MOTORS AND CONTROLLERS

STREET-RAILWAY MOTORS

INTRODUCTION

1. Street-railway motors have to meet several conditions not imposed on motors used for stationary work. Their design is limited to a large extent by the fact that they must be placed wholly beneath the car. They must be dustproof and waterproof, because they may have to run through all kinds of dirt and water, and must be arranged so that they can be readily suspended from the car axle. Railway motors must be substantial in every particular, because they are called on to stand harder usage than almost any other kind of electrical machinery.

Practically all railway motors, whether for direct or alternating current, are of the series-wound type. For this service, a motor must be able to give a strong starting effort and an increasing torque with decreasing speed. Shunt-wound motors run at a nearly constant speed regardless of load, and a car equipped with them would ascend grades at about the same speed that it would run on the level; whereas, a series-wound motor, when the load is increased, will decrease its speed automatically. Variable speed is essential for railway operation and the shunt-wound motor is a constant-speed machine; hence, it has never been used, to any extent, for this class of work. Another great advantage of the series motor is that it can be made to exert a very strong starting effort. All current that flows through the armature also flows through the field, and a very strong field is thus obtained at starting. With a shunt motor, the current in the

For notice of copyright, see page immediately following the title page

field is fixed by the resistance of the winding and the line E. M. F.; consequently, the field cannot be strengthened when an especially strong torque is desired. Another incidental advantage of the series motor is that the field coils consist of a few turns of coarse wire and are much more substantial and cheaper to wind than fine-wire shunt coils.

2. Speed Reduction.—It has not been found practicable or economical to drive ordinary electric cars by means of motors having their armatures mounted directly on the axles, though such motors may be used to advantage in special cases when they are of large size, as, for example, on heavy, high-speed, electric locomotives. For ordinary work, motors are always geared to the axle; a pinion on the armature shaft engages with a gear keyed to the axle, both gears being covered by a gear-case that contains a quantity of heavy oil. The reduction in speed depends on the relative number of teeth in the two gears; the smaller the pinion, as compared with the gear, the greater will be the reduction.

The **gear-ratio** of an equipment will here be understood as the ratio of the number of teeth in the gear to the number in the pinion; this is the more usual way of expressing it, though it is sometimes given as the ratio of the number of teeth in pinion to the number in gear. The pinion has, in nearly every case, a number of teeth considerably smaller than that in the gear, so that there is little cause for confusion no matter which way the ratio is stated. If, then, a motor has 14 teeth in the pinion and 68 in the gear, the gear-ratio is $\frac{68}{14} = 4.86$ and the motor armature runs 4.86 times as fast as the axle. Table I gives the speed of car axles, in revolutions per minute, for different car speeds and diameters of wheels. By multiplying the revolutions given in the table by the gear-ratio in any given case, the speed of the motor armature is obtained.

EXAMPLE.—A car is mounted on 33-inch wheels and runs at a speed of 20 miles per hour; how many revolutions per minute do the motor armatures make if there are 65 teeth in the axle gear and 15 in the pinion?

SOLUTION.—The speed of the car axle, Table I, for 33-in. wheels and a speed of 20 mi. per hr., is 203.7 rev. per min. The gear has 65 teeth and the pinion 15, hence the gear-ratio is $\frac{65}{15} = 4.33$. The speed of the armature is, therefore, $203.7 \times 4.33 = 882$ rev. per min., approximately. Ans.

TABLE I

REVOLUTIONS OF CAR AXLE CORRESPONDING TO VARIOUS CAR SPEEDS

Speed of Car Miles per Hour	Speed of Car Feet per Minute	Speed of Car Axles (Revolutions per Minute)						
		30-Inch Wheels	31-Inch Wheels	32-Inch Wheels	33-Inch Wheels	34-Inch Wheels	35-Inch Wheels	36-Inch Wheels
6	528	67.2	65.0	63.0	61.1	59.3	57.6	56.1
8	704	89.6	86.7	84.0	81.5	79.1	76.8	74.7
10	880	112.0	108.4	105.0	101.8	98.9	96.1	93.4
12	1,056	134.4	130.0	126.0	122.2	118.6	115.2	112.1
14	1,232	156.9	151.7	147.0	142.6	138.4	134.5	130.7
16	1,408	179.2	173.4	168.0	163.0	158.2	153.6	149.4
18	1,584	201.7	195.1	189.0	183.4	178.0	172.9	168.1
20	1,760	224.0	216.8	210.0	203.7	197.8	192.1	186.8
22	1,936	246.5	238.4	231.0	224.1	217.5	211.3	205.5
24	2,112	268.8	260.0	252.0	244.4	237.3	230.4	224.2
26	2,288	291.3	281.8	273.0	264.8	257.1	249.7	242.9
28	2,464	313.8	303.4	294.0	285.2	276.8	268.9	261.4
30	2,640	336.1	325.1	315.0	305.6	296.6	288.2	280.2
32	2,816	358.4	346.8	336.0	326.0	316.4	307.4	298.8
34	2,992	380.9	368.4	357.0	346.3	336.2	326.6	317.6
36	3,168	403.4	390.2	378.0	366.7	356.0	345.8	336.2
38	3,344	425.8	411.8	399.0	387.1	375.7	365.0	354.9
40	3,520	448.0	433.6	420.0	407.4	395.6	384.2	373.6
42	3,696	470.6	455.2	441.0	427.8	415.3	403.5	392.3
44	3,872	493.0	476.8	462.0	448.1	435.1	422.6	411.0
46	4,048	515.4	498.5	483.0	468.5	454.8	441.9	429.7
48	4,224	537.6	520.0	504.0	488.8	474.6	461.1	448.4
50	4,400	560.2	541.8	525.0	509.2	494.4	480.3	467.0

3. Various gear-ratios are used in practice, depending on the size of the motor and the speed at which the cars must run. Usually, the axle gear has from two to five times as many teeth as the pinion, the first value being found only on heavy high-speed cars. For ordinary city street cars, the

gear will usually have from four to five times as many teeth as the pinion. Involute teeth are used and the diametral pitch for ordinary street-car gears is three; i. e., there are three teeth for each inch diameter of the pitch circle. For heavy traction work, gears having a diametral pitch of two and one-half are employed in many cases. The distance between gear-centers for a given motor is fixed, hence the sum of the circumferences of the two pitch circles is fixed and any increase in the number of teeth in one gear must be accompanied by a corresponding decrease in the other; the sum of the number of teeth in the two gears must be constant. For example, suppose that a motor has a 15-tooth pinion meshing with a 65-tooth gear; if the speed of the car is to be reduced by using a 14-tooth pinion, a 66-tooth gear must be used. No matter what combination of gear and pinion is used, the total number of teeth must be 80, otherwise with the given distance between centers, the gears will not mesh properly.

SELECTION OF MOTORS

4. The selection of the type of motor for a given service is a subject that cannot be given too careful consideration. If the motors are not powerful enough, the cars will not be able to maintain the required schedule; or if forced to do so, there will be a large number of breakdowns and the bill for repairs will be heavy to say nothing of the loss due to interference with the traffic. On the other hand, if motors much larger than required are installed, an unnecessary outlay of capital is entailed and the road is burdened with an expense that might have been avoided. Again, unnecessarily large and heavy motors involve a waste of power, because of the extra weight that must be propelled and also, to some extent, because of the greater iron losses in the larger motor. Finally, excess of weight means unnecessary pounding of joints and deterioration of track.

In order to secure the best results, the selection can be made only after a careful consideration of all local conditions

affecting the power necessary to propel the cars. It is better to have the motors a little too large than too small, but at the same time it is not economical, from either the standpoint of investment or power consumption, to install motors much larger than are necessary.

RATING OF MOTORS

5. There has been much discussion as to the manner in which the output of street-railway motors should be expressed. The load that a motor can carry is limited by the heating effect, and it has become customary to rate motors according to the output, or brake horsepower, that they will deliver continuously for a period of 1 hour with a limiting rise in temperature of 75° C. above surrounding air at 25° C. For example, according to this rating, a 150-horsepower railway motor is one that will deliver 150 horsepower for 1 hour with a rise in temperature not exceeding 75° C. above the temperature of surrounding air at 25° C. This method of rating is not wholly satisfactory, but it is useful in giving a comparative idea as to the capacities of motors and it is also of value in that it shows the performance of the motor as regards sparking and general behavior of the commutator and brushes. Moreover, it is a difficult matter to give a motor a shop test that exactly duplicates its service conditions; whereas, the 1-hour test at full load is easily applied.

6. Service Capacity.—In order to express more closely the output of which motors are capable in regular service, they are now very generally rated by the current that they can carry continuously, without overheating, under conditions that duplicate, as far as possible, those met with in regular service.

The heating of a motor is due to the I^2R loss in the windings and the core loss in the armature. The copper losses depend on the current, which, on a car in regular operation, is continually changing in amount. The current is large at starting, but rapidly falls off as speed is attained; while at times the car may coast along without any current. The

heating effect of the current is proportional to the square of the current at any given instant and the heating effect of the variable current will be the same as a steady current equal in amount to the square root of the mean square of the various values of the variable current. If then a motor is to operate without overheating, this square-root-of-mean-square, or effective, value must not exceed that which the motor could carry continuously and not for 1 hour only. It should be noted that the effective current is not the same as the average current taken by the car. If a test be made on a car during an extended run, the current can be recorded by means of a recording ampere meter or the total quantity of electricity applied can be measured by means of an ampere-hour meter. The number of ampere-hours divided by the number of hours during the test run gives the average value of the current. The heating effect is, however, proportional to the effective value and not to the average value, and the effective value can be found by taking the square of the current at sufficiently close intervals, finding the average value of these squares and extracting the square root of the average so found. In fact, the terms average and effective have here the same meanings that were explained in connection with alternating currents. The effective value of the current must be obtained from the current curve, because this curve is very irregular and does not follow any fixed law. There is no fixed relation between the effective value and the average value, though for a given class of service the relation can be determined approximately. The effective value may be anywhere from 25 to 100 per cent. greater than the average value, depending on the kind of service; for ordinary street-car service it will be about 35 per cent. greater. If, therefore, a number of trial runs showed that each motor of a car had to carry an average current of 30 amperes, the effective current would be approximately $30 + .35 \times 30 = 40.5$ amperes and the motors selected for the work should be able to carry continuously a steady current of this amount. On the other hand, a motor rated as being able to carry a steady current of, say, 30 amperes, should

not be made to carry an average current of more than $\frac{30}{1.35} = 22.2$ amperes in regular service. These values are, of course, only approximate, because the variable character of the service, number of stops, grades, curves, etc., make it practically impossible to give any relation between average and effective current that will be applicable to all classes of service.

7. In testing a motor to determine its service capacity, the voltage applied should be the average voltage on which the motor operates when used on a car. The core loss increases with the voltage, because the higher the voltage the higher is the speed of the armature and the more rapid are the reversals of the magnetism in the core. When a motor is in operation on a 500-volt circuit, the average voltage applied is not 500 volts but is usually considerably less. When the car is at a standstill, no pressure is applied; and when being started a part of the applied pressure is taken up in the starting resistance. Again, as explained under the heading Speed Control, there are times when two motors are connected in series across the line, under which condition the pressure applied to each motor is only one-half the line voltage, or about 250 volts. For these reasons, the average pressure applied to the motors in ordinary city traffic will seldom exceed 300 volts, and even in suburban traffic, where there are fewer stops, it will not often exceed 400 volts. In giving the rating of a motor in terms of the current that it can carry continuously, it is necessary, therefore, to state also the average voltage at which the current is supplied; in many cases, two current ratings are given, one at an average pressure of 300 volts and the other at 400 volts.

MOTOR CHARACTERISTICS

8. In determining the suitability of a motor for a given class of service, it is necessary to have information showing the performance of the motor. This is obtained from tests

made by the manufacturers, and is usually given in the form of curves, known as **motor characteristics**, that show the relation between the current, speed, tractive effort, brake horsepower, and heating effect. Fig. 1 is a set of these curves for a No. 68 Westinghouse motor.

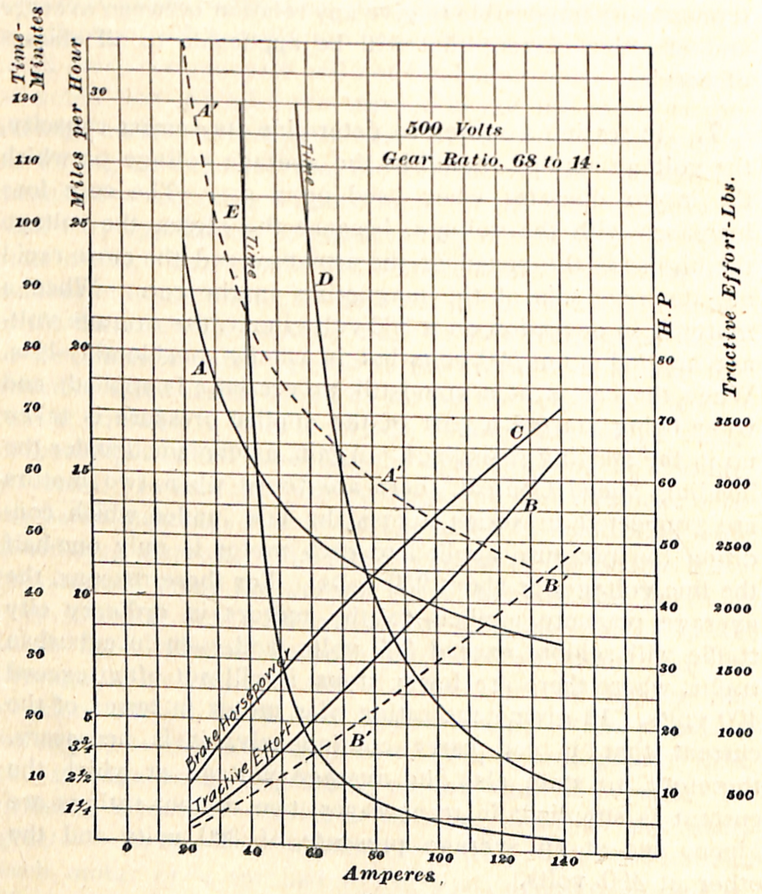


FIG. 1

9. Speed Characteristic.—The curves, Fig. 1, are drawn for a constant applied E. M. F. of 500 volts, which is the normal voltage at which the motor is intended to operate. As the current increases the speed decreases,

because of the increase in field strength, and the speed of the car, therefore, decreases as shown by the speed curve A. The speed of the car corresponding to any given current depends on the gear-ratio and the diameter of the wheels, hence both of these must be stated in connection with the curves. In this case, there are 14 teeth in the motor pinion and 68 in the axle gear, and the wheels are 33 inches in diameter. A curve showing the relation between armature speed and current would have the same general shape as A.

10. Effect of Increase in Voltage.—An increase in voltage increases the speed in almost direct proportion. For example, in Fig. 1, the speed corresponding to 60 amperes is 12.5 miles per hour; if the pressure were increased from 500 volts to 600 volts, the speed corresponding to the same current would be approximately $12.5 \times \frac{600}{500} = 15$ miles per hour.

11. Tractive Effort Characteristic.—Curve B shows the relation between current and tractive effort. This, of course, refers to the effort exerted by a single motor and gives the total force at the two wheels on which the motor is mounted; thus, for a current of 50 amperes, the total tractive effort at the rail head is 750 pounds, or 375 pounds at each driving wheel. The torque of a series motor increases rapidly with the current; hence, the tractive effort also increases, curve B having the same general shape as one showing the relation between motor torque and current.

12. Relation Between Motor Torque, Gear-Ratio, Speed, and Tractive Effort.—Fig. 2 shows the forces acting on a car wheel, gear, and pinion; r is the radius of the pitch circle of the pinion, r' that of the gear, and r'' that of the car wheel. When current flows through the motor, the torque or twisting action that is exerted on the armature and pinion depends on the value of the current and the electrical design of the motor. The motor torque will be $F' r$, when F' is the force exerted at the pitch circle; torque is always expressed as force $\times$ radius and

must not be confused with the force F'. For a given torque, F' will vary with the radius of the pinion, but the product $F'r$ will remain constant, because if r is increased or decreased F' will be decreased or increased by a corresponding amount. The torque exerted on the axle is $F'r'$ and is greater than $F'r$ because the radius, or lever arm r', is greater than r. Since the number of teeth in a gear is proportional to its diameter or radius $\frac{r}{r'} = \frac{n}{n'}$, or $r' = r\frac{n'}{n}$, where n is the number of teeth in the pinion and n' the number of teeth in the gear. The torque exerted on the axle is $F'r'$, or $F' \times r\frac{n'}{n} = F'r \times \frac{n'}{n}$. But $F'r$ is the motor torque, hence the torque exerted on the axle is equal to the motor torque multiplied by the number of teeth in the gear and divided by the number of teeth in the pinion, or, in other words, the torque exerted on the drivers is equal to the motor torque multiplied by the gear-ratio.

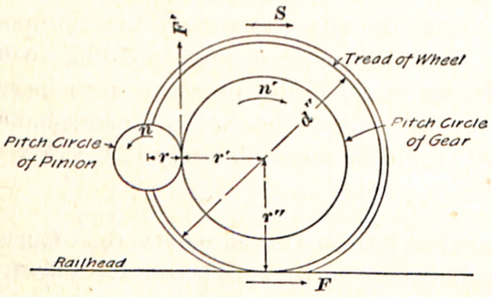


FIG. 2

The total tractive effort F, Fig. 2, exerted at the rail head by both wheels, is equal to the torque $F'r'$ divided by the wheel radius r''. Thus, $F = \frac{F'r'}{r''} = F'\frac{r\frac{n'}{n}}{r''} = \frac{F'r}{r''} \times \frac{n'}{n}$. If $F'r$ is expressed in pound-feet, and, if instead of r'', the wheel diameter d'' is used, the formula becomes

$$F = \frac{24\,F'r}{d''} \times \frac{n'}{n} \qquad (1)$$

where F = total tractive force, in pounds per motor;
$F'r$ = motor torque, in pound-feet;
d'' = diameter of wheel, in inches;
n' = number of teeth, in gear;
n = number of teeth, in pinion.

EXAMPLE.—A car is equipped with motors, having 15-tooth pinions and 65-tooth gears, mounted on 33-inch wheels. What will be the tractive effort per motor when the current is such as to give a motor torque of 300 pound-feet?

SOLUTION.—In formula **1**, $F'r = 300$, $d'' = 33$, $n' = 65$, $n = 15$. Hence,

$$F = \frac{24 \times 300}{33} \times \frac{65}{15} = 945 \text{ lb., approximately.} \quad \text{Ans.}$$

13. The number of feet traveled per minute by a car is $\frac{3.1416\,d''s'}{12}$, where d'' is the wheel diameter, in inches, and s' the axle speed, in revolutions per minute. Since 1 mile per hour is equivalent to 88 feet per minute, the speed, S, of the car, in miles per hour, is $S = \frac{3.1416\,d''s'}{12 \times 88}$ or

$$S = \frac{d''s'}{336.1} \qquad (2)$$

14. Effect on Speed of Change in Gear-Ratio.—In Fig. 1, the curves of tractive effort and speed are drawn for a gear-ratio of 68 to 14 and for 33-inch wheels. Assuming that the wheel diameter remains unchanged, let us see what change will be made by substituting gears having a ratio of 64 to 18. The ratio is thus decreased from $\frac{68}{14} = 4.86$ to $\frac{64}{18} = 3.56$. From formula **2**, the car speed is $S = \frac{d''s'}{336.1}$. But s', the speed of the axle, is equal to $\frac{s}{\frac{n'}{n}}$, where s is the motor speed and $\frac{n'}{n}$ the gear-ratio; hence, $S = \frac{d''s}{336.1\frac{n'}{n}}$. For a given current, the speed s of the motor has a certain fixed

value and if $\frac{n'}{n}$ is made smaller, i. e., if the number of teeth in the gear is decreased and the number in the pinion correspondingly increased, it follows that, for the given current, the speed S of the car will be increased. The speed corresponding to the new gear-ratio will be equal to the speed at the original ratio multiplied by the original ratio and divided by the changed ratio. In this case, the original ratio is $\frac{68}{14} = 4.86$ and the changed ratio $\frac{64}{18} = 3.56$. Taking a current of, say, 50 amperes, the speed with the original ratio is, from curve A, about 13.8 miles per hour. With the changed ratio, the speed corresponding to the same current would be $\frac{13.8 \times 4.86}{3.56} = 18.8$ miles per hour. In order, however, to obtain the higher speed with the same current, the weight of car would have to be lessened. By calculating the speed corresponding to various currents, the dotted curve $A' A'$ can be drawn to represent the speed for all current values at the new gear-ratio $\frac{64}{18}$.

15. Effect on Tractive Effort of Change in Gear-Ratio.—A change in gear-ratio affects the tractive effort as well as the speed. For a given current, the power delivered by the motor remains the same, no matter what the speed or tractive effort may be. A decrease in the gear-ratio causes an increase in speed, as indicated by curve $A' A'$; and, as the power curve C remains unaltered, the increased speed corresponding to a given current must be accompanied by a decreased tractive effort. This is also plain from formula **1**, in which any decrease in $\frac{n'}{n}$ makes F smaller. The tractive effort with the changed ratio will therefore be equal to the tractive effort with the original ratio, multiplied by the changed ratio and divided by the original ratio. For example, in Fig. 1, the tractive effort for a current of 50 amperes is 750 pounds with the original ratio; with the new ratio, the effort will be $\frac{750 \times 3.56}{4.86} = 549$ pounds. By calculating the tractive effort corresponding to a number of different current values, the dotted curve $B' B'$ can be drawn, and curves $A' A'$ and $B' B'$ taken together represent the changed performance due to the change in gear-ratio from $\frac{68}{14}$ to $\frac{64}{18}$.

16. Effect of Change in Wheel Diameter.—With a given gear-ratio and current, a reduction in the wheel diameter causes a corresponding reduction in the speed of the car and vice versa. A decrease in the wheel diameter has the same effect as an increase in the gear-ratio.

17. Effect of Changing Gear-Ratio on a Given Equipment.—It is sometimes important to know the probable change that will be made in the speed of a given car when the gear-ratio is changed, the weight of the car and all other parts of the equipment remaining the same. If the motor characteristics for the original gear-ratio are at hand, the new speed under the changed conditions can be determined approximately, as follows: Calculate two curves, as explained for $A' A'$ and $B' B'$, Fig. 1, to suit the new conditions. From the known weight of car, the tractive effort can be determined approximately, and the speed and current corresponding thereto can be read off from the curves drawn for the new gear-ratio. For example, suppose that curves A and B represent the performance with the original gear-ratio of $\frac{68}{14}$ and that the ratio is changed to $\frac{64}{18}$. Curves $A' A'$ and $B' B'$ then represent the performance under the changed conditions. With the original gearing, a test showed that the car ran at a speed of 13.8 miles per hour on the level and required a current of 50 amperes per motor; the corresponding tractive effort was therefore 750 pounds per motor. With a fixed weight of car the increase in speed does not cause much change in the tractive effort and for low speeds, such as are now under consideration, it may be taken as

750 pounds under the changed conditions. With the changed gear-ratio, a tractive effort of 750 pounds corresponds to a current of about 61 amperes, as shown by curve $B'B'$; and a speed of about 17.25 miles per hour as shown by $A'A'$. The change in gear-ratio has therefore caused an increase in speed, but the increase is not as great as the mere change in gearing would lead one to expect. If the change in gearing alone were considered, the speed would be $\frac{13.8 \times 4.86}{3.56}$ = 18.8 miles per hour. However, in order to drive the car at the higher speed, more power must be supplied and the current must therefore increase, thus necessitating an actual decrease in the motor speed. Because of this change in motor speed, with change in current, the final speed of the car must be determined from the characteristic curves for tractive effort and speed, drawn so as to take into account the change in gearing. Since, with a fixed weight of car, an decrease in gear-ratio is accompanied by an increase in current, a point is soon reached beyond which any further change in gearing will cause serious overheating of the motors.

18. High-geared motors take very large currents during the acceleration period unless the controllers are carefully handled, and as a general rule motors should not be geared any higher than is necessary to allow the cars to maintain their schedule with a fair margin; any higher gearing simply causes waste of current and throws an unnecessary load on the equipment. In case the weight of the car is not fixed, a motor can be geared for higher speed without increasing the current. For example, a pair of motors might be taken off a heavy car and placed on a lighter one that requires a smaller tractive effort. If the limiting current is to be the same in each case, the motor torque and the speed of the armature will remain unchanged. Hence, assuming that the wheel diameters are not changed, the smaller tractive force can be obtained by increasing the gear-ratio and, since the armature speed remains constant, there will be a corresponding increase in the car speed. The power supplied to the

motors remains the same as when they were on the heavier car, the tractive effort being smaller and the speed correspondingly higher.

Therefore, in making changes in the gearing, the weight of car must be kept in mind; if it is not changed in any way, the increased speed may be obtained at the expense of overloading the motors; but if the motors are placed on a lighter car, the increased speed may be secured without any increase in the current or even with smaller current if the second car is very much lighter than the first.

19. Heating Characteristics.—Curve D, Fig. 1, shows the time that it takes the temperature of the motor to rise from 25° C. to 75° C. when carrying various currents. Thus, a load of 70 amperes can be carried for 60 minutes if the motor is started at a temperature of 25°, so that on the 1-hour rating this motor will have a capacity of about 38 brake horsepower. However, under ordinary running conditions, the motor is much hotter than 25° C., and the time during which it can carry a given current without rising above 75° C. will be much less than is indicated by curve D; the length of time that the motor can carry a given current without overheating is shown approximately by curve E, which allows for a rise of 20° C. in the interior of the motor after the motor has attained a temperature of about 55° C. For example, if it is running at 55° C., it will carry a steady current of, say, 50 amperes, or a variable current of which the effective value is 50 amperes, for 30 minutes before reaching 75° C. If the average working temperature were less than 55° C., the currents could be applied for a proportionally longer period without causing a temperature exceeding 75° C.; the current referred to is the current per motor, not the current per car. In making current tests on a motor, the ammeter should be connected in series with the motor and not in series with the trolley. Most cars are equipped with at least two motors operated in series at low speeds, in which case the current in each is the same as the total current, but at high speeds the motors are in parallel

and the current in each is approximately half the total. The average current per motor is, therefore, more than half the total current. Curve E is useful in fixing the maximum loads that the motor may take during rush hours or periods of unusually heavy load.

EXAMPLES FOR PRACTICE

1. If a car is mounted on 34-inch wheels and the motors have a gear-ratio of $\frac{68}{16}$, what will be the total tractive effort per motor, when the motor torque is 300 pound-feet? Ans. 900 lb.

2. If the gearing on a car is changed as shown in Fig. 1, and if the tractive effort per motor remains constant, at 1,000 pounds, what will be the change in car speed caused by the change in gearing? Ans. From $12\frac{1}{2}$ mi. per hr. to about 15.3 mi. per hr.

3. A car is mounted on 33-inch wheels and the motors have a gear-ratio of $\frac{65}{15}$; what will be the speed of the armature, in revolutions per minute, when the car is running 16 miles per hour? Ans. 706 rev. per min.

TYPES OF MOTORS

20. Direct-current motors, series-wound for 500 to 650 volts, are used on nearly all electric railways. At first, two-pole motors were used but these soon gave place to the four-pole type. Fig. 3 shows some of the field constructions used for well-known motors. (*a*) is the old Thomson-Houston W. P. 50 (waterproof) motor; it has a two-pole field with a single magnetizing coil. (*b*) is the old Edison No. 14, which has a four-pole field with two field coils. (*c*) is the General Electric 800 (G. E. 800) motor field which is similar to the Edison No. 14, but is turned up the other way. (*d*) shows the four-pole magnet frame introduced about 1891 by the Westinghouse Company in their No. 3 motor; it has four poles set on the diagonal, each pole being provided with a field coil. (*e*) shows a field about as used on a modern motor. The frame is of cast steel in order to secure lightness and the pole pieces, instead of being cast with the frame, are built up of sheet-iron stampings bolted

to the frame. This laminated-pole construction reduces heating in the pole pieces and also tends to keep down sparking at the commutator. The constructions indicated in (*a*), (*b*), (*c*), and (*d*) are now obsolete, but many motors in which they are used are still in operation.

Railway-motor armatures are always of the slotted type, the coils being wound on forms and then placed in slots on the core. In the earlier slotted armatures, a large number of slots were used, generally from 87 to 105. This was necessary because, if the slots were made coarse, it was found that they caused the magnetism in the pole pieces to

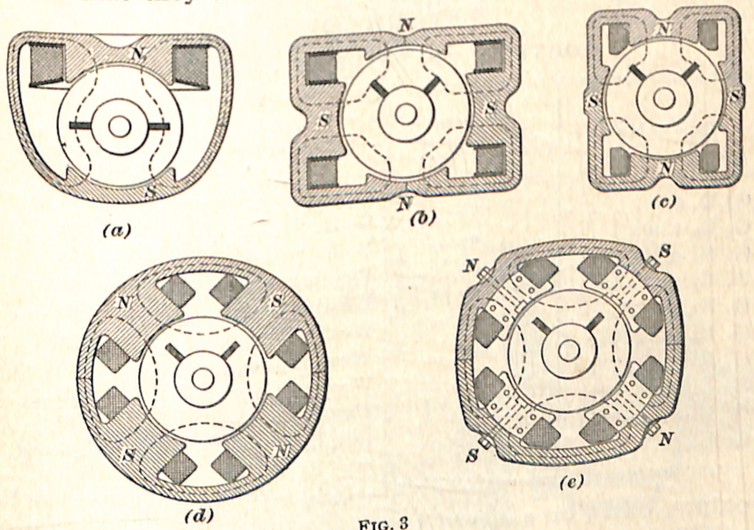


FIG. 3

vary to such an extent that the solid poles would heat considerably. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making them very much larger, cheapening the cost of production, and making the motor operate better generally.

A number of sizes and types of railway motors have been brought out from time to time by the leading manufacturing companies, in order to keep pace with improvements in design or to meet new traffic conditions. Some of the older

motors made by the General Electric Company were designated by the number of pounds tractive effort they could exert with full-load current when provided with standard gearing and mounted on 33-inch wheels. Thus, the G. E. (General Electric) 800 motor can exert a tractive effort of 800 pounds under these conditions; a G. E. 1,000 motor can exert 1,000 pounds; and so on. This method of rating has been abandoned and motors are now designated by arbitrary numbers, as, for example, G. E. 52, G. E. 54, etc. Westinghouse motors are also designated by numbers, as, for example, No. 3, No. 49, No. 56, etc. Table II gives the horsepower

TABLE II

OUTPUT OF RAILWAY MOTORS

Type of Motor	Output in Horsepower (Railway Rating)	Type of Motor	Output in Horsepower (Railway Rating)
G. E. 800	27	G. E. 73	75
G. E. 1,000 . . .	35	G. E. 74	65
G. E. 51B . . .	80	Westinghouse 12A	30
G. E. 52	27	Westinghouse 38B	50
G. E. 54	25	Westinghouse 49 .	35
G. E. 55	160	Westinghouse 50L	150
G. E. 57	50	Westinghouse 56 .	60
G. E. 66	125	Westinghouse 69 .	30
G. E. 67	38	Lorain No. 34 . .	50
G. E. 70	40		

output, based on a run of 1 hour, with a rise in temperature of 75° C. above surrounding air at 25° C., for a number of the motors in most general use. Since all modern railway motors are very similar in their general construction, it will be sufficient to describe here a few typical examples.

G. E. 52 MOTOR

21. Field-Frame Construction.—As an example of a small motor intended for ordinary city traffic where light cars are operated, the **G. E. 52 motor** may be taken. Fig. 4 is a rear view showing the general shape of the field frame,

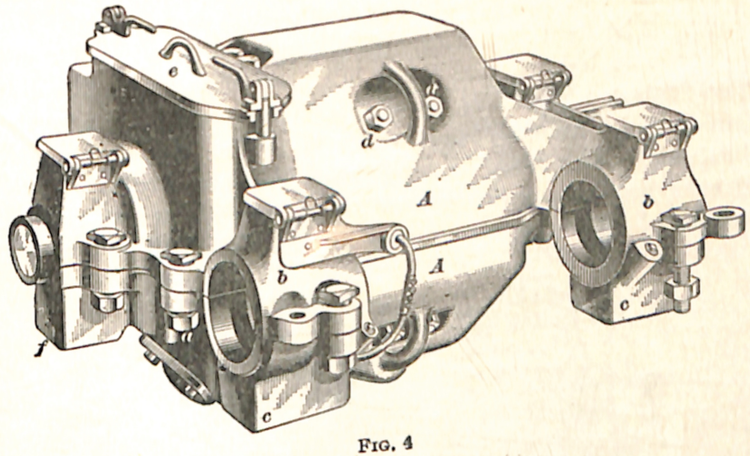


FIG. 4

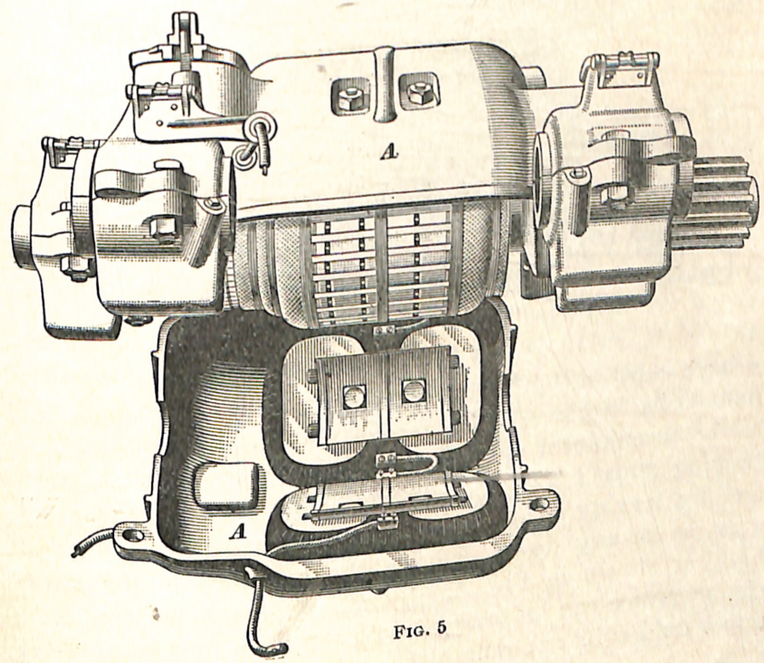


FIG. 5

which, as in all modern motors, is shaped so as to completely enclose the armature, commutator, brushes, and field coils. The field frame is roughly hexagonal in outline and is made in halves, which are held together by bolts. The two arms b, b extending from the back of the motor receive one-half the axle bearing, which is in the shape of a split bushing. The axle-bearing caps c, c are provided with grease boxes, and the grease or oil is fed on the axle by means of pieces of felt from underneath as well as from the

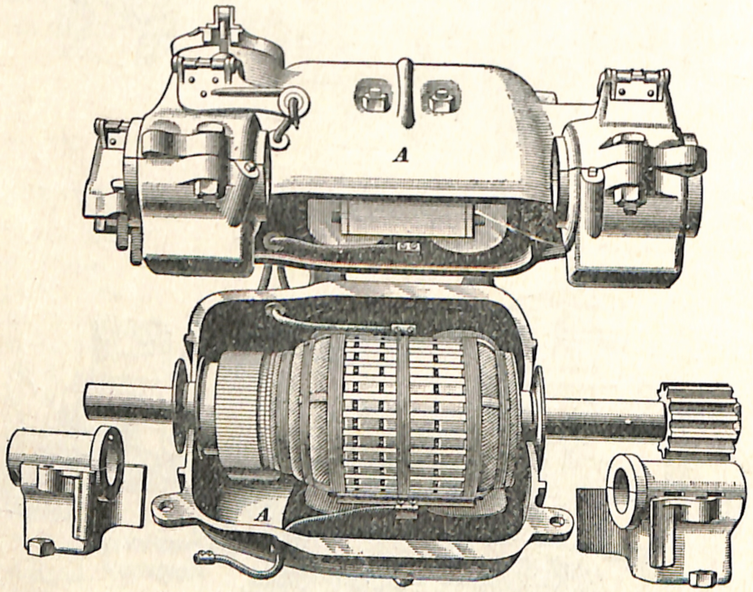


FIG. 6

grease cups on top. The bolts d, d hold the pole pieces and field coils in place. The removable cover e allows access to the commutator and brush holders. The lower armature-bearing caps f are separate from the lower half field A, and by leaving these caps in position, the lower half field may be swung down, leaving the armature in the upper half, as shown in Fig. 5. By removing the bearing caps, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 6.

22. Capacity.—The G. E. 52 motor has an output of 27 horsepower, based on a run of 1 hour with a 75° C. rise in temperature. The motor is intended for ordinary street-railway work and is not recommended for the heavier kinds of traffic.

23. Pole Pieces.—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place, and the laminations not only do away with a great deal of heat in the pole piece, but from the way in which they are built up they produce a magnetic field that does away with much of the sparking at the brushes. The pole pieces are made of iron plates shaped like the full-line part of Fig. 7 (b). In building up the pole piece of these plates every other plate is turned end for end with the result that, along the center part of the pole piece, the plates are close together, but on the horns only half of the plates come out on each side, as shown in Fig. 7 (a). This plate construction largely prevents sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces a *shaded field* or *fringe*. This shaded field provides a fringe that reverses the current in the coil passing under the brush, and hence brings about the change in the direction of the current with but little sparking.

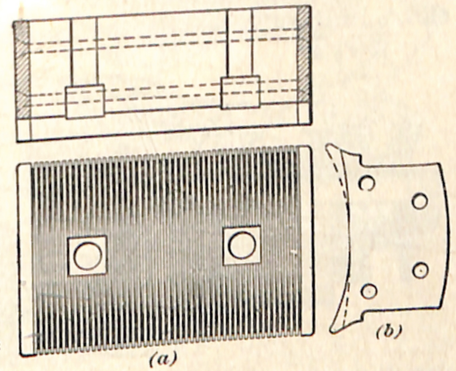


FIG. 7

24. Field Coils.—The field coils are wound on forms, and while the asbestos-covered wire is being wound it is treated with a mixture of chalk and japan and afterwards baked. The coils are heavily insulated with tape and insulating varnish and are given a glazed surface that will readily turn off water and prevent moisture from getting in.

25. Armature.—Fig. 8 shows a half section of the G. E. 52 armature, and its construction is typical of many of the railway-motor armatures now in use. The core is provided with 29 slots. One side of 6 coils goes into each slot, so that there are 87 coils altogether, and the commutator has 87 bars. The coils are bunched in groups of three, one side of one bunch going into the bottom of a slot, and one side of another into the top of the same slot. In Fig. 8, *a a* is the laminated armature core and

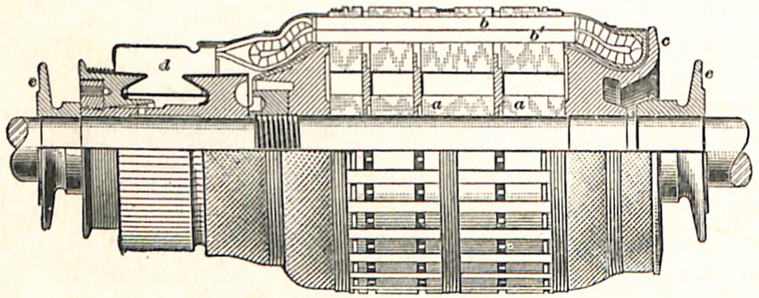


FIG. 8

b, *b'* the upper and lower halves of two coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted as shown. The flanges *e*, *e* are for preventing grease and oil working their way into the armature. The bearings are so arranged that any oil getting on *e*. *e* drops through an opening to the street.

26. Brush Holders.—Railway-motor brush holders are fixed permanently at the neutral point and are not arranged so that they can be shifted, as is the case with many other direct-current machines. The reason for this is twofold: In the first place, the motor has to run in either direction; and in the second place, the variations in load are so sudden that any brush-shifting arrangement is out of the question. The brushes are, however, mounted so that

they can be moved radially toward the center of the commutator as the latter wears away.

Fig. 9 shows the brush holders and brush-holder yoke of the G. E. 52 motor. The yoke *a*, which is made of well-seasoned hardwood treated with insulating material, is bolted to the upper field frame by means of bolts *b*, *b*. The brush holders *h*, *h* are fastened to brass slides on *a* by means of bolts *c*, *c*. All railway motors use carbon brushes; in this case, two brushes $2\frac{1}{4}$ in. $\times$ $1\frac{1}{4}$ in. $\times$ $\frac{1}{2}$ in. are used in each holder.

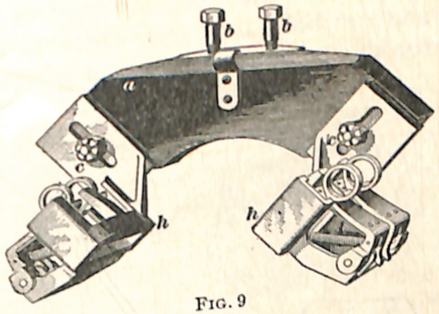


FIG. 9

G. E. 70 MOTOR

27. Figs. 10 and 11 show the G. E. 70 motor, which represents one of the latest types having an output sufficiently large to adapt it for use on suburban cars; its output is 40 horsepower based on the 1-hour rating. The field is made in halves, as shown in Fig. 10, but unlike nearly all the earlier types of motor, the dividing line between the upper half *a* and the lower half *b* is not through the center line of the motor. The upper part lifts off as shown, and dowels *c*, *d* serve to guide it into place when it is lowered into position. The armature bearings are carried in malleable cast-iron frame heads *e*, *f*, Fig. 11, and after these have been unbolted and the top part of the field removed, the whole armature can be lifted out. The object of this design is to make it convenient to work on the motor, from above rather than from a pit underneath, as it is becoming common practice to remove the car bodies from the trucks and work on the motors from above when thorough overhauling is required.

The bearings consist of a bronze lining, or shell, lined with a very thin layer of Babbitt metal that is thoroughly

soldered to the bronze. The Babbitt is so thin that even should the box become hot enough to melt it, the armature will not be lowered sufficiently to rub on the pole pieces. The bronze linings are held securely in the frame heads *e*, *f*, and as the latter have a large bearing surface on the frame and are bolted securely thereto, it is practically impossible for the bearings to get out of line.

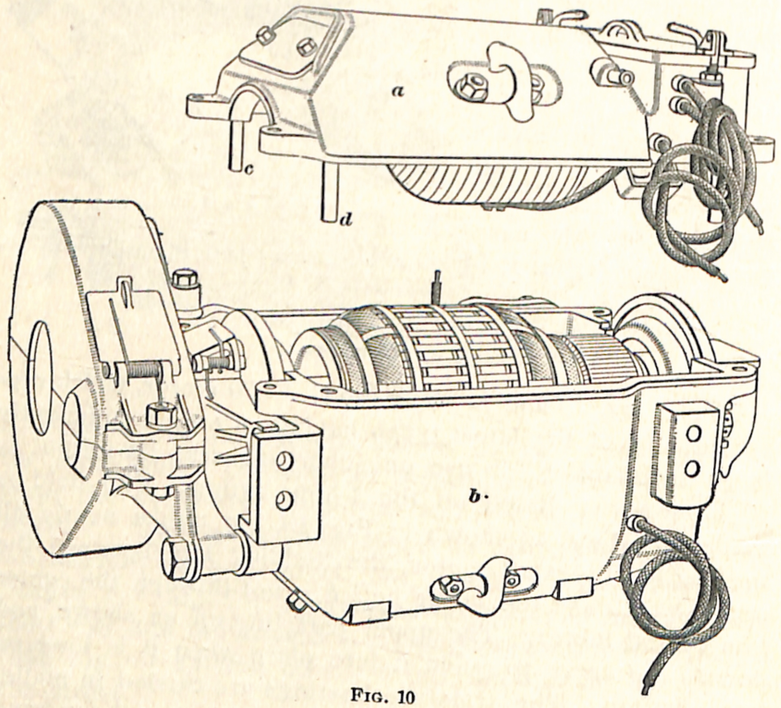


FIG. 10

All bearings are designed for oil lubrication, which is effected in much the same way as on regular car-axle bearings. The linings are in the form of sleeves with openings cut in one side so as to expose the shaft to oily waste that is packed in oil wells, or boxes, cast in the frame heads or in extensions of the brackets that form the axle bearings. The oil boxes are protected by hinged covers held closed by springs. The waste is arranged so that it presses against

the lower part of the shaft and all oil before reaching the shaft must filter through the waste above. If any dirt accidentally gets into the boxes, it is thus prevented from reaching the shaft. This method of lubrication has been found superior to the old method of using grease. Oil deflectors on the armature shaft prevent oil from reaching the armature and commutator, by throwing it into recesses from whence it drops through to the street.

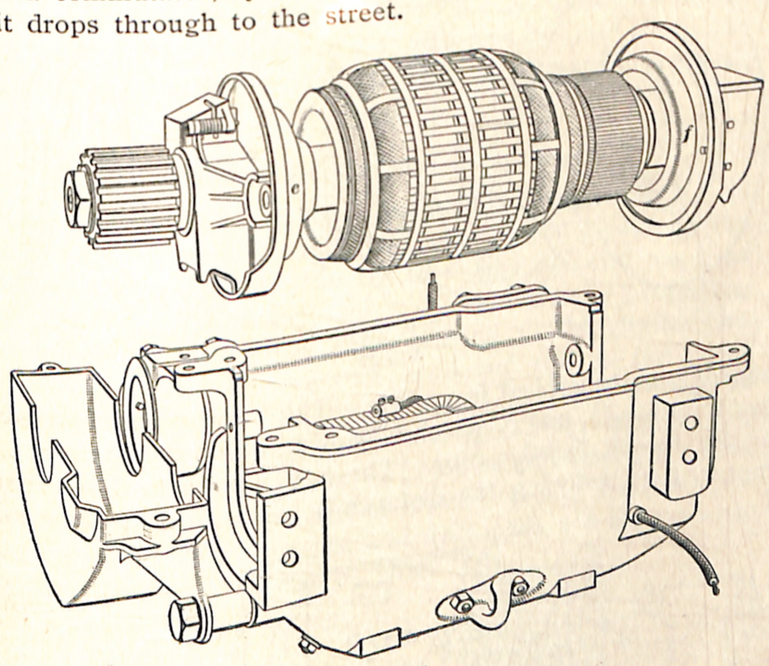


FIG. 11

The four field coils are held in place by the projecting flanges of the laminated pole pieces and, to minimize the chances of abrasion, flanges of steel are placed between the coils and the surfaces with which they come in contact. The coil winding is of the so-called "mummified" type, mica and asbestos being used as insulating materials. Each coil is covered with insulating fabric thoroughly treated with waterproof compound.

G. E. 69 MOTOR

28. This motor, Fig. 12, is of 200-horsepower capacity and represents one of the most powerful types used on elevated and underground roads. Its field frame *a* is of the *box type*, so called because it is cast in one piece, and is

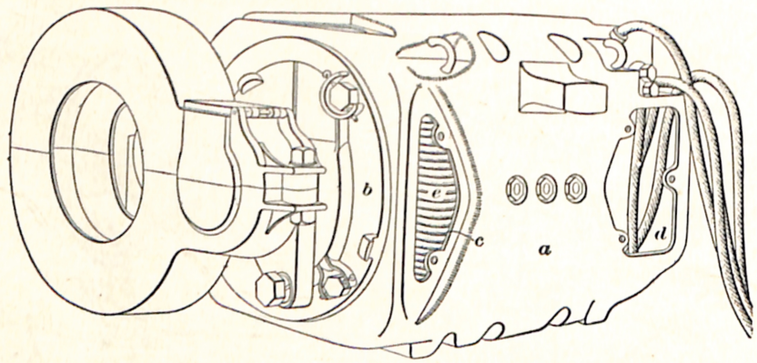


FIG. 12

approximately cubical in outline. The bearings are carried in frame heads, one of which is shown at *b*, in the same way as for the G. E. 70 motor. The heads project within the motor, thus reducing the distance between centers of bear-

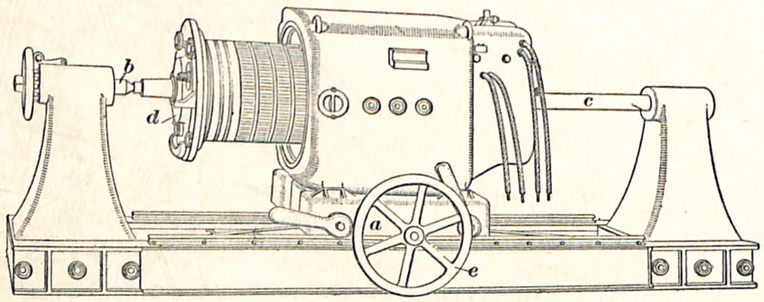


FIG. 13

ings and economizing space, because with these large motors it is difficult to find sufficient space for them between the wheel hubs. Openings *c*, *d* are provided on each side and on top of the motor in order to give access to the inside; under

normal conditions, these openings are covered by plates bolted in place; one of the field coils is shown at *e*. With motors of the box-frame type, the armature is removed endwise by taking out either frame head and sliding the armature through the opening. Fig. 13 shows a stand by means of which armatures can be easily removed from this type of field. The motor is placed on a sliding carriage *a* and the armature held between centers *b*, *c*. After the frame head *d* has been loosened, the field can be moved to the right by turning wheel *e*, thus leaving the armature exposed.

WESTINGHOUSE NO. 86 MOTOR

29. Fig. 14 is a sectional view of a Westinghouse No. 86 motor, having an output of 200 horsepower based on the 1-hour rating, and intended for the same class of work as the G. E. 69. The arrangement of the inwardly projecting bearings is clearly shown—the bearing at the pinion end projecting under the armature head and that at the other end projecting under the commutator. The field is made in two parts and the four poles are arranged diagonally instead of vertically and horizontally, as in the large General Electric motors in which the box type of frame is used. In nearly all large motors, both armature and field coils are wound with copper strip or bar instead of wire.

WESTINGHOUSE NO. 56 MOTOR

30. The motor shown in Fig. 15 is typical of a number of Westinghouse motors that vary in size but have the same general construction. This motor, the No. 56, is designed for the heavier kinds of city and suburban traffic, and is capable of carrying continuously a current of 50 amperes at an average pressure of 300 volts. On the basis of a 1-hour rating, its capacity would be about 60 horsepower. In Fig. 15, *A*, *A'* are the top and lower halves of the field frame, which is made of mild cast steel; lid *C* may be thrown back to get at the commutator and brushes. The armature

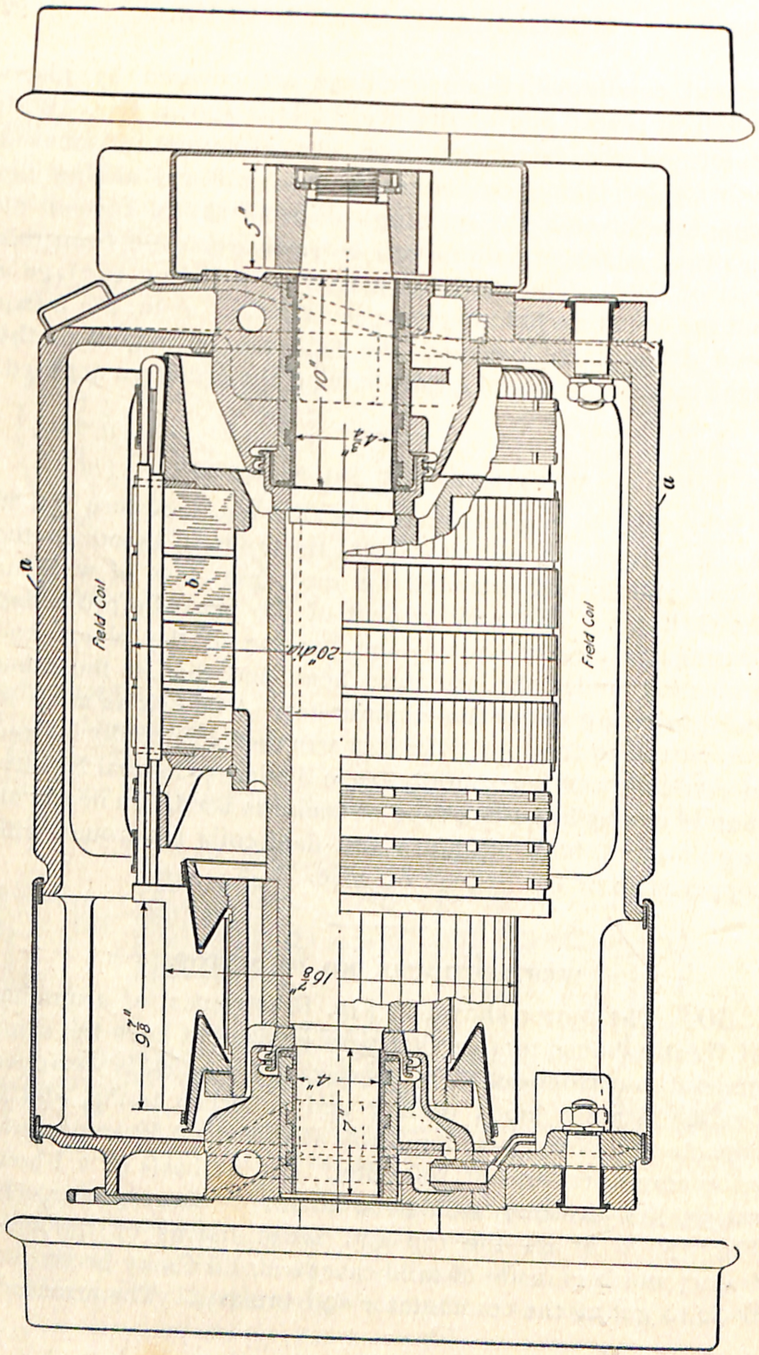


FIG 14

leads are shown at a, a' and the field leads at f, f'; post g is used for making the connection to the ground. The lug l is for hanging the motor when a nose suspension is used. With a cradle suspension, the side bars pass through the rectangular openings r at each end of the motor. The wires

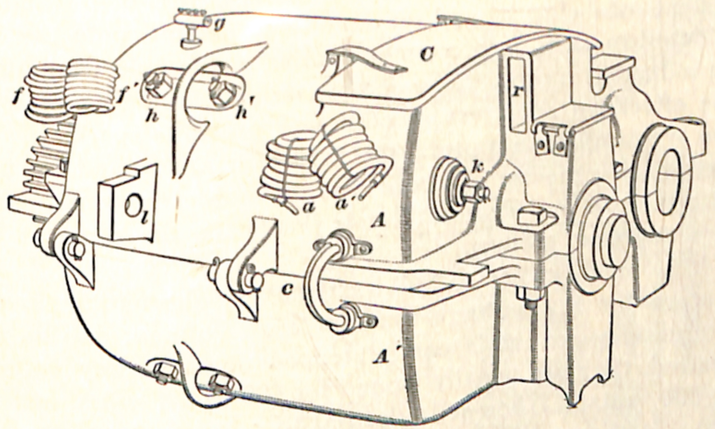


FIG. 15

shown at c connect the top and bottom field coils together. The pole pieces are laminated and held in position by the bolts h, h', and the armature bearings are so arranged that the armature may be either swung down with the lower half or retained in the upper half.

ALTERNATING-CURRENT MOTORS

31. Alternating-current motors for railway work have so far been used comparatively little. Both the Westinghouse and General Electric motors are of the series type and their construction and general appearance are on the whole very similar to ordinary direct-current motors; in fact, they will operate on either direct or alternating current. One of the chief points of difference is that the whole magnetic circuit of the alternating-current motor field must be laminated in order to prevent eddy-current loss due to the alternating magnetic flux. The field core is built up of iron

stampings and slipped inside of a housing, so that the outward appearance and general mechanical construction are practically the same as for direct-current motors. The motors also include some special features in design, introduced to prevent sparking at the brushes. In the General Electric so-called compensated motors, the field winding instead of being wound on definite projecting poles, is distributed in slots in a manner similar to the field winding of an induction motor. The compensating winding counteracts the effects of armature reaction and prevents sparking. In the Westinghouse motors, the field coils are wound on projecting pole pieces. In both types of motor, the construction of armature and commutator is practically the same as for direct-current motors.

It is much easier to build satisfactory alternating-current motors for low voltage than for high voltage, and as the alternating current is easily stepped down to any voltage desired, they are usually wound for 200 to 225 volts, instead of 500 volts. When it is desired to operate the motors on 500-volt direct current, as well as on alternating current, they are connected permanently in series, in pairs. The standard frequency is 25 cycles per second, since a low frequency is necessary for satisfactory operation of motors of this type.

MOTOR LUBRICATION

32. The question of proper lubrication for railway motors is an important one. Insufficient lubrication not only causes a waste of power but it may lead to much damage to the equipment by allowing the bearings to wear so as to let the armature down on to the pole pieces. In the older motors grease was used as a lubricant, but it is fast being superseded by oil. Grease does not feed down until the bearing becomes warm enough to melt it, whereas oil furnishes continuous lubrication. On many of the later motors, lubrication is effected by means of wool waste saturated with oil, as described in connection with the G. E. 70 motor, this method having proved very simple and efficient.

In order to allow oil lubrication on old motors provided with grease cups, a number of oil lubricators have been designed. In some cases, these have not proved satisfactory because the oil fed down while the cars were standing in the barn at night, thus causing much waste. Fig. 16 shows an oil lubricator, made by the Standard Automatic Lubricator Company, for attaching to motors built for grease lubrication. The cast-iron oil cup *a*, provided with a lid *b* normally held closed by a spring, is mounted on top of the grease cup; the cover on the old cup is removed and *a* is held in place by the projecting lug *c*; the lower part *d* projects into the grease cup, which is filled with loosely packed waste. The opening in *d* is closed by a ball valve *e* held against its seat by a spring *f*, the tension on which is adjusted by nut *g* so that no oil can pass out while the car is standing still. When the car is in motion, the vibration and knocks to which it is subjected unseat *e* so that oil can flow on to the waste. Thus, there is no waste of oil while the car is standing still, but the oil feeds as long as the car is in motion. For shafts less than $2\frac{3}{4}$ inches diameter, a feed of $\frac{1}{8}$ inch of oil in the cup should be sufficient for 100 miles of car travel; for larger shafting a feed of about $\frac{3}{16}$ inch should be allowed.

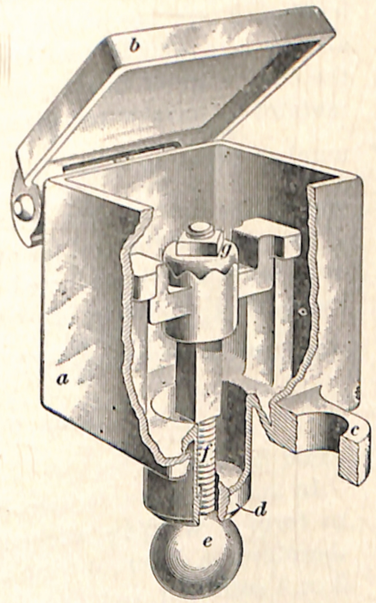
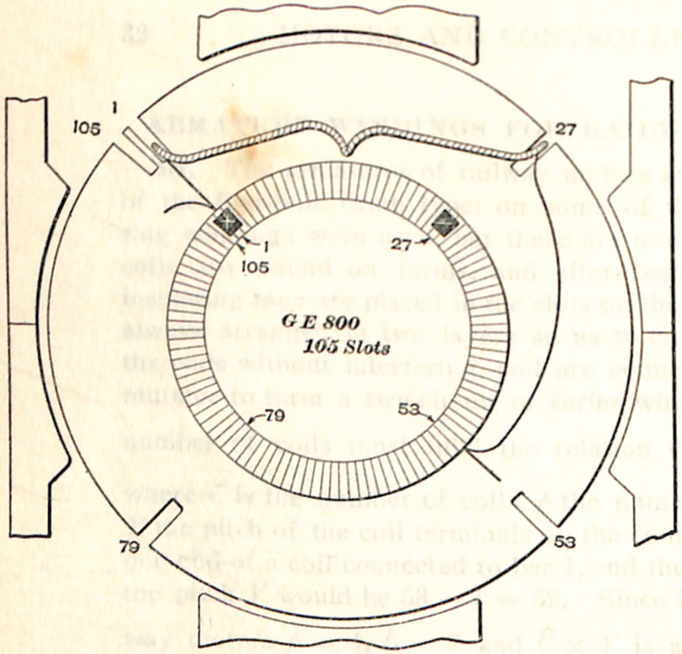


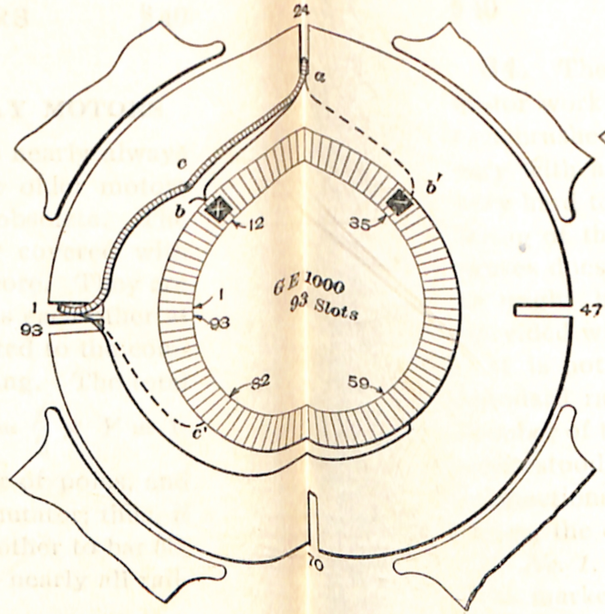
FIG. 16

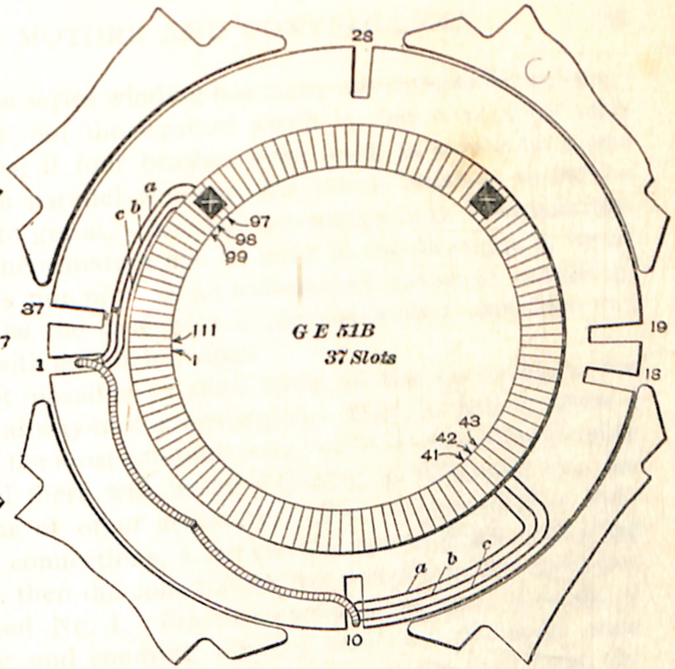
ARMATURE WINDINGS FOR RAILWAY MOTORS

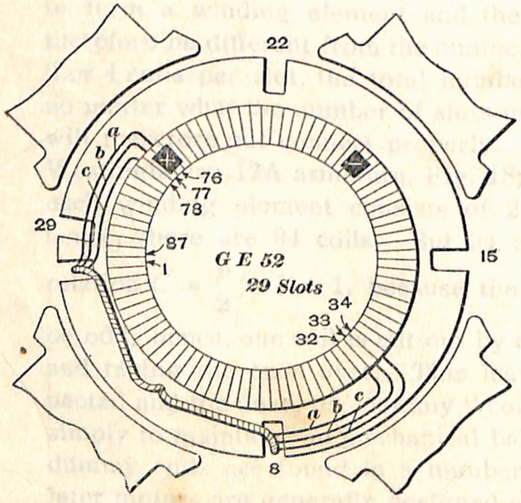
33. The armatures of railway motors are nearly always of the four-pole drum type; on some of the older motors ring windings were used, but these are now obsolete. The coils are wound on forms, and after being covered with insulating tape are placed in the slots on the core. They are always arranged in two layers so as to cross each other at the ends without interfering, and are connected to the commutator to form a two-circuit or series winding. The total number of coils must fulfil the relation $C = \frac{p}{2} \times Y \pm 1$, where C is the number of coils, p the number of poles, and Y the pitch of the coil terminals on the commutator; thus, if one end of a coil connected to bar 1, and the other to bar 53, the pitch Y would be $53 - 1 = 52$. Since in nearly all railway motors $p = 4$, $\frac{p}{2} = 2$ and $\frac{p}{2} \times Y$ is an even number; hence, $\frac{p}{2} \times Y \pm 1$ is an odd number no matter what the value of Y may be.

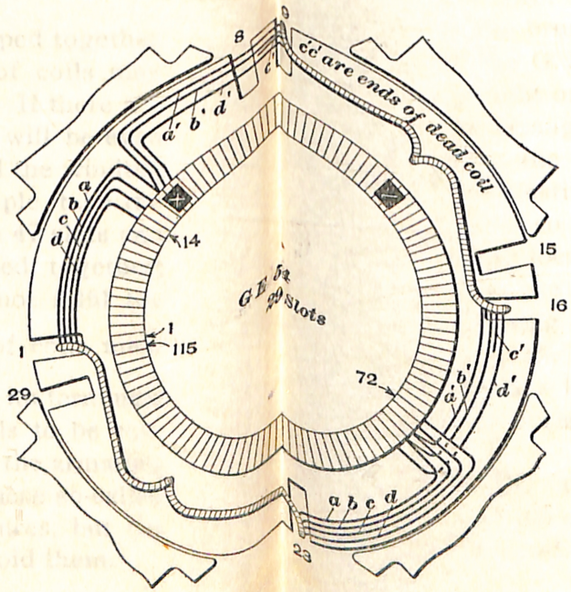
In many armatures, two or more coils are taped together to form a winding element and the number of coils may therefore be different from the number of slots. If there are 2 or 4 coils per slot, the total number of coils will be even no matter what the number of slots may be, and the winding will therefore not connect properly. For example, take the Westinghouse 12A armature, Fig. 18; there are 47 slots and each winding element consists of 2 coils taped together; hence, there are 94 coils. But 94 coils will not fulfil the relation $C = \frac{p}{2} \times Y \pm 1$, because the number of coils must be odd; hence, one coil is cut out by cutting off its terminals and taping the ends over. This leaves 93 coils to be connected and the dead, or "dummy," coil is left in the armature simply to maintain the mechanical balance. These so-called dummy coils are found in a number of armatures, but the later motors are generally designed so as to avoid them.


GE 800
105 Slots
1
105
27
79
53


GE 1000
93 Slots
24
47
70
93
12
35
82
59


GE 51B
37 Slots
28
19
18
10
37
97
98
99
111
43
42
41


GE 52
29 Slots
22
15
8
29
76
77
78
87
34
33
32


GE 52
29 Slots
c c' are ends of dead coil
9
15
16
23
29
14
115
72

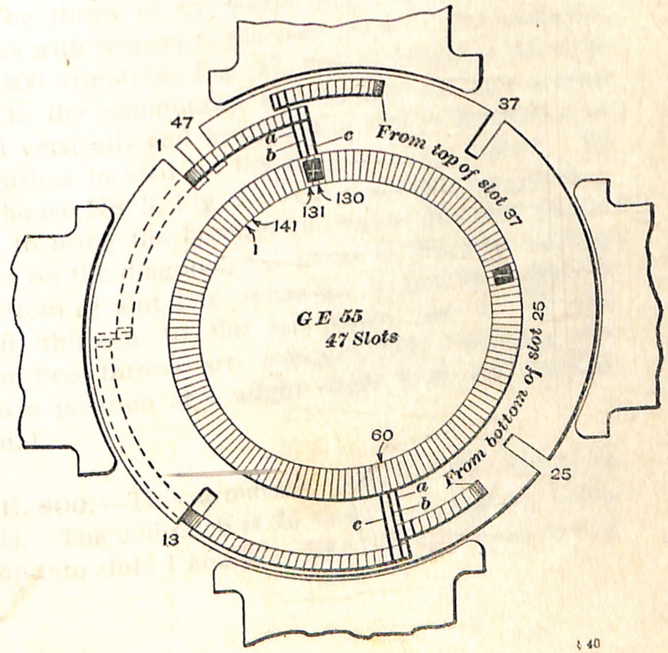
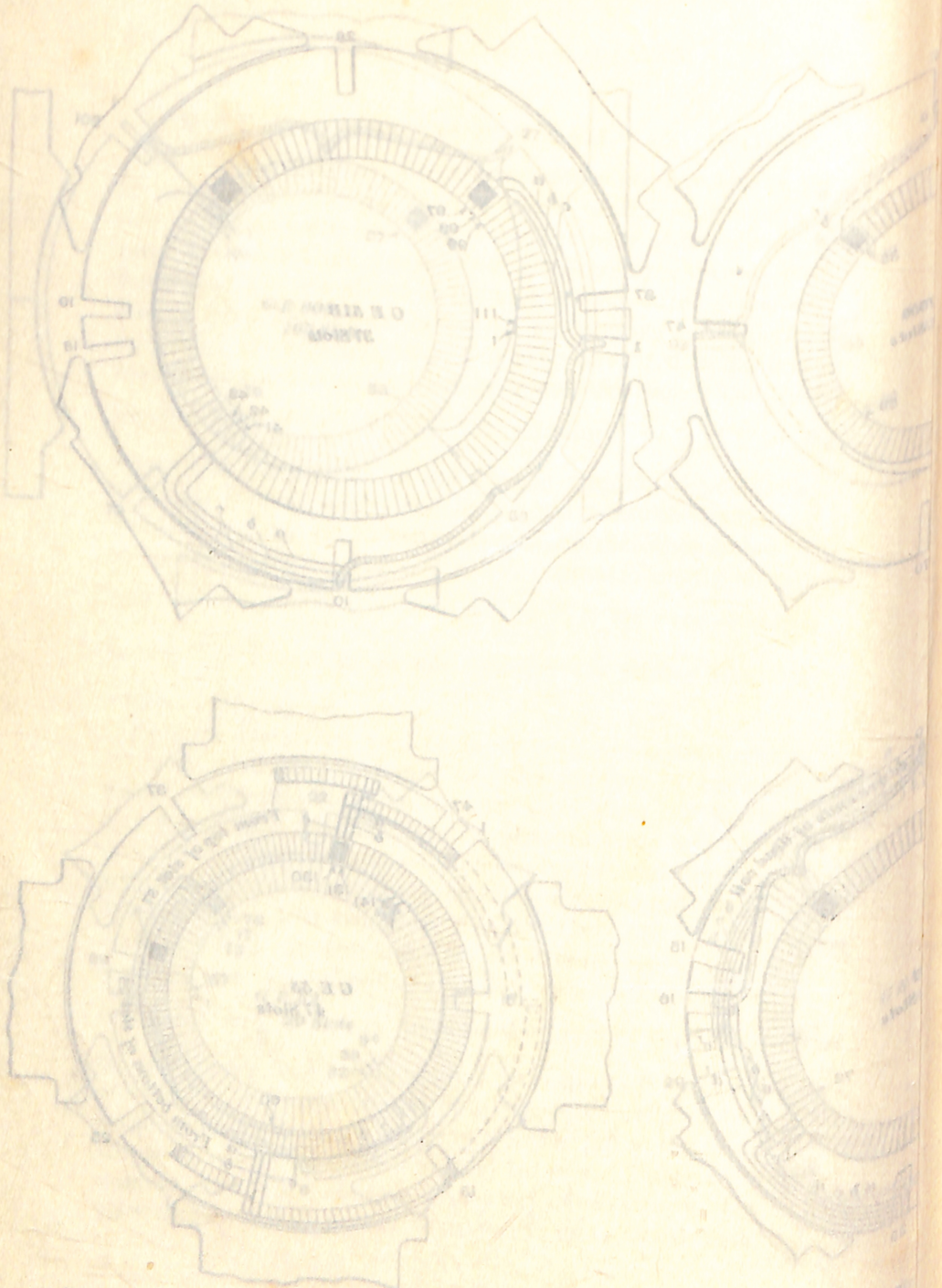

GE 55
47 Slots
From top of slot 37
From bottom of slot 25
37
25
13
47
130
131
141
60

Fig. 2



34. The series winding has many advantages for railway-motor work, not the least of which is that it requires only two brushes; if four brushes were used, as would be necessary with a parallel winding, the lower brushes would be very hard to get at. Another advantage is that uneven centering of the armature due to wear in the bearings or other causes does not produce an unbalanced electrical condition, as might be the case with a parallel-wound armature not provided with equalizing rings.

It is not possible to show here all the connections for standard railway-motor armatures. Figs. 17 and 18 show a number of the most common ones, and if these are thoroughly understood there will be no difficulty in following out the connections of other armatures. For convenience in indicating the connections, a slot on the core is taken and called *slot No. 1*, then the commutator bar directly in line with slot 1 is marked No. 1. Practice varies as to the methods of numbering and counting off the bars, but the three main things to be considered are: the throw of the coil leads, the number of bars between leads, and the spread of the coils on the core. The throw of the leads determines the location of the brushes with respect to the pole pieces. For example, in the G. E. 800 armature, Fig. 17, one coil lead is brought straight out to the commutator bar because the pole pieces are arranged vertically and horizontally and it is desired to have the brushes located on the diagonals as shown. In the Westinghouse No. 3, Fig. 18, both coil leads are given a throw so as to bring the brushes as shown, the pole pieces being located on the diagonal; for example, the lead coming from the bottom of slot 1 is connected to bar 84, found by counting off thirteen to the left from bar 1. In the G. E. 55, the two throws are unequal, thus bringing the brushes into a position at a slight angle from the vertical and horizontal.

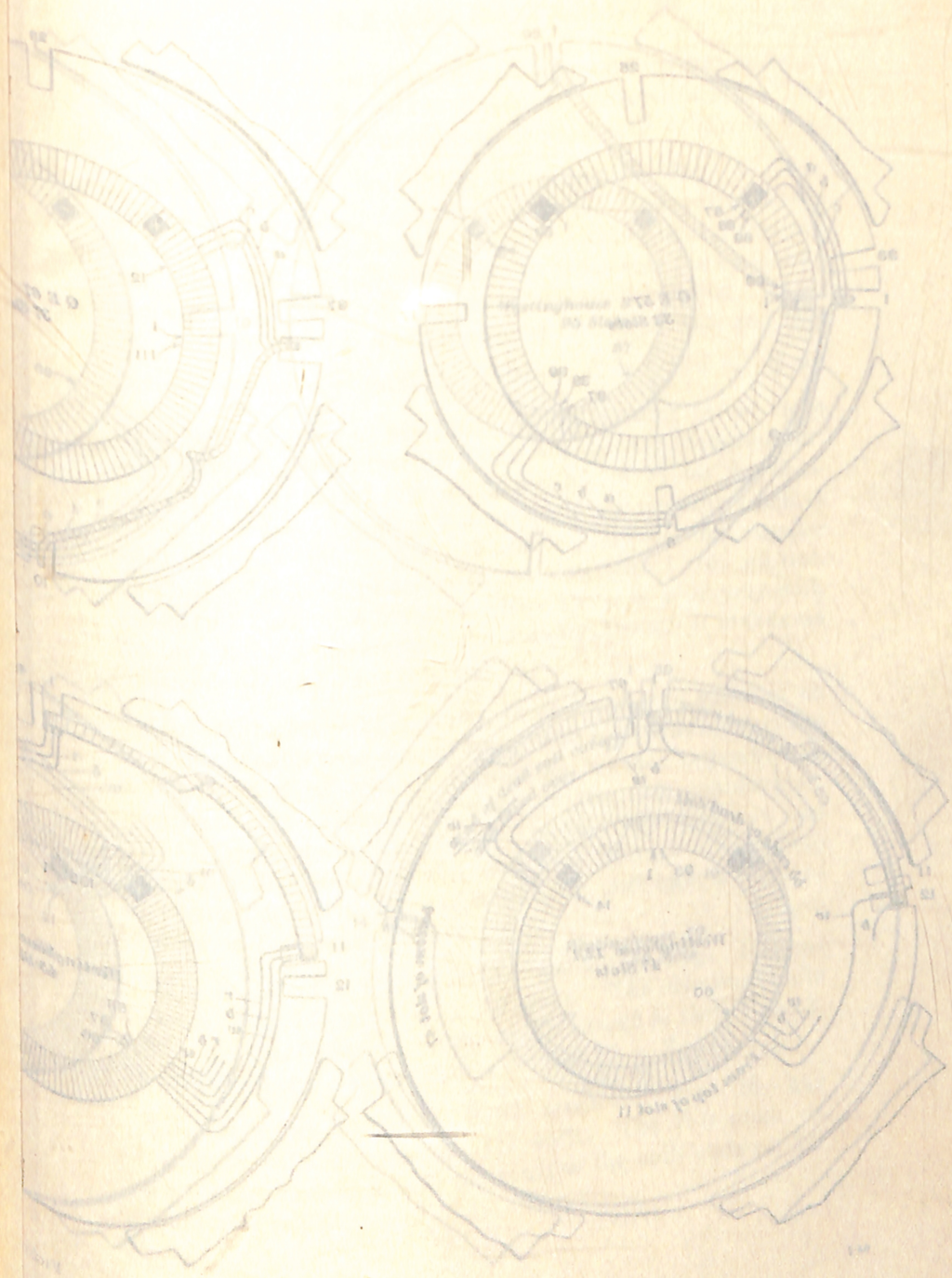
35. G. E. 800.—This armature, Fig. 17, has 105 slots and 105 coils. The coil pitch is 26 slots; i. e., the two sides of a coil drop into slots 1 and 27. The coil terminals have a

pitch of 52 bars on the commutator, or if one end connects to bar 1, the other connects to 1 + 52 or bar 53. Thus, $Y = 52$, $105 = 2 \times 52 + 1$, and the requirements for a two-circuit winding are fulfilled. The second coil would be dropped into slots 2 and 28, and its terminals connected to bars 2 and 54. After the first coil has been placed in position and its leads connected the others follow in rotation, so that in nearly all the diagrams only one coil is shown.

36. G. E. 1,000.—The G. E. 1,000 armature, Fig. 17, has 93 slots and 93 coils having a pitch of 23 slots on the core. The pitch of the coil terminals on the commutator is 46 bars. The coil lead *a b* is thrown back as shown, but in many cases it is taped in with the coil and appears as a lead coming out at the bend *c* of the coil and is therefore connected to the bar directly opposite the bend. This armature could also be connected as shown by the dotted lines, thus making the coil leads more symmetrical. With the same field connections, an armature connected as shown by the dotted lines would run in the opposite direction from one connected as shown by the full lines.

37. G. E. 51B.—The G. E. 51B armature, Fig. 17, has 37 slots, 3 coils per slot, or 111 coils. This is an example of an armature where each winding unit consists of 3 coils taped together. The pitch on the armature core is 9, the coils dropping into slots 1 and 10. The corresponding coil leads are marked *a*, *b*, *c*, and the throw is the same at each side of the coil, thus bringing the brushes opposite the center of the pole pieces. The pitch of the coil leads on the commutator is 55. The commutator pitch Y in any of the diagrams can be found as follows: Take, for example, the G. E. 51B, and call the bar to which the upper middle lead *b* is connected bar 1, instead of 98 as marked. Then count around under the coil until the bar to which lower lead *b* connects is reached. This will be bar 56, and the commutator pitch Y is therefore $56 - 1 = 55$.

38. G. E. 52.—The G. E. 52 armature, Fig. 17, has 29 slots; 3 coils per slot, or 87 coils; the coils span 7 slots.



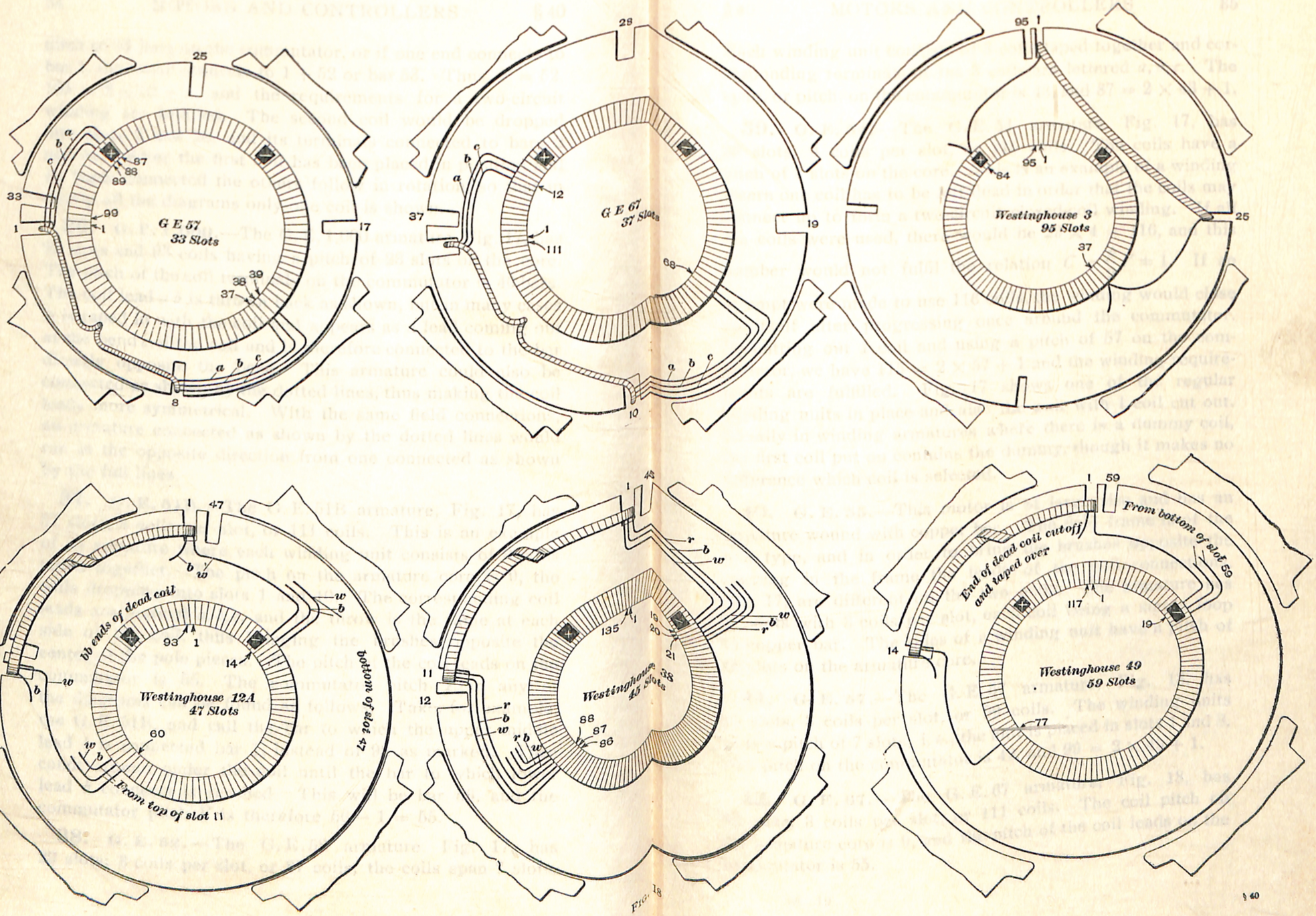

G E 57
33 Slots
G E 67
37 Slots
Westinghouse 3
95 Slots
Westinghouse 12A
47 Slots
bb ends of dead coil
From top of slot 11
bottom of slot 47
Westinghouse 38
45 Slots
Westinghouse 49
59 Slots
End of dead coil cut off and taped over
From bottom of slot 59

FIG. 18



Each winding unit consists of 3 coils taped together and corresponding terminals of the 3 coils are lettered a, b, c. The span, or pitch, on the commutator is 43, and $87 = 2 \times 43 + 1$.

39. G. E. 54.—The G. E. 54 armature, Fig. 17, has 29 slots; 4 coils per slot, or 115 coils. The coils have a pitch of 7 slots on the core. This is an example of a winding where one coil has to be left dead in order that the coils may connect up to form a two-circuit closed-coil winding. If all the coils were used, there would be $29 \times 4 = 116$, and this number would not fulfil the relation $C = \frac{p}{2} Y \pm 1$. If an attempt were made to use 116 coils, the winding would close on itself after progressing once around the commutator. By cutting out 1 coil and using a pitch of 57 on the commutator, we have $115 = 2 \times 57 + 1$ and the winding requirements are fulfilled. Fig. 17 shows one of the regular winding units in place and also the unit with 1 coil cut out. Usually in winding armatures where there is a dummy coil, the first coil put on contains the dummy, though it makes no difference which coil is selected.

40. G. E. 55.—This motor is of large size and has an armature wound with copper bar. The field frame is of the box type, and in order to bring the brushes opposite the opening in the frame the leads of the coil connections, Fig. 17, are different on the two ends. The armature has 47 slots with 3 coils per slot, each coil being a single loop of copper bar. The sides of a winding unit have a pitch of 12 slots on the armature core.

41. G. E. 57.—The G. E. 57 armature, Fig. 18, has 33 slots, 3 coils per slot, or 99 coils. The winding units have a pitch of 7 slots; i. e., the unit is placed in slots 1 and 8. The pitch on the commutator is 49, and $99 = 2 \times 49 + 1$.

42. G. E. 67.—The G. E. 67 armature, Fig. 18, has 37 slots, 3 coils per slot, or 111 coils. The coil pitch on the armature core is 9, and the pitch of the coil leads on the commutator is 55.

43. Westinghouse No. 3.—The Westinghouse No. 3 armature, Fig. 18, has 95 slots and 95 coils. The pitch of coils on armature core is 24. The pitch of coil leads on commutator is 48, and $95 = 2 \times 48 - 1$.

44. Westinghouse No. 12 or 12A.—The Westinghouse No. 12 or 12A armature, Fig. 18, has 47 slots, 2 coils per slot, or 93 coils. The pitch of the coils on the core is 11 slots. This armature has a dummy coil, so that the number of coils to be connected is one less than twice the number of slots. In order to distinguish the corresponding ends on each winding unit, they are marked white and black, as indicated by the letters *w* and *b*.

45. Westinghouse No. 38 or 38B.—The Westinghouse No. 38 or 38B armature, Fig. 18, has 45 slots, 3 coils per slot, or 135 coils. The coil pitch on the armature core is 10, the coils dropping into slots 1 and 11. The coil terminals are marked red, black, and white, as indicated by the letters *r*, *b*, and *w*.

46. Westinghouse No. 49.—The Westinghouse No. 49 armature, Fig. 18, has 59 slots, 2 coils per slot, or 117 coils. This armature has a dummy coil, otherwise the number of coils would be even and the armature would not connect up. The coil pitch on the armature core is 13.

FIELD COILS

47. One of the most common sources of trouble in connection with street-railway motors is wrongly placed or connected field coils. Few have any idea of the great amount of trouble a wrongly connected field coil may cause; its effect is felt long after the trouble has been found and removed. It not only injures itself, but it injures the other field coils and the armature. The armature probably heats to such an extent that the commutator connections become unsoldered and the fields gradually bake inside. The chances are that before the trouble is discovered and removed there may be grounded brush holders, armatures, or

fields, due to the current jumping across to the frame of the motor, because the weak fields in the first place cause poor commutation, and in the second place reduce the counter E. M. F. and allow more current to flow than the brushes can stand. It is safe to say that one-half of the trouble on cars turned in for blowing fuses can be traced directly or indirectly to defects in the field coils.

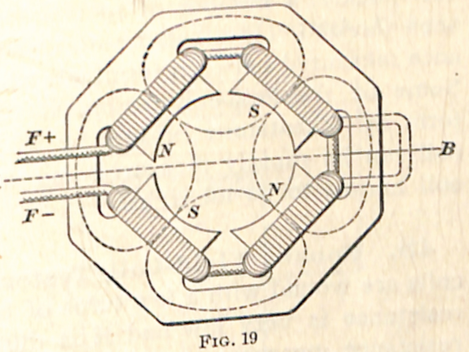


FIG. 19

Fig. 19 shows a section through a four-pole motor with a coil on each pole; the coils are so connected that the pole pieces alternate in polarity. In Fig. 20, the coils are not shown but the top left-hand coil is supposed to be connected incorrectly, with the result that the lines of force are very much twisted out of their path. However, it will be noticed that two sides of the four-sided figure made by the path of the lines of force can still be seen. Part of the armature is therefore effective, and the car will run on the faulty motor, but the brushes will spark badly, and there will be great consumption of current. The large current soon roasts the insulation on the coils, thus short-circuiting the turns and making matters still worse.

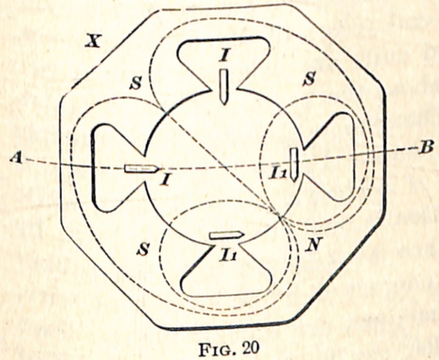


FIG. 20

Even if field coils are not incorrectly connected, they will in time become roasted, especially if the motors are worked hard. The insulation may become so charred as to allow

current to pass from turn to turn without encircling the pole piece, thus decreasing the magnetizing power of the coil. The field coils should therefore be tested from time to time to make sure that there is no short-circuiting due to roasting or other causes. In order to permit such tests to be carried out quickly, a number of special testing instruments have been devised. If a coil becomes short-circuited, its resistance measured between terminals will be lower than normal. Some of the field-coil testing instruments are a modified form of Wheatstone bridge, by which the resistance of a coil can be rapidly measured and compared with that of a coil known to be all right.

48. Conant Field-Coil Tester.—Railway-motor field coils are wound with a few turns of heavy wire; hence, their resistance is very low and it is difficult to make accurate resistance measurements with any form of bridge that can be handled quickly in a motor repair shop. The inductance of a field coil, as compared with a good coil, is more easily determined, and any change in the effective number of turns has a marked effect on the inductance, because, other things being equal, the inductance varies as the square of the number of turns. In the field-coil tester of Mr. R. W. Conant, the inductances of two field coils are balanced against two adjustable inductances in about the same manner as resistances are balanced in a Wheatstone bridge. The principle of the instrument will be understood from Fig. 21. A and B are two coils, one of which A is known to be all right, while B is to be tested. Connection is made to the cable leads by means of points f, f that are worked through the rubber insulation until they make contact with the strands of wire; in this way temporary connections are quickly made. Two coils a, b with iron cores that can be moved into or out of them are connected in series, as shown. The coils a, A, b, B correspond to the four arms of a Wheatstone bridge, but instead of balancing the resistances of a and b against those of A and B their inductances are balanced by varying the inductances of a and b. If, for example, the iron core a_1 is

moved into a, the effect is to increase the inductance of a, and vice versa. A few cells c send a current through the coils, and in order that induced E. M. F.'s may be set up, the current is interrupted by a clockwork mechanism d that drives a toothed contact wheel. A telephone is connected at e in order to indicate when the instrument is balanced. Suppose, for the present, that A and B are perfect coils and

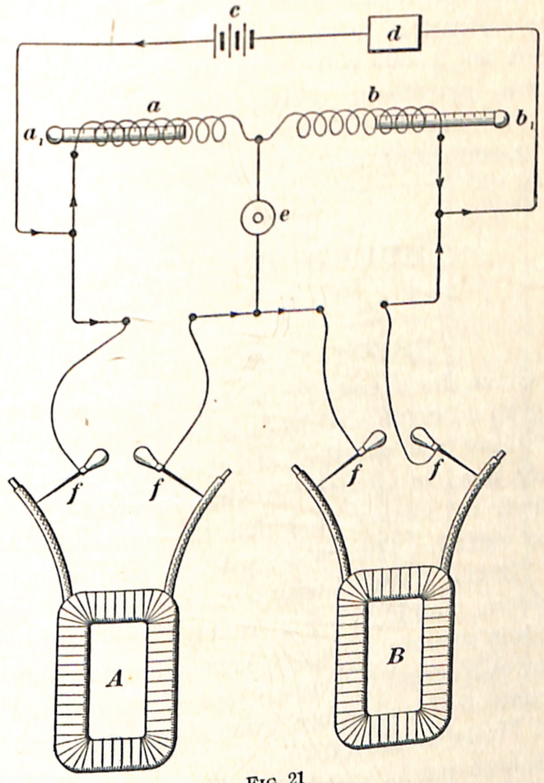


FIG. 21

alike in every particular. The minimum sound will then be obtained when cores a_1 and b_1 are adjusted so that the induced E. M. F.'s in a, b, A, B are equal, and the position of the cores can be noted by the graduations marked on them. If, however, coil B is defective because of a number of short-circuited turns, its inductance will be less than that

of A, and core b_1 must be drawn out farther than a_1 in order to obtain a balance; i. e., the inductance of b must be made less than that of a. In this manner the condition of a coil, as compared with a good coil, can be quickly determined, and from a knowledge of the readings obtained with good and bad coils it can be easily determined whether a given coil should be left in service or taken out and repaired. In another form of tester working on much the same principle, the operating current is obtained by connecting the instrument to a 500-volt lamp circuit of five lamps in series, the instrument taking the place of one of the lamps. This supplies about $\frac{1}{2}$ ampere; a magnetic vibrator is used to interrupt the current.

SPEED CONTROL

RHEOSTATIC CONTROL

49. Since the speed of a series motor can be varied by inserting an adjustable resistance in series, the first method of controlling the speed of street cars was by means of a resistance used in connection with a **controller,** or pair of controllers, by means of which the amount of resistance could be varied. This is known as the *rheostatic method of control.* It can be used with one or more motors, but it is now seldom employed for regular street-railway work, because it is wasteful of power, especially at the lower speeds. It is, however, used in those cases where only one motor is to be controlled and where gradual variations in speed are desired. It is employed to some extent in connection with mine-haulage plants and hoisting apparatus; also for cars operated by a single motor.

On account of the somewhat extended use of rheostatic control in connection with haulage and hoisting apparatus, some of its more important features will be considered briefly. This will also serve as a good introduction to the widely used series-parallel method described later.

R11 CONTROLLER

50. General Construction.—Fig. 22 shows a rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors; it is known as the **R11 controller** and was formerly called the KR. All General Electric type R controllers are

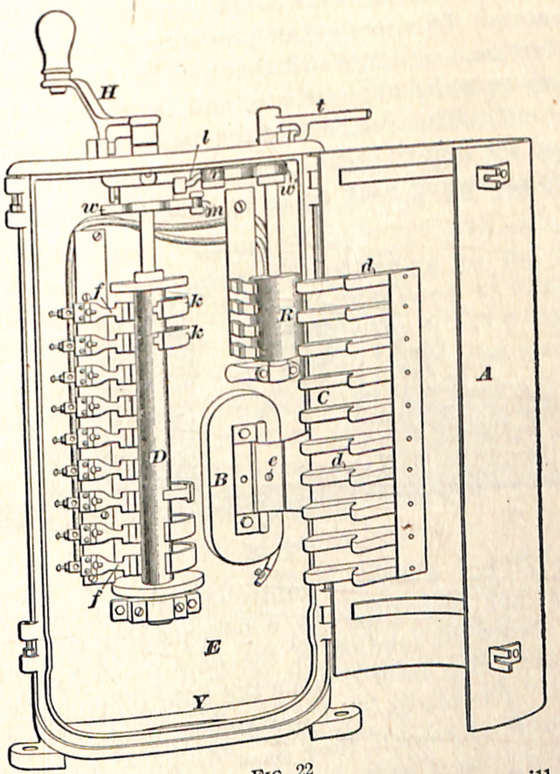


FIG. 22

intended for rheostatic control. This controller will be considered in detail because it contains many of the features found on controllers used on street cars and will serve as a good introduction to the study of them. It is designed to handle one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor; i. e., its contacts are large enough to

carry about 75 amperes. The figure shows the cover *A* thrown back so as to expose the working parts. The changes in the connections are effected by a *cylinder*, or *drum*, *D*, provided with contact segments that make connection with fingers *f*, *f* when the cylinder is rotated by means of the operating handle *H*. This controller is of the magnetic blow-out type, because a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning. This method of preventing arcing has proved very effective. *B* is the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the *blow-out coil*. The iron back of the controller forms one pole piece and the hinged polar extension *C* the other; pole piece *C* is shown swung back so as to give access to the power

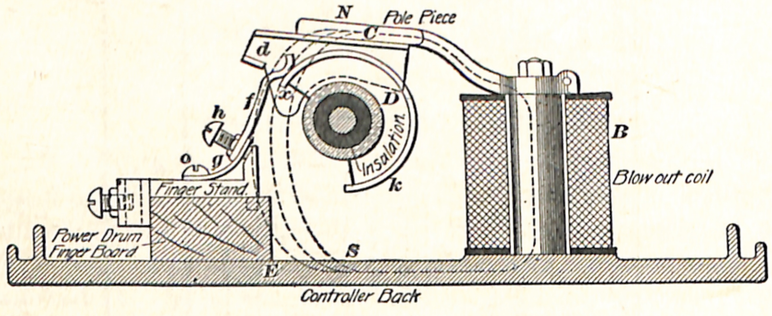


FIG. 23

cylinder *D*, but when the controller is in use, *C* is swung over and held in position by a bolt passing through hole *e*. Fig. 23 shows the relation of the pole piece *C*, cylinder *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are *arc guards*, made of vulcabeston (vulcanized asbestos); they pass between the contact segments and prevent arcing across from segment to segment. All the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines. When the cylinder is revolved far enough, tip *x* of segment *k* leaves finger *f* and an arc tends to form. This arc acts in the same way as a flexible wire carrying current, and is therefore forced across

the field and stretched out until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and segments. Fingers *f* are stamped out of thick copper and are attached to a flat phosphor-bronze spring *g*, which is in turn fastened to the cast-brass finger stand by means of screws *o*, so that fingers can be replaced at any time. Screw *h* is for adjusting the amount that the finger drops when the segment passes from under it. This affects the pressure with which the fingers press on the segments, and they should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. The cylinder segments should be rubbed frequently with a little vaseline so as to prevent wear and cutting.

51. Star Wheel, or Index Wheel.—The power cylinder is operated by means of handle *H*, Fig. 22, which fits on the top of the shaft. In order to compel the cylinder to take up a definite position corresponding to the various steps, it has a **star wheel**, or **index wheel**, *w* attached to the shaft. This engages with a spring-actuated roller *m*, which is pulled into the various notches on the star wheel and forces the cylinder into its proper position. It is this star wheel and roller that gives the movement of a controller handle its springy feeling.

52. Reverse Cylinder.—The reversing switch, or reverse cylinder, as it is called, is shown at *R*. This is much smaller and simpler than the power cylinder and is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections in case it is desired to run the car in the opposite direction. It is not intended to turn the current on or off or effect any changes in the resistance. For this reason, the reverse cylinder is not provided with any device for suppressing arcing, and its contact fingers are somewhat lighter than those on the main cylinder.

53. Interlocking Device.—In order to make sure that the reverse cylinder shall not be moved while the current is on, the controller is provided with an interlocking device that makes it impossible to move the reverse cylinder unless

the power cylinder is at the off-position. The reverse cylinder shaft is provided with a star wheel w' having three notches, corresponding to the off-, ahead-, and back-positions. The lever carrying the roller r that engages this star wheel has a link l attached to it, which runs across to the hub of the star wheel w. The hub of w has a notch in it that comes opposite the end of l when the power cylinder D is at the off-position, and when the reverse handle t is moved, the end of link l is forced into the notch until the roller r passes over the projection on the star wheel w', when l falls back far enough to allow D to be turned. At any position of D other than the off-position, there is no notch opposite the end of l; hence, when an attempt is made to move t, link l butts against the hub and the reverse cylinder is locked.

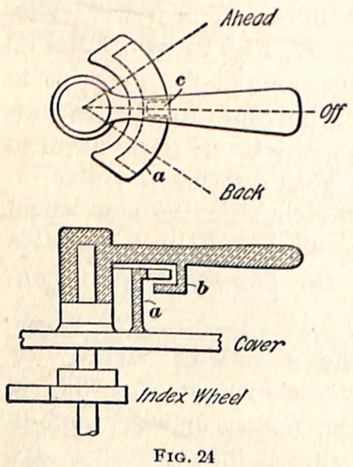


FIG. 24

When the reverse lever points ahead, the car runs forwards, and when it points back, the car runs backwards.

The reverse handle is also arranged so that it cannot be removed unless the power drum is at the off-position. An L guard a, Fig. 24, is cast on the controller cap and overhangs a hook b cast on the handle. A notch c is cut in the guard, so that the handle can be lifted off at the off-position and no other.

54. Operation.—This controller has six points, and a development of the cylinder with the various connections is shown in Fig. 25. This diagram shows a single motor, of which A' and F' are the armature and field, respectively, operated by a single controller. In this diagram and in those to follow, the cylinder segments are indicated by black bands, which represent the segments straightened or developed out flat. The finger stands on the power

cylinder and on the reverse cylinder connection boards are represented by vertical rows of black spots. The vertical dotted lines represent the various positions of the cylinder, and in studying the connections resulting from a movement of the operating handle to a given position, the developed cylinder can be considered as sliding under the contact fingers until it occupies a position indicated by the vertical

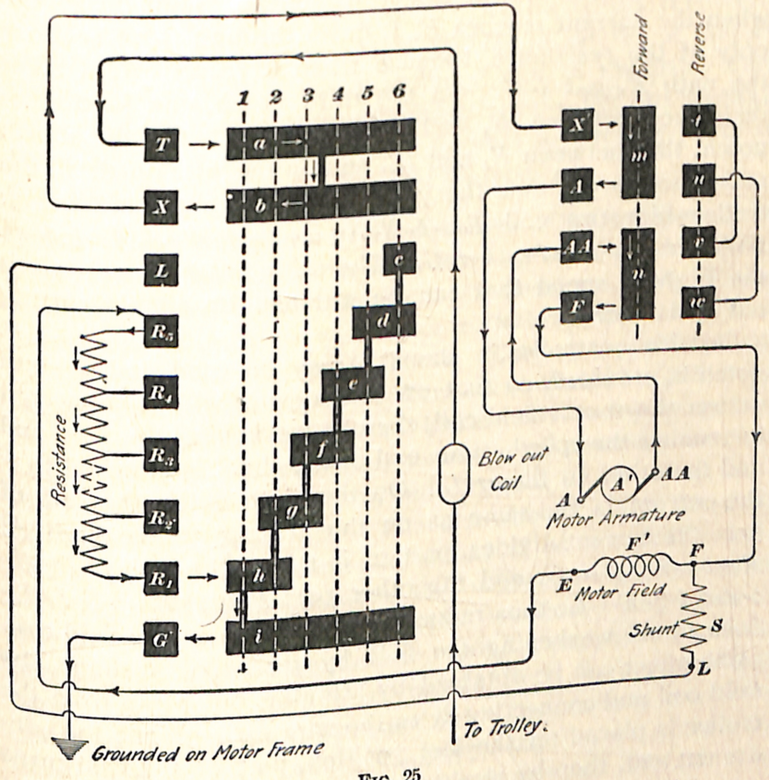


FIG. 25

dotted line that corresponds to the notch, or position, on which the handle is placed. In this case the power cylinder is in two parts. Contact segments a and b are connected together, but are insulated from c, d, e, f, g, h, and i, which are all connected together because they constitute a single casting. On the first notch, fingers T, X, R_1, and G make

contact with their respective cylinder segments; all the others hang over and touch nothing.

The path of the current on the first notch, indicated by the arrows, is: Trolley–blow-out coil–*T–a–b–X–X′–m–A–A–* armature *A′–A A–A A–n–F–F–*field *F′–E–R*$_5$ through the whole of the resistance–*R*$_1$*–h–i–G–*ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger *R*$_2$ touches segment *g*, and when the current reaches *R*$_5$ it flows through three sections only of the resistance, because when it reaches *R*$_2$ it takes the path *R*$_2$*–g–h–i–G*. On the third notch, the section of resistance between *R*$_2$ and *R*$_3$ is cut out. On the fourth notch, that between *R*$_3$ and *R*$_4$, and on the fifth notch all the resistance is cut out, the path of the current there being: trolley–blow-out coil–*T–a–b–X–X′–m–A–A–A′–A A–A A–n–F–F–F′E–R*$_5$*–d–e–f–g–h–i–G*. The fifth notch, then, gives the highest speed that can be attained by simply cutting out resistance.

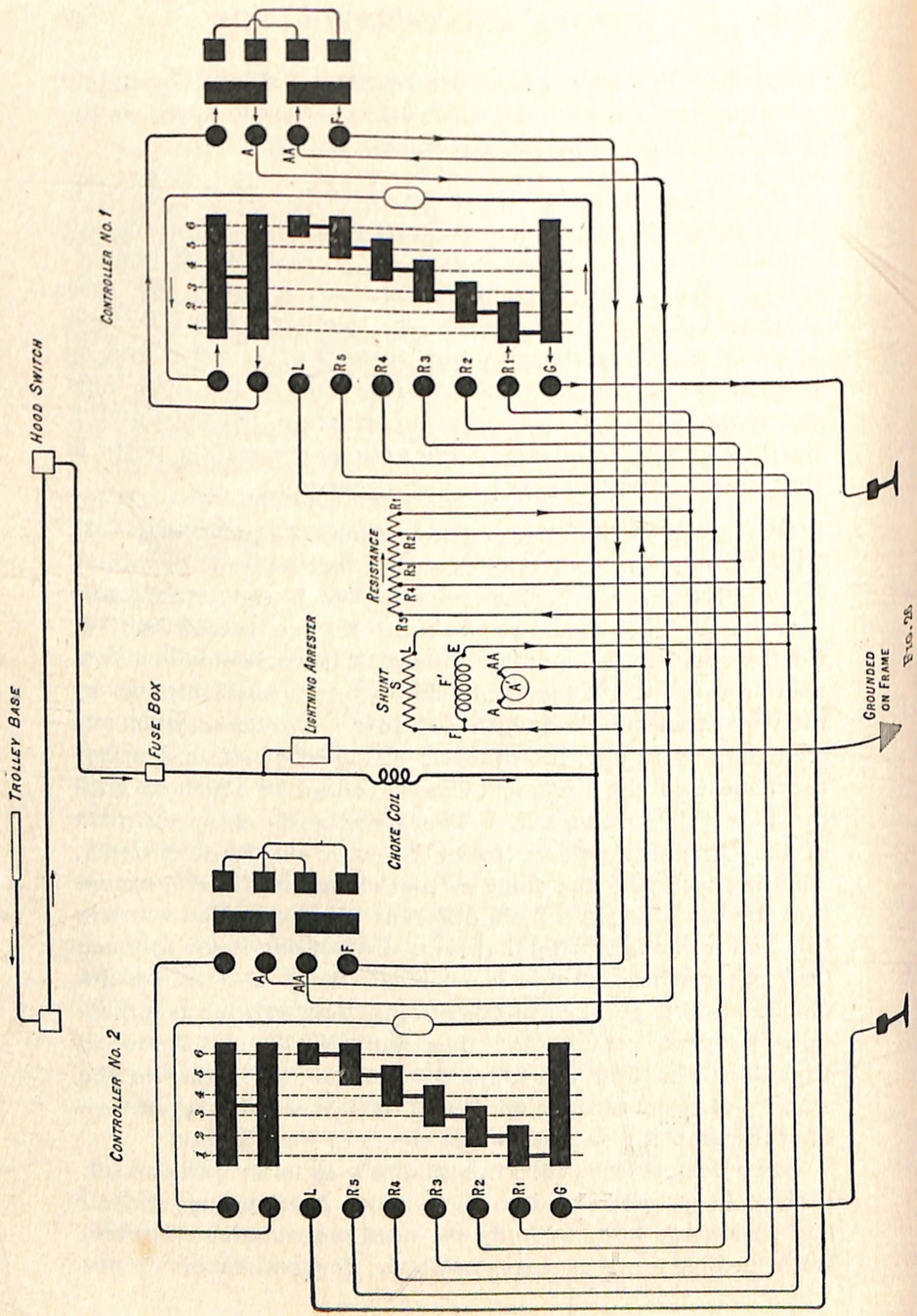
On this controller, a shunt *S* may be used and a sixth notch is provided, so that on it the shunt will be connected across the motor field coil, thereby weakening the field and increasing the speed. One end of the shunt is attached to *F* and the other to finger *L*. On the sixth notch, the path of the current is the same as on the fifth up to the point *F*; here the current divides, part of it taking the path *F–F′–E–R*$_5$*–d–e–f–g–h–i–G*, and the other part the path *F–S–L–L–c–d–e–f–g–h–i–G*, thus reducing the current in the field coil. Instead of weakening the field by means of a shunt, the same effect can be obtained by bringing out a tap from the field coil and connecting it to the wire *L L*. When the controller is placed on the last position, part of the field turns are cut out, thereby weakening the field and increasing the speed. These so-called *shunt* or *loop methods* of control are now little used for street-railway work; they introduce undesirable complications and it has been found that a sufficient range of speed can be secured without them. Most recent types of controllers are therefore designed for use without loops or shunts. It is easily seen that the

controller, Fig. 25, could be used without a shunt *S* by simply omitting the connection *L L*, in which case the speed on the sixth notch would be the same as on the fifth.

55. Operation of Reverse Switch.—If the motor is to be reversed, the reverse cylinder is thrown over, bringing contacts *t*, *u*, *v*, *w* under fingers *X′*, *A*, *A A*, and *F*, respectively. When the current reaches *X′*, it takes the path *X′–t–v–A A–A A–A′–A–A–u–w–F*. In other words, it flows in at the *A A* end of the armature instead of at the *A* end as before, but it still flows in at the *F* end of the field, thus reversing the current through the armature, but not through the field. The lettering of the various connecting posts is that used by the General Electric Company.

56. Car With Two Rheostatic Controllers.—In Fig. 25, only one controller is shown, but on a car or mining locomotive two controllers, one on each end, are usually necessary. Fig. 26 shows two controllers connected together for the operation of a single motor. The corresponding connecting posts of the two controllers are connected together by the wires that run the length of the car. Of course, when one controller is in use, the other is at the off-position, because the handle of the reverse cylinder cannot be removed until the power is thrown off. The arrowheads show the path of the current when controller No. *1* is on the first notch. This is practically the same as that shown in Fig. 25, except that the parts are in a little different location. The wires in this and in the following diagrams are not supposed to touch each other where they cross unless there is a round dot placed at their point of intersection. The various combinations may be represented diagrammatically, as shown in Fig. 27. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field *F* is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches. With ordinary street cars, however, the resistance is not



supposed to be used for speed-controlling purposes. It is only intended to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current first enters the motor. In most controllers, the resistance is placed ahead of the motors; but on the whole, it makes no difference so far as the effect of the resistance itself goes; it sometimes does, however, make a difference in regard to

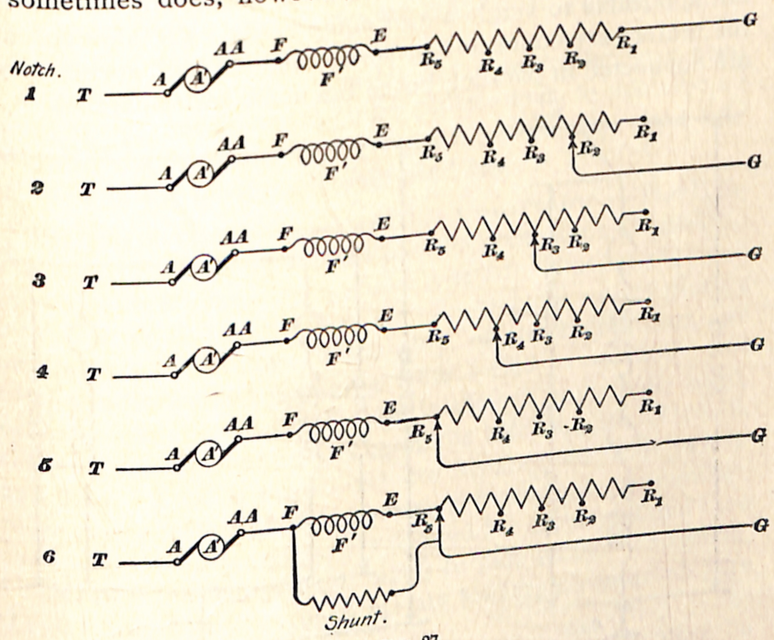


Fig. 27

the amount of trouble that arises on account of grounds occurring on the resistance. Also notice, in Fig. 26, that the post marked *A A* on controller No. *1* is connected to post *A* on controller No. *2*, and post *A A* on controller No. *2* is connected to post *A* on controller No. *1*. It is necessary to interchange the armature wires in this way so that the car will move forwards when the reverse handle on the end from which it is run points ahead.

SERIES-PARALLEL CONTROL

57. General Description.—The method of speed control now almost universally used for street-railway work is known as the **series-parallel** method. It enables the voltage applied to the motors to be cut down for slow-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required; hence, this method is not applicable to single-motor equipments. For slow speed, the motors are connected in series, and for high speed, they are connected in parallel; hence the name series-parallel.

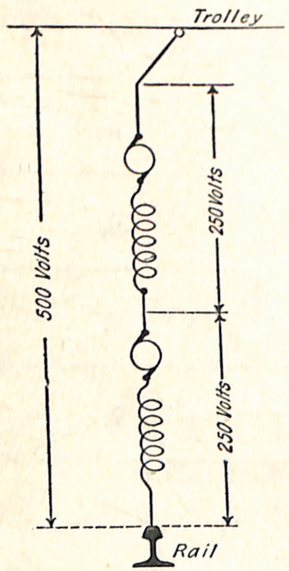


FIG. 28

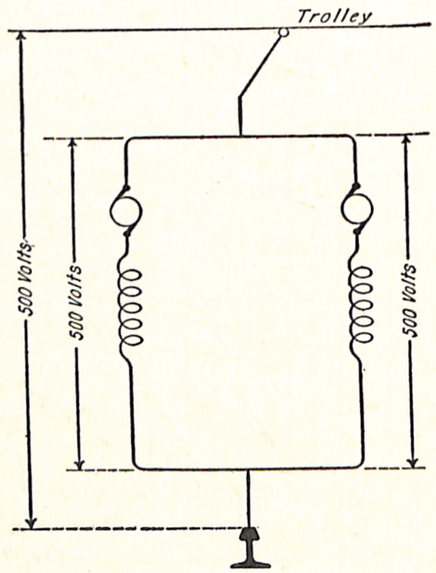


FIG. 29

Let us assume that the pressure is 500 volts; then, if the two motors on a car are connected in series, as shown in Fig. 28, the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter E. M. F., and the result is that a slow speed is obtained w thout the use of any resistance.

When the higher speed is desired, the controller is thrown around to the "multiple notches" and effects the combinations necessary to change the motors from series to parallel. When they are in parallel, as shown in Fig. 29, a pressure of 500 volts is applied to each motor and the car runs at full speed. Of course, at starting it is necessary to include some resistance, and when changing from series to parallel, resistance is also cut in to prevent an excessive rush of current and to give a smooth acceleration to the car; but the resistance is cut out as soon as the car gets under headway and is not used on the running notches.

A great many types of series-parallel controller have been brought out, and it would be an endless task to describe all of them; the diagrams here given will, therefore, relate only to a few of the most commonly used types.

58. Types of Series-Parallel Controller.—The General Electric Company's series-parallel controllers are divided in two general types: type K and type L. Those designated by the letter K are intended for two or more series motors and include the feature of shunting, or short-circuiting, one of the motors when changing from series to parallel. For ordinary street cars, the K type is almost universally used, the most common controllers being the K2, K6, K10, K11, K12, and K14. Type L controllers are also intended for two or more series motors, but in changing from series to parallel, the power circuit is completely opened for an instant and then closed after the change from series to parallel has been made. Type L controllers are used mostly for large interurban cars equipped with heavy motors.

Another class of controller, known as type B, may be either rheostatic or series-parallel, but they are always provided with the necessary contacts and connections for the operation of electric brakes. Westinghouse controllers are designated in the same way as those of General Electric make and their construction is also the same.

K2 CONTROLLER

59. General Description.—Type K controllers embody many of the features described in connection with the type R controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, though, of course, the type K is more complicated, because it must handle all the connections for two or more motors and effect the changes necessary to throw the motors from series to parallel. It is also provided with switches, by means of which either motor may be cut out, in case it becomes disabled, allowing the car to be operated on the other motor. The K2 controller is designed for use with shunts; i. e., on the last series notch the fields of both motors are shunted and the same is also the case on the last multiple notch. The controllers may, however, be used without shunts and they are frequently run in this way.

The K2 controller is used with two motors of 40 horsepower or under and has 9 notches. There are more positions than this, but only 9 of them are marked on the controller top, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the cylinder will not hang between notches and cause burning inside the controller. Fig. 30 shows the controller with the door opened so that the inside parts can be seen.

In Fig. 30, *1* is the operating handle that turns the controller or power cylinder *2*; *3* is the reverse handle that turns the reverse cylinder *4*; *9*, *9* are the fingers that make contact with the power cylinder and *6* is the blow-out magnet. The reverse cylinder has no blow-out coil, because it cannot be moved while the current is on. The *cut-out switches*, by means of which a disabled motor can be cut out, are shown at *7*, *7*; *8* (in the lower right-hand corner) is the *connection board*, into which run all wires from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown in another diagram. The door,

or cover *12*, swings back as shown, and the bolt and wrench *10* is used for holding the pole piece in place when it is swung over; *5*, *5* are the arc guards. Both the power cylinder

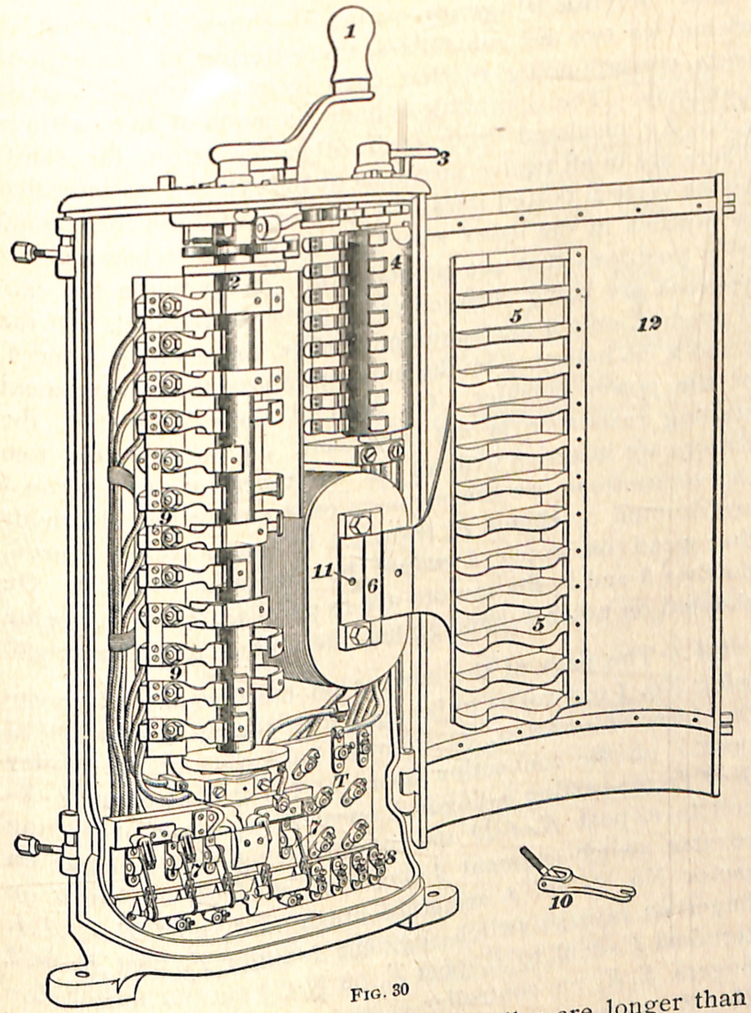


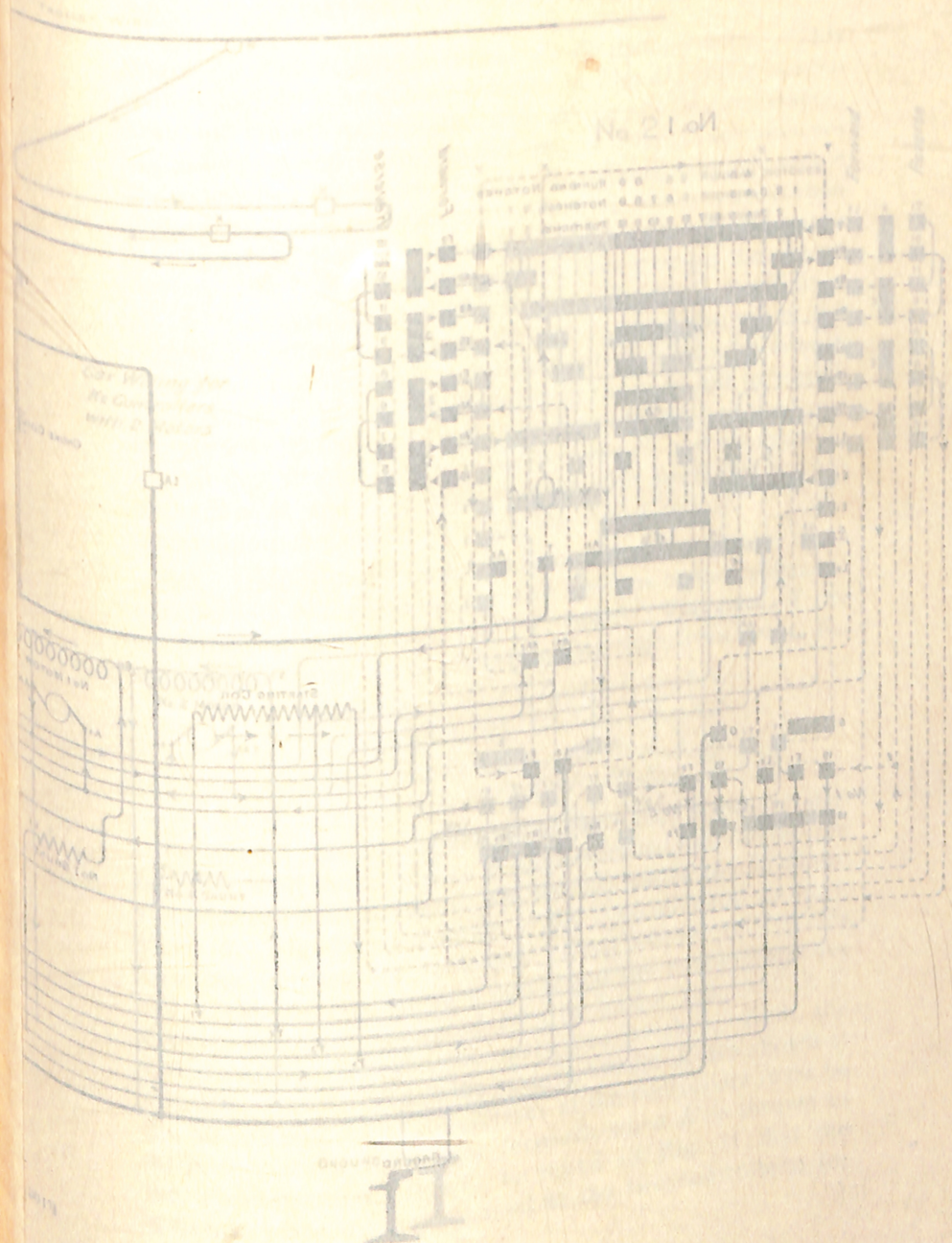
FIG. 30

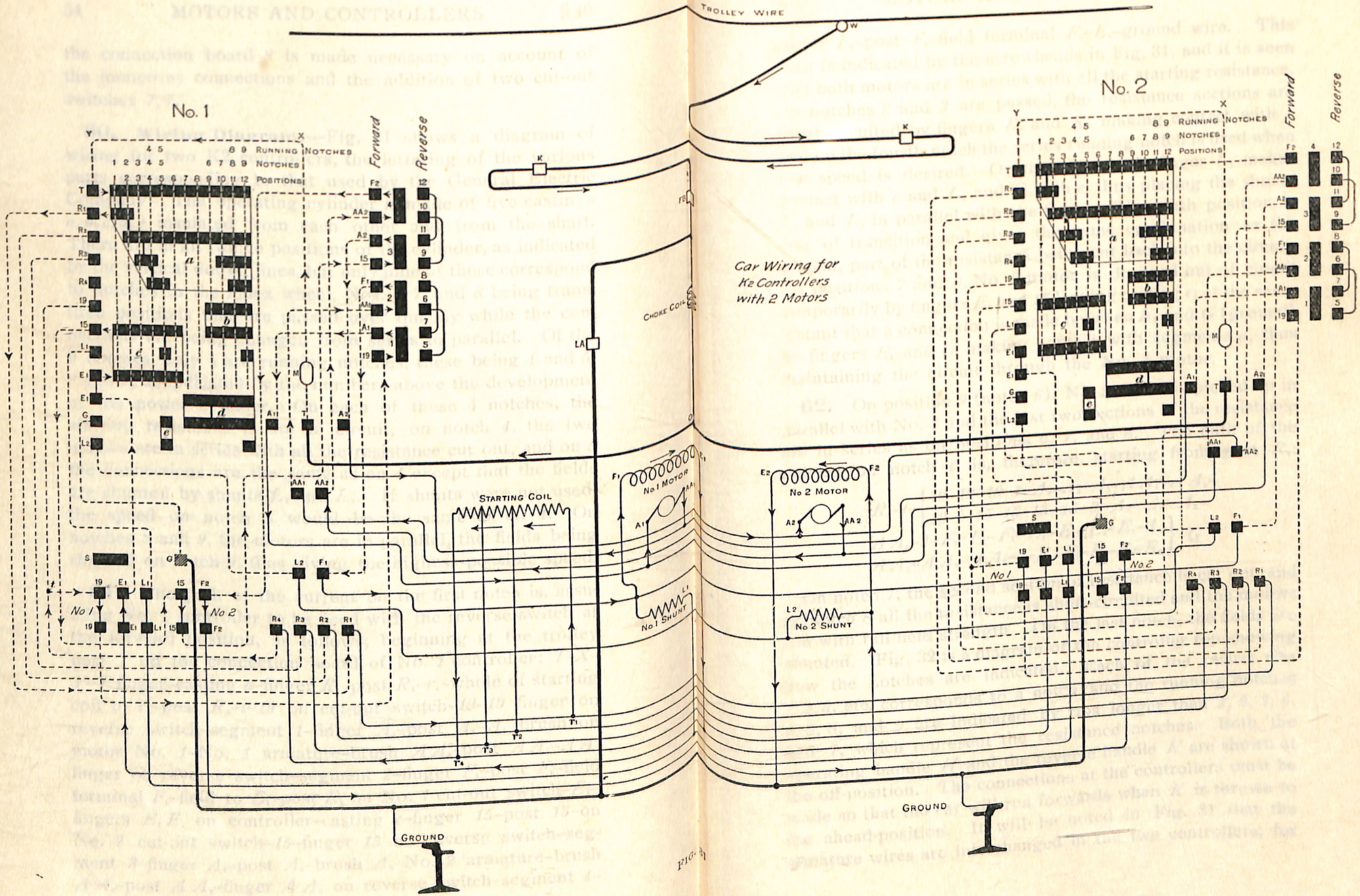
and the reverse cylinder of this controller are longer than those of the rheostatic controller. The interlocking device between the two cylinders is practically the same on both, but

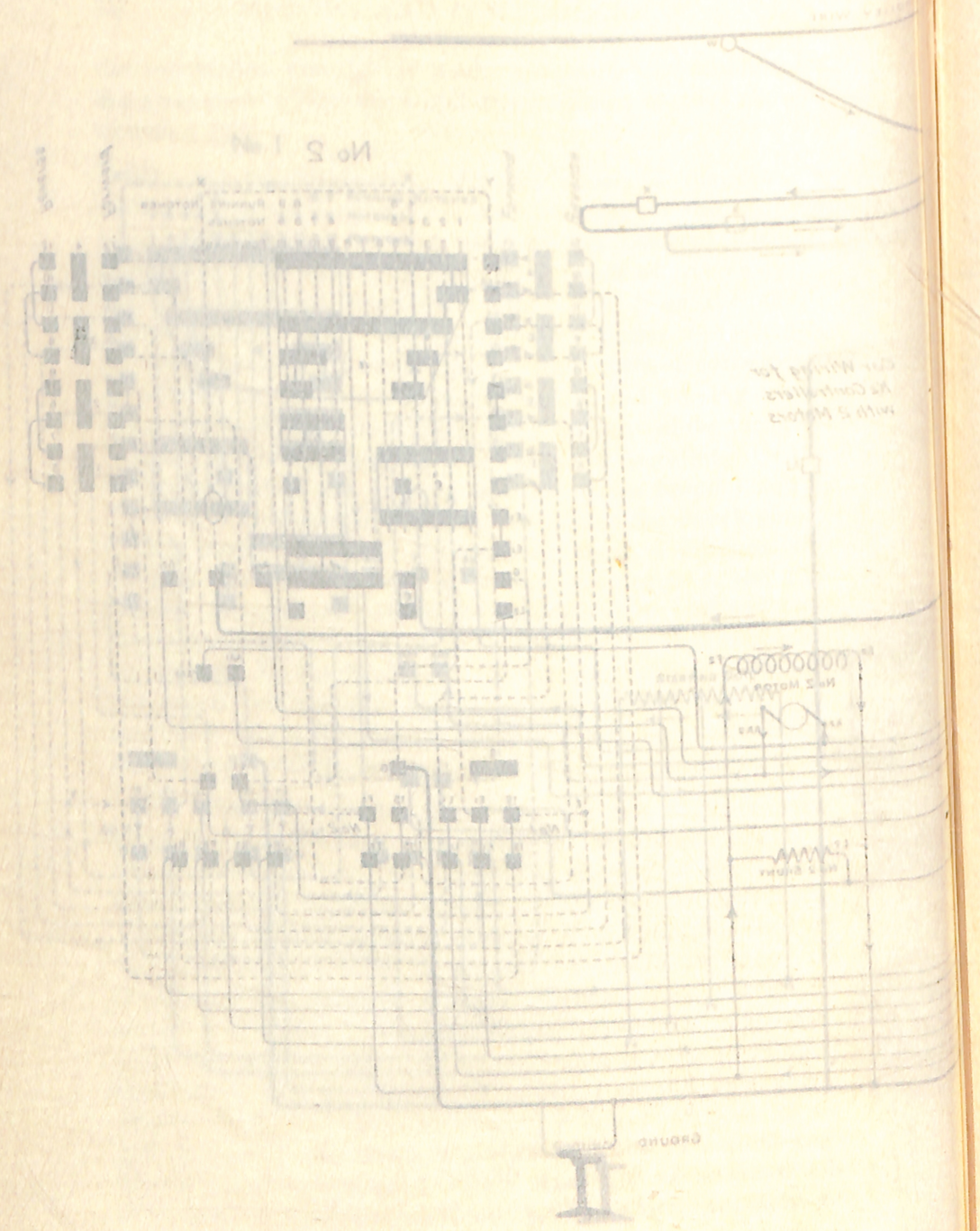
the connection board *8* is made necessary on account of the numerous connections and the addition of two cut-out switches 7, 7.

60. Wiring Diagram.—Fig. 31 shows a diagram of wiring for two K2 controllers, the lettering of the various parts corresponding to that used by the General Electric Company. The operating cylinder is made of five castings *a*, *b*, *c*, *d*, *e* insulated from each other and from the shaft. There are in all twelve positions of the cylinder, as indicated by the vertical dotted lines, but only nine of these correspond to notches in the index wheel, Nos. *6*, 7, and *8* being transition positions that are passed over quickly while the connections are being changed from series to parallel. Of the 9 notches, only 4 are running notches, these being *4* and *5*, *8* and *9*, as indicated by the numbers above the development of the power cylinder. On each of these 4 notches, the starting resistance is not in circuit; on notch *4*, the two motors are in series with all the resistance cut out, and on *5* the connections are the same as on *4* except that the fields are shunted by shunts L_1 and L_2. If shunts were not used, the speed on notch *5* would be the same as on *4*. On notches *8* and *9*, the motors are in parallel, the fields being shunted on notch *9*, thus giving the highest possible speed.

61. The path of the current on the first notch is, assuming No. *1* controller to be used with the reverse switch at the forward position, as follows, beginning at the trolley post *T* on the connection board of No. *1* controller: *T*–*X*–*Y*–*T* finger–casting *a*–finger R_1–post R_1–r_1–whole of starting coil to r_4–post R_4–*t*–*19* on cut-out switch–*19*–*19* finger on reverse switch–segment *1*–finger A_1–post A_1–A_1 brush on motor No. *1*–No. *1* armature–brush $A\,A_1$–post $A\,A_1$–$A\,A_1$ finger on reverse switch–segment *2*–finger F_1–post F_1–field terminal F_1–field to E_1–post E_1 on No. *1* cut-out switch–E_1–fingers $E_1\,E_1$ on controller–casting *c*–finger *15*–post *15* on No. *2* cut-out switch–*15*–finger *15* on reverse switch–segment *3*–finger A_2–post A_2–brush A_2–No. *2* armature–brush $A\,A_2$–post $A\,A_2$–finger $A\,A_2$ on reverse switch–segment *4*–




TROLLEY WIRE
W
K
K
No. 1
No. 2
Forward
Reverse
Car Wiring for
Ke Controllers
with 2 Motors
CHOKE COIL
LA
STARTING COIL
No. 1 MOTOR
No. 2 MOTOR
No. 1 SHUNT
No. 2 SHUNT
GROUND
GROUND



finger F_2–post F_2–field terminal F_2–E_2–ground wire. This path is indicated by the arrowheads in Fig. 31, and it is seen that both motors are in series with all the starting resistance. As notches *2* and *3* are passed, the resistance sections are short-circuited by fingers R_2 and R_3 making contact with *a* and on the fourth notch the series running notch is used when low speed is desired. On the fifth notch, finger L_1 makes contact with *c* and L_2 and G with *e*, thus placing the shunts L_1 and L_2 in parallel with the fields. The sixth position is one of transition and gives the same combination as the second, part of the resistance being cut back into the circuit. On positions *7* and *8*, No. *2* motor is dropped out of circuit temporarily by fingers E_1 and *15* leaving casting *c*; at the same instant that a connection is made between E_1 and G (ground) by fingers E_1 and G making contact with segments *d*, thus maintaining the circuit through the No. *1* motor.

62. On position *9* (notch *6*), No. *2* motor is picked up in parallel with No. *1* and the last two sections of the resistance are in series as on positions *6*, *7*, and *8*. The path of the current on notch *6* is, therefore, starting from post R_4:

$$R_4\text{–}t\text{–}\begin{cases} 19\text{–}19\text{–}19\text{–}1\text{–}A_1\text{–}A_1\text{–}A_1\text{–}A\,A_1\text{–}A\,A_1\text{–} \\ 19\text{–}b\text{–}15\text{–}15\text{–}15\text{–}15\text{–}3\text{–}A_2\text{–}A_2\text{–}A_2\text{–} \\ A\,A_1\text{–}2\text{–}F_1\text{–}F_1\text{–}F_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}d \\ A\,A_2\text{–}A_2A_2\text{–}A\,A_2\text{–}4\text{–}F_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}E_2 \end{cases}\text{–}G$$

On notch 7, the second section of resistance is cut out, and on notch *8* all the resistance is short-circuited and the motors run with full field strength. On the last notch, the fields are shunted. Fig. 32 is a diagram of the controller top showing how the notches are indicated. Each of the raised ribs *1*, *2*, *3*, etc. corresponds to a notch, and the running notches *4*, *5*, *8*, and *9* are indicated by ribs longer than *1*, *2*, *3*, *6*, and *7*, which represent the resistance notches. Both the operating handle H and the reverse handle K are shown at the off-position. The connections at the controllers must be made so that the car will run forwards when K is thrown to the ahead-position. It will be noted in Fig. 31 that the armature wires are interchanged in the two controllers; for

example, the wire connecting to post AA_1 in No. *1* controller connects to post A_1 in No. *2* controller. If this were not done, the movement of the car would agree with the direction in which the reverse handle pointed when operated from one controller but would not agree when operated from the other. Also, since the motors are mounted back to back on the truck, they must run in opposite directions when viewed, say, from the commutator end, in order that they may both propel the car in the same direction. In Fig. 31 the connections are such that the current flows through both armatures in the same direction, but the direction through No. *2* field is opposite to that through No. *1* field, and No. *2*

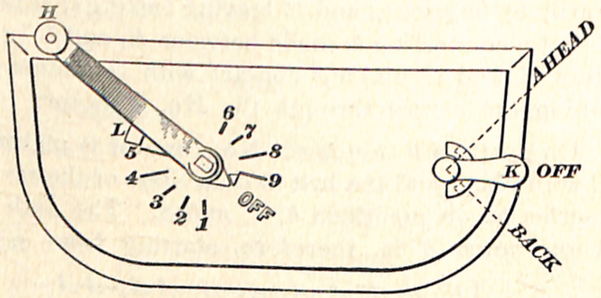


FIG. 32

motor would therefore run in a direction opposite to No. *2* when viewed from the same end. The usual method is to connect up the motors and turn on the current; if it is found that one or more of the motors are trying to drive the car in the wrong direction, they can easily be reversed by interchanging the field terminals. Fig. 33 shows diagrammatically the various combinations corresponding to the different controller positions; *S*, *S* represent the shunts across the fields and positions *4*, *5* and *11*, *12* are the only ones that should be used for steady running. The others are provided to prevent a rush of current at starting and when changing from series to parallel; also, to give a smooth acceleration.

63. Motor Cut-Out Switches.—In the lower part of the K2 controller, just below the power cylinder, the two motor cut-out switches are located. These are seen at 7, 7,

Fig. 30, and are marked No. *1* and No. *2* in Fig. 31. As mentioned before, the two motor cut-out switches are used to run the car on one motor if the other motor or any part of its circuit gives out. These two switches may be thrown up or down, and when the car is in good shape and both motors in use, both switches should be down, as indicated by the

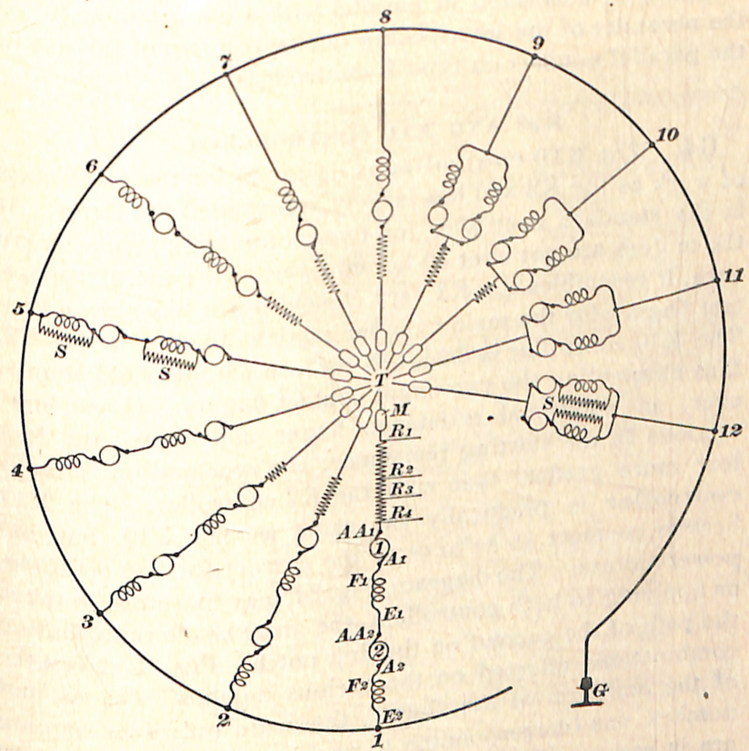


FIG. 33

connecting lines in Fig. 31. When No. *1* switch is thrown up, posts *19* and E_1 are connected together by casting *S*. Assuming that the controller is on the first notch, the path of the current beginning at point *t* is: *t*–*19*–*S*–E_1–E_1–E_1–*c*–*15*–*15*–*15*–*15*–*3*–A_2–A_2, etc. No. *1* motor is cut out and the current flows through No. *2* motor to ground. If No. *2* switch is thrown up, No. *1* being down, the current on

reaching post *15* on No. *2* switch goes directly to ground post *G* and No. *2* motor is cut out. When either of these switches is used, it operates an interlocking device that interferes with a collar on the power-cylinder shaft and prevents the cylinder from being moved beyond the last series position. It is obvious that if one motor is disabled it cannot be connected in parallel with a good motor, hence the necessity of the interlocking device to prevent the use of the parallel notches on type K controllers.

K10 AND K11 CONTROLLERS

64. The **K10 controller** is designed for the same class of work as the K2 and has largely superseded the latter. It is the standard controller for two-motor equipments where the motors are not over 40 horsepower. In general appearance, it resembles the K2 very closely but it has eleven contact fingers for the main cylinder against twelve on the K2. The K10 controller is designed for use without field shunts, thus eliminating the two shunt contact fingers. It has, however, an additional resistance finger and there are four sections in the starting resistance; the acceleration is therefore more gradual than with the K2 controller. The **K11 controller** is practically the same as the K10, but has heavier contacts so as to carry the current for two 60-horsepower motors. The diagram, Fig. 34, may therefore be taken as applying to both controllers, the arrowheads representing the path of the current on the first notch. Fig. 35 shows the combinations effected on the various notches. On account of the omission of the shunts, there are only two running notches, one (corresponding to position *5*) where the motors are in series with all resistance cut out and the other (position *12*) where they are in parallel with all resistance cut out.

K12 CONTROLLER

65. The **K12 controller** is similar to the K11, but is arranged for the control of four 30-horsepower motors. Fig. 36 shows the general layout of the wiring for a car equipped with four motors and K12 controllers. The

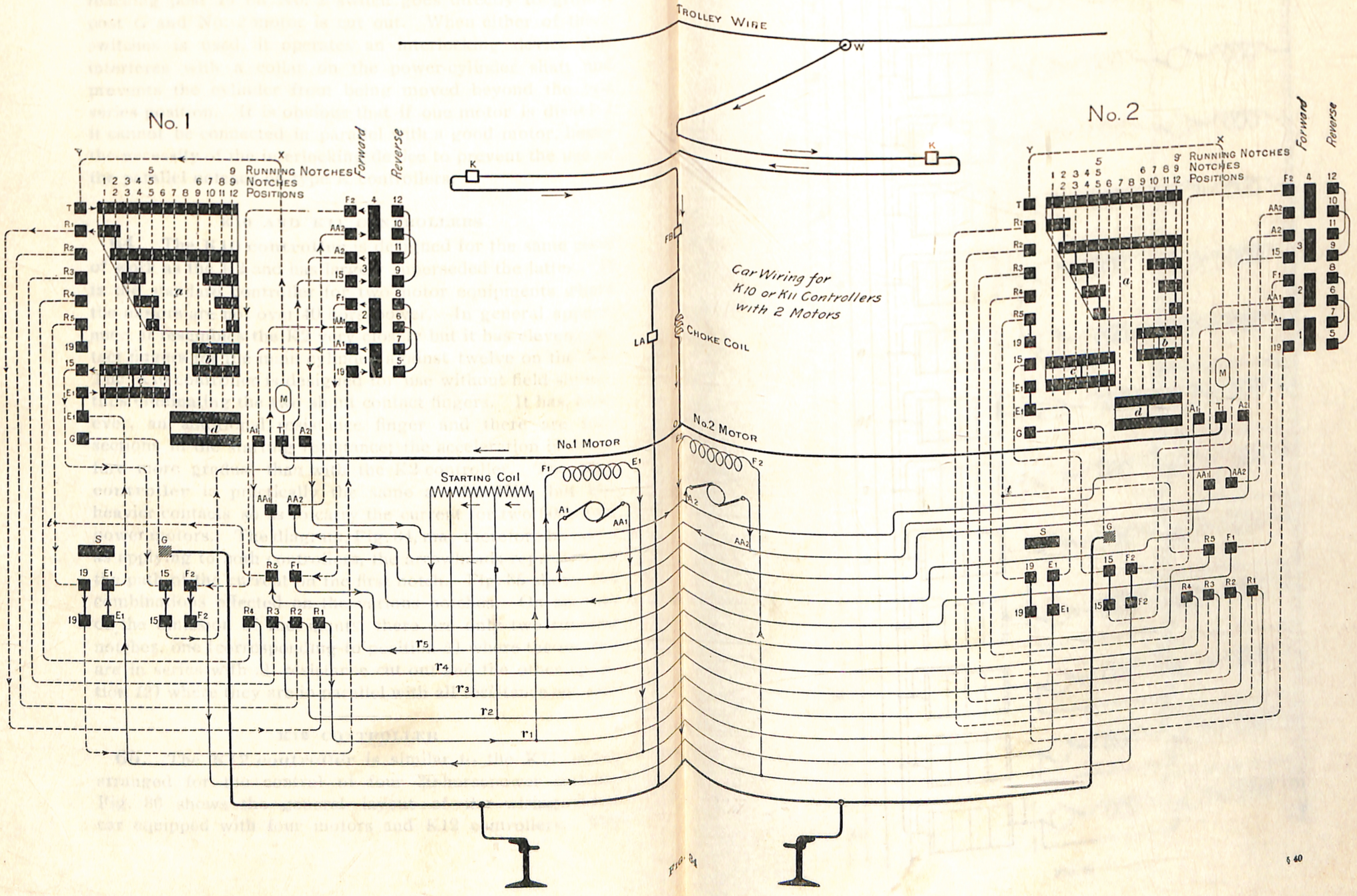

Trolley Wire
W
K
K
FB
LA
Choke Coil
No. 1
No. 2
Car Wiring for
K10 or K11 Controllers
with 2 Motors
No.1 Motor
No.2 Motor
Starting Coil
Running Notches
Notches
Positions
Forward
Reverse
r5
r4
r3
r2
r1

Fig. 84

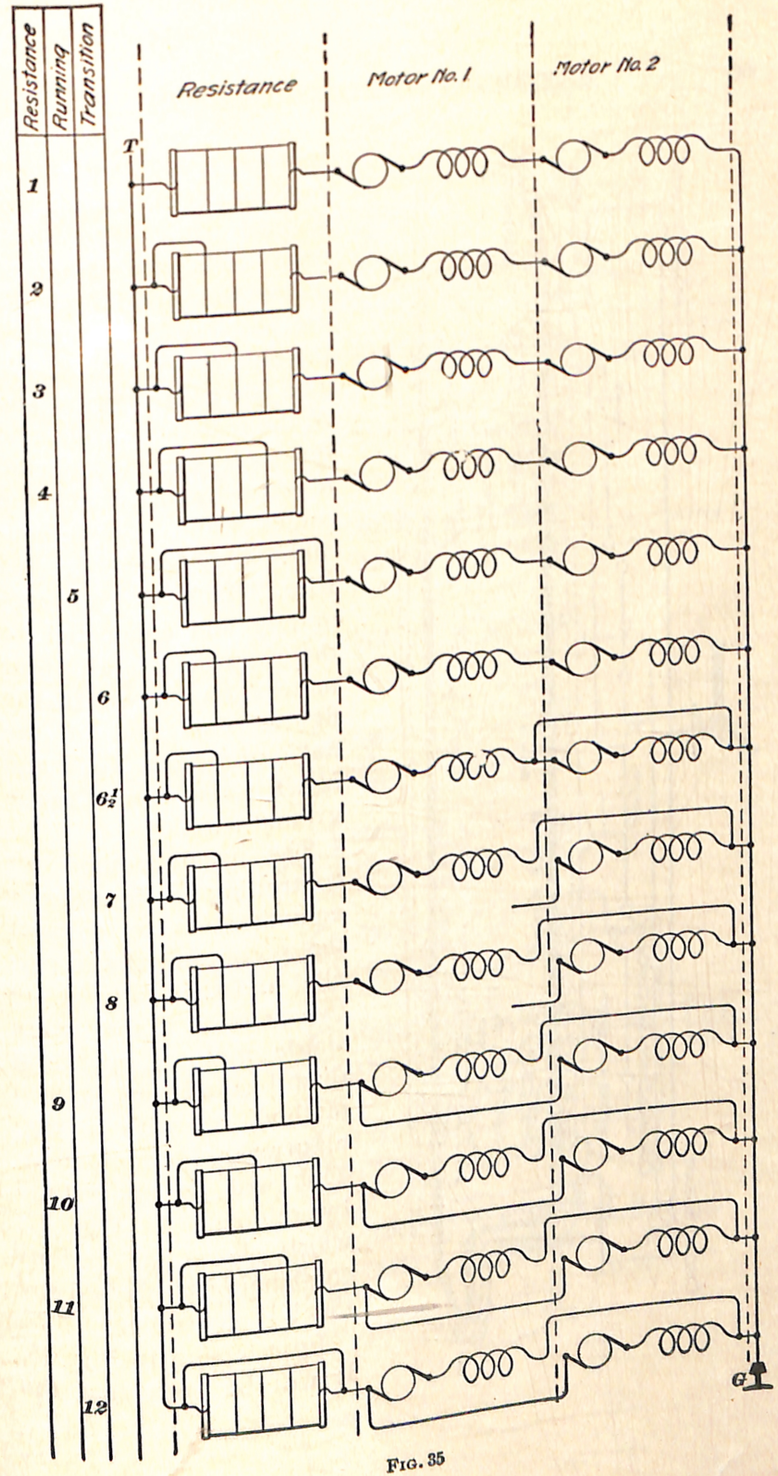

Resistance
Running
Transition
Resistance
Motor No. 1
Motor No. 2
T
1
2
3
4
5
6
6½
7
8
9
10
11
12
G

FIG. 35

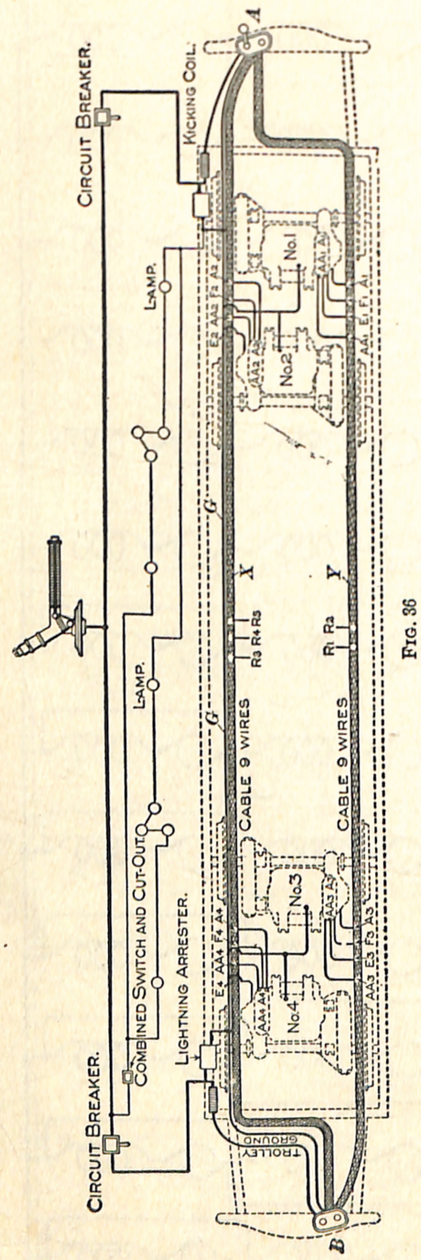


FIG. 36

motors, *1*, *2*, *3*, and *4*, are mounted back to back, two on each truck. The resistance coils are mounted under the middle of the car and are connected to the taps R_1, R_2, R_3, R_4, R_5. The two controllers *A* and *B*, the resistance coils, and the motors are connected together by wires run in the cables *X* and *Y*, or in conduit. *G G* is the ground wire, which is run separately and connected to the frames of all four motors, as shown in the figure. One end of the fields of motors No. 2 and No. *4* is also tapped to the ground wire.

The usual method for controlling a four-motor equipment is to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as with a regular two-motor equipment. This will be understood by referring to Fig. 37, which shows the various combinations effected by the K12 controller.

By referring to Fig. 35, it will be seen that the

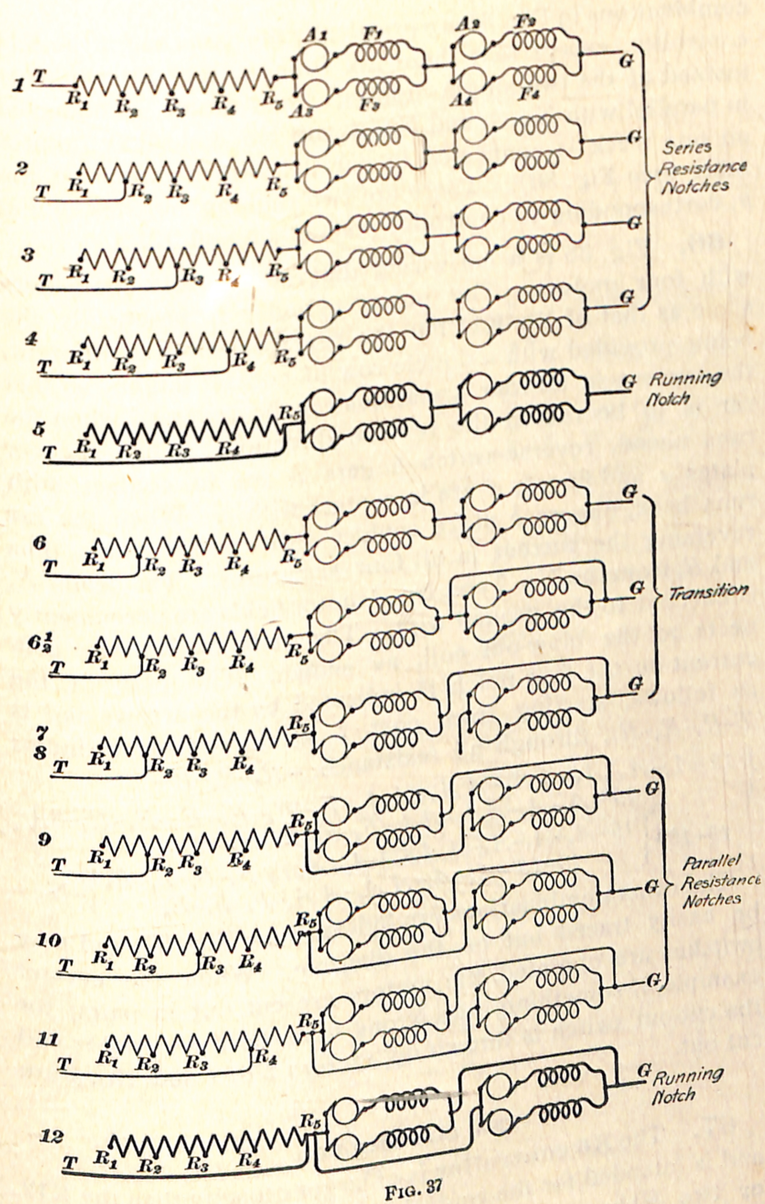


FIG. 37

combinations in Fig. 37 are practically the same as for the K11 controller, except that there are four motors in two pairs instead of the two single motors; No. *1* motor is connected in parallel with No. *3*, and No. *2* with No. *4*, so that a motor on one truck is connected in parallel with a motor on the other (see Fig. 36). There are two running notches, *5* and *9*, corresponding to controller positions *5* and *12*.

66. Fig. 38 is a car-wiring diagram for K12 controllers with four motors. The power cylinder is practically the same as that of the K11 but the reverse switch is different, being provided with a double row of contact fingers so that the current in all four armatures can be reversed when the car is to be run in the reverse direction. When the car runs ahead, reverse-switch fingers *b* are in contact with plates *a* and fingers *d* are in contact with *c*. When the car runs back, fingers *b* make contact with *c* and *d* with *e*, thus reversing the current in all four armatures. The leads E_2 and E_4 from the No. 2 and No. 4 motor fields are permanently connected to the ground wire. The main trolley wire connects to the blow-out coil, as shown. The path of the current on the first notch is indicated by the arrows and is as follows, starting from post *T* at the power cylinder: T–R_1–R_1–R_1, through all resistance, $-R_5-R_5-19-$

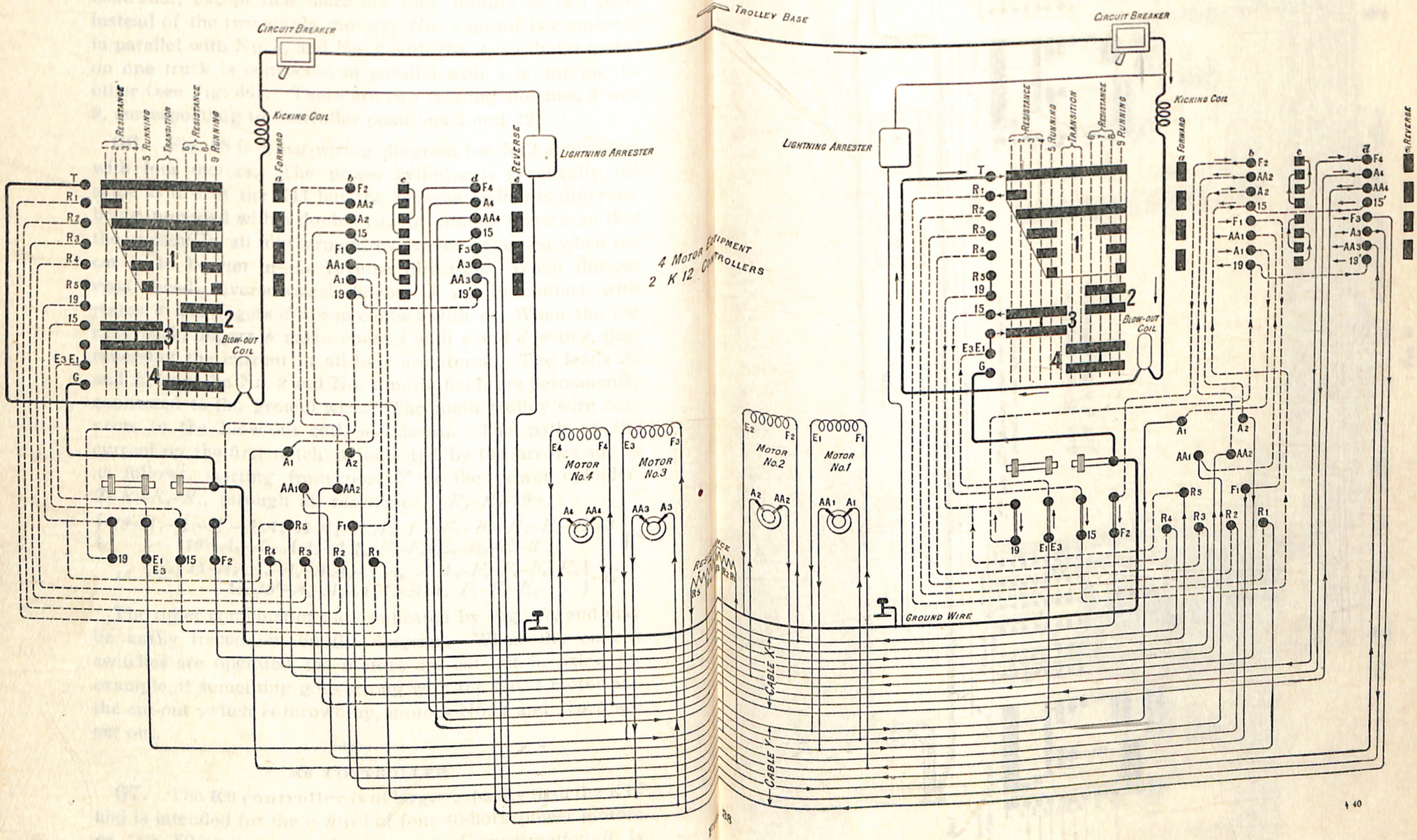
$$\left\{\begin{matrix} 19-A_1-A_1-A_1-A\,A_1-A\,A_1-A\,A_1-F_1-F_1-F_1-E_1-E_1-E_1-3 \\ 19'-A_3-A_3-AA_3-AA_3-F_3-F_3-E_3-E_3-E_3-3 \end{matrix}\right\}-$$

$$15-15-\left\{\begin{matrix} 15-A_2-A_2-A_2-A\,A_2-A\,A_2-A\,A_2-F_2-F_2-F_2-E_2 \\ 15-15'-A_4-A_4-A\,A_4-A\,A_4-F_4-F_4-E_4 \end{matrix}\right\}-G$$

The other combinations are indicated by Fig. 37, and may be easily traced out on the diagram. When the cut-out switches are operated, the motors are cut out in pairs; for example, if something goes wrong with the No. *1* motor and the cut-out switch is thrown up, motors No. *1* and No. *3* are cut out.

K6 CONTROLLER

67. The **K6 controller** is of larger capacity than the K12 and is intended for the control of four 40-horsepower motors or two 80-horsepower. In its general construction it is


Trolley Base
Circuit Breaker
Kicking Coil
Lightning Arrester
1 Resistance
5 Running
Transition
7 Resistance
9 Running
Forward
Reverse
Blow-out Coil
Motor No.4
Motor No.3
Motor No.2
Motor No.1
Ground Wire
Cable X
Cable Y
4 Motor Equipment
2 K 12 Controllers

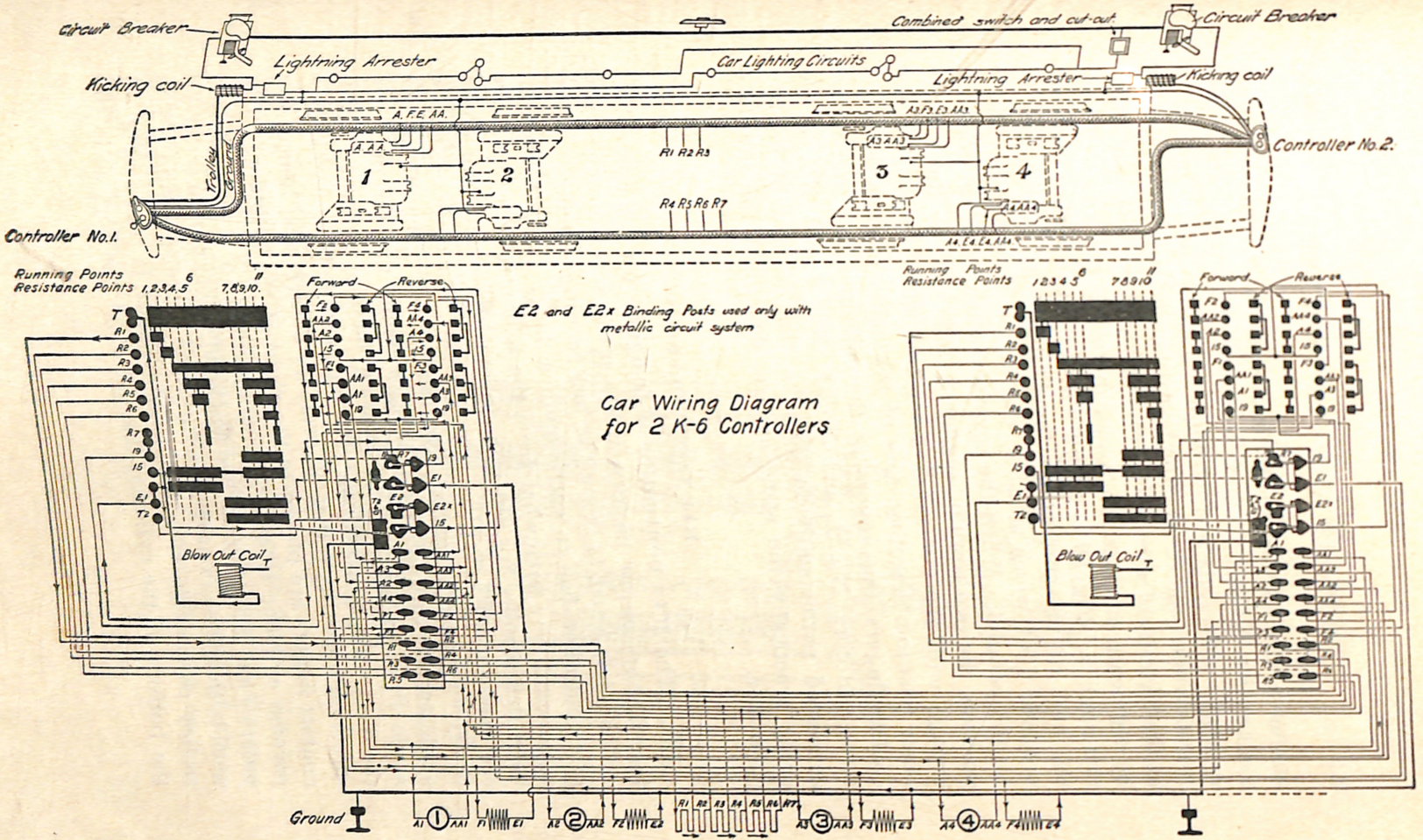

Circuit Breaker
Lightning Arrester
Kicking coil
Combined switch and cut-out
Car Lighting Circuits
Lightning Arrester
Circuit Breaker
Kicking coil
Controller No.2.
Controller No.1.
Trolley
Ground
Running Points
Resistance Points
1,2,3,4,5
6
7,8,9,10.
11
Forward
Reverse
Blow Out Coil
E2 and E2x Binding Posts used only with metallic circuit system
Car Wiring Diagram for 2 K-6 Controllers

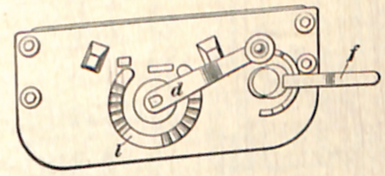
FIG. 39

similar to the K12 but the main cylinder and contact fingers are heavier. The pole piece carrying the arc guards is also arranged differently and the blow-out coil is in the bottom of the controller, the connection board being arranged vertically at the right-hand side. The reverse cylinder has four rows of segments mounted on it and there are two rows of contact fingers. Fig. 39 is a diagram of the car wiring showing the path of the current on the first notch. There are 11 notches, 6 of which are for the series connections and 5 for the parallel. When the reverse switch is on the forward position, the two rows of segments indicated by the arrows engage with the contact fingers, and when thrown to the other position the other sets of segments engage with the contact fingers, thus reversing the current in all four armatures. Motors No. *1* and No. *3*, No. *2* and No. *4* are connected permanently in parallel, the method of control being practically the same as was described for the K12 controller.

K14 CONTROLLER

68. The **K14 controller** is designed for the control of four 60-horsepower motors; it has seven series notches and six parallel, 7 and *13* being the two running notches. Since this controller has to carry quite a large current, its construction differs somewhat from the K controllers that have been described. Fig. 40 is a general view with the cover removed and the pole piece swung back. The main cylinder *a* is driven through gears *b*, *c* by the operating handle *d*, the angle turned through by the drum being greater than the angle through which the operating handle is turned from the on- to the off-position. The main cylinder rotates in a direction opposite to that on ordinary controllers; hence, the contact fingers are placed to the right of the cylinder. The reverse cylinder is at *e* and is operated by handle *f*; cylinders *e* and *a* are interlocked and handle *f* cannot be removed until both cylinders have been turned to the off-position. The trolley connection with the main cylinder is made at *g*, at the bottom of the cylinder, instead of at the top, as in the

controllers so far described. Instead of using a regular contact finger at *g*, contact is made with the cylinder by means of a split casting passing completely around a collar. This casting can be adjusted by nut *h*, so as to make a good contact without interfering with the movement of the cylinder, and it affords a better contact surface for the larger current than would be provided by a contact finger. The cut-out switches are located at *k*, *k* and are arranged in connection with an interlock to prevent the drum from being moved to the parallel position when either motor is cut out. This controller has no index wheel, but the notches are located by a hinged lever *m*, under the operating handle, that drops into notches, in an index *l* mounted on top of the controller. Lever *m* is raised so as to clear the notches, by the motorman pressing down on knob *n* on top of the operating handle. The controller has no connection board, the terminal wires being brought out of the bottom of the controller and fastened to the car wires by means of clamp terminals that are thoroughly taped over after the connections have been made.



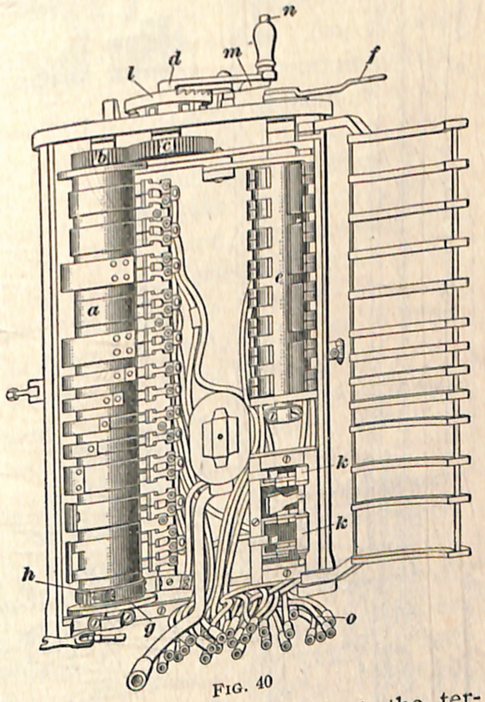


FIG. 40

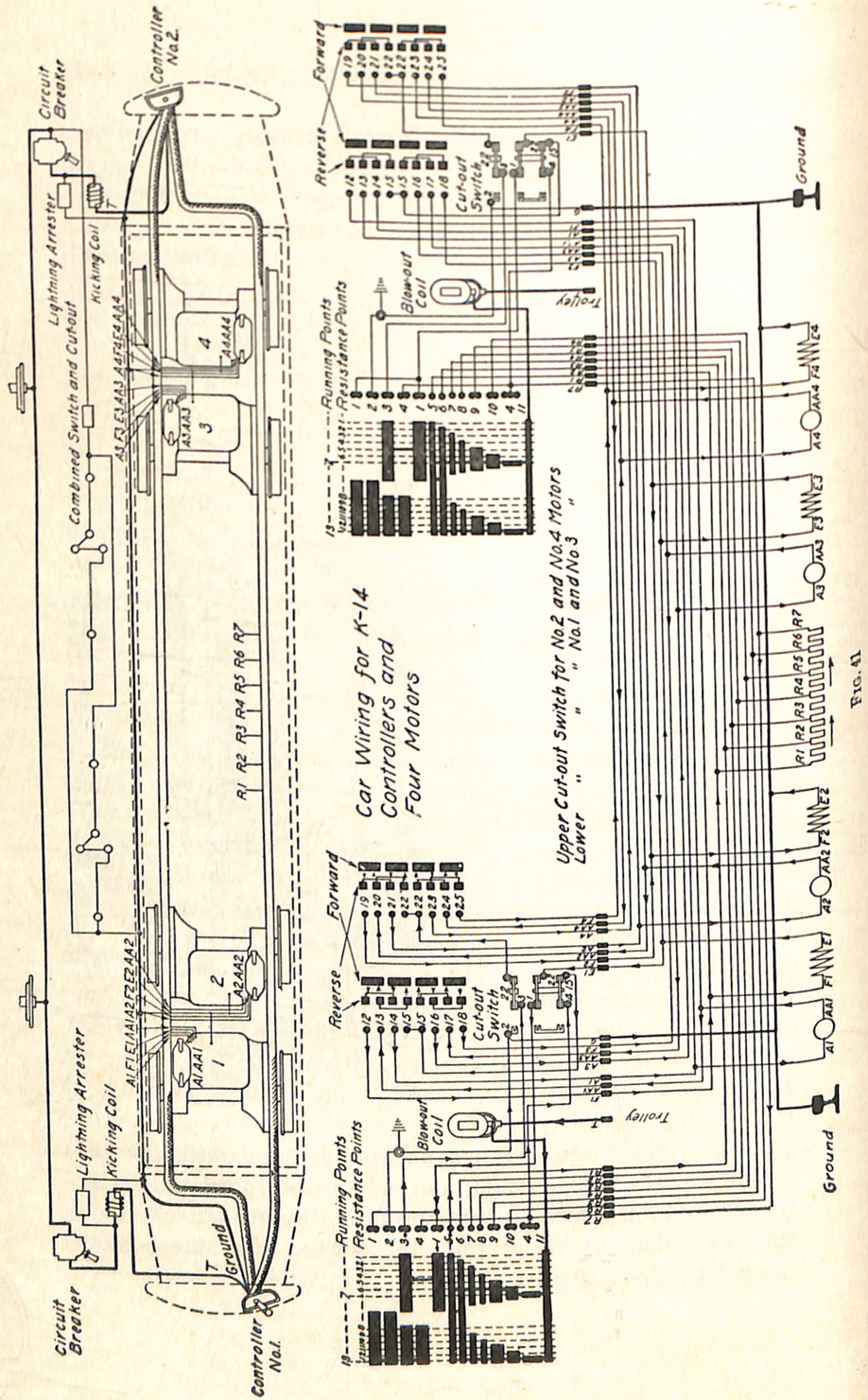


Fig. 41

Fig. 41 is a car-wiring diagram for K14 controllers with four motors, the path of the current on the first notch being indicated by the arrows. Motors *1* and *3*, and *2* and *4* are connected permanently in parallel.

K27 CONTROLLER

69. The K27 controller, for which Fig. 42 is a car-wiring diagram, is intended for use with two motors, not exceeding 60-horsepower, on metallic-return systems. It is used mostly on conduit systems, which are particularly liable to grounds, and on this account the controller contains a few features not found on ordinary K controllers. Any type K controller can be used for operating cars on a conduit system so long as both car and conductor rails are free from grounds; but should a car with a grounded connection run on to a section of conductor rail that is also grounded, conditions may arise where one of the motors would take current even with the controller thrown to the off-position, thus making the motorman lose control of the car and necessitating the opening of a circuit-breaker or hood switch in order to stop the car. The K27 cylinder is therefore designed so as to open both sides of the circuit when it is thrown to the off-position.

Suppose, for the present, in Fig. 42, that main cylinder fingers E_2 and T_2 are connected by a piece of wire. This will make the conditions the same as if an ordinary K10 controller were used, since with it, the end E_2 of the No. *2* field is connected to the negative, or ground side of the circuit, which with a metallic-return system corresponds to the T_2 terminal, or collecting shoe. Also suppose, in Fig. 42, that the A_2 brush, or a wire connected to it, becomes grounded as indicated by the dotted connection at G', and assume that the car runs on to a section where the conductor rail to which T_1 connects is grounded. Current can then flow from the positive conductor rail through the ground and enter No. *2* motor through the ground G' and flow through the path: A_2–A A_2–A A_2–A A_2–F_2–F_2–F_2–E_2–post E_2 on controller. Now we have assumed E_2 and T_2 to be connected;

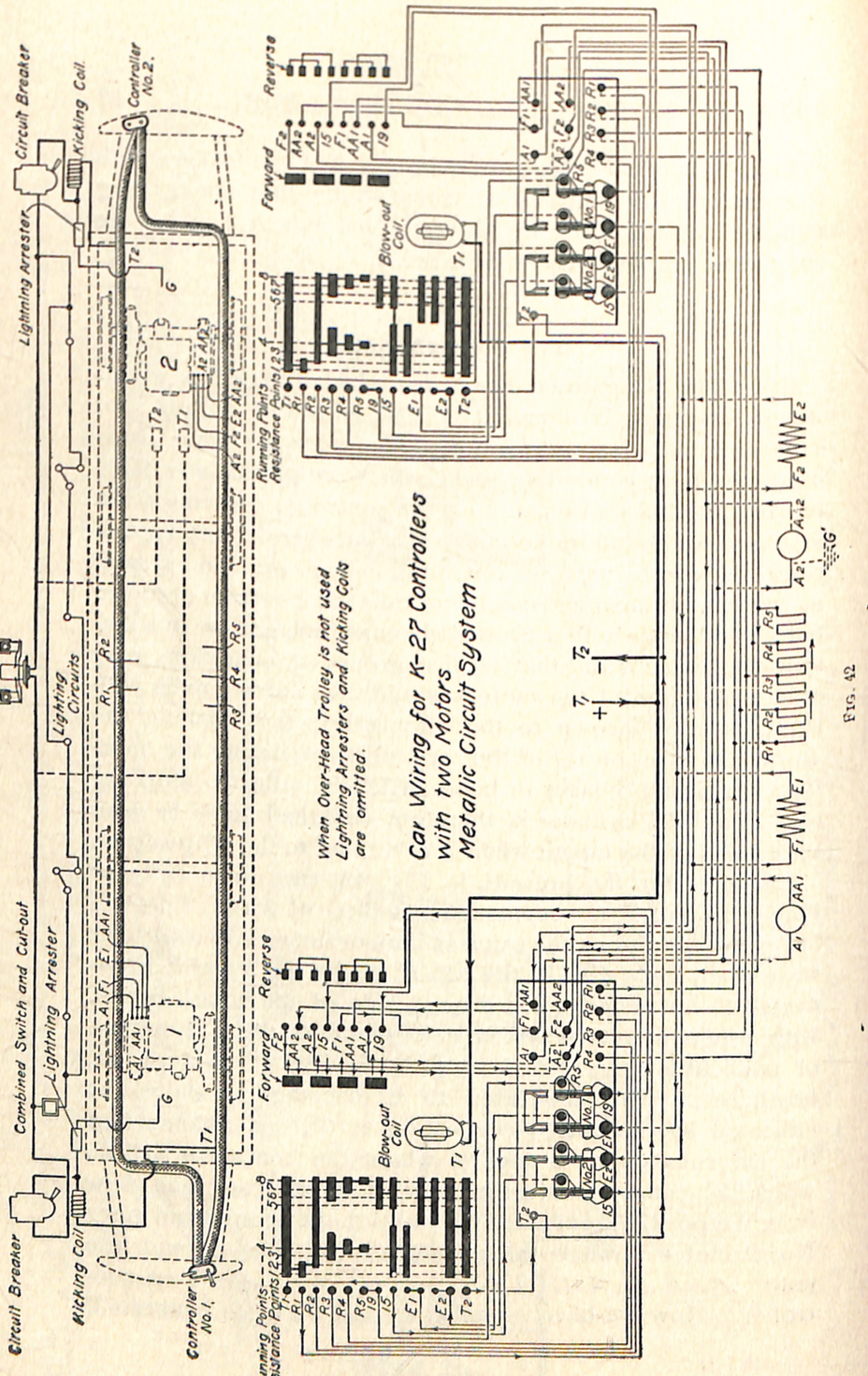


FIG. 42

hence, the current passes to T_2 and to the other conductor rail. Throwing the main cylinder to the off-position does not interrupt this current though a movement of the reverse switch would. In order to avoid this condition, the K27 controller is provided with fingers T_2 and E_2 so that the current must pass through the main cylinder, and hence throwing the cylinder to the off-position interrupts this current. Also, the E_2 field wire runs through the No. *2* cut-out switch, so that if this motor becomes grounded and is cut out by throwing up the No. *2* cut-out switch, all connections between the No. *2* field and the T_2 terminal will be broken. This is not possible with an ordinary type K controller where the end of No. *2* field runs directly to the ground wire without being brought to the controller.

70. The K6 controller, Fig. 39, can be arranged for use on metallic-return systems, by making a few changes in the connections. Instead of connecting the E_2 and E_4 field terminals to the ground wire (or T_2 wire on a metallic-return system), as indicated in Fig. 39, they are connected to a wire running to post E_2 on the connection board of, say, No. *1* controller. The ground wire, shown in Fig. 39, is connected to the T_2 collecting shoe, and a wire is run between posts $E_2 x$ on the two connecting boards. On the No. *2* connecting board, i. e., on the board to which the E_2 wire is not run, a connection is made between the E_2 post on the No. *2* cut-out switch, and the T_2 or G post. The object of these connections is to allow No. *2* and No. *4* fields to be disconnected from the T_2 side of the circuit in case of a ground, as explained in connection with Fig. 42. The K6 controller is not, however, arranged like the K27, so that the main cylinder will open both sides of the circuit and break any current that may flow through motors No. *2* or No. *4* because of grounds.

L2 CONTROLLER

71. The **L2 controller** is intended for heavy high-speed interurban cars and will control two 175-horsepower motors. On account of the large current, the main cylinder

contacts, and also any other contacts that have to carry the current while the motors are in operation, are made unusually large by connecting a number of fingers in parallel.

The L2 controller differs considerably from those of the K type, both in its construction and method of operation. The main cylinder simply cuts out the starting resistance and the changing over of connections from series to parallel is effected by a separate commutating arm or switch. While the commutating switch is changing from the series to the parallel position, the motor circuit is kept open by the main cylinder so that the commutating switch does not interrupt the current. Another feature is that the starting resistance is reduced by connecting resistance sections in parallel with the first section instead of cutting out sections, as in the K controllers.

72. Fig. 43 is a wiring diagram for L2 controllers as used on a car intended for operation either from an overhead trolley or from a third rail. Single-pole double-throw switches t, t' are provided in each vestibule, so that the main car wiring can be connected either to the overhead trolley or third rail. Thus, when the switches are thrown to the upper position, the car being supplied from an overhead trolley, the third-rail shoes are dead. There are two reverse switches on each controller, each serving to reverse the armature connections of one motor. The reverse switches are operated by a single handle at the side of the controller which when thrown to the ahead-position makes contact segments e, f, e', f' occupy the position indicated by the vertical dotted lines, thus connecting F_2 and $A A_2$, F_1 and $A A_1$, etc. When the reverse switch is moved to the back-position, segments e, f, e', f' are rotated so that contact is made between A_2 and F_2, A_1 and F_1, etc., thus reversing the current in the armatures. The main cylinder, shown at the left, cuts out the starting resistance. There are 4 notches for the series combinations and 4 for the parallel, the last notch on each being a running notch. To throw the controller from the off-position to the last series notch, the operating handle is turned through half a revolution, thus moving the main

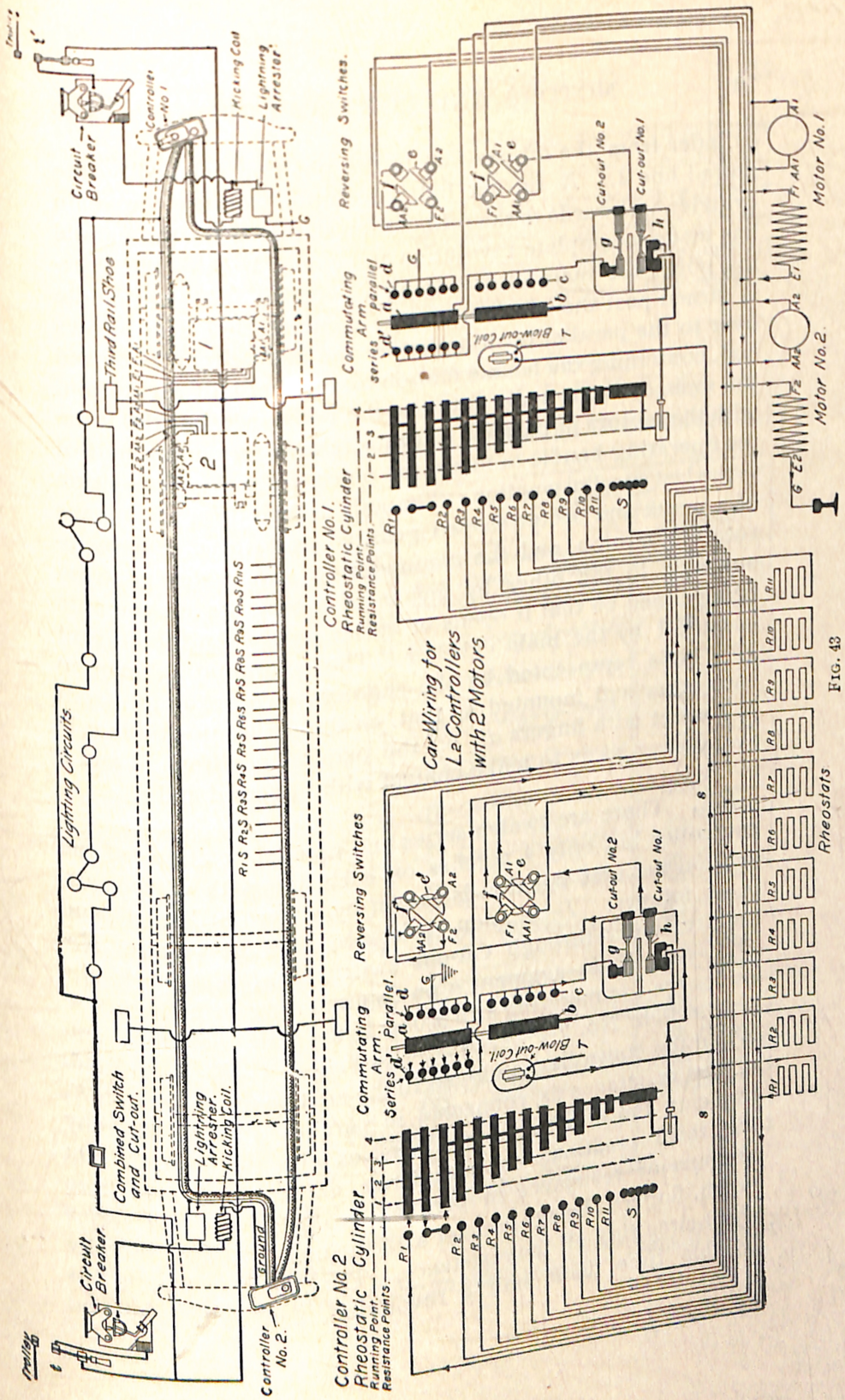


FIG. 43

cylinder from the off-position to the position marked by the dotted line *4*. A further half revolution rotates the main cylinder backwards to the off-position so that when the handle has made a complete revolution and comes back to the starting point, the main circuit is again opened. As the handle is turned past the off-position, the commutating arm throws over to the parallel position before the main circuit is closed and, continuing the handle motion for another half revolution, the main cylinder again cuts out the resistance but this time with the motors in parallel. It thus takes a turn and a half of the operating handle to throw the power from the off-position to the last parallel position. The main drum is driven by means of a crank and sector-shaped gear, so as to give it a reciprocating motion, and the commutating arm is thrown from one side to the other by means of a cam, its movements being timed so that it opens or closes only when the current is cut off by the main cylinder. The commutating arm in Fig. 43 is represented by the segments a, b, insulated from each other and mounted so that, on the series positions a is in contact with fingers d'; on the parallel positions, a and b swing over so as to make contact with fingers d and c.

73. There are twelve series and parallel positions of the controller but only 4 notches on each; the path of the current on the first position is shown by arrows in Fig. 43 and is as follows: T–common resistance wire S–R_1–finger R_1–main cylinder–through cut-out switch No. *1*–e–A_1–A A_1–A_1–A A_1–f–F_1–F_1–E_1–segment a on commutating arm–fingers d' (since the commutating arm is now in the series position)–cut-out switch No. *2*–e'–A_2–A A_2–A_2–A A_2–f'–F_2–F_2–E_2–ground. When the controller is moved to the next position, section R_2 of the resistance is connected in parallel with R_1, thereby reducing the total resistance in series with the motors. On the third position, or first series notch, there are three sections of resistance in parallel; finally on the last series notch, fingers S make contact with the main cylinder, thereby short-circuiting all the resistance. The operating handle has by this time made half a revolution, and as it is moved

quickly around for another half revolution, the main cylinder reverses its motion, thereby cutting the resistance back in, and finally opening the circuit. Just as the operating handle begins its second revolution the commutating switch throws over so that a makes contact with d and b with c, the path of the current on the first parallel position being: T–S–R_1–R_1–main cylinder–cut-out No. *1*–

$$\left\{\begin{array}{l} e\text{–}A_1\text{–}A\ A_1\text{–}A_1\text{–}A\ A_1\text{–}f\text{–}F_1\text{–}F_1\text{–}E_1\text{–}a\text{–}d \\ b\text{–}c\text{–cut-out No. } 2\text{–}e'\text{–}A_2\text{–}A\ A_2\text{–}A_2\text{–}A\ A_2\text{–}f'\text{–}F_2\text{–}F_2\text{–}E_2 \end{array}\right\}\text{–}G$$

As the motion of the operating handle is continued for another half revolution, the main cylinder repeats the resistance combinations that it made during the first half revolution, and when the last parallel notch is reached, the resistance is short-circuited by fingers S again making contact with the main cylinder. Fig. 44 shows the combinations made on each of the series and parallel notches.

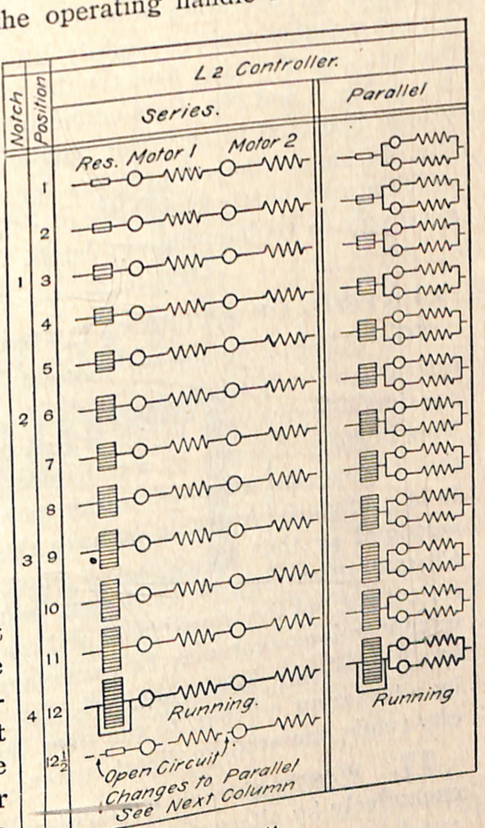


FIG. 44

74. Cut-Out Switches.—The cut-out switches simply open the circuit through the defective motor and if either motor is cut out, the commutating arm must be in the parallel position or there will be an open circuit. Thus, if motor

No. *1* is defective, it is cut out by opening switch blade *h*, and the controller is run on the last half revolution of the operating handle, in which case the commutating switch is on the parallel position and the current can take the path from cut-out No. *1*–*b*–*c*–No. *2* reverse switch and No. *2* motor to ground.

L4 CONTROLLER

75. The **L4 controller** is similar to the L2 but is provided with four reverse switches, the controller being designed for operating four 100-horsepower motors. The cut-out switches are also slightly different, but the main cylinder and commutating arm are the same. Motors No. *1* and No. *3*, No. *2* and No. *4* are connected in parallel and the two groups operated in series or parallel as with single motors. Fig. 45 shows the connections for a single L4 controller, which are so nearly like those of Fig. 43 that it will not be necessary to explain them in detail.

CONTROL OF ALTERNATING-CURRENT MOTORS

76. Alternating-current motors are specially adapted to interurban roads where the current has to be transmitted a considerable distance; hence, a high trolley pressure is used. This is stepped down by a transformer carried on the car so that the current supplied to the motors is at low pressure. It is frequently desirable to have the controlling apparatus arranged so that the cars can operate on either direct or alternating current, in which case switches must be provided for cutting out the transformer and making any other changes in connections that may be necessary. An arrangement of this kind allows interurban cars, that are normally operated by alternating current, to run over the tracks of connecting city roads operated by direct current.

77. Westinghouse Control.—Where a car is operated exclusively by alternating current, the speed of the motors can be regulated by varying the pressure, applied to the motors, by means of a potential regulator, or for small

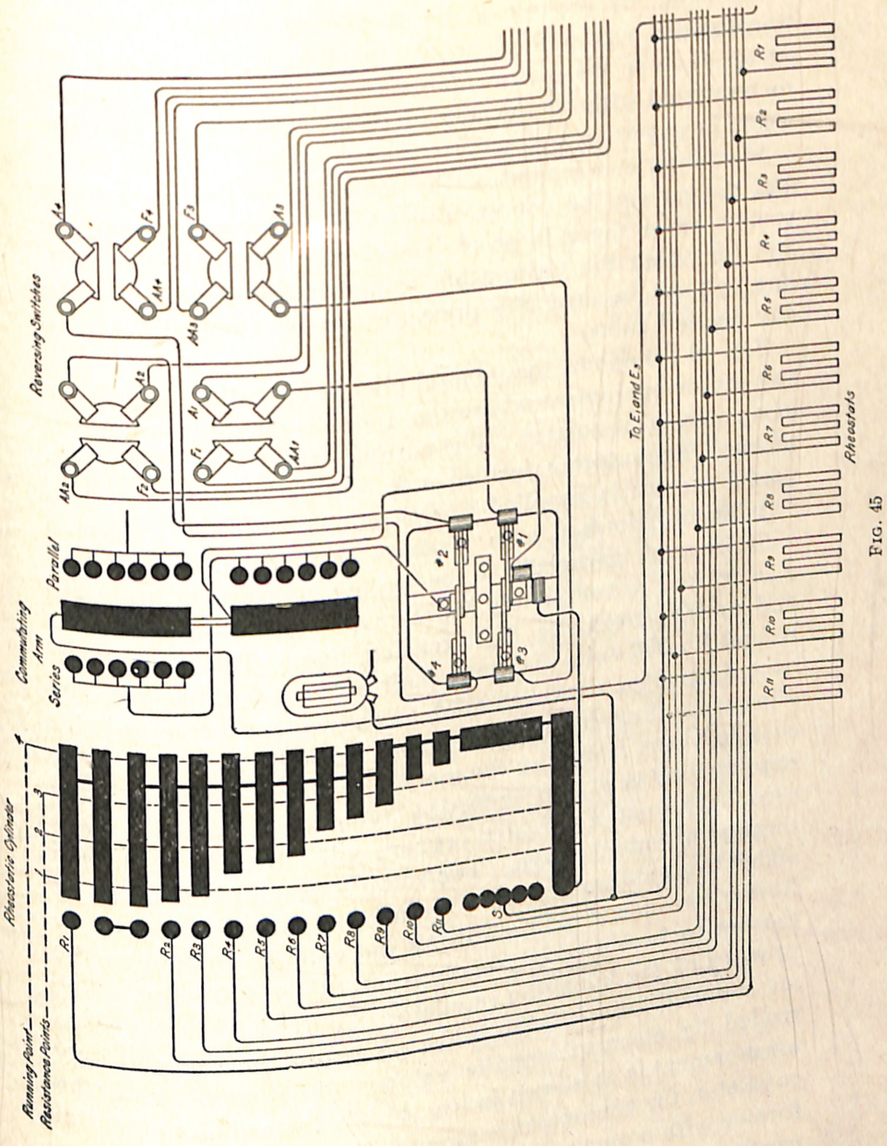
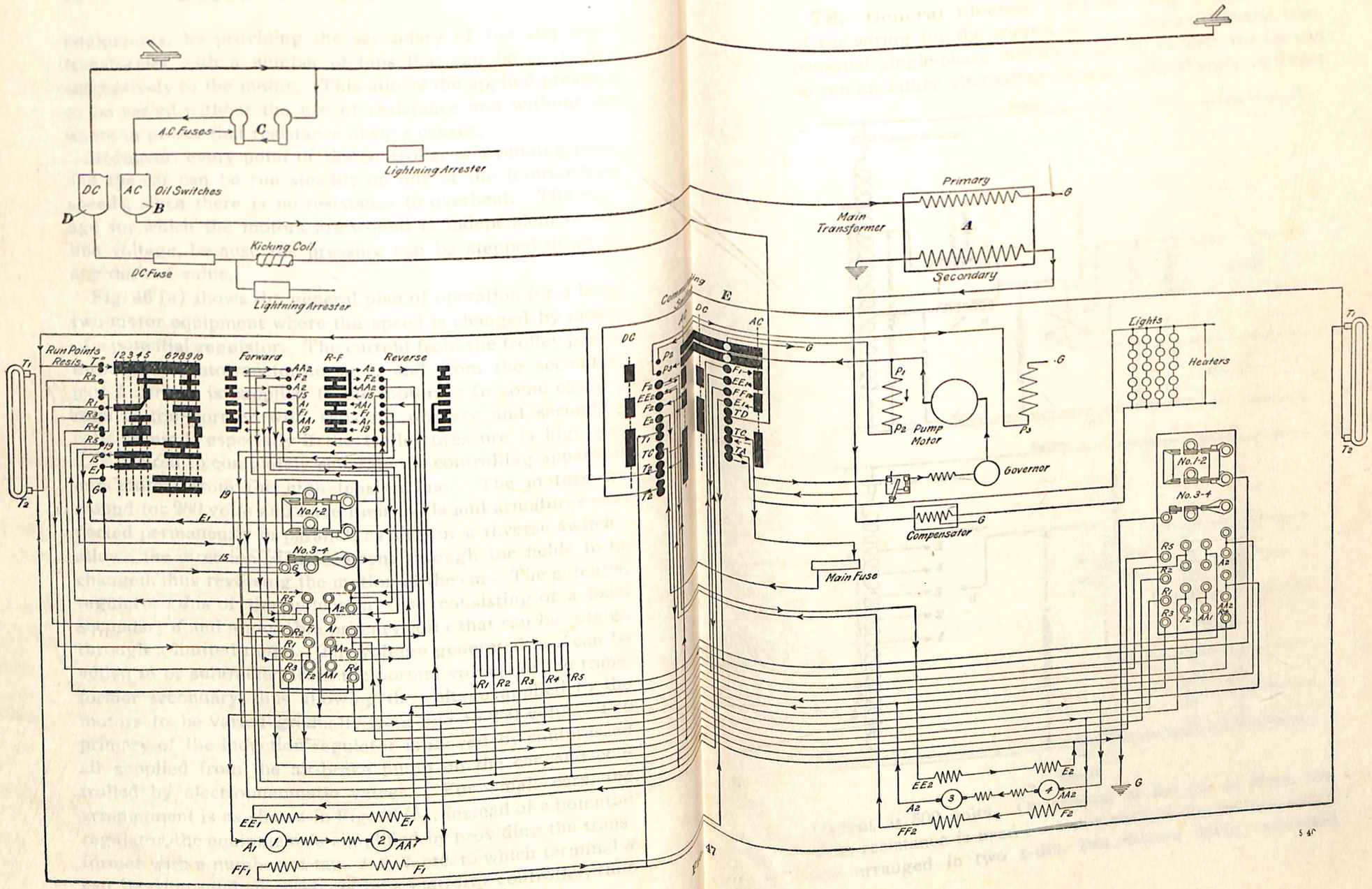


FIG. 45

equipments, by providing the secondary of the step-down transformer with a number of taps that can be connected successively to the motor. This allows the applied pressure to be varied without the use of resistance and without the waste in power that resistance always causes.

Moreover, every point of the controller is a running point and the car can be run steadily on any of the intermediate speeds, since there is no resistance to overheat. The voltage for which the motors are wound is independent of the line voltage, because the pressure can be stepped down to any desired value.

Fig. 46 (*a*) shows the general plan of operation for a large two-motor equipment where the speed is changed by means of a potential regulator. The current from the trolley passes through an autotransformer *a*, *b*, and from the secondary part *b* current is supplied to the motors. In some cases, a regular transformer with separate primary and secondary coils is used, especially if the trolley pressure is high and it is desired to completely separate the controlling apparatus and motors from the high tension line. The motors are wound for 250 volts and have their fields and armatures connected permanently in parallel, as shown; a reverse switch *e* allows the direction of the current through the fields to be changed, thus reversing the motion of the car. The potential regulator *c d* is of the induction type consisting of a fixed secondary *d* and a movable primary coil *c* that can be rotated through a limited range. The voltage generated in *d* can be added to or subtracted from the normal voltage of the transformer secondary, thus allowing the voltage applied to the motors to be varied gradually from 125 to 250 volts. The primary of the induction regulator is moved by compressed air supplied from the air-brake pump on the car, and controlled by electropneumatic valves. For small cars, the arrangement is as shown in Fig. 46 (*b*); instead of a potential regulator, the equipment is simplified by providing the transformer with a number of taps *1*, *2*, *3*, etc. to which terminal *d* can be connected successively by a platform controller, thus increasing the voltage applied to the motors.


A.C Fuses
C
Lightning Arrester
DC
AC
Oil Switches
D
B
Kicking Coil
DC Fuse
Lightning Arrester
Primary
Main Transformer
A
Secondary
G
E
Run Points
Resis.
1 2 3 4 5
6 7 8 9 10
Forward
R-F
Reverse
T1
T2
R1
R2
R3
R4
R5
E1
G
19
15
No.1-2
No.3-4
EE1
E1
A1
FF1
F1
1
2
P1
P2 Pump Motor
P3
Governor
Compensator
Main Fuse
Lights
Heaters
EE2
E2
A2
FF2
F2
3
4
AA2

78. General Electric Control.—Fig. 47 is a diagram of car wiring for the control of four General Electric compensated single-phase motors arranged so that the car can be run on either alternating current at 2,200 volts, or direct

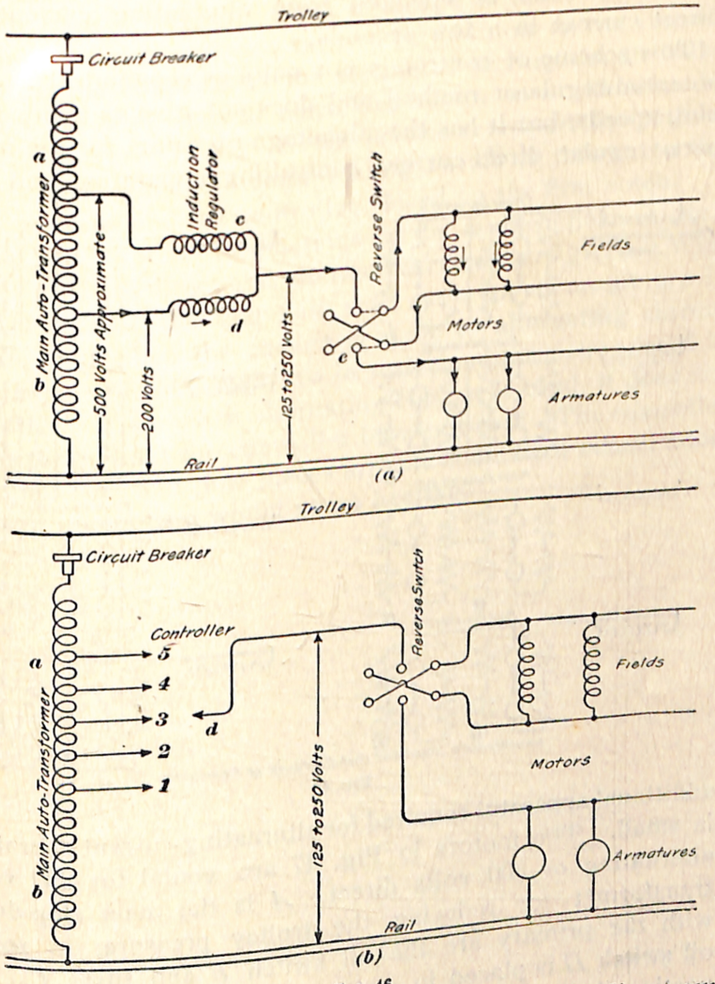


FIG. 46

current at 500 volts. On account of the use of direct current, resistance is used for the control of the motors, which are arranged in two pairs, two motors being connected

permanently in series for each pair. The regular series-parallel method of control is used and standard K28 controllers, as employed for the operation of direct-current cars, are connected to a separate commutating switch so that the connections can be changed from alternating current to direct current in a few seconds.

This scheme of control is not quite as economical as the potential-regulator method and does not give as many running speeds, but it has the advantage of using, for the most part, regular direct-current controlling apparatus, and the

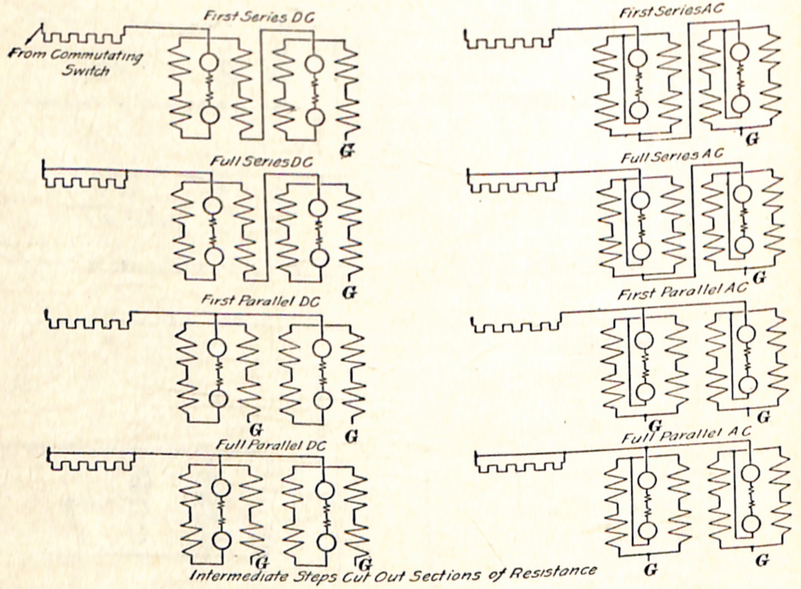


FIG. 48

additional apparatus required for alternating-current operation is small. The motors in Fig. 47 are wound for 200 volts alternating or 300 volts direct. *A* is the main step-down transformer for reducing the trolley pressure; in series with the primary are the oil switch *B* and fuses *C*. An oil switch *D* is placed in series with the direct-current connection also and both switches are interlocked with the commutating switch *E* so that the latter cannot be moved while either *B* or *D* is closed. The switches are also interlocked

so that only one switch can be closed at a time, thus precluding any possibility of trouble, on account of both currents being on at once. The commutating switch makes the necessary changes in field connections, and cuts out the step-down transformer, etc. when a change is made from alternating to direct and vice versa. In addition to the regular motors, the connections for the motor driving the air-brake pump are also shown, since this motor must likewise be changed over. In Fig. 47, the arrows represent the path of the current when the commutating switch is thrown to the *A C* position and the controller placed on the first notch.

In Fig. 48, the combinations on the most important positions for both direct and alternating current are given. With direct current, the four field coils on a given motor are in series, but when the change is made to alternating current the fields are connected two in series and the pairs placed in parallel. Also, when alternating current is used, it does not pass throughout the controller blow-out coil. The controller magnet core and pole pieces are not laminated; hence, alternating magnetism would cause heating.