desired, it may conveniently be found from curve B, Fig. 1055. By following the line upwards, which starts from 1.8 in the line of numbers, it will be seen to cross the curve at a point corresponding to a value of 0.255 in the vertical scale of logarithms.

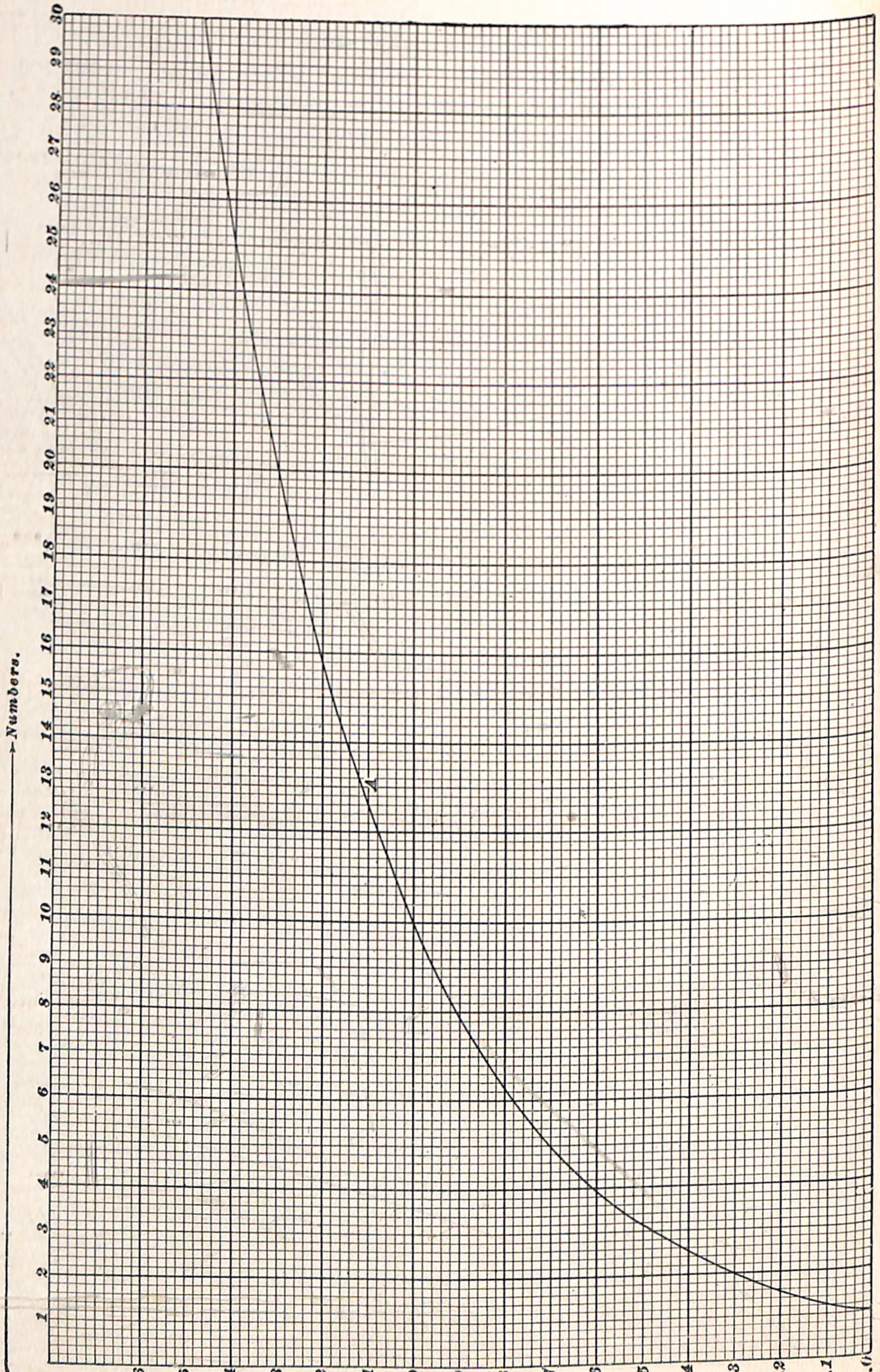

FIG. 1054.

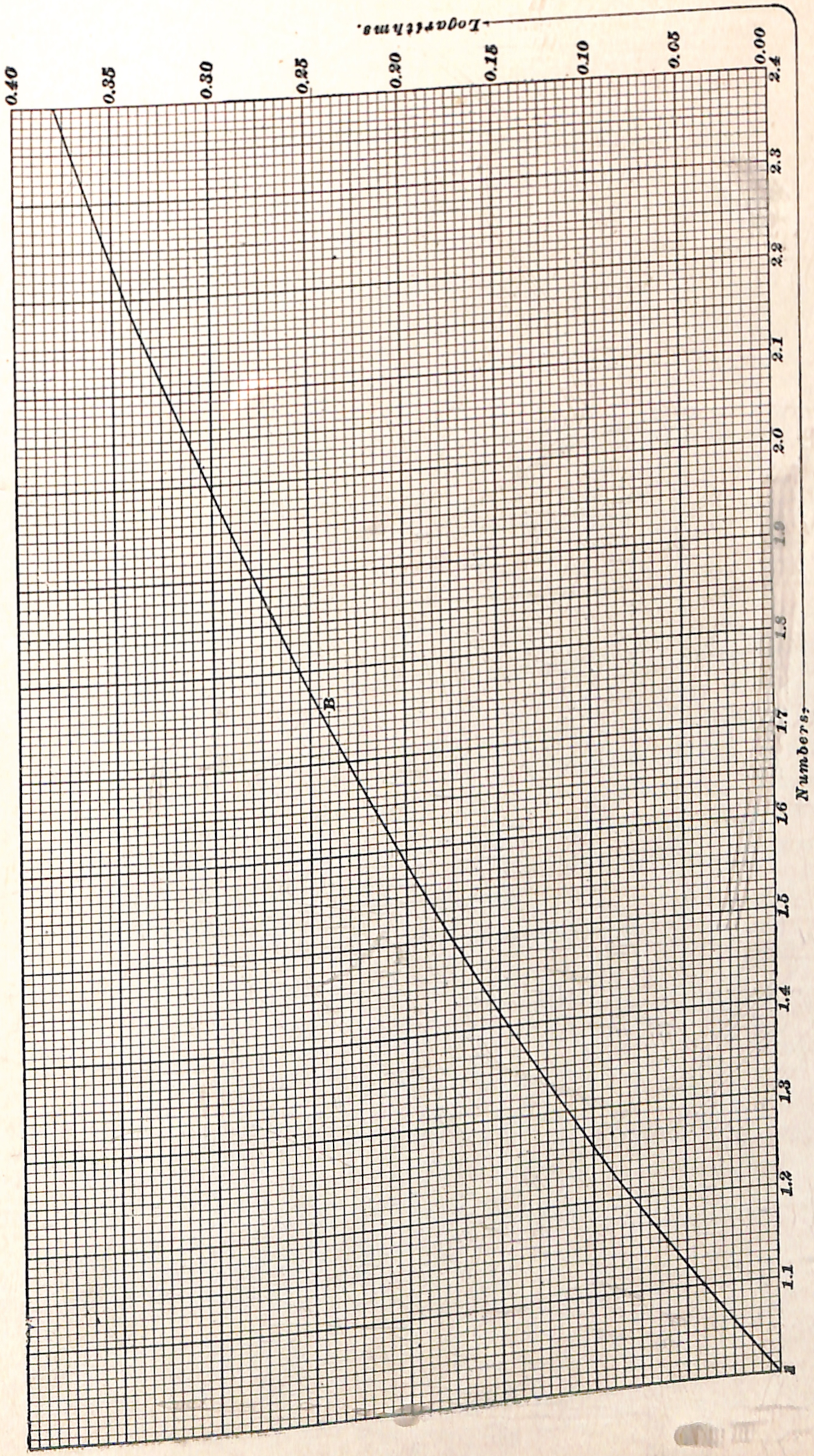

FIG. 1055.