TRAMWAY MOTORS AND CONTROLLERS

TRAMWAY MOTORS

SELECTION, RATING, AND LUBRICATION OF MOTORS

DETERMINATION OF TYPE, SIZE, AND RATING

1. General Features of Traction Motors. — Traction motors must be substantially constructed because the duty imposed on them is very different to, and usually much heavier than, the duty of stationary motors of similar size. Their design, also, is limited by the fact that they must be placed beneath the floor of the tramcar they drive and between the car wheels. They must be dust-proof and waterproof because they will have to run in all kinds of weather, and must be so arranged as to be readily suspended from the car frame and axle. The frame of a tramway motor is always of cast steel in order to secure lightness, and the pole pieces, instead of being cast with the frame, are generally built up of sheet-iron laminations and are bolted to the frame, as shown in Fig. 1. This laminated-pole construction reduces heating in the pole pieces and also tends to minimize sparking at the commutator. The

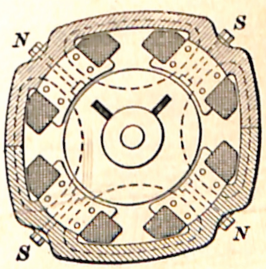


FIG. 1

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armatures of traction motors are always of the slotted type, with former-wound coils placed in the slots on the core. In the earlier types of armature, a large number of slots were used, generally from 87 to 105, the reason being that, if the slots were made wide, they caused the magnetic density in the pole pieces to vary to such an extent as to cause hysteresis and eddy-current losses in the solid poles, which were consequently overheated. 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. The field coils should be connected so as to give alternately north and south poles, as indicated by the letters *N* and *S*.

2. Comparison of Types of Motors.—Nearly all the motors used on tramways are of the direct-current series-wound type; alternating current has not been used practically for tramway work, apart from the transmission between the power station and substations. For tramway service, a motor must have a strong starting effort and must supply an increasing torque with decreasing speed. Shunt-wound motors run at a nearly constant speed regardless of load, and a car equipped with them will ascend inclines at about the same speed that it will run on the level, and will then take an excessive current from the trolley wire, if special controlling devices are not used. A series-wound motor, on the contrary, will decrease its speed automatically when the load is increased. Variable speed is essential for traction working, and the shunt-wound motor is a constant-speed machine; hence, for this class of work, it has never been widely used. The series motor can be made to exert a very strong starting effort; all the current that flows through the armature also flows through the field coils, and a very strong field is thus obtained at starting. With a shunt motor, the amount of field excitation is fixed by the line voltage and the resistance of the shunt winding; consequently, the field cannot be strengthened to any great extent in order to obtain an especially strong torque. Another incidental advantage of the series motor is that the field coils consist of a comparatively small number of turns of

coarse wire, and are much cheaper to wind and more substantial to withstand service conditions than fine-wire shunt coils.

3. Shunt motors have one advantage over series motors, however; they may be used for **regenerative working**, that is, they can be used to generate and return power to the line automatically when descending hills and when stopping. Besides being economical in current, this regenerating action assists in braking the car when descending hills and it is not possible for cars fitted with this control system to run away. The various accidents which have occurred owing to tramcars getting beyond control on steep hills make the braking property of the shunt motor with regenerative control a most valuable one.

4. Armature Windings.—The armatures of traction motors are practically always wound with a drum winding of the series or wave type, which has only two circuits, whatever the number of poles of the machine. The two-circuit or wave winding has many advantages for traction motor work, not the least of which is that it requires only two brushes. If four brushes had to be used, as would be necessary with a multiple-circuit or lap winding, access to the lower brushes would be difficult. Another advantage of the two-circuit winding is that uneven centring of the armature due to wear in the bearings or other causes does not produce unequal distribution of current in the armature and sparking at the brushes, such as would be the case with a lap-wound armature.

5. Choice of Size.—The selection of the proper size of motor to be used for a given car service is a subject that must be carefully considered. If the motors provided are not powerful enough, the cars will not be able to maintain the required schedule time; or, if forced to do so, there will be a large number of breakdowns and the cost of repairs will be heavy, to say nothing of the loss due to the dislocation of the service. On the other hand, if motors much larger than required are installed, an unnecessary outlay of capital is entailed and the system is burdened with an expense that might have been avoided. Besides, unnecessarily large and heavy motors involve waste of

power, because of the extra weight that must be propelled and also because of the greater iron losses in the larger motor. Finally, excessive dead weight on the car causes an unnecessary pounding on the rail joints and consequent deterioration of the track. Usually, in the British Isles, the size of motor lies between 25 horsepower and 35 horsepower, two motors being used per car. In order to secure the best results, the selection of the motor can be made only after a careful consideration of all local conditions affecting the power necessary to propel the cars ; and it is always better to have the motors a little too large than too small.

6. Rating of Traction Motors.—As a tramway motor is always worked on a varying load, it is difficult to rate the output of the motor so that the practical load conditions are imitated exactly. The load that a motor can carry is limited by the heating effect, and it has become customary to rate traction motors according to the output, in brake horsepower, that they will deliver continuously for a period of 1 hour with a temperature rise not exceeding 75° C. above surrounding air at 25° C. For example, according to this rating, a 35-horsepower tramway motor is one that will deliver 35 horsepower for 1 hour with a rise in temperature of 75° C., providing the temperature of the surrounding air is not more than 25° C. This method of rating is not wholly satisfactory, and it does not follow that 35 horsepower in this case is the best rating to put on the motor when driving a tramcar, but the rating is useful in giving a comparative idea as to the capacities of motors, and the performance, as regards sparking and general behaviour, of the commutator and brushes.

7. Average and Effective Values of Current.—The heating of a traction motor is due to the copper or C^2R loss in the windings and the iron loss in the armature. The copper losses depend on the current, and this 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 taking 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 that of a steady current having a value equal 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** of the current must not exceed that which the motor could carry continuously. It should be noted that the effective current is not the same as the average current taken by the car, nor the same as the current that can be carried at the 1-hour rating. To find the average power, in kilowatts, in any particular case, the average value of the current may be estimated by dividing the number of kilowatt-hours per car, taken during any given interval of time, by the time, in hours. The average watts can be determined by multiplying the average kilowatts by 1,000. If this value is divided by the average line voltage, the quotient will be the average value of the current, in amperes. The effective value of the current may be assumed to be 1·35 times the average value for ordinary conditions of tramway working.

LUBRICATION OF MOTORS

8. Lubricants.—The question of proper lubrication for tramway motors is an important one. Insufficient lubrication not only causes a waste of power, but may lead to serious damage if the bearings are allowed to wear rapidly down so as to let the armature rub on the pole pieces. Either grease or oil may be used for lubricating. A drawback of grease is that it does not feed down until it is melted by the bearing becoming warm, while, with oil, it is difficult to limit the flow, and any excess of oil fed into the bearings may find its way into the motor case, where it causes a great deal of harm to the insulation of the field coils and armatures. Perhaps the most satisfactory method is to use grease for the armature bearings and oil for the axle bearings. As the motor case is always slightly warm when running, the feeding of the grease is helped, while the axle bearings are slow-running and cold, and are situated where any excess of oil cannot do damage.

9. Methods of Lubrication.—Both the armature and axle bearings of most tramway motors are provided with some kind

of absorbent wick or pad which carries the oil or grease to the journal and distributes it over the bearing surface. The oil or grease may be placed above the journal to be lubricated or in a reservoir beneath. If the first arrangement is used, the renewal of the wick or pad when necessary is a very easy matter, but there is a tendency for too much lubricant to reach the journal immediately after oiling. The method of using an oil reservoir below the shaft and using a wick to carry the oil to the bearing surface has given very satisfactory results, as the supply of oil is nearly constant. In some cases, both the wick and pad methods of lubrication are used. Some types of the Dick-Kerr tramway motors have ring-oiled armature bearings such as are used on stationary motors. The axle bearings are lubricated in all cases by means of pads or wicks.

GEARS AND MOTOR CHARACTERISTICS

GEAR RATIOS

10. Speed-Reducing Gear.—It is not practicable nor economical to drive electric tramway cars by means of motors having their armatures mounted directly on the axles, because the low-speed motors then required will be too large and too heavy. The motors are therefore always geared to the axle. A pinion on the armature shaft engages with a spur wheel keyed to the axle, and both pinion and wheel are enclosed by a gear-case that contains a quantity of heavy oil. The reduction in speed that will be obtained from the motor shaft to the axle depends on the ratio of the number of teeth in the spur wheel and pinion; the larger the pinion gearing into a given size of spur wheel, the smaller will be the reduction of speed.

11. The **gear ratio** of any combination is the ratio of the number of teeth in the spur wheel to the number in the pinion. The number of teeth in the pinion is always considerably smaller than the number in the spur wheel. If, then, a motor has 14 teeth in the pinion and 68 in the spur wheel, the gear ratio

is $\frac{68}{14} = 4{\cdot}86$, and the motor armature must rotate 4·86 revolutions for each revolution of the car axle; that is, the motor armature must run 4·86 times as fast as the axle. Table I

TABLE I

SPEEDS OF CAR AXLE CORRESPONDING TO VARIOUS SPEEDS OF CAR

Speed of Car		Speed of Car Axles, in Revolutions Per Minute						
Miles Per Hour	Feet 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

gives the speed of car axles, in revolutions per minute, for different car speeds and diameters of wheels. In any given case, the speed of the motor armature is obtained by multiplying the speed of the axle, in revolutions per minute, as given in Table I, by the gear ratio.

EXAMPLE.—A car mounted on 33-inch wheels 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 spur wheel on the axle and 15 teeth in the motor 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 R.P.M. The gear has 65 teeth and the pinion 15; hence, the gear ratio is $\frac{65}{15} = 4{\cdot}33$. The speed of the armature is therefore $203{\cdot}7 \times 4{\cdot}33 = 882$ R.P.M., approximately. Ans.

12. Gears Used in Practice.—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 spur wheel on the axle has from 4 to 5 times as many teeth as the pinion, although smaller gear ratios are sometimes used if the motors are of large size and the speed of the car is high. The gears have involute teeth and, as a rule, a diametral pitch of 3; that is, there are three teeth on the wheel and pinion for each inch diameter of their respective pitch circles. For very heavy traction work, gears having a diametral pitch of $2\frac{1}{2}$ are sometimes used. The distance between gear centres, that is, between the shaft and axle centres, is fixed for a given motor; hence, the sum of the circumferences of the two pitch circles is also fixed. Any increase in the number of teeth in one gear must therefore be accompanied by a corresponding decrease in the other, as the sum of the number of teeth in the two gears must be constant. For example, if a 15-tooth motor pinion gears with a 65-tooth spur wheel on the car axle and it is to be replaced by a 14-tooth pinion, a 66-tooth spur wheel must be used. Whatever combination of gear and pinion is used, the distance between centres being fixed, the total number of teeth in spur wheel and pinion must be 80, otherwise the gears will not mesh properly.

CHARACTERISTIC CURVES

13. 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 the **characteristic curves** or **performance curves** of the machine; these show the relation between the current, speed, tractive effort, brake horsepower, and heating effect. A set of the performance curves for a 500-volt 38-horsepower motor is given in Fig. 2.

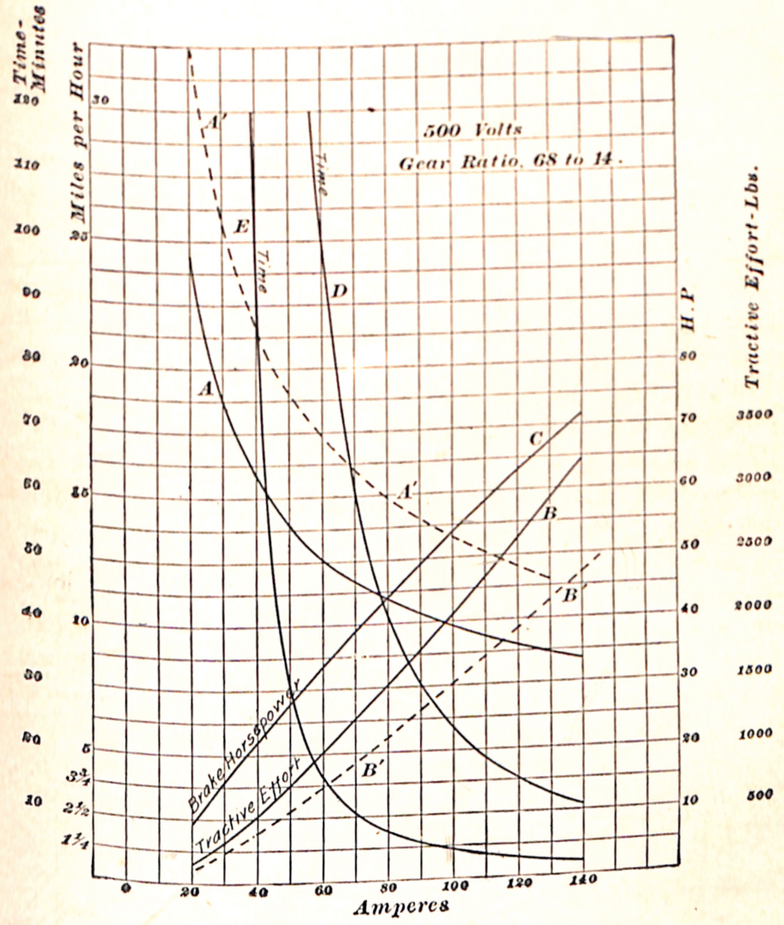


FIG. 2

14. Speed Characteristic.—The curves, Fig. 2, are drawn for a constant terminal P.D. of 500 volts, this being the normal voltage at which the motor is intended to operate. As the load and current of a series motor increase, the speed decreases,

because of the increase in field strength; the variation of the current and of the speed of the car are shown by the curve *A*. For instance, when the car is running at 20 miles per hour, the motor current is 27 amperes; if the speed is 10 miles per hour, the current is 96 amperes. The speed of the car corresponding to any given current depends on the gear ratio and the diameter of the wheels, and both of these must be stated in connection with the characteristic curves for any given motor. In this case there are 14 teeth in the motor pinion and 68 in the spur wheel, and the car wheels are 33 inches in diameter. A curve showing the relation between armature speed in revolutions per minute and current would have the same general shape as *A*.

15. Effect of Increase in Voltage.—An increase in the voltage applied to the terminals of a series motor causes the speed to increase in almost direct proportion. For example, reading from curve *A*, Fig. 2, 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, $12{\cdot}5 \times \frac{600}{500} = 15$ miles per hour.

16. Tractive Effort Curve.—Curve *B*, Fig. 2, shows the relation between the current and tractive effort of a single motor, and gives the total tractive force exerted on the rails by 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; since the tractive effort is proportional to the torque of the motor, curve *B* has the same general shape as a curve showing the relation between motor torque and current.

17. Heating Characteristics.—Curve *D*, Fig. 2, shows the time taken for the temperature of the motor to rise 75° C., or from 25° C. to 100° C., when carrying various currents. Thus, reading from the curve, 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, with a temperature rise of 75° C., this motor will develop a rated output, reading from the horsepower curve *C*, of about 38 brake horsepower. However, under ordinary running conditions, the motor is much hotter than 25° C. to begin with, if it has been working under service conditions before the test commences, and the further time during which it can carry a given steady current without rising in temperature above 100° C. will be much less than is indicated by curve *D*. The time taken for the temperature of the motor to increase to 100° C., after the motor has attained a temperature of 80° C., is shown approximately by curve *E*. For example, if the motor is running at 80° C., it will carry a steady current of 50 amperes, or a variable current of which the effective value is 50 amperes, for 30 minutes before reaching 100° C. If the average working temperature were less than 80° C., the load could be applied for a proportionately longer period without causing the final temperature to exceed 100° C. The current referred to is the current per motor, of course, not the current per car; in making current-consumption tests on a car motor, therefore, the ammeter should be connected in series with the motor and not in series with the trolley. Most tramcars are equipped with at least two motors, and these are connected in series at low speeds, in which case the current in each motor is the same as the total current supplied to the car. At high speeds the motors are usually connected in parallel, and the current in each is then approximately half the total current. Curve *E* is useful in determining the maximum loads that a motor may take during times of unusually heavy load.

18. Relation Between Motor Torque, Gear Ratio, and Axle Torque.—Fig. 3 is drawn to show the relation between the forces acting on a car wheel, spur wheel, and pinion; r is the radius of the pitch circle of the pinion, r' that of the spur wheel, and r'' that of the car wheel. When current flows through the motor, the torque or twisting action that is exerted on the armature shaft and pinion depends on the value of the current and on 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 a moment equal to force × radius, and if the force is given in pounds and the length of the radius in feet, the torque will be in pound-feet, which terms are those generally used in calculations of torque and power. For a given torque, F' will vary inversely as 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 proportionate amount. The torque exerted on the car 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 any toothed wheel, the pitch or size of teeth being fixed, 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 in the spur wheel. 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 spur wheel and divided by the number of teeth in the pinion, or, in other words, the torque exerted on the driving wheels is equal to the motor torque multiplied by the gear ratio.

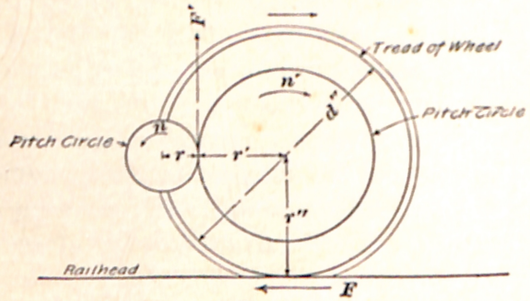


FIG. 3

19. Total Tractive Effort.—The total tractive effort F, Fig. 3, exerted at the rail head by both wheels, is equal to the torque $F'r'$ divided by the wheel radius r''. Thus, $F = \frac{F'r'}{r''} = F'\frac{r\frac{n'}{n}}{r''} = \frac{F'r}{r''} \times \frac{n'}{n}$. Instead of the radius r'', in feet, the wheel diameter d'', in inches, may be used, in which case $d'' = 2 \times 12r''$, or $r'' = \frac{d''}{24}$

Let F = tractive force, or effort, per motor, at the rail head, in pounds;
$F'r$ = motor torque, in pound-feet;
d'' = diameter of car wheel, in inches;
n' = number of teeth in spur wheel;
n = number of teeth in pinion.

Then, $$F = \frac{24F'rn'}{d''n}$$

EXAMPLE.—A car is equipped with motors, each of which drives through a 15-tooth pinion and a 65-tooth spur wheel, and the car is mounted on 33-inch wheels. What will be the tractive effort due to each motor when the current is such as to produce a motor torque of 300 pound-feet?

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

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

20. Determination of Speed of Car.—The number of feet per minute travelled by a car is $\frac{3{\cdot}1416\,d''s'}{12}$, 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 $S = \frac{3{\cdot}1416\,d''s'}{12 \times 88}$, or

$$S = \frac{d''s'}{336{\cdot}1}$$

21. Change of Speed Due to Change in Gear Ratio.—In Fig. 2, the curves of tractive effort and speed are drawn for a gear ratio of 68 to 14, or 4·86, and for 33-inch wheels. Assuming that the wheel diameter remains unchanged, the effect of substituting gears having a ratio of 64 to 18 is that the gear ratio is decreased from $\frac{68}{14} = 4{\cdot}86$ to $\frac{64}{18} = 3{\cdot}56$. From the formula in Art. **20**, the car speed is $S = \frac{d''s'}{336{\cdot}1}$. But s', the speed of the axle, is

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' and B' then represent the performance under the changed conditions. With the original gearing, the tests showed that when the car ran at a speed of 13·8 miles per hour on the level, a current of 50 amperes per motor was required, and the corresponding tractive effort was 750 pounds per motor. If the weight of the car is unchanged, the increase in speed does not cause much change in the tractive effort, and for low speeds, such as are now under consideration, the change in tractive effort may be neglected, and the tractive effort taken as 750 pounds under the new conditions. With the new gear ratio, therefore, a tractive effort of 750 pounds corresponds to a current of about 61 amperes, as shown by curve B', and to a speed of about 17·25 miles per hour, as shown by curve A'.

25. A change in gear ratio therefore causes an increase in speed, but the increase is not proportional to the change in the ratio of the gearing. If a change in gearing alone were considered, in the example given in the preceding article, the speed would be $\frac{13{\cdot}8 \times 4{\cdot}86}{3{\cdot}56} = 18{\cdot}8$ miles per hour. In order to drive the car at this higher speed, more power must be supplied, and the current must therefore increase; in order to develop the increased power and torque, the motor will run more slowly. Because of this change in motor speed and current, the final steady speed of the car must be determined from 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, a 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.

26. Motors on cars having low gear ratios take very large currents during the accelerating period unless the controllers are carefully handled. In case the weight of the car is not fixed, a motor can sometimes 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, at the same time putting in a gear with a smaller ratio. If the permissible current is the same in both cases, the motor torque and the speed of the armature will remain unchanged. Hence, assuming that the wheel diameters are the same on the two cars, a smaller tractive force and increased car speed are obtained by decreasing the gear ratio, since the armature speed remains constant.

EXAMPLES FOR PRACTICE

27. 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 indicated by the curves in Fig. 2, 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 R.P.M.

EXAMPLES OF TRAMWAY MOTORS

WESTINGHOUSE No. 200 MOTOR

28. Field Frame.—The Westinghouse No. 200 traction motor is designed to develop on the 1-hour rating, under ordinary tramway conditions, a tractive effort of 1,400 pounds, with 30-inch wheels, when running at a speed of 9 miles per hour; the motor is rated at 35 brake horsepower at this speed. The external appearance of the motor is shown in Fig. 4. The frame a is made in halves, as usual; the top half carries the armature-bearing boxes b, and extension arms are cast on to support the axle-bearing boxes c. The bearings are designed to allow the use of both oil and grease. The method of supporting the bottom

half of the frame on hinges *d* allows it to be swung down from the axle end for inspection of the armature, field coils, etc. The cable connections for the armature and field coils are shown at *e*. The inspection cover *f* at the commutator end of the motor gives access to the brush holders. The bolts *g* secure the pole pieces to the motor frame, and the lug *h* is provided for hanging the motor from the car truck. The forged-steel pinion *i* is normally enclosed, with the spur wheel which meshes with it,

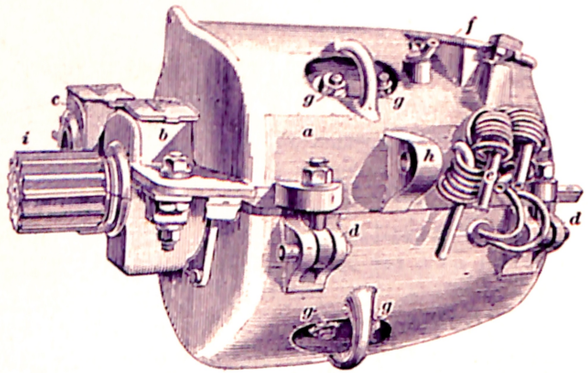


FIG. 4

in a cast-iron gear-case. The standard gear ratio for this motor is 4·86, obtained by the use of a 14-tooth pinion and a 68-tooth spur wheel.

29. Armature and Bearings.—A longitudinal section showing the general dimensions of the No. 200 motor is given in Fig. 5. The frame or casing is of cast steel and is split, as already stated, along the centre line, the top halves *a* of the bearing boxes being cast in one with the top half *b* of the frame. The lower halves *c* of the bearing boxes are made separate, so that the bottom half *d* of the frame may be lowered either with or without the lower halves of the bearings. The bearing shells are of cast iron, lined with white metal. The grease boxes and oil wells, respectively, are shown at *e* and *f*. Any oil that tends to pass along the shaft into the motor case is thrown off by the oil-throwing rings *g* and drains out through the openings *h*. A ball of waste *i* is placed inside the handhole cover *j* to absorb any oil which may pass the oil-throwing rings and enter the case.

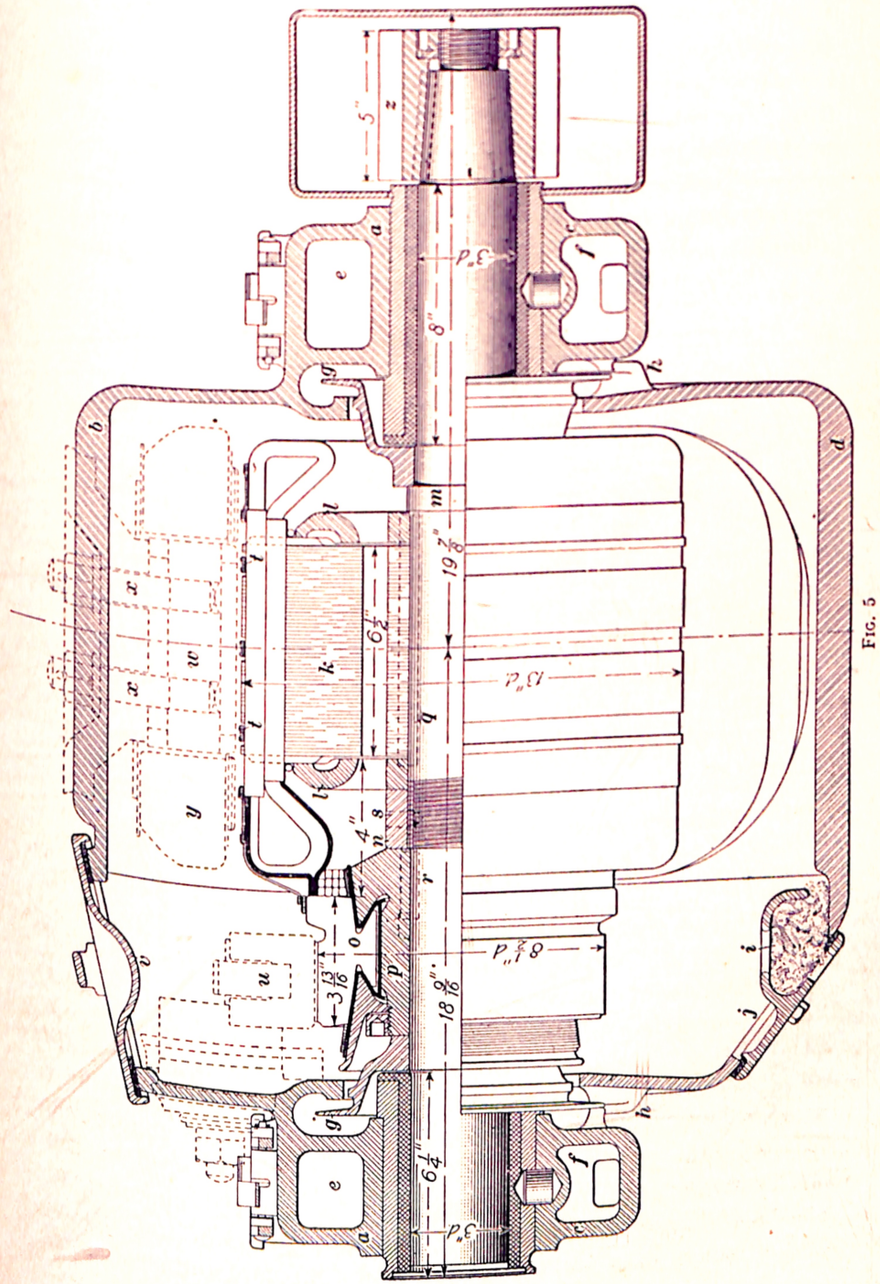


FIG. 5

30. Arrangement of Armature on Shaft.—The compactness of the motor on the shaft, in order to get the motor and gear-case on the car truck between the wheels, should be specially observed. The armature core *k* is pressed tightly between two end rings *l*, one of which bears against a collar *m* on the shaft, while a nut *n* is screwed hard up against the other. The nut *n* runs on a thread screwed on the shaft itself, and is locked by a setscrew *s*. The commutator *o* is secured on its own hub *p*, and keys *q* and *r* prevent the armature and the commutator from turning on the shaft.

31. Method of Securing Armature Windings.—The armature windings are secured in the slots by means of wire bands *t*. These are sunk in grooves in the armature core, so that the maximum amount of wear can be permitted in the bearings without the armature touching the pole pieces, and so that in the exceptional event of the armature being let down on the poles the binding wires shall not be torn off.

32. Brush Gear and Poles.—The brush gear of the motor is shown in dotted lines at *u*, Fig. 5, the cover *v* providing access to the brushes from the top of the motor. The section of the frame and pole piece at an angle of 45°, through the centre line of the poles, is shown at *w*. Each pole is built up of laminations riveted together, and is attached to the frame by means of the two bolts *x*. A cross-section of the field coils is seen at *y*. The pinion *z* is fastened to the tapered armature shaft by means of a nut screwed on the shaft end and countersunk into the boss of the pinion, and a key prevents its turning on the shaft. Since the pinion is overhung, the armature bearing at the pinion end is increased to 8 inches long, the length at the commutator end being 6 inches only.

33. Armature-Winding Connections.—A diagram of the connections of an armature coil of the No. 200 motor is shown in Fig. 6. The armature has 37 slots, with 3 commutator bars per slot, or 111 segments in all. The pitch of the coils is rather less than one-quarter of the complete circumference of the armature, or actually 8 slots; that is, from slot *1* to slot *9*; the throw of the bottom leads of the coils is from commutator segment *17* to

segment *1*, and of the top leads is from commutator segment *41* to segment *57*. In commencing to rewind an armature with spare coils, a diagram similar to Fig. 6 should be drawn, and the figures followed in assembling and connecting up the armature coils. Looking at the armature from the commutator end, the lower half of one coil is assumed to go into the bottom of slot No. *1*. To find the proper slot in which to put the upper

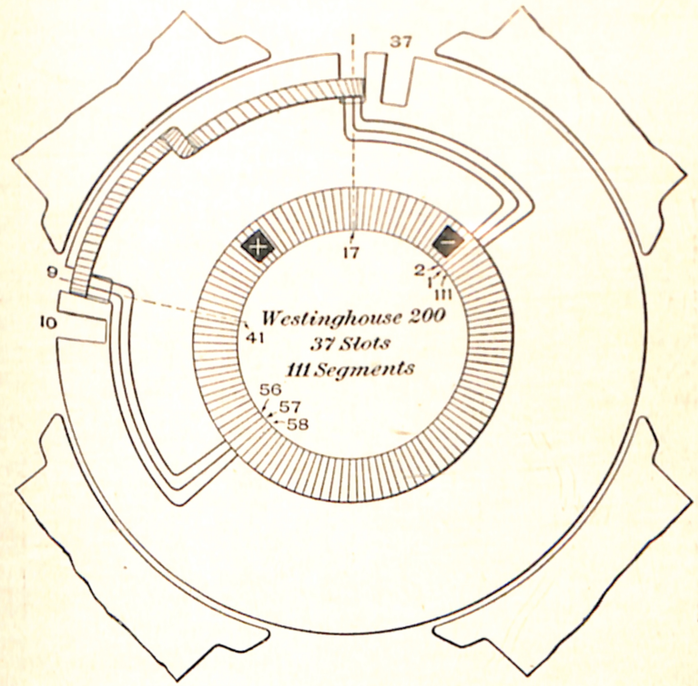


FIG. 6

half of the same coil, count the slots from right to left until slot *9* is reached; in this slot the upper half of the coil is placed, and all other coils on the armature follow, with a similar pitch or span between the two sides. Each armature coil has three bottom ends or leads and three top leads, or six in all. These are usually coloured red, blue, and white. Find the commutator segment immediately below the middle of slot *1* and call it segment *17*, and then count the segments backwards in a clockwise direction until segment *1* is reached. To segment *1* is

connected the *middle* one of the three bottom leads, the other wires going to the adjoining segments on each side of segment *1*. Now count the segments forward again from segment *1* in a counter-clockwise direction. It will be found that segment *41* is immediately opposite the centre of slot *9*, and counting on until segment *57* is reached, nearly opposite to segment *1* on the commutator, the middle lead of the top half-coil must be connected to segment *57*. The remaining coils on the armature must now be connected up in regular sequence until the winding is complete.

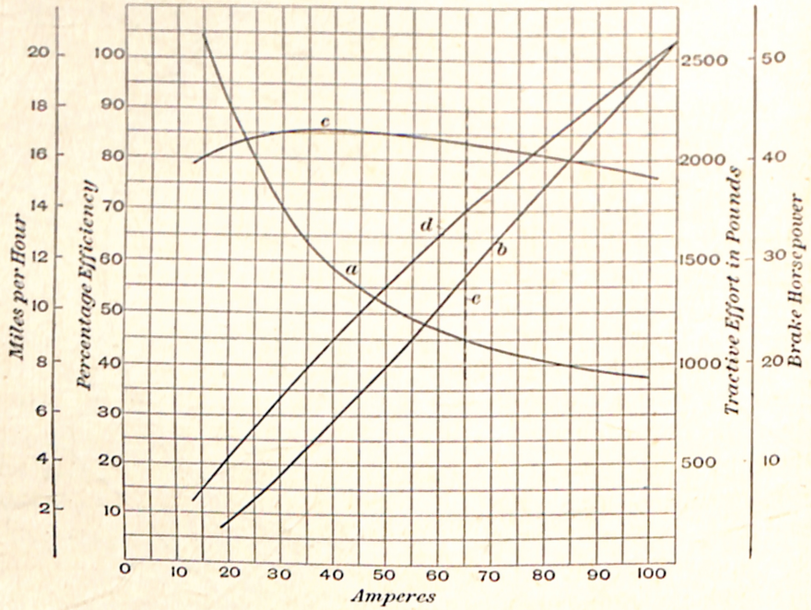


FIG. 7

34. Performance of Motor.—The characteristic curves or performance curves of the No. 200 tramway motor are shown in Fig. 7. Curves representing the variation of speed, tractive effort, efficiency, and brake horsepower are plotted on a base representing the current input of the motor, in amperes, when the full normal pressure of 500 volts is applied to the motor terminals.

The curve *a* representing the speed of the car, in miles per hour, and the tractive-effort curve *b* representing the force exerted

at the rail head, in pounds, are based on the standard gear ratio of 68 to 14 and car wheels 30 inches in diameter. Following the usual characteristic of the series-wound motor, the speed decreases with increased current, on account of the strengthening of the field flux when the current in the armature- and series-field windings increases. Thus, the current per motor is 17 amperes when the speed of the car is 20 miles per hour, 32 amperes when the speed is 13·5 miles per hour, and 83 amperes when the speed is 8 miles per hour.

35. Tractive Effort.—The tractive effort of the motor, as shown by curve *b*, Fig. 7, increases with increase of current independent of the speed of the car. Since the motor torque, and therefore the tractive effort, are proportional both to current and field flux, the tractive-effort curve bends upwards, showing that the tractive effort increases even more rapidly than the current increases, due to the strengthening of the field flux. The tractive effort is about 190 pounds when the current per motor is 20 amperes, 500 pounds at 32 amperes, and 2,000 pounds when the current is 84·5 amperes.

36. Efficiency and Output.—The efficiency of the motor, as shown by curve *c*, Fig. 7, is a maximum at about 86 per cent. when the motor current is 40 amperes. At lower currents the efficiency is less, owing to the fact that the combined iron losses and friction losses do not decrease as rapidly as the current decreases, and at greater currents the efficiency falls because the copper losses increase at a greater rate than the current. The efficiency falls to 80 per cent. when the motor current is 85 amperes.

The brake horsepower of the motor is measured with the gear in operation ; that is, the brake-horsepower curve *d*, Fig. 7, represents the horsepower actually delivered to the car axle. The horsepower increases proportionately to the product of speed, tractive effort, and efficiency. The increase in brake horsepower is thus nearly proportional to the increase in current, but above 40 amperes the actual increase is slightly less than proportional to the current, because the efficiency falls off as the current increases. When the motor takes 15 amperes it develops

7·5 brake horsepower, at 32 amperes 17·5 horsepower, and at 80 amperes 42 horsepower. The vertical dotted line *e* denotes that rating of the motor corresponding to a temperature rise of 75° C. after 1 hour's run. Under these conditions the motor takes 65 amperes while developing 35 brake horsepower.

BRITISH THOMSON-HOUSTON G.E. 52 MOTOR

37. Field-Frame Construction.—As an example of a small motor rated at 20·5 horsepower and intended for driving light single-truck cars, the **G.E. 52 motor** of the British Thomson-Houston Company will first be described. A rear view of the motor in Fig. 8 shows the general shape of the field frame, which, as in all modern traction motors, is shaped so as to enclose completely the armature commutator, brushes, and field coils.

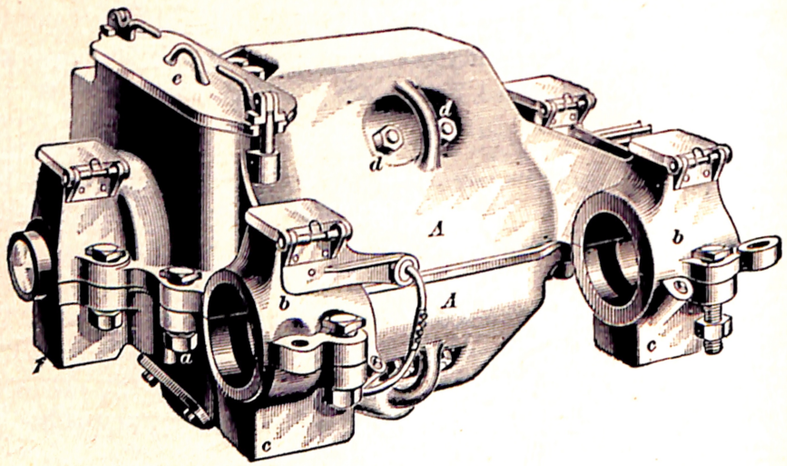


FIG. 8

The field frame *A* is roughly hexagonal in outline and is made in halves, which are held together by bolts. The two arms *b* extending from the back of the motor carry the upper halves of the axle bearings, which are provided with grease boxes. The lower bearing blocks *c* are fitted with oil wells, and oil is fed into the bearing by means of pieces of felt underneath the axle. The bolts *d* hold the pole pieces in place. The removable cover *e* allows access to the commutator and brush holders. The lower

halves *f* of the armature bearings are separate from the lower half of the field frame *A*, and by unbolting the field frame, but not the bearings, and leaving the latter in position, the lower half of the field frame may be swung down for inspection or repair of the armature or field coils, leaving the armature in the upper half, as shown in Fig. 9. By unbolting the armature bearings, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 10.

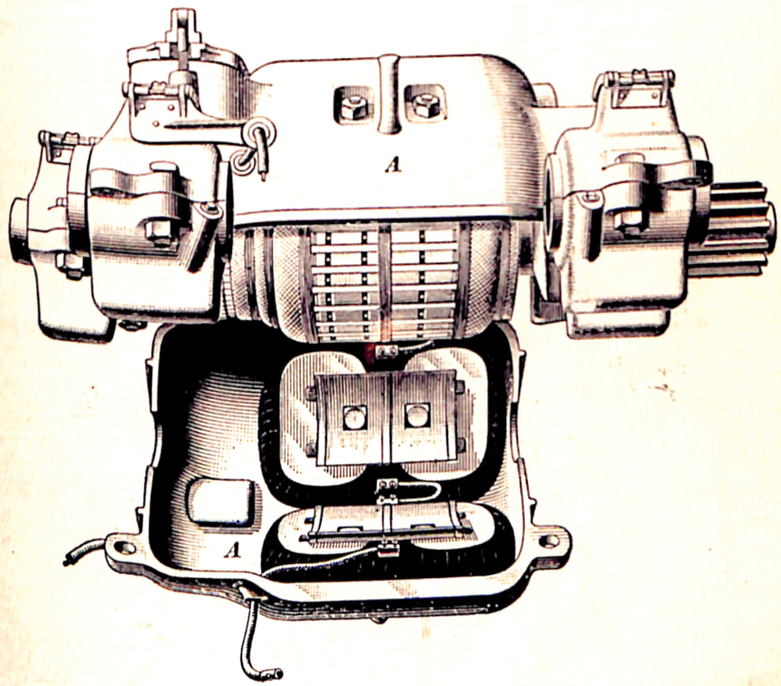


FIG. 9

38. Pole Pieces.—The motor is provided with four flanged and laminated pole pieces; the flanges serve to hold the field coils in place, while the lamination of the pole pieces serves to keep the iron losses in the pole faces low, thus reducing the heating. The pole pieces are made of iron plates of the shape shown by the full lines of Fig. 11 (*b*). In building up the pole piece every other plate is reversed, with the result that, along the centre line of the pole, the plates are close together and the

pole face is solid, but at the pole horns only half of the plates extend on each side, as shown in Fig. 11 (*a*). This construction produces a *fringed* magnetic field under the pole horns. This fringe largely prevents distortion of the magnetic field, and

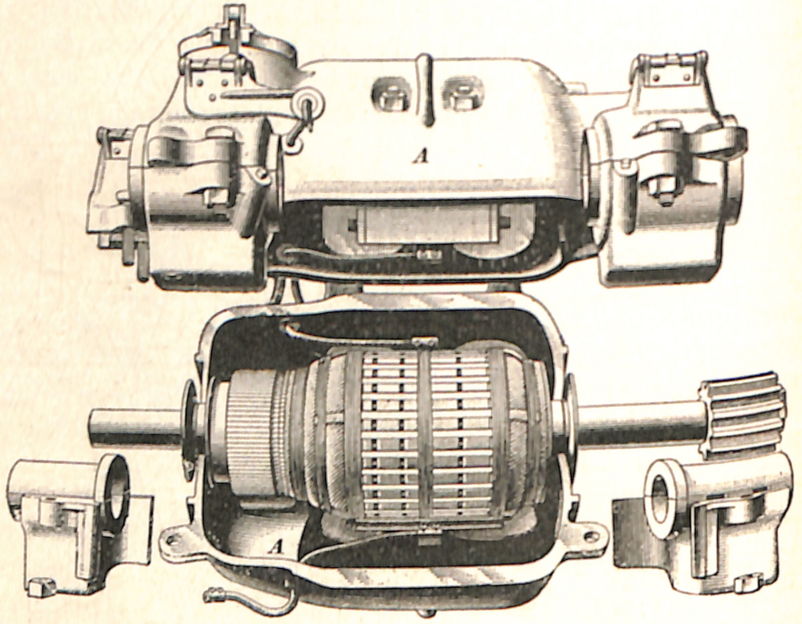


Fig. 10

provides the proper field for reversing the current in the armature coils passing under the brush with but little sparking. Each pole piece is held in place by two bolts which pass through the casing.

39. Field Coils.—The field coils are former-wound, and in course of winding, the asbestos-covered wire is treated with a mixture of chalk and japan; the whole is afterwards baked. The coils are well insulated with tape and insulating varnish, and are finished with a glazed surface that prevents moisture from getting into the coils.

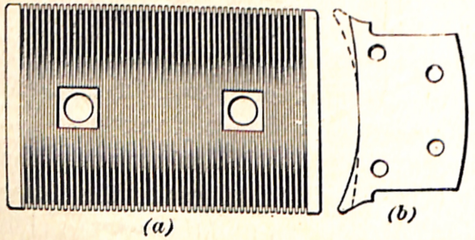


Fig. 11

40. Brush Holders.—Traction-motor brush holders are fixed permanently at the neutral point and cannot be shifted, as in the case of most 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 the use of any brush-shifting arrangement to alter the position of the brushes to suit the load is out of the question. The brush holders are, however, mounted so that they can be moved radially toward the centre of the commutator as the latter wears away.

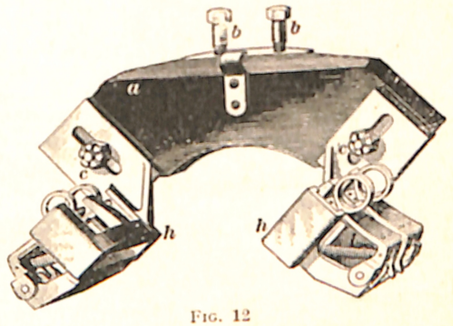


Fig. 12

Fig. 12 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 an insulating solution, is bolted to the upper field frame by means of bolts *b*. The brush holders *h* are secured against brass slides on the yoke *a* by means of bolts *c*. Carbon brushes are always used for traction motors, the dimensions of each brush in this instance being $2\frac{1}{4}$ inches by $1\frac{1}{4}$ inches by $\frac{1}{2}$ inch; two brushes are used in each holder.

41. Armature.—Fig. 13 shows a half section of the G.E. 52 armature, and its construction is typical of many of the traction-motor armatures now in use. The core is provided with 29 slots. Each slot contains one side of 6 coils, so that there are 87 coils altogether, and the commutator has 87 bars. The winding is called a six-turn winding, to distinguish it from the four-turn winding which is sometimes used with the same size of machine, but which has only 4 half-coils per slot. The coils of the six-turn winding 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. The laminated armature core is shown at *a*, and at *b* and *b'* the upper and lower halves,

respectively, 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 between V rings,

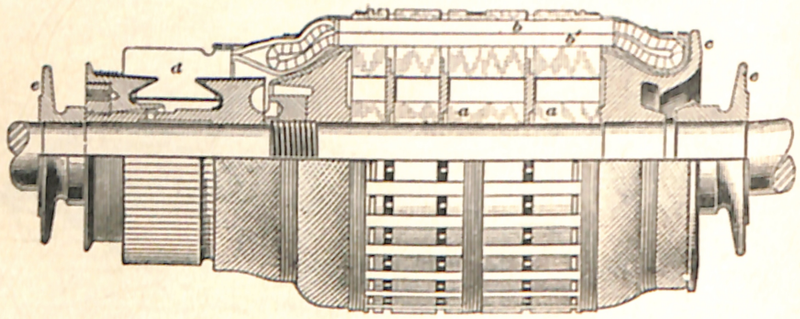


Fig. 13

as shown. The oil-throwing flanges *e*, *e* prevent grease and oil working their way into the armature from the bearings.

42. Armature-Coil Connections. — A diagram of the connections of an armature coil of the G.E. 52 six-turn motor is shown in Fig. 14. There are 29 slots and 3 commutator segments per slot, making the total number of segments 87. The leads of one coil to the commutator segments are lettered *a*, *b*, and *c*. If the segment under the centre of slot *1* is called segment No. *1*, the bar to which the middle lead of the bottom half-coil is to be connected may be found by counting round in a

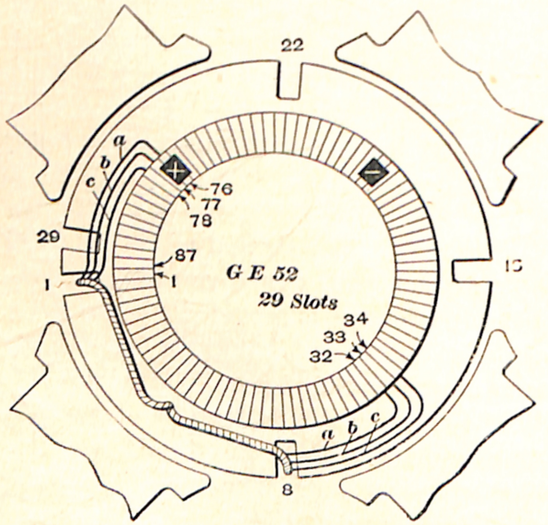


Fig. 14

counter-clockwise direction past the coil until segment 77 is reached. The same segment may be found by counting 12 segments back in a clockwise direction from the starting point *1*. The middle lead from the top half-coil is connected to segment *33*, as shown. The pitch of the coils is 7, or from *1* to *8*.

43. Characteristic Curves of G.E. 52 Motor. — The various characteristics of the G.E. 52 six-turn motor are shown in Fig. 15. Curve *a* shows the variation of speed with the load on the motor,

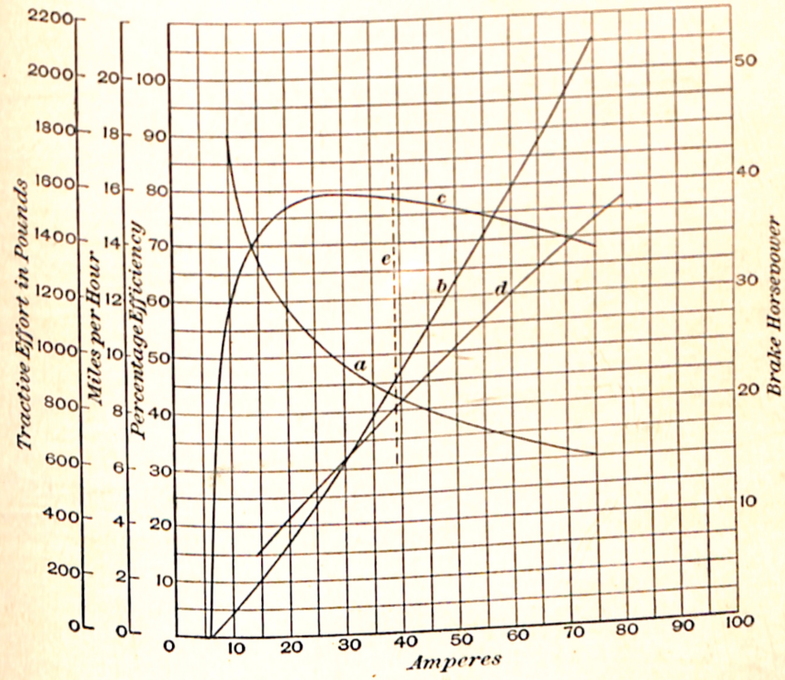


Fig. 15

and curve *b* shows the tractive effort at the rail head, in pounds, for various values of current. The efficiency curve *c* shows the efficiency of the motor, including the gearing and car-axle friction. The brake horsepower is given by curve *d* and represents the power delivered at the car axle. The output of the motor corresponding to a temperature rise of 75° C. after 1 hour's run is 20·5 brake horsepower, corresponding to a current input of 39 amperes, as shown by the vertical dotted line *e*.

DICK-KERR 25A MOTOR

44. General Features.—A view of a Dick-Kerr traction motor, known as the D.K. 25A, is shown in Fig. 16. It is rated at

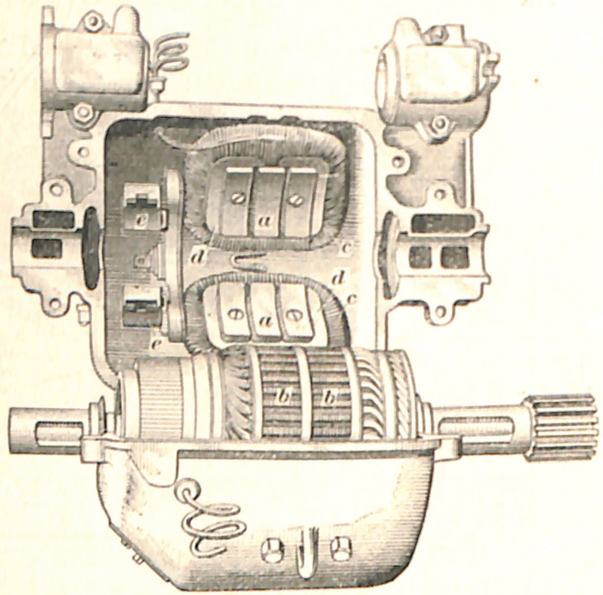


Fig. 16

26 horsepower and is suitable for single-truck double-deck cars. The illustration shows the motor with the upper half of the frame

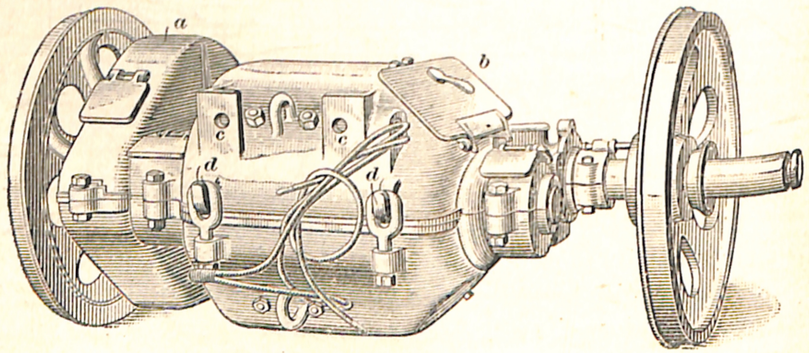


Fig. 17

raised. The field poles *a* are laminated and arranged with two ventilating ducts in each, so that a circulating current of air is

maintained from the armature ventilating ducts *b* through the field cores and round the back of the field coils against the motor shell, thus helping to keep the motor cool. The field coils *c* are held in place by bronze frames *d*. The brush holders are seen at *e*. In Fig. 17 is shown the motor mounted on the axle with the gear-box *a* in place. The door *b* is for access to the commutator, and the lugs *c* are bolted to a suspension bar

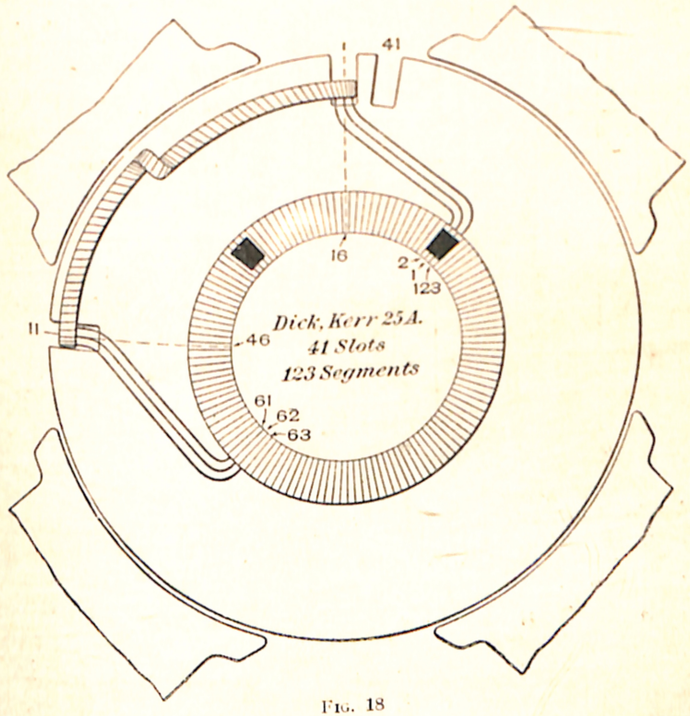


Fig. 18

to carry the motor on the truck. The motor is fitted with a 5 to 1 gear ratio. The eyebolts *d* are used for bolting the top and bottom halves of the frame together, and fit over hooks on the upper half of the frame.

45. Armature-Coil Connections.—The armature of the Dick-Kerr 25A motor has 41 slots and 123 commutator segments. The field poles are on the diagonals, and in order to bring the brushes opposite the centres of the poles the armature leads are

given a throw of about one-eighth, as shown in Fig. 18. The commutator segment under the centre of slot *1* is taken as *16*, and the middle lead from the bottom coil in the slot is connected to commutator segment *1*, counting back in a clockwise direction. The other terminal of the coil is connected to segment *62*. The pitch of the coils is 10 slots, or from slot *1* to slot *11*.

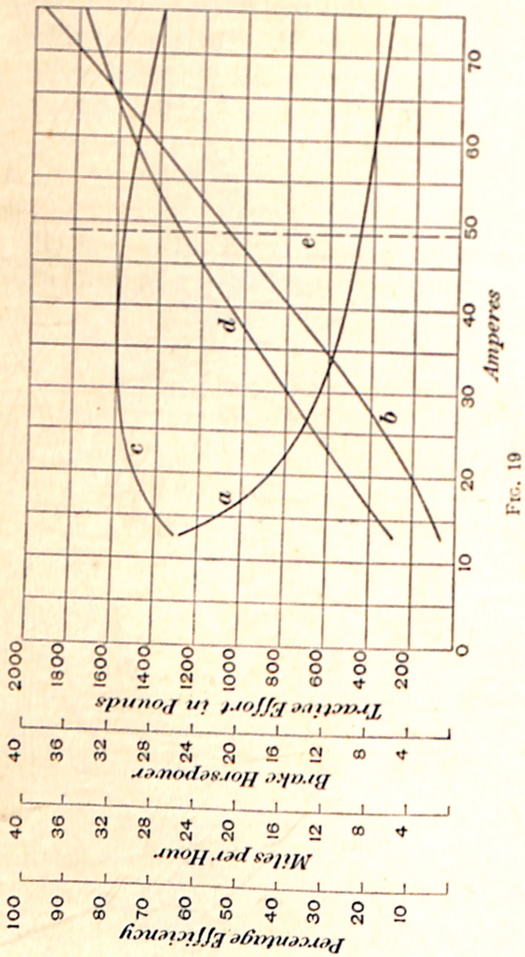


Fig. 19

46. Characteristic Curves of D.K. 25A Motor.—The curve *a*, Fig. 19, shows the variation in speed with the load on a D.K. 25A traction motor fitted with a gear ratio of 71 to 14. The tractive-effort curve *b* and horsepower curve *d* are plotted as in the previous cases. The efficiency curve *c* shows the net efficiency of the motor, including the gearing, and indicates that the maximum efficiency is obtained when the speed is about 11·5 miles per hour, the horsepower about 19, and the current 35 amperes. The efficiency of the motor under these conditions reaches just 80 per cent. The vertical dotted line *e*, at a current of 49 amperes, corresponds to a temperature rise of 75° C. after 1 hour's run at a rated output of 26 horsepower.

DICK-KERR INTERPOLE MOTOR

47. Use of Interpoles. — It was explained in connection with stationary motors that **interpoles** are small poles placed between the main field poles and wound with series coils, their function being to improve commutation by providing a field of the proper strength and direction to reverse the current in the coils short-circuited by the brushes during commutation. In this way, sparkless commutation is secured. The series coils of the interpoles are connected in series with the armature, so that the commutating field produced is always proportional to the current flowing. An interpole motor will operate without

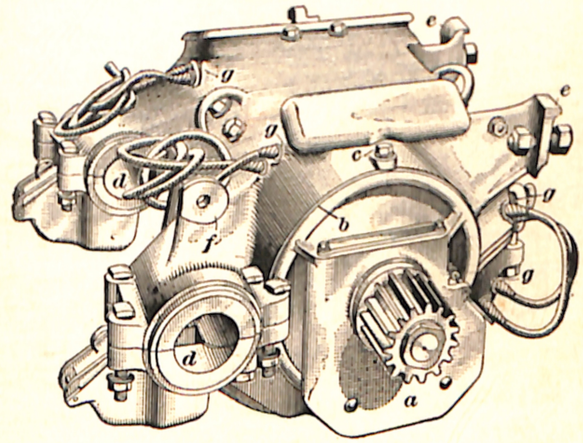


Fig. 20

sparking even on heavy overloads, and with interpoles it is possible to use a smaller and lighter motor in any given case than if no interpoles were provided. Owing to the absence of sparking at the brushes of interpole motors, it is possible that pressures of 800 to 1,200 volts may come into use for the operation of tramcars. There are a few installations on the Continent using supply pressures of 800 volts or more, and the success of these has proved the feasibility and safety of high-voltage systems.

48. General Construction.—The Dick-Kerr interpole traction motor, known as the D.K. 9, is shown in Fig. 20. It is designed for an output of 40 horsepower at the standard 1-hour rating.

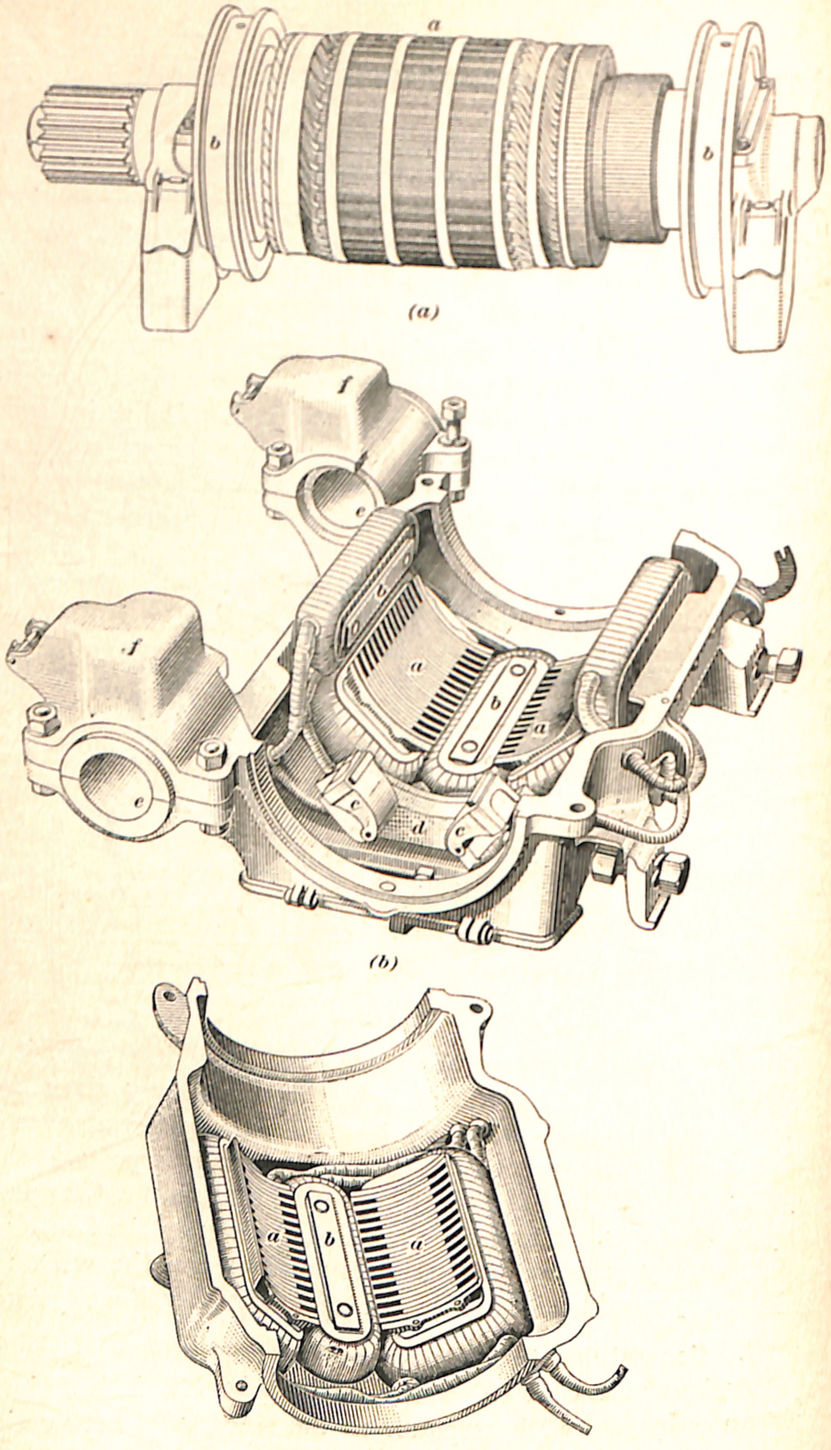


FIG. 21

The armature-bearing boxes and motor end casings *a* are cast quite separate from the main motor frame, and are held in position between the top and bottom halves of the frame by means of a circular tongued-and-grooved joint *b*. Setscrews *c* prevent the bearing boxes turning in the frame. The supporting arms for the axle bearings *d* are cast with the upper portion of the frame, as usual. The lugs *e* are provided for suspending the motor from the truck, and the lug *f* is provided for supporting the gear-case, which encloses the pinion and spur wheel. The armature and field-coil leads are brought out of the case at the points *g* for convenience in connecting up and testing.

49. Views of the main parts of the D.K. 9 tramway motor are given in Fig. 21 (*a*), (*b*), and (*c*). In view (*a*) is shown the armature *a* mounted in the end casings *b*, which are circular in form and fit into circular openings in the motor frame, thus ensuring the proper centring of the armature. In view (*b*) is shown the upper part of the casing, inverted so that the two main field poles *a* and the three interpoles *b* which are attached to it may be seen. The brush holders *c* are attached to a brush yoke *d*. The axle bearings *e* are lubricated by means of wicks which dip into the oil reservoirs *f*. The lower part of the casing is shown in view (*c*) with the main poles *a* and interpole *b*.

TRAMWAY CONTROLLERS

RHEOSTATIC CONTROL

50. General Principles.—Since the speed of a series motor can be varied by inserting an adjustable resistance in series with it, the simplest method of controlling the speed of street cars is by means of a series resistance used in connection with a switching device called a **controller,** by means of which the amount of resistance in circuit can be varied. This is known as the **rheostatic method of control.** It is used in cases where only one motor is to be controlled and where gradual variations in speed are desired, as for cars driven by a single motor, and to some extent in connection with mine-haulage plants and cranes.

Some of the more important features of rheostatic control will be considered briefly; this will also serve as an introduction to the series-parallel method of control for two motors which is to be described later.

RHEOSTATIC CONTROLLER

51. General Construction.—A rheostatic controller, known as the **R11 controller,** made by the British Thomson-Houston Company for the control of cars, haulage locomotives, or crane motors

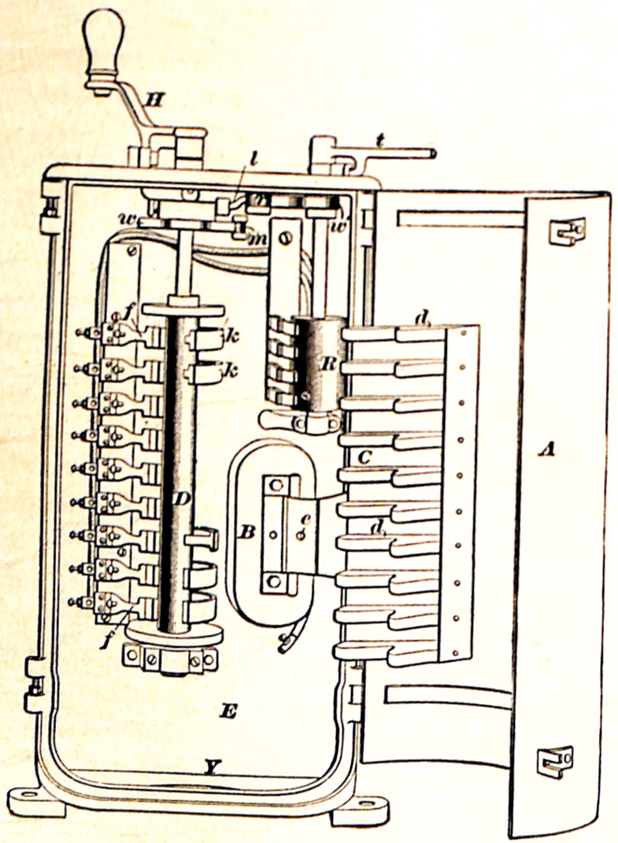


FIG. 22

is shown in Fig. 22 with the cover *A* thrown back to expose the working parts. This controller will be considered in detail because it contains many of the features found on controllers

used on tramcars. It is designed to control one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor; that is, its contacts are large enough to carry about 75 amperes. The changes in the connections to the resistance are effected by a *drum*, *cylinder*, or *barrel*, called the **power drum,** or **barrel,** to distinguish its duty from that of drums used in controllers for reversing and braking. The drum *D* is provided with contact segments *k* that pass under and make electrical connection with the fingers *f* when the drum is rotated by means of the handle *H*. Each finger and contact segment is separated from the adjacent ones by fireproof insulating partitions *d* carried on a frame *C*. The latter is swung into position close to the power drum and held in place by a screw through the hole *e*. The frame *C* also forms one pole of the *blow-out magnet B*, the other pole being formed by the iron back *E* of the controller. The wires are brought into the controller through an opening in the bottom *Y*.

52. Star, or Index, Wheel.—In order to compel the power cylinder to take up definite positions corresponding to the various steps, and to prevent it remaining in any intermediate position, there is a **star wheel,** or **index wheel,** *w*, Fig. 22, attached to the shaft. This wheel engages with a spring-actuated roller *m*, which is pulled by its spring into the various notches on the star wheel as the latter rotates and allows the cylinder to remain only in the proper positions. It is the action of this star wheel and roller that gives the movement of a controller handle its springy feeling.

53. Reverse Cylinder.—The reversing switch, called also the **reversing drum, barrel,** or **cylinder,** is shown at *R*. This is much smaller and simpler than the power cylinder, and in this instance is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections, when no current flows, in case it is desired to run the car in the opposite direction. The reversing drum is not intended to switch the current on or off or to 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 made somewhat lighter than those on the main cylinder.

54. Interlocking Devices.—In order to ensure that the reverse cylinder shall not be moved while current is flowing, 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', Fig. 22, which has three notches, corresponding to the off-, ahead-, and back-positions of the handle t. The roller r engages with this star wheel, and a link l is attached to the lever carrying the roller. The hub of the star wheel w on the power drum has a notch in it that comes opposite the end of the link l when the power drum D is at the off-position, and when the reverse handle t is moved, the end of link l can pass into the notch and allow the roller r to pass over the projections on the star wheel w'; when roller r rests in a notch on star wheel w' the link l falls back far enough to allow the power drum to be turned. At any position of the power drum other than the off-position, there is no notch opposite the end of link l; and if any attempt is made to move reverse handle t, link l butts against the hub and the reverse cylinder is locked.

When the reverse lever is turned to the position marked *Ahead*, the car runs forwards, and when it is turned to the position marked *Back*, the car runs backwards. The respective positions are often arranged so that the reversing lever points in the direction in which the car is to run, forwards or backwards, as the case may be.

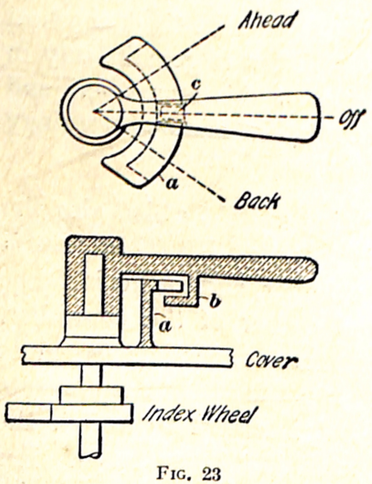


Fig. 23

The reverse handle is also fitted with a locking arrangement, so that it cannot be removed unless the power drum is at the off-position. An angle guard a, Fig. 23, is cast on the cover of the controller and overhangs a hook b cast on the handle. A notch c is cut in the guard, so that the handle of the reverse drum can be lifted off at the off-position and no other.

55. Magnetic Blow-Out Device.—The R11 controller is of the magnetic blow-out type, so called because a magnetic field is used to extinguish the arc formed at the contact tips when a circuit carrying current is broken. Were the arc not extinguished promptly, it would cause blistering and burning of the contacts. This method of preventing damage due to arcing has proved very effective, and it is used on most modern tramway controllers. The coil B, Fig. 24, sets up the magnetic field necessary to blow out the arc, and is therefore called the **blow-out coil.** Fig. 24 shows in plan the relative positions of the pole piece C of the blow-out coil, cylinder D, and the controller

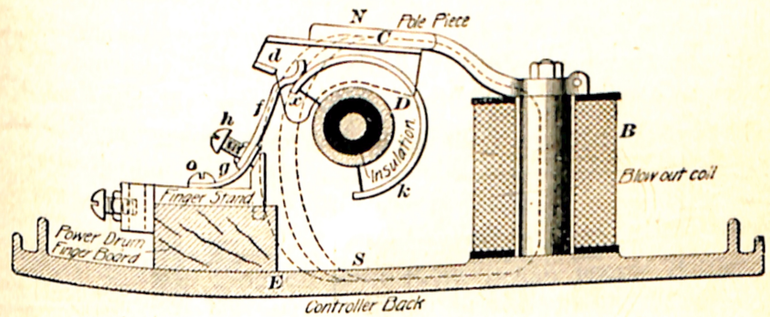


Fig. 24

back E when the pole piece is swung into position. The insulating partitions d, made of vulcabeston (vulcanized asbestos), pass between the contact segments as shown.

56. All the current supplied to the car passes through the blow-out coil B, Fig. 24, so that the strength of the magnetic field set up between poles N and S increases with an increase in the strength of the current. The direction of the field is 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 between x and f. 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. The fingers f are stamped out of thick copper; each finger is 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 which are accidentally broken or burnt can be replaced at any time. Screw h is provided in order to adjust the pressure with which the fingers press on the segments and the amount that the finger drops when the segment passes from under it. The fingers should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. In a tramway system employing a large number of cars the controllers and the brush gear of the motors should be inspected regularly when the cars are out of service; the brushes should then be trimmed and the contact segments of the controllers rubbed with a little vaseline, so as to prevent wear and cutting.

57. Controller Diagram.—The R11 controller has six points, and a diagram of the cylinder with the various connections,

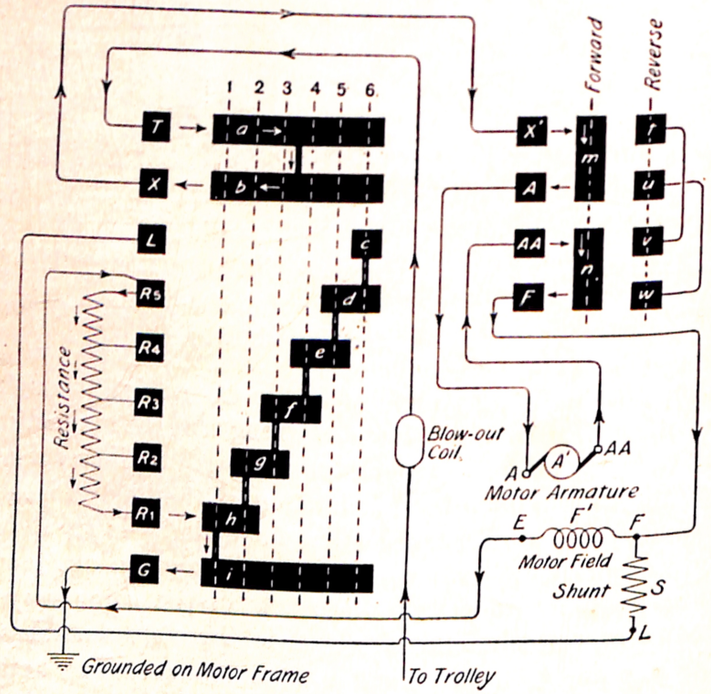


FIG. 25

called a **controller diagram**, is shown in Fig. 25. This diagram shows the connections suitable for controlling a single motor,

of which A' and F' are the armature and field, respectively. 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 fingers on the connection boards of the power cylinder and the reverse cylinder are represented by vertical rows of black squares or spots. The vertical dotted lines represent the various positions of the cylinder, and in studying the connections made by moving the controller handle to any given position, the developed cylinder can be considered as sliding under the contact fingers until the fingers are on the vertical dotted line corresponding to the notch, or position, on which the handle is placed. In this case, the power cylinder has two sets of contact segments. Contact segments a and b are connected together electrically, as shown by the black line drawn from one to the other, but they are insulated from c, d, e, f, g, h, and i, which are all connected together. Groups of adjacent segments that are electrically connected, as in this case, are often made of a single casting.

58. Controller Circuits.—On the first notch, fingers T, X, $R1$, and G make contact with their respective cylinder segments; none of the other segments and fingers is in contact. The path of the current on the first notch, when the fingers are on the vertical dotted line numbered *1*, Fig. 25, and the reversing switch is closed in the forward position, is indicated by the arrows, and is: trolley–blow-out coil–T–a–b–X–X'–m–A–A–armature A'–AA–AA–n–F–F–field F'–E–$R5$–through the whole of the starting resistance–$R1$–h–i–G. The last contact finger G is earthed, or grounded, on the motor frame, thus completing the circuit from the trolley to the rail.

On the second notch, finger $R2$ touches segment g, and when the current reaches $R5$ it flows through three sections only of the resistance, because when it reaches $R2$ it takes the path $R2$–g–h–i–G. On the third notch, the section of resistance between $R2$ and $R3$ is cut out. On the fourth notch, that between $R3$ and $R4$, and on the fifth notch all the resistance is cut out, the path of the current then being: trolley–blow-out coil–T–a–b–X–X'–m–A–A–A'–AA–AA–n–F–F–F'–E–$R5$–d–e–f–g–h–i–G. The fifth

notch therefore allows the full line voltage to be applied to the motor terminals, and gives the highest speed that can be attained by simply cutting out resistance.

59. Use of Diverter for Maximum Speed.—On the R11 controller a *shunt* or *diverter* S, Fig. 25, is used, so that on the sixth notch the shunt will be connected across the terminals of the motor field coil, thereby weakening the field and increasing the speed. One end of the shunt is attached to point 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; there the current divides, part of it taking the path F–F'–E–$R5$–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 winding each field coil in two sections, joining up the field winding in two portions in series, and connecting an intermediate tapping point to the wire L L. When the controller handle is on the last position, part of the field winding is cut out, thereby weakening the field and increasing the speed. These so-called *shunt* or *diverter methods* of control are not much used for traction work; they introduce undesirable complications into the field connections of the motor, and it has been found that a sufficient range of speed can be secured without them. The controller 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.

60. Operation of Reverse Drum.—If the motor is to be reversed, the reverse drum is rotated by the handle into the reverse position, bringing contacts t, u, v, w, Fig. 25, under fingers X', A, AA, and F, respectively. When the current reaches X', it therefore takes the path X'–t–v–AA–AA–A'–A–A–u–w–F and thence to the motor field circuit. In other words, the current flows to the brush at the AA side of the armature instead of to the brush at the A side as before, but it still flows through the field winding from F to E, in the same direction as before, thus reversing the current through the armature, but not through the field.

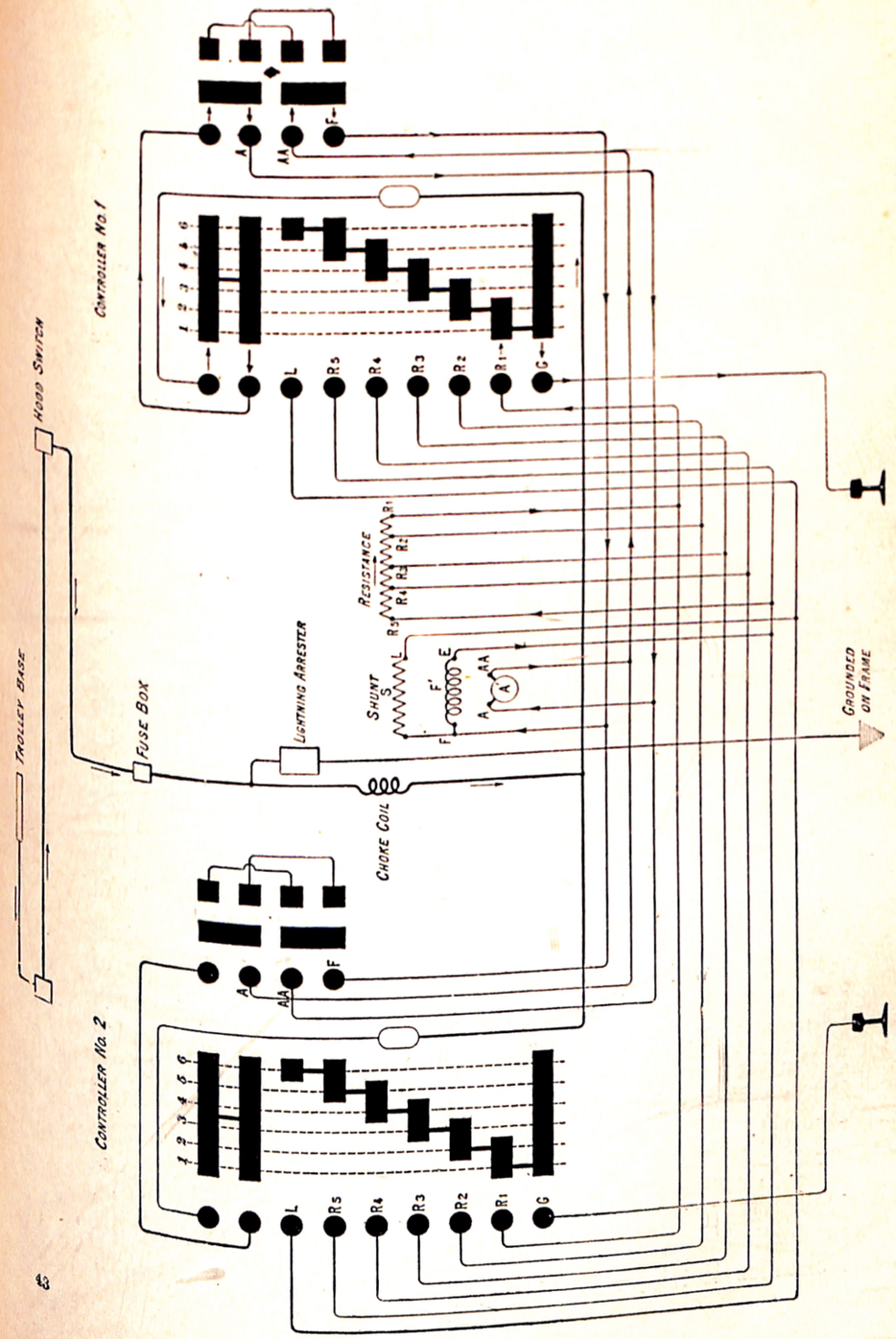


Fig. 25

CAR-WIRING DIAGRAM FOR R11 CONTROLLERS

61. Use of Two Controllers.—In Fig. 25, only one controller is shown, but on a car or mining locomotive two controllers, one at each end, are usually necessary in order that the driver may control the car or locomotive from either end. Fig. 26 shows the method of connecting two R11 controllers together in parallel, either being available for controlling a single motor. The corresponding terminals of the power drums of the two controllers are connected together by wires that run the whole length of the car. However, on the reversing drums the terminal marked *A A* on controller No. *1* is connected to the terminal marked *A* on controller No. *2*, and *A A* on controller No. *2* is connected to *A* on controller No. *1*. It is necessary to interchange the armature wires in this way so that the reverse handle will point in the direction in which the car is to run, at whichever end the driver may be standing.

62. When either of the two controllers on a car is in use, the other is at the off-position, because only one handle is supplied for the reverse cylinder, and this cannot be removed until the power is switched 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 arrangement of the parts is a little different. The wires in this and in the following diagrams are not supposed to be in electrical connection with each other where they cross, unless there is a round dot placed at their point of intersection. A convenient method by which the various combinations and connections of a controller may be represented diagrammatically, step by step, is shown in Fig. 27. The first five steps differ from one another in the amount of resistance included in circuit, and the last step is the same as the fifth, with the exception that the field *F′* is shunted.

63. Arrangement of Resistance.—If a controller resistance is used continuously to control the speed of any motor, it must be proportioned so as to avoid overheating, and so that all the resistance notches may be used as running notches. With

ordinary tramcars, the controller resistance is not intended to be used for speed-controlling purposes. It is only intended to give the car a smooth start, and should not be kept in circuit when the car has once got well under way. Before leaving the study of the rheostatic controller, it should be noticed that the resistance coils are shown connected on the earthed side of the motor, so that the current first enters the motor, and the motor is subjected to the full line voltage during both running and

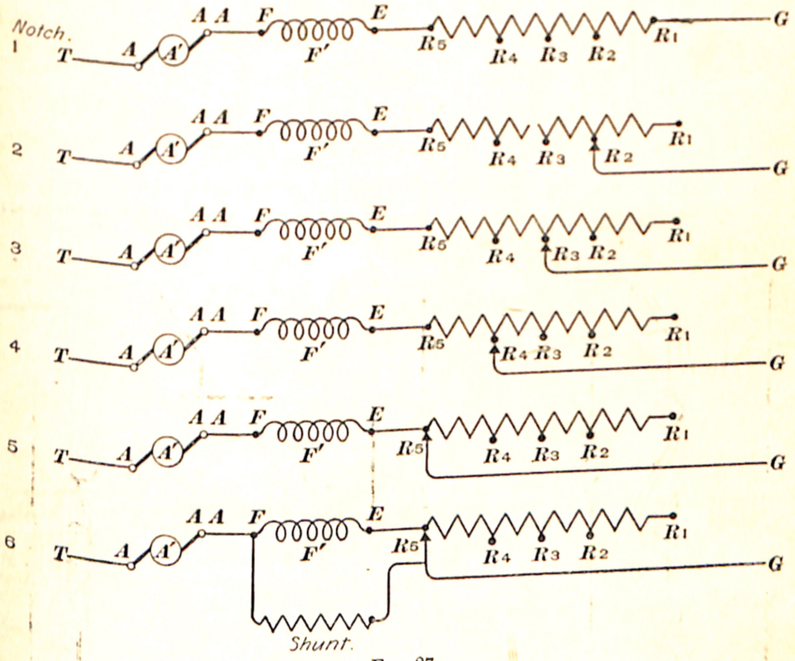


FIG. 27

starting. In most controllers the resistance is placed on the line side of the motors; the relative position of the motor and the resistance makes no difference so far as the effect of the resistance itself is concerned; it may sometimes, however, make a difference in regard to the trouble that may arise when an earth occurs on the resistance. If the motor is connected on the line side of the resistance, short-circuit current may flow through the motor. If the resistance is connected on the line side, the motor will be protected.

SERIES-PARALLEL CONTROL

64. General Description.—The method of speed control now almost universally used for direct-current traction work is known as the *series-parallel control*. It enables the motors to be run at low speed without the continuous use of resistance, and hence is more economical on low speeds than the simple rheostatic method. The series-parallel control is only applicable to equipments of at least two motors per car. For low speed, the motors are connected in series between the trolley wire and earth, and for high speed, the motors are connected in parallel; hence, this system is known as the **series-parallel control.**

65. If the line pressure is 500 volts and 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

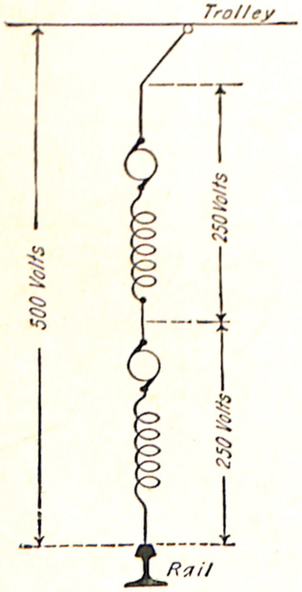


FIG. 28

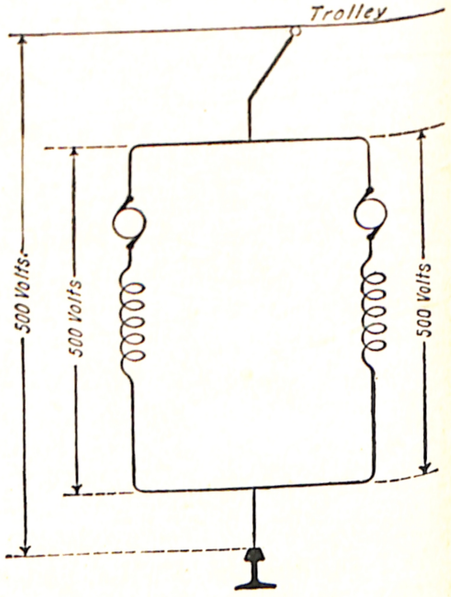


FIG. 29

have to run at only about half its normal speed in order to generate the required back E.M.F., and the motors can run economically at half speed without the use of any resistance.

When the motors are to run at a higher speed, the controller drum is moved round to the *parallel notches* and effects the combinations necessary to change the connections of 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 in circuit with the motors, 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 way and is not used on the running notches for either high or low speed.

BRITISH THOMSON-HOUSTON K2 CONTROLLER

66. Development and Types.—The General Electric Company of America were among the earliest makers of tramway controllers, their series-parallel controllers being of three types, respectively termed type K, type L, and type B. Controllers designated by the letter K are intended for controlling two or more series motors, and include the feature of shunting or short-circuiting one of the motors when changing from series to parallel. 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 for large cars equipped with heavy motors. Type B controllers are arranged for magnetic and rheostatic braking, but are in general similar to type L. These various controllers either with or without modification are supplied by the British Thomson-Houston Company.

67. Features of K2 Controllers.—All type K controllers embody many of the features described in connection with the R11 type of controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, although, of course, the type K is more complicated, because it must control all the connections for two or more motors and

effect the necessary changes of connections from series to parallel. It is also provided with switches, by means of which either motor may be cut out, allowing the car to be operated on the other

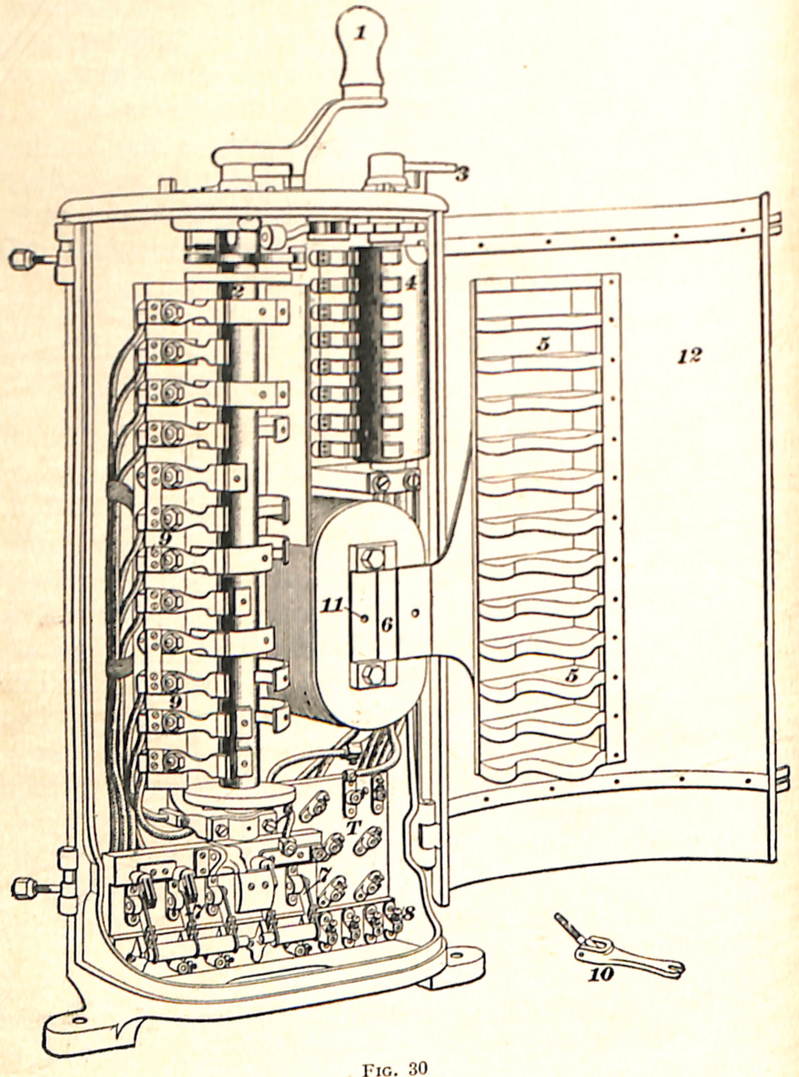


FIG. 30

motor. The K2 controller is designed for use with diverters for obtaining the maximum speed; that is, both on the last series notch and on the last parallel notch the fields of both motors

are shunted by diverter resistances. The controllers may, however, be used without shunts, if the top speed obtained without them is sufficiently high, and they are frequently run in this way.

The K2 controller is capable of controlling two motors of 40 horsepower or under and has 9 notches. There are 12 combinations or positions on the controller in all, but only 9 of them are marked on the controller top, and the star wheel of the controller is so cut that the handle cannot be made to rest at the passing or changing positions, or anywhere except on a marked notch.

68. Construction of Controller.—Fig. 30 shows a K2 controller with the door opened so that the inside parts can be seen. The operating handle *1* is used to turn the controller or power cylinder *2*, and *3* is the reverse handle for rotating the reverse cylinder *4*. The fingers *9* make contact with the segments of the power cylinder, which are separated by the insulating partitions *5*. These partitions are carried on the movable pole of blow-out magnet *6*. The combined bolt and wrench *10* is used to screw the pole piece of the blow-out magnet to the pole at *11*. The reverse cylinder has no blow-out coil, because its connections cannot be broken while current is flowing. Two **cut-out switches** *7*, by means of which a disabled motor can be cut out of circuit, are provided. All wires entering the controller are connected to terminals on the *connection board 8*. The terminals on the connection board are joined to the various parts of the controller, as shown for one case by terminal *T* attached to the lead from the blow-out coil. Both the power drum and the reverse drum of this controller are longer and carry more contact segments than those of the rheostatic controller. The interlocking device between the two drums is practically the same on both controllers.

69. A view of the controller cover showing how the notches are indicated is given in Fig. 31. 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 main handle *H* and

the reverse handle *K* are shown at the off-position ; the index of the main drum is a small pointer, pointing in the opposite direction to the handle.

The connections to the motors are such that when the reverse handle points ahead the car runs in that direction, and when

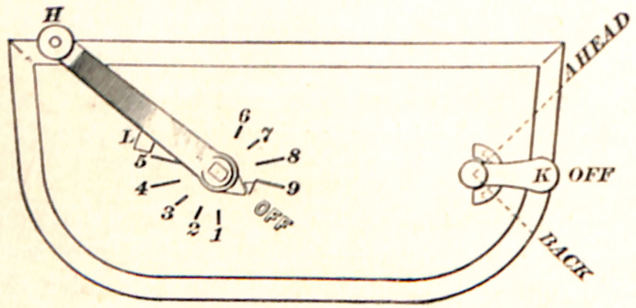


Fig. 31

the handle points back the car runs in the reverse direction ; the direction in which the reverse handle points thus indicates the direction of running.

70. Simplified Connection Diagram.—The various combinations affected by a K2 controller are indicated in Fig. 32. The connections to the motors and resistances for each of the positions of the power drum from *1* to *12* are shown, it being assumed that power is supplied from the point *T* and that the outer circle represents the connection to earth at *G*. In position *1* current flows from *T* through the blow-out coil *M*–all the sections of resistance from *R1* to *R4*–*AA1*–armature *1*–*A1*–*F1*–field *1*–*E1*–*AA2*–armature *2*–*A2*–*F2*–field *2*–*E2*–earth at *G*. In position *2* the first section of the resistance is short-circuited, the other connections remaining as before. In position *3* only one section of resistance remains in circuit, and in position *4* all the resistance is cut out, so this position is also a running notch. In position *5* the fields are shunted by the resistances or diverters *S*, so that the speed is greater than on position *4*. Position *5* is also a running notch, as there is no resistance in series with the motors. Positions *6*, *7*, and *8* are transition positions in the change from series to parallel connection of the motors. In position *9* there

are two sections of resistance in series with the motors which are in parallel, and in position *10* there is only one section of resistance remaining in circuit. Positions *11* and *12* are both

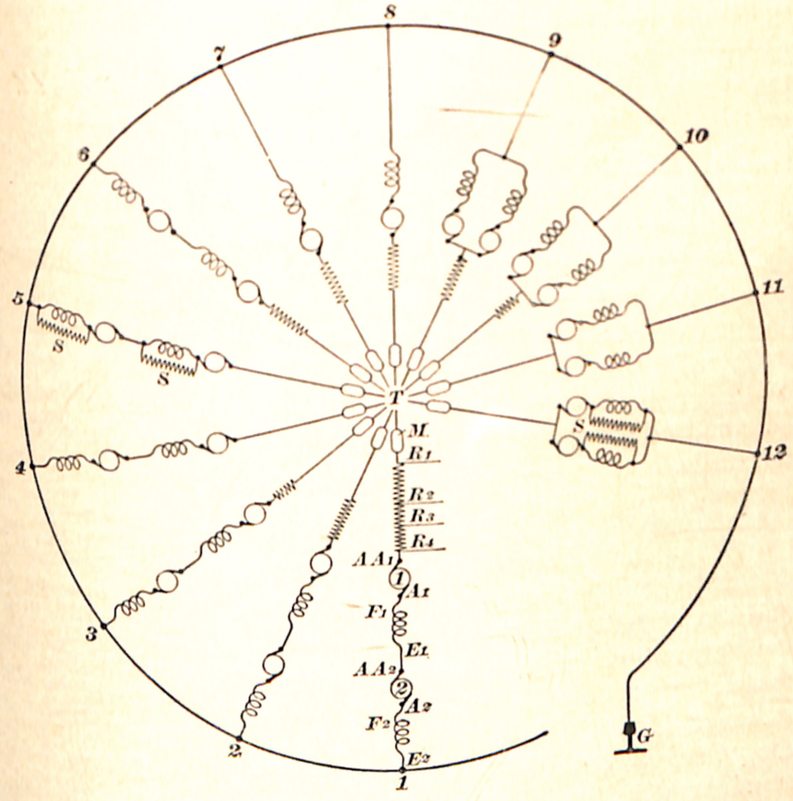


Fig. 32

running notches, as the resistance has all been short-circuited ; in the latter position the fields are shunted.

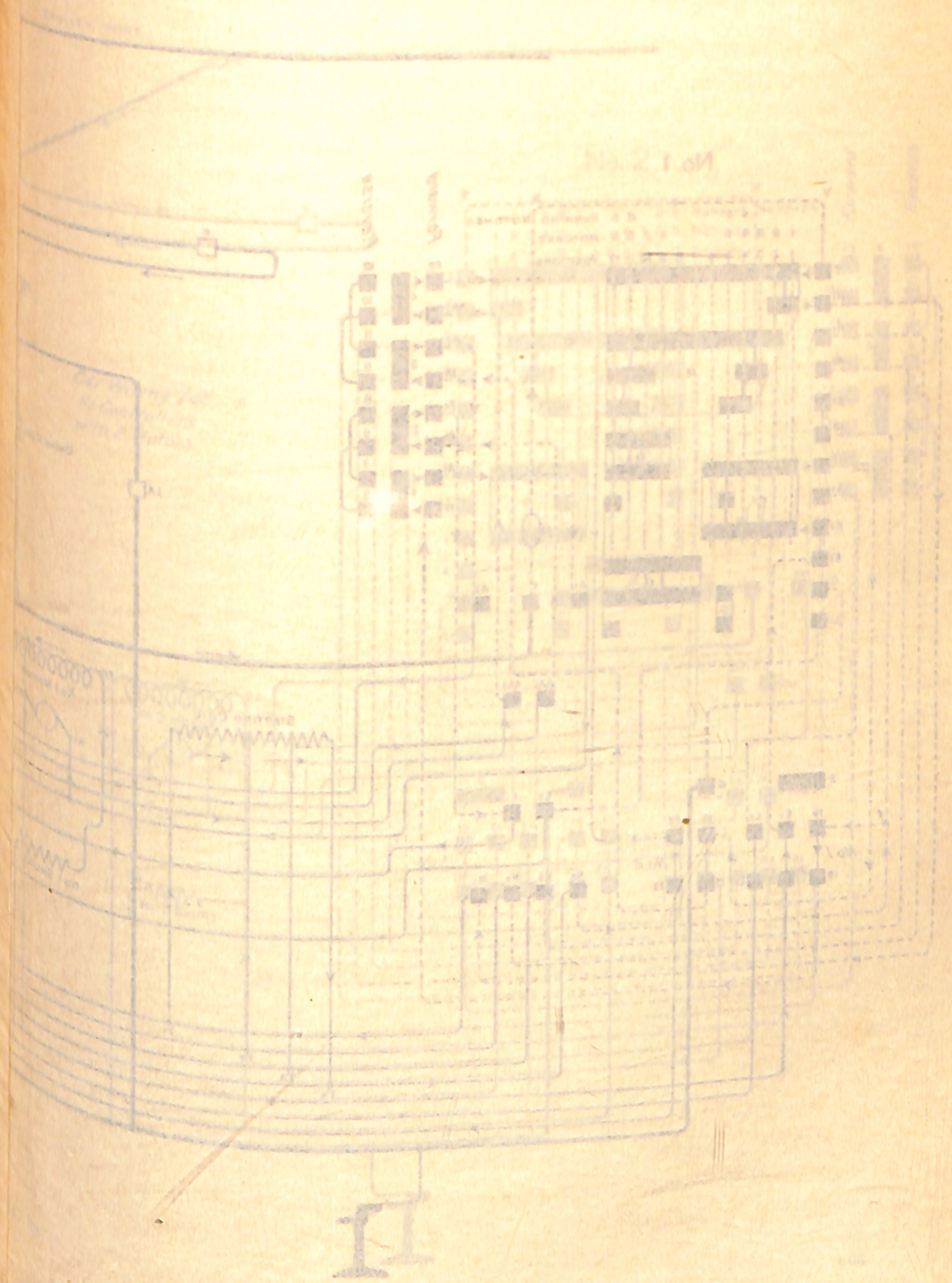
CAR-WIRING DIAGRAM FOR K2 CONTROLLERS

71. Connections to Armatures.—In the diagram of the car wiring for two K2 controllers, Fig. 33, the armature wires are interchanged in the two controllers ; for example, the wire connecting to terminal *AA1* in No. *1* controller connects to terminal *A1* in No. *2* controller. If this precaution is neglected, the car will

move in the direction in which the reverse handle points at one end of the car, but in the opposite direction at the other. Moreover, since the motors are mounted back to back on the truck, that is, with their commutators toward opposite sides of the car, they must run in opposite directions when each is viewed from the commutator end, in order that both the motors may propel the car in the same direction. In the wiring diagram 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* motor would therefore run in a direction opposite to No. *2* when viewed from the commutator end. The usual method of testing the correctness of the connections is to connect up the motors and switch on the current ; if it is found that either or both of the motors tend to drive the car in the opposite direction to that indicated by the reverse handle, the motor or motors at fault can easily be reversed by interchanging the connections to the field terminals.

72. Controller Positions and Notches.—The power drum or cylinder of the K2 controller is made of five castings, which are designated on the diagram, Fig. 33, by the letters *a*, *b*, *c*, *d*, *e*, and are insulated from one another and from the shaft. The twelve positions of the cylinder are indicated by the vertical dotted lines ; only nine of these correspond to notches in the index, or star, wheel, *6*, *7*, and *8* being transition positions that are passed over quickly. Of the 9 notches, *4*, *5*, *8*, and *9* are running notches, as indicated by the numbers above the development of the power cylinder. On the first running position, notch *4*, the two motors are in series and all the resistance is cut out of circuit. On notch *5* the connections are the same as on *4*, except that the fields are shunted by shunts *L1* and *L2*. 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, both on line voltage, and as the fields are shunted on notch *9*, this gives the highest possible speed.

73. Connections With Motors in Series.—Assuming No. *1* controller to be used, with the reverse switch at the forward



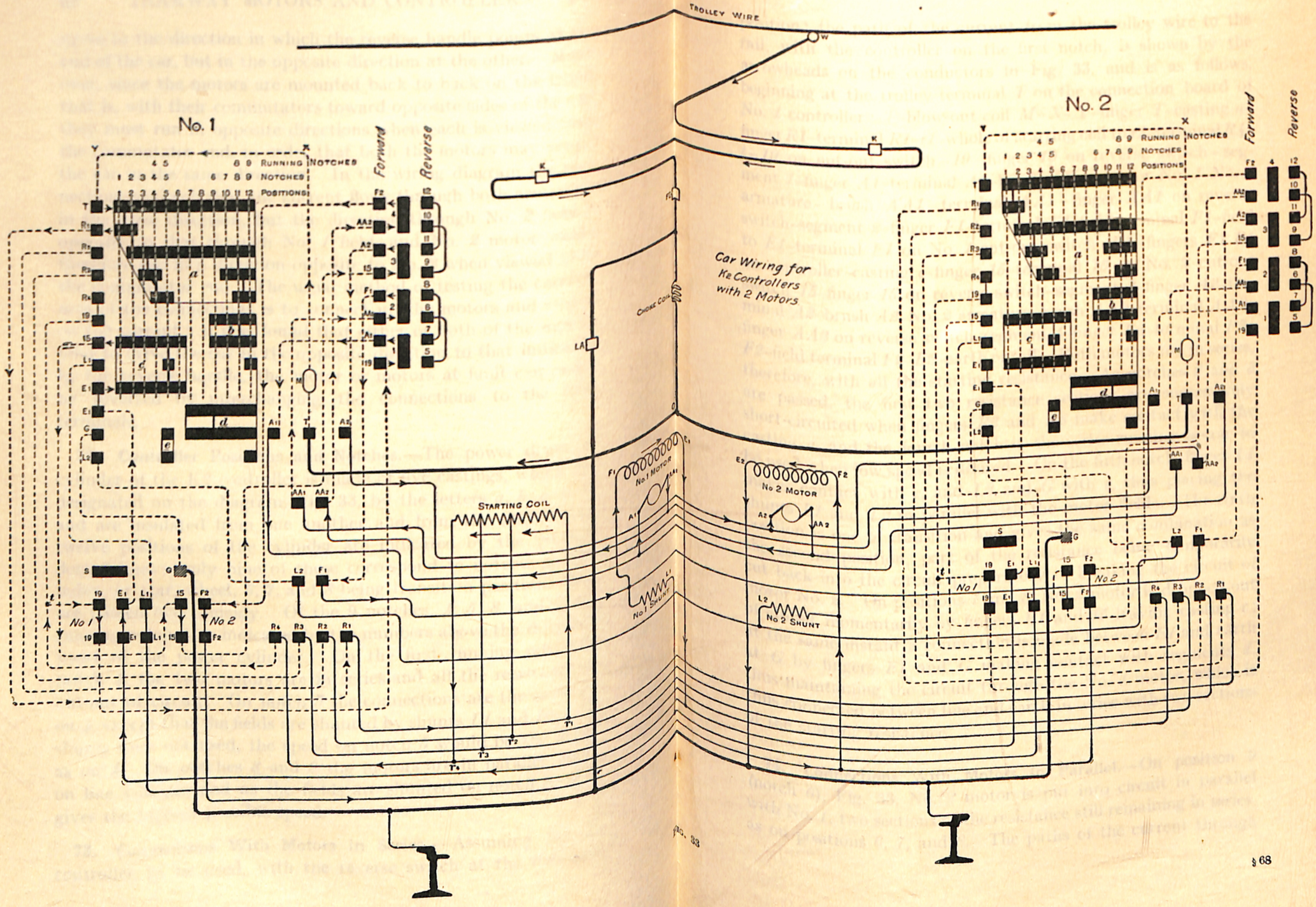
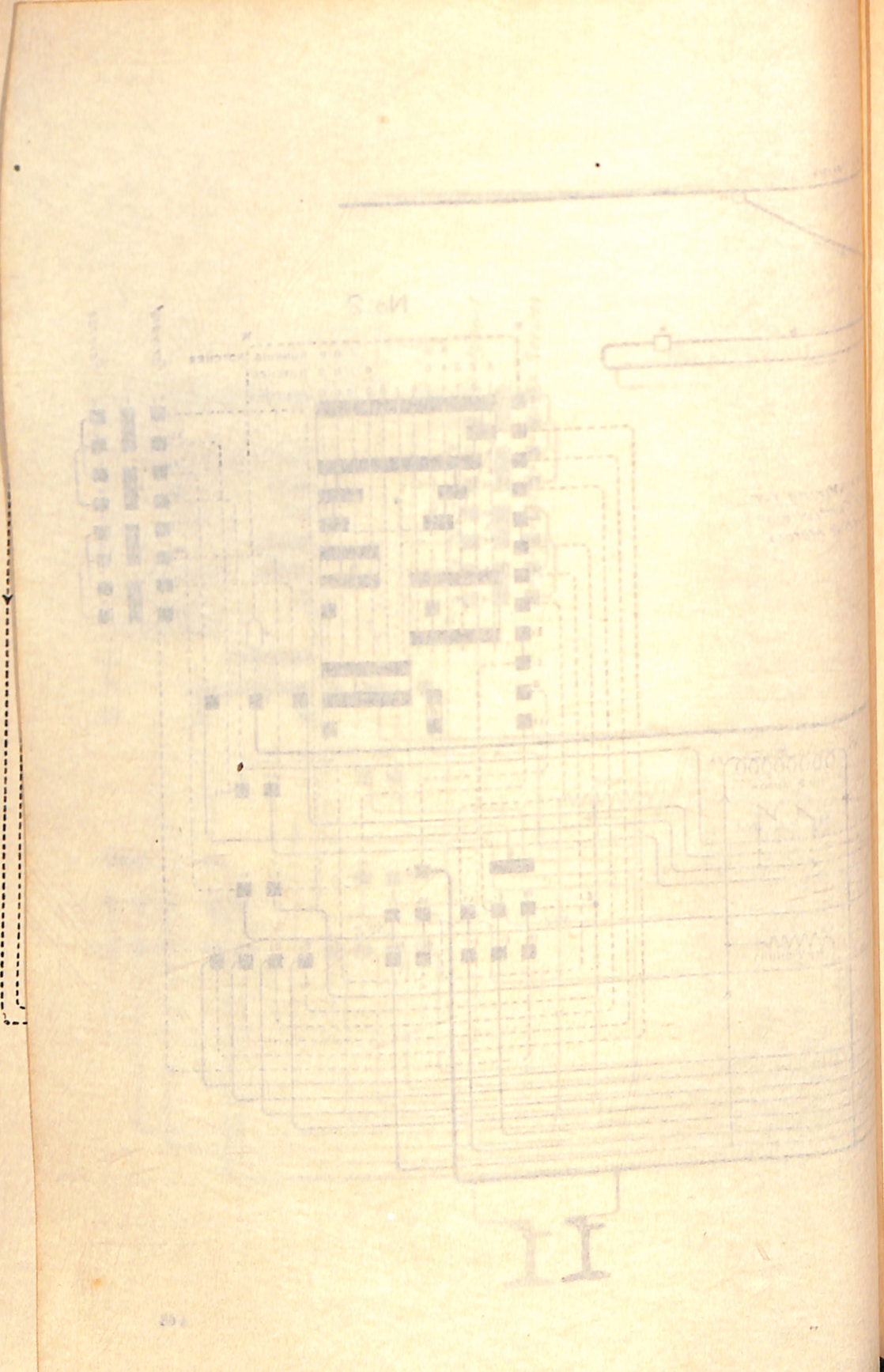

TROLLEY WIRE
W
K
K
No. 1
No. 2
Forward
Reverse
Car Wiring for
K2 Controllers
with 2 Motors
CHOKE COIL
LA
STARTING COIL
No 1 MOTOR
No 2 MOTOR
No 1 SHUNT
No 2 SHUNT
No 1
No 2
RUNNING NOTCHES
NOTCHES
POSITIONS

FIG. 33



position; the path of the current from the trolley wire to the rail, with the controller on the first notch, is shown by the arrowheads on the conductors in Fig. 33, and is as follows, beginning at the trolley terminal *T* on the connection board of No. *1* controller: *T*–blow-out coil *M*–*X*–*Y*–finger *T*–casting *a*–finger *R1*–terminal *R1*–*r1*–whole of starting coil to *r4*–terminal *R4*–*t*–*19* on cut-out switch–*19*–finger *19* on reverse switch–segment *1*–finger *A1*–terminal *A1*–brush *A1* on motor No. *1*–No. *1* armature–brush *AA1*–terminal *AA1*–finger *AA1* on reverse switch–segment *2*–finger *F1*–terminal *F1*–field terminal *F1*–field to *E1*–terminal *E1* on No. *1* cut-out switch–*E1*–fingers *E1 E1* on controller–casting *c*–finger *15*–terminal *15* on No. *2* cut-out switch–*15*–finger *15* on reverse switch–segment *3*–finger *A2*–terminal *A2*–brush *A2*–No. *2* armature–brush *AA2*–terminal *AA2*–finger *AA2* on reverse switch–segment *4*–finger *F2*–terminal *F2*–*F2*–field terminal *F2*–*E2*–earth or rail. Both motors are in series, therefore, with all the starting resistance. As notches *2* and *3* are passed, the first two resistance sections are successively short-circuited when fingers *R2* and *R3* make contact with the casting *a*, and the fourth notch is the series running notch to be used when low speed is desired. On the fifth notch, finger *L1* makes contact with *c*, and *L2* and *G* with *e*, thus placing the shunts *L1* and *L2* in parallel with the motor fields. The sixth position is one of transition and gives the same combination as the second position, part of the resistance being temporarily cut back into the circuit preparatory to breaking the circuit of motor No. *2*. On positions *7* and *8*, No. *2* motor is dropped out of circuit momentarily by fingers *E1* and *15* leaving casting *c*; at the same instant a connection is made between *E1* and earth at *G* by fingers *E1* and *G* making contact with segments *d*, thus maintaining the circuit through the No. *1* motor, which is thus connected between line and earth in series with two sections of the starting resistance.

74. Connections With Motors in Parallel.—On position *9* (notch *6*), Fig. 33, No. *2* motor is put into circuit in parallel with No. *1*, two sections of the resistance still remaining in series, as on positions *6*, *7*, and *8*. The paths of the current through

the two motors on notch *6*, therefore, starting from terminal *K4*, are:

R4–t–

19 on cut-out switch *1–19–19* on reversing drum–segment *1–A1–A1–A1*–armature of motor *1–AA1–AA1–AA1* on reversing drum–segment *2–F1–F1–F1*–field of motor *1–E1–E1–E1*–finger *E1* on main drum–segment *d*–finger *G*–

finger *19* on main drum–casting *b*–finger *15–15* on cut-out switch *2–15–15* on reversing drum–segment *3–A2–A2–A2*–armature of motor *2–AA2–AA2–AA2* on reversing drum–segment *4–F2–F2–F2–F2*–field of motor *2–E2–*

earth wire from *G*.

On notch *7*, the second section of starting resistance is short-circuited, and on notch *8* all the resistance is short-circuited; the motors, however, run with full field strength. On the last notch, the fields are shunted and the motors run at full speed.

75. Motor Cut-Out Switches.—The two motor cut-out switches are represented on Fig. 33 by black squares below the diagram of the power drum and are marked No. *1* and No. *2*. These two switches are two-way, and when both motors are in use, both switches should be closed in the lower contacts as indicated by the connecting lines. When No. *1* switch is closed in the top contacts, terminals *19* and *E1* are connected together through the connector *S*, and assuming that the controller is on the first notch, the path of the current beginning at point *t* is: *t–19–S–E1–E1–E1–c–15–15–15–15–3–A2–A2*, etc. No. *1* motor is cut out and the current flows through No. *2* motor to earth. If No. *2* switch is closed in the top contacts, switch No. *1* being down, the current on reaching terminal *15* on No. *2* switch goes directly to the earth terminal *G* and No. *2* motor is cut out. When either of these switches is used, it brings into action a device which interlocks with a collar on the power-cylinder shaft to prevent the cylinder from being moved beyond the last series position. Thus, if one motor is disabled and short-circuited it cannot be connected in parallel with a good motor, which would then also be short-circuited.

76. Lightning-Arrester Circuit.—In the wiring diagram, Fig. 33, for two K2 controllers there are two alternative circuits from the trolley wire to the rail: the main circuit through the motors and a **lightning-arrester circuit** through the lightning arrester *LA*. The latter usually includes an air gap, or series of small air gaps, so that under ordinary conditions no current flows through the lightning-arrester circuit. If the trolley wire becomes charged at high pressure, however, due to lightning or other abnormal condition, the current passes to earth across the air gap of the arrester, the circuit being as follows: Trolley wheel *W*–canopy switches *K*, *K*, one at each end of the car–fuse or circuit-breaker *F B*–lightning arrester *LA*–earth wire–rail. A **choke coil**, termed also a **choking**, or **kicking, coil**, is inserted in the main motor circuit between the fuse *F B* and the connection *O* leading to the trolley terminals *T* of the controllers. The coil is simply a highly inductive coil, through which the ordinary direct current flows without check, but which chokes back the alternating or pulsating current of a lightning discharge and protects the motors by compelling the discharge to take the direct path to earth through the arrester.

BRITISH THOMSON-HOUSTON K12 CONTROLLER

77. Method of Connecting Four Motors.—The usual method of controlling a four-motor equipment is permanently 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 in the case of a regular two-motor equipment. Fig. 34 shows the various combinations effected by the K12 controller, which provides four series resistance notches and one running notch with the motors in series. No diverter resistances are used to give extra-high speed, and the car should be operated only on one running notch with either the series or parallel connection. The resistance tappings are lettered *R1* to *R5*, the position of the connection from the trolley *T* indicating the number of resistance sections included at any position of the controller drum from *1* to *12*. For example, in position *1* the circuit is as follows: $T - R1$ to $R5 - \begin{cases} A1-F1 \\ A3-F3 \end{cases} - \begin{cases} A2-F2 \\ A4-F4 \end{cases} - G.$

In the transition from series to parallel running, the pair of

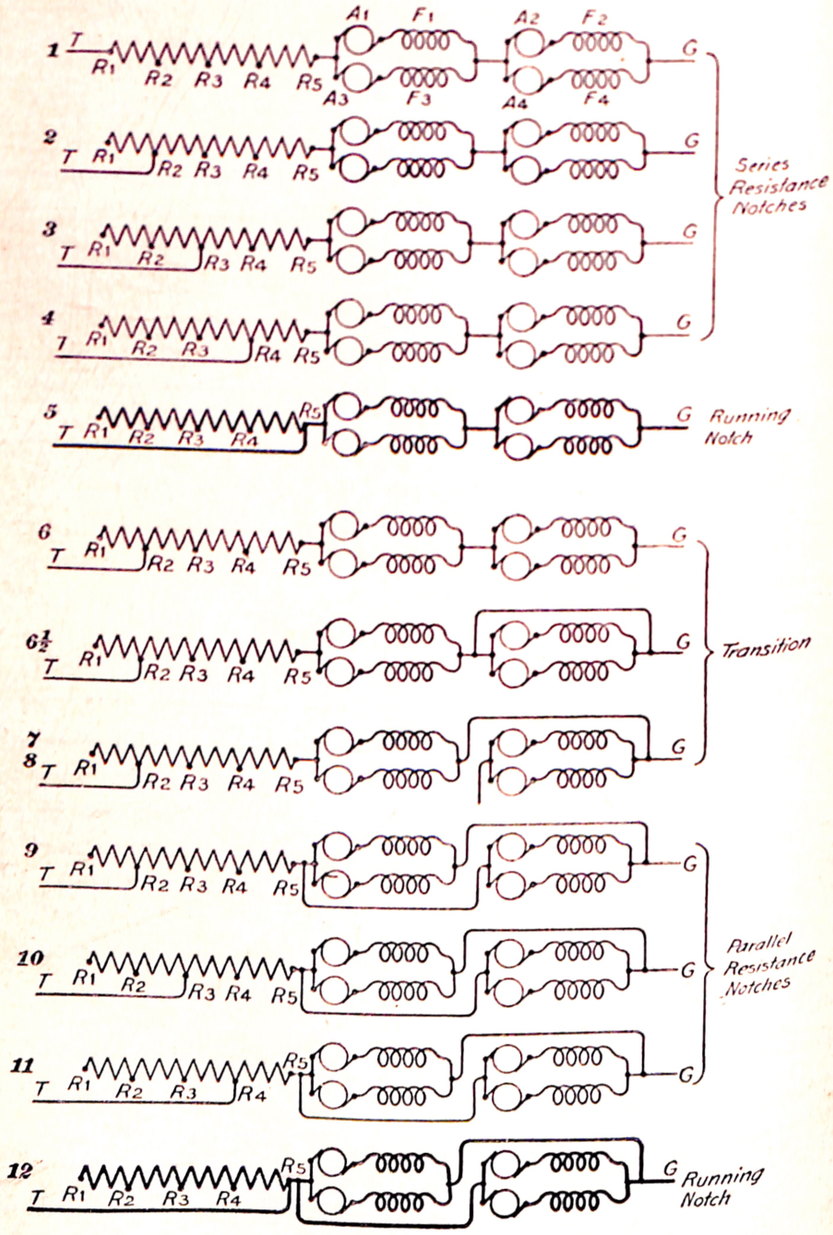


FIG. 34

motors nearest the earth connection are first short-circuited, as

indicated at position $6\frac{1}{2}$, and then open-circuited, as shown on the diagram at positions *7* and *8* before making the parallel connection indicated at position *9*.

CAR-WIRING DIAGRAM FOR K12 CONTROLLERS

78. Connections on Series Notches.—A diagram of the wiring of a car equipped with two K12 controllers and four motors is shown in Fig. 35. The power cylinder has five resistance segments, but no diverter segment. The reversing drum is 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 forward, reverse-drum fingers *b* are in contact with the segments *a* and fingers *d* are in contact with segments *c*. When the car runs back, fingers *b* make contact with segments *c* and fingers *d* with segments *e*, thus reversing the current in all four armatures. The leads *E2* and *E4* from the No. *2* and No. *4* motor fields are permanently connected to the earth or ground wire. The main trolley wire is connected to finger *T* on the power cylinder through the blow-out coil, as shown. The path of the current when the right-hand controller is on the first notch is indicated by the arrows and is as follows, starting from finger *T* at the power cylinder: *T*–*R1*–*R1*–*R1*– through all resistance –*R5*–*R5*–*19*–*19* on reversing drum–

A1–*A1*–*A1*–armature of motor *1*–*AA1*–*AA1*–*AA1* on reversing drum – *F1*–*F1*–*F1*– field of motor *1*–*E1*–

19′–*A3*–*A3*–armature of motor *3*–*AA3*–*AA3* on reversing drum – *F3*–*F3*– field of motor *3*–*E3*–

E1, *E3*–*E3*, *E1*–segment *3*–*15*–*15*–*15*–

A2–*A2*–*A2*–armature of motor *2*–*AA2*–*AA2*–*AA2* on reversing drum – *F2*–*F2*–*F2*– field of motor *2*–*E2*–

15′–*A4*–*A4*–armature of motor *4*–*AA4*–*AA4* on reversing drum – *F4*–*F4*– field of motor *4*–*E4*–

earth wire – rail.

The resistance sections are successively cut out until the motors are in full series on notch *5*.

The other combinations are indicated by Fig. 34, and may be traced out on the diagram, Fig. 35, in a similar way. The cut-out switches are arranged to cut out the motors in pairs; for example, if No. *1* motor breaks down and the cut-out switch lettered *19 E1 E3* is closed in the top contacts, motors No. *1* and No. *3* are cut out.

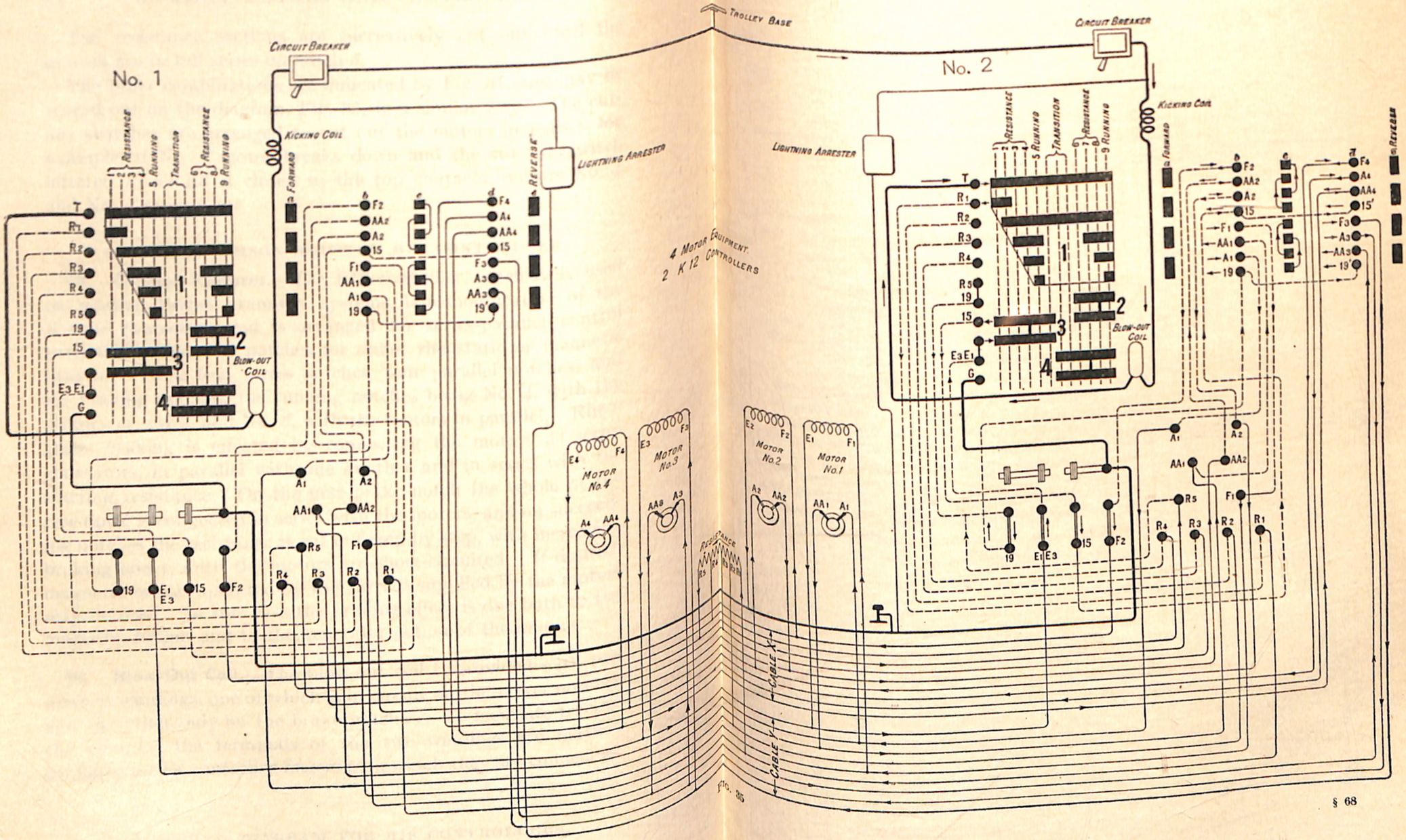
BRITISH THOMSON-HOUSTON B18 CONTROLLER

79. General Features.—The B18 controller, extensively used on modern British tramway systems, is a modification of the K-type controller, and is arranged for series-parallel control with the addition of notches for either rheostatic or magnetic brakes. It has four series notches, four parallel notches, and six braking notches, the running notches being No. *4*, with the motors in series, and No. *8*, with the motors in parallel. Rheostatic braking is effected by connecting the motors as series generators, in parallel with one another and in series with the starting resistance. On the first brake notch the whole of the resistance is connected in series with the motors, and on succeeding notches the resistance is cut out step by step, with increasing braking effect, until the motors are short-circuited. If desired, magnetic brakes operated by the current supplied by the motors may be used. In this case the braking effect is due both to the magnetic brakes and to the generator action of the motors.

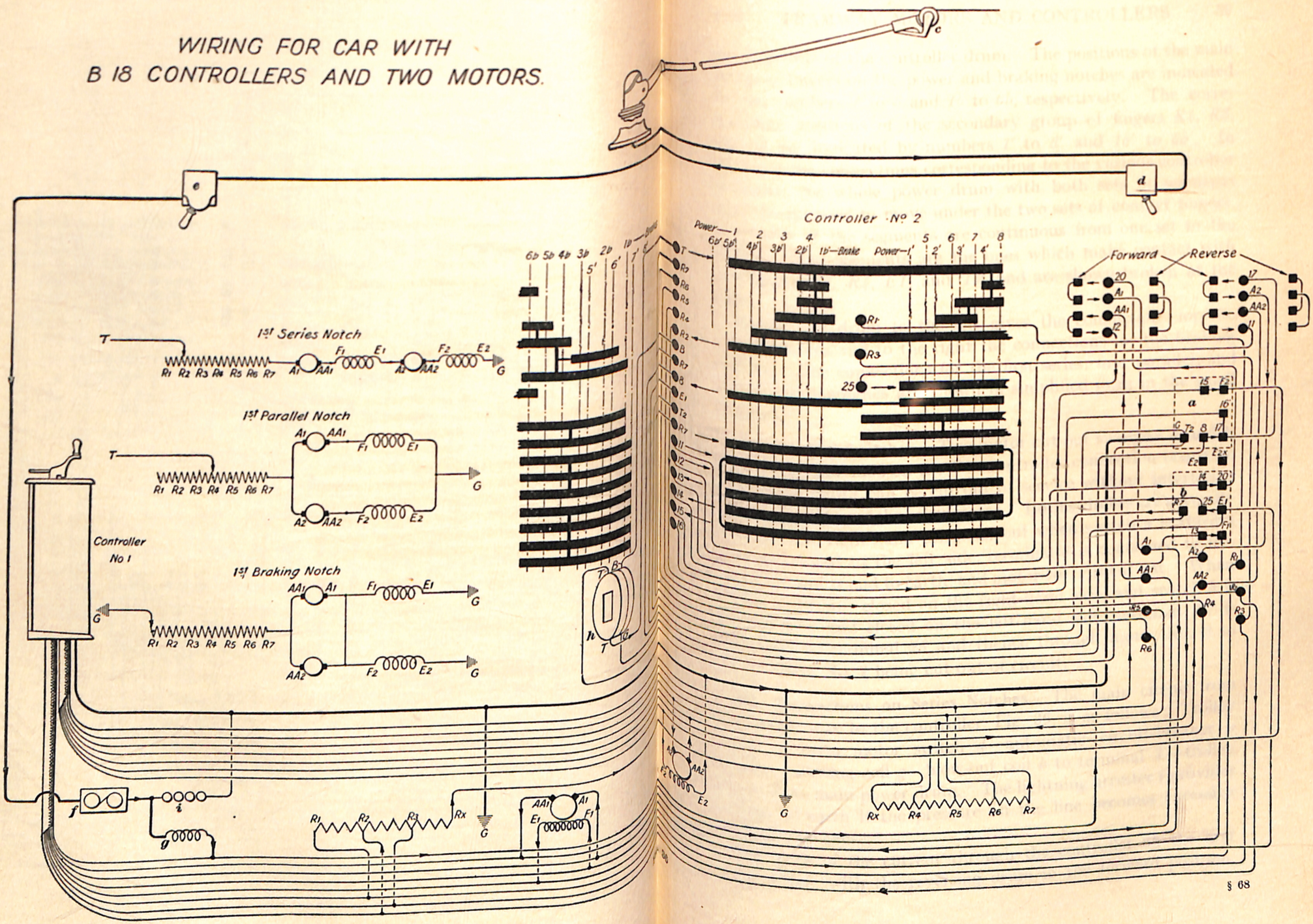
80. Blow-Out Coil.—The blow-out coil is provided with two distinct windings, one of which is in circuit on the power notches and the other only on the brake notches. To facilitate tracing the circuits, the terminals of the two windings are marked similarly to the controller fingers with which they are connected.

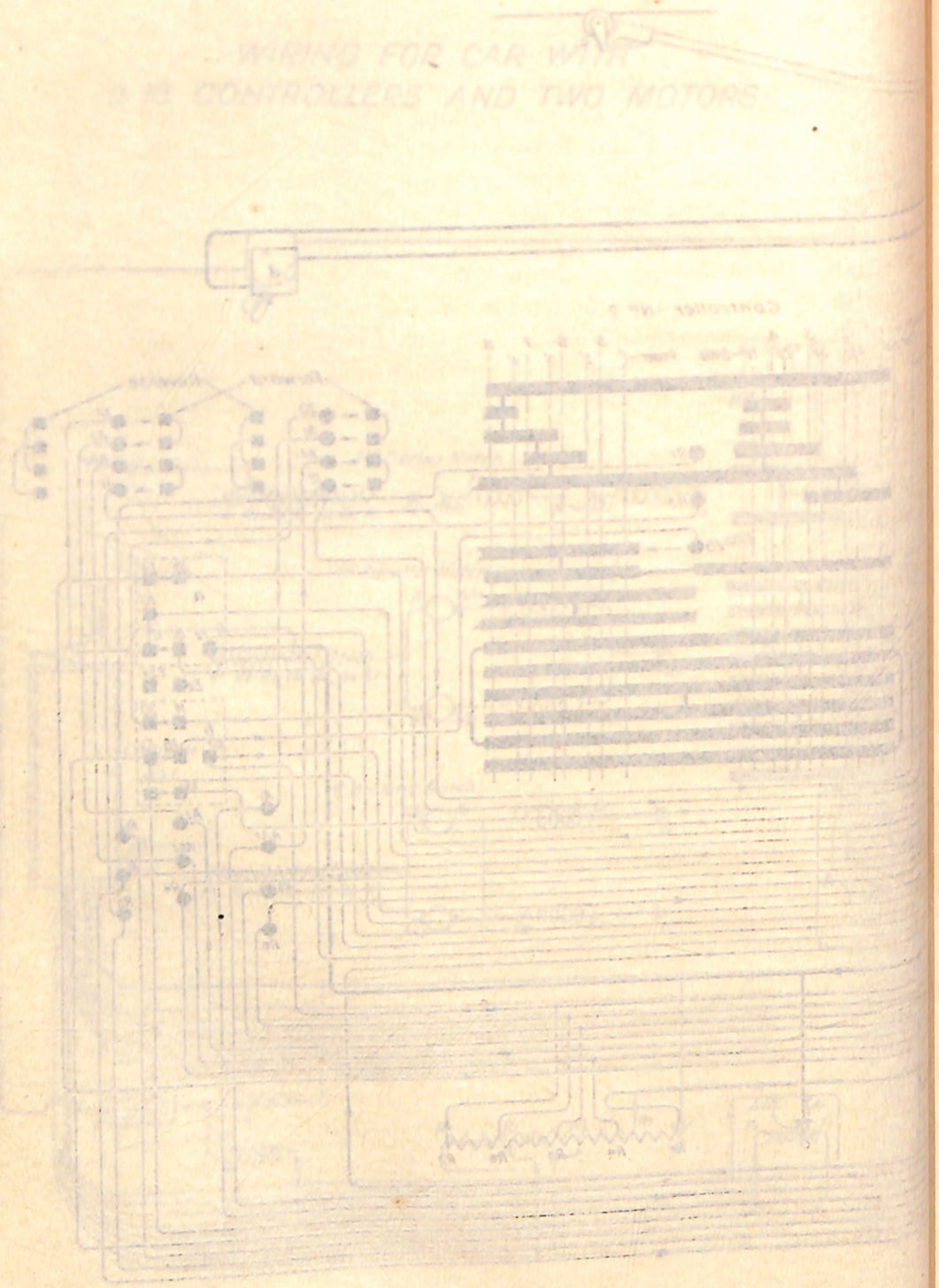
CAR-WIRING DIAGRAM FOR B18 CONTROLLERS

81. Controller Positions.—A diagram of the wiring of a car fitted with two B18 controllers and two motors is shown in Fig. 36. There are two sets of contact fingers which bear against


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

WIRING FOR CAR WITH B 18 CONTROLLERS AND TWO MOTORS.





the segments of the controller drum. The positions of the main group of fingers on the power and braking notches are indicated by the numbers *1* to *8* and *1b* to *6b*, respectively. The corresponding positions of the secondary group of fingers *R1*, *R3*, and *25* are indicated by numbers *1'* to *8'* and *1b'* to *6b'*. In studying the connections corresponding to the various controller positions, the whole power drum with both sets of segments must be assumed to move under the two sets of contact fingers. A number of the segments are continuous from one set to the other. These segments are the ones which make contact with the fingers *R7*, *R4*, *E1*, and *T2*, and are shown broken at the ends.

Moving the drum to the left gives the connections for the power notches and to the right the connections for the braking notches. The connections for the first series, first parallel, and first braking notches are shown in simplified form in the small diagrams.

82. Cut-Out Switches.—Two motor cut-out switches *a* and *b*, Fig. 36, are provided on the B18 controller connection board, so that either motor can be cut out of service without interfering with the working of the other motor. Both switches are normally closed in the right-hand contacts, but when switch *a* is thrown over and closed to the left side, terminal *8* is connected to terminal *T2* and *G* and to earth, and motor No. *2* is cut out. When switch *a* remains closed on the right-hand side, and switch *b* is thrown over and closed on the left-hand side, terminal *R7* is connected to terminal *25* and thence through motor No. *2* to earth, motor No. *1* being cut out of circuit.

83. Connections on Series Notches.—The main circuit from the trolley wire to the controller, Fig. 36, is as follows: Trolley wheel *c* – main motor switch *d* – automatic circuit-breaker *e* – fuse *f* – kicking coil *g* – blow-out coil *h* to terminal *T* – trolley finger *T* on main power drum. The lightning arrester *i* provides a path to earth if the pressure on the line becomes excessive through any cause.

The path of the current through the controller on the first series notch, with the reversing drum in the forward position,

is as follows: Trolley finger *T* – drum contact – finger *R2* – terminal *R2* – through rheostat to terminal *R7* – finger *R7* – main drum to finger *14* – cut-out switch terminal *14* – terminal *20*–finger *20* on reversing drum–finger *A1*–terminal *A1* – armature terminal *A1* – armature of motor *1* – *AA1* – controller terminal *AA1* – finger *AA1* – finger *12* on reversing drum – finger *12* on main drum – finger *13* – terminal *13* on cut-out switch – *F1* – *F1* – field of motor *1* – terminal *E1* – cut-out switch terminal *E1* – *25* – finger *25* – drum contacts – finger *8* – cut-out switch terminal *8* – terminal *17* – finger *17* on reversing drum – finger *A2* – terminal *A2* – armature terminal *A2* – armature of motor *2* – *AA2* – controller terminal *AA2* – finger *AA2* – finger *11* – finger *11* on main drum – finger *15* – cut-out switch terminal *15* – terminal *F2* – *F2* – field of motor *2* – *E2* – earth at *G*. On the second notch the first section of resistance is cut out. The remaining sections of resistance are cut out in two steps, on the third and fourth notches, giving the full line pressure across the motors in series.

84. Connections on Parallel Notches.—On notch *5*, Fig. 36, the motors are connected in parallel with resistance in series. The path of the current, with the reversing drum in the forward position, is as follows: Finger *T* – finger *R4* – terminal *R4* – resistance *R4* – *R7* – terminal *R7* –

finger *R7* – finger *14* – terminal *14* on cut-out switch–*20*–finger *20* on reversing drum – finger *A1* – terminal *A1* – *A1* – armature of motor *1*–*AA1*–*AA1*–finger *AA1*–*12*–*12*–*13*–*13*–*F1*–*F1*–field of motor *1*–*E1*–*E1*–finger *E1*–*T2*–*T2*–

finger *R7*–finger *8*–terminal *8* on cut-out switch–*17*–finger *17* on reversing drum – finger *A2*–terminal *A2*–*A2*–armature of motor *2* – *AA2* – *AA2* – finger *AA2*–*11*–*11*–*15*–*15*–*F2*–*F2*–field of motor *2*–*E2*–

earth at *G*.

On notches *6*, *7*, and *8* resistance is successively cut out, the last notch giving the motors full parallel connection across the line with all resistance cut out of circuit.

85. Connections on Brake Notches.—In order to operate the electric brake the controller handle is turned backwards past the off-position. On the first brake position fingers *R1*, *R3*, and *25* are in the position indicated by the dotted line *1b'*, and the main fingers are in the position indicated by dotted line *1b*. The path of the current through the motors, which are in parallel, is as follows: Earth at *G* – *T2* – blow-out coil *h* – *B* – *B* – finger *R1* – *R1* – resistance *R1* to *R7* – *R7* –

12 – *12* – *AA1* – *AA1* – *AA1* – armature of motor *1*–*A1*–*A1*–*A1* – finger *20* on reversing drum–*20*–terminal *14*–finger *14*

11 – *11* – *AA2* – *AA2* – *AA2* – armature of motor *2*–*A2*–*A2*–*A2*–finger *17* on reversing drum –*17*–terminal *16*–finger *16*–

segments of main power drum–

finger *13*–*13*–*F1*–*F1*–field of motor *1*–*E1*–terminal *E1*–*E1*–finger *T2*–terminal *T2*–

finger *15*–*15*–*F2*–*F2*–*F2*–field of motor *2*–*E2*–

earth at *G*.

In tracing the brake circuits, it should be noted that the relative connections of the fields and armatures have been reversed so that the motors may act as generators. On the second brake notch *2b* finger *R2* makes contact with a segment and one section of the resistance is cut out. On the third notch, finger *R3* takes a position as indicated by *3b'*, and a second section of resistance is cut out of the motor circuit. The resistance is thus successively cut out until on notch *6b* the motors are short-circuited.

WESTINGHOUSE T1 CONTROLLER

86. General Features.—The T1 controller is designed for controlling two motors on tramway systems with the ordinary earth return, and combines series-parallel features with rheostatic or magnetic braking, as desired. The controller has four series, four parallel, and seven braking notches; the large number of braking notches gives a very smooth braking effect. The

reversing drum is carried by a loose sleeve on the upper part of the power-drum shaft. The lower part of the shaft is square and the power-drum segments are rigidly attached thereto.

87. Interlocking Devices.—The interlocking and notching gear of the two drums is shown in Fig. 37. The cover-plate of the controller has been removed, but the power handle *a* and reversing handle *b* are shown in place, both at the off-position. The star wheel *c* of the power drum has four series notches *d*, four parallel notches *e*, and seven braking notches *f*. The stops *g* and *h* carried on the star wheel and the controller cover, respectively, prevent the main drum from being rotated too far in

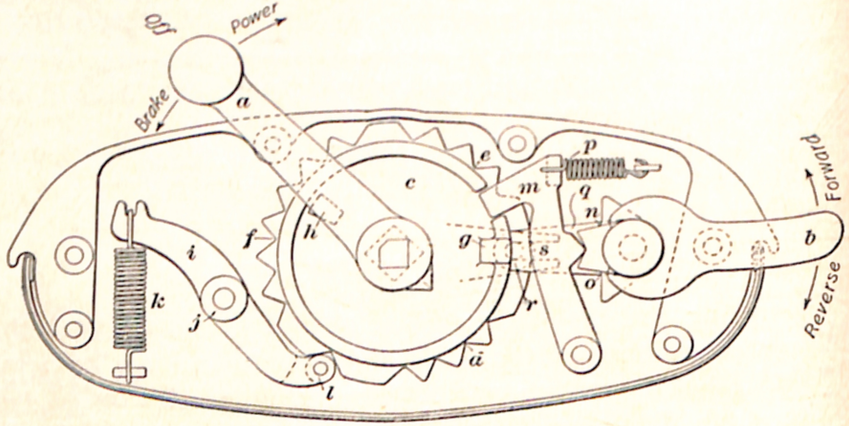


FIG. 37

either direction. The lever *i*, pivoted at *j*, and actuated by the spring *k*, prevents the star wheel from remaining in any but the definite notch positions by the roller *l* engaging with the star-wheel notches. Normally, when the reverse handle *b* is in the off-position the power drum is prevented from moving by the hook *m* engaging with a notch in the star wheel *c*. When the reversing handle is moved to the forward or reverse position, deep **V** notches *n*, *o* in a segmental casting at the end of the handle of the reverse drum allow the hook *m* to be withdrawn from the notch in the main star wheel by the spring *p*. A lever arm *q*, which moves below the star wheel *c* and hook *m*, is also rotated by the reverse handle. The arm *q* carries a roller *r*, shown dotted, which moves a fork *s* attached to the loose sleeve

of the reversing drum on the main shaft, and thus turns the reversing drum through a sufficient angle to make the necessary connections.

CAR-WIRING DIAGRAM FOR T1 CONTROLLERS

88. Notches and Cut-Outs.—The wiring diagram of a car provided with two T1 controllers and two motors is given in Fig. 38. There are two sets of fingers, *A* and *B*, and the respective power positions of these are indicated by the dotted vertical lines numbered *1* to *8* and *1′* to *8′*. The positions for the fingers in group *A* on the brake notches are marked *1b* to *7b*, and the positions for the fingers in group *B* are numbered *1b′* to *7b′*. No connection board is provided, the wires being connected directly to the respective contact fingers. To cut out motor No. *1*, fingers *2* and *F1* are raised, and similarly motor No. *2* may be cut out by raising fingers *4* and *F2*.

Key diagrams of the connections on the first series, first parallel, and first braking notches are shown in the lower right-hand corner of the car-wiring diagram.

89. Connections on Series Notches.—If the reversing handle of controller No. *1*, Fig. 38, is placed in the forward position, and the power handle is in the first position, the path of the current is as follows: Trolley tapping *T*–finger *T*–finger *R1*–resistance *R1* to *R7*–terminal *R7*–blow-out coils *a* and *b*–finger *1*–finger *2*–finger *2* on reversing drum–finger *A1*–*A1*–armature of motor *1*–*AA1*–finger *AA1* on reversing drum–*3*–finger *3* on main drum–*F1*–*F1*–field of motor *1*–*E1*–finger *E1*–*4*–finger *4* on reversing drum–*A2*–*A2*–armature of motor *2*–*AA2*–finger *AA2* on reversing drum–*5*–finger *5* on main drum–*F2*–*F2*–field of motor *2*–*E2*–earth at *G*.

On position *2* the resistance sections between *R1* and *R3* are short-circuited, and on position *3* all resistance sections between *R1* and *R5* are short-circuited. On position or notch *4* the motors are in series with all the starting resistance cut out.

90. Connections on Parallel Notches.—The motors are connected in parallel with part of the resistance in series when the controller drum is in position *5*, Fig. 38. The path of the

current is as follows: Trolley tapping *T*–finger *T*–finger *R4*–resistance *R4* to *R7*–terminal *R7*–blow-out coils *a* and *b*–

finger *1*–finger *2*–finger *2* on reversing drum–*A1*–*A1*–armature of motor *1*–*AA1*–*AA1* on reversing drum–*3*–finger *3* on main drum–*F1*–*F1*–field of motor *1*–*E1*–finger *E1*–finger *G*–

finger *1*–finger *4*–finger *4* on reversing drum–*A2*–*A2*–armature of motor *2*–*AA2*–*AA2* on reversing drum–*5*–finger *5* on main drum–*F2*–*F2*–field of motor *2*–*E2*–

earth at *G*.

On the other parallel positions the resistance is successively short-circuited until the motors are running in full parallel.

91. Connections on Brake Notches.—The operation of braking by means of the controller, when magnetic brakes are provided on the car, consists in reversing the connections to the motor armatures and in switching the two motors in parallel with each other and in series with the starting resistance and magnetic brakes. On the first braking notch the group of fingers *A* occupies the position *1b*, Fig. 38, and group *B* occupies position *1b'*. The path of the current when No. *1* controller is in use is as follows: Earth at *G*–magnetic brakes *c* and *d*–finger *B1*–main drum segments–finger *R1*–resistance *R1* to *R7*–terminal *R7*–blow-out coils *a* and *b*–finger *1*–main drum segments–

finger *3*–finger *3* on reversing drum–*AA1*–*AA1*–armature of motor *1*–*A1*–finger *A1* on reversing drum–*2*–finger *2* on main drum–

finger *5*–finger *5* on reversing drum–*AA2*–*AA2*–armature of motor *2*–*A2*–finger *A2* on reversing drum–*4*–finger *4* on main drum–

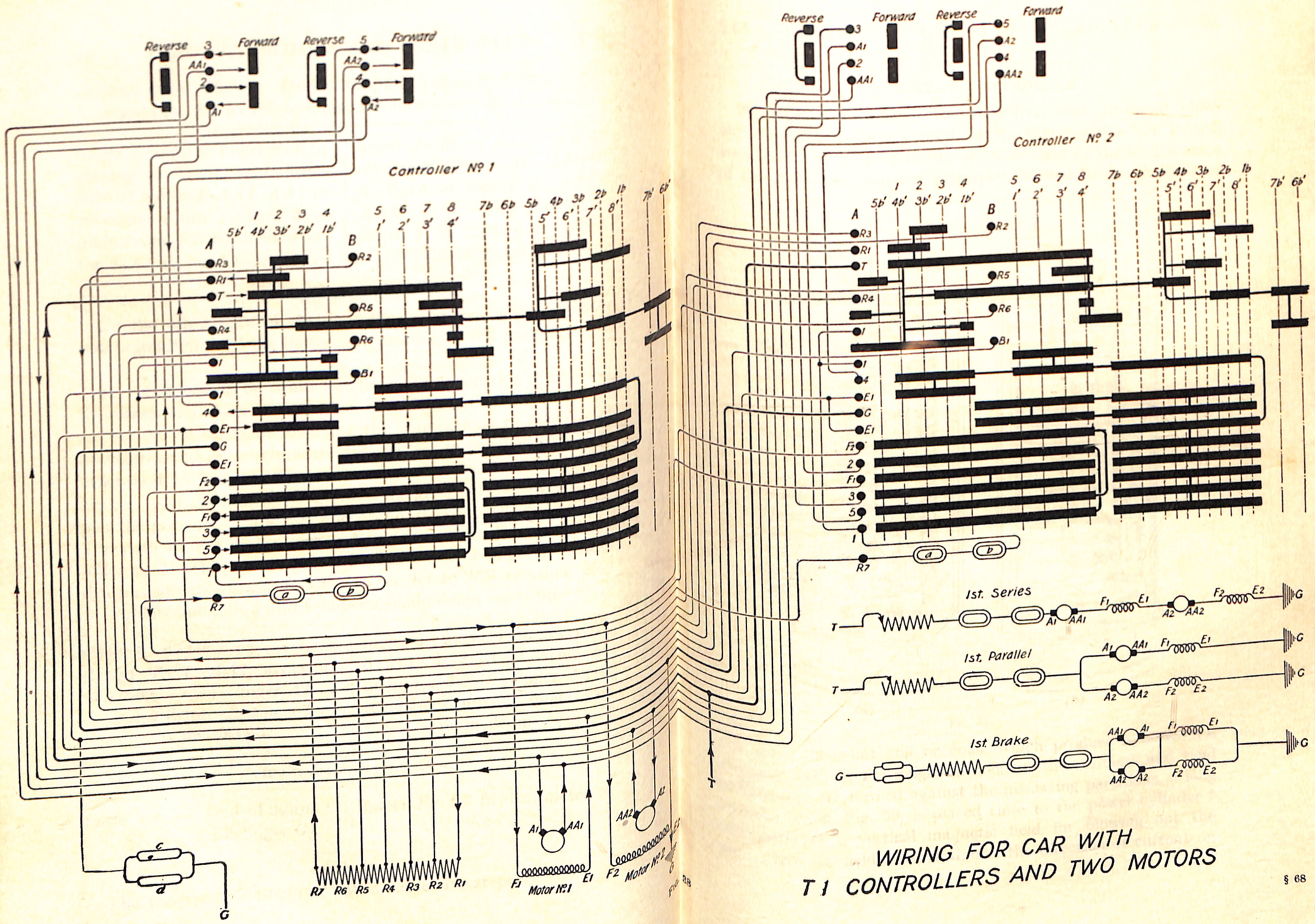
main drum segments–

finger *F1*–*F1*–field of motor *1*–*E1*–finger *E1*–finger *G*–

finger *F2*–*F2*–field of motor *2*–*E2*–

earth at *G*.

The resistance is then cut out in successive steps.



WIRING FOR CAR WITH T 1 CONTROLLERS AND TWO MOTORS

DICK-KERR CONTROLLER

92. Special Features.—The Dick-Kerr metallic-shield blow-out controller is largely used for traction work in the British Isles, and it is of special interest on account of the modification of the magnetic blow-out principle adopted in it. Instead of

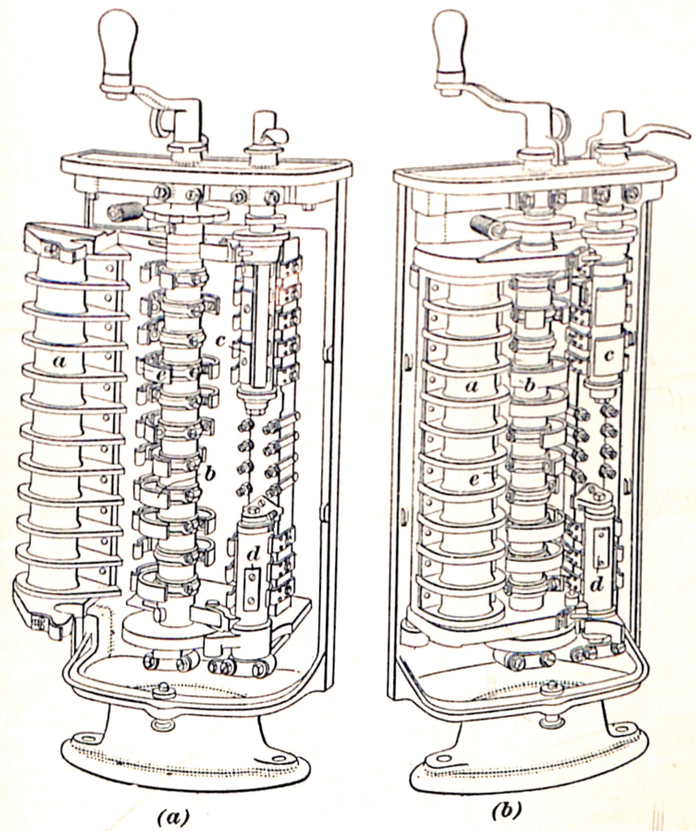


FIG. 39

the usual blow-out coil or coils, which produce a horizontal magnetic field in the neighbourhood of the contacts and tend to blow any arc formed against the insulating partitions, a long solenoid coil *a*, Fig. 39, is placed close to the power cylinder *b* and produces a vertical magnetic field for blowing out the arc. Since the field is vertical, and the direction of current on

breaking circuit between the contact fingers and segments is horizontal, the tendency will be to make the arc travel outwards horizontally from the point of the break in the circuit, until the arc is broken.

In view (*a*) the controller is shown with the solenoid and insulating partitions thrown back; in view (*b*) the parts are in their normal closed position. The reversing cylinder *c*, and a brake cylinder *d*, carrying separate contacts for reversing the armature connections of the motors when braking, are not provided with any blow-out devices, since the connections are not opened when the current is flowing. The contact fingers for the power drum are shown at *e*.

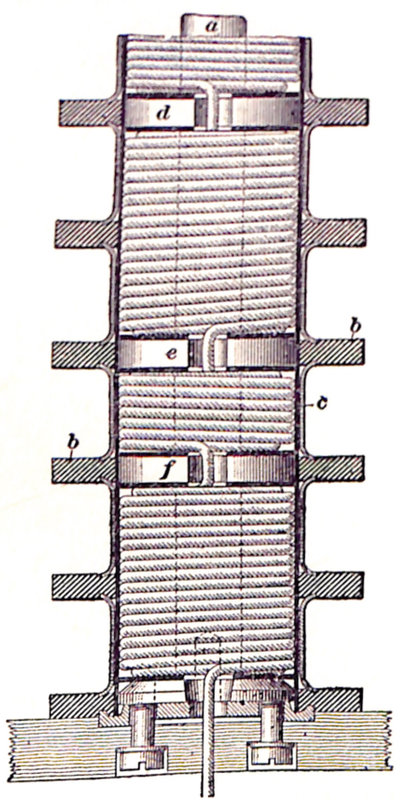


FIG. 40

93. Blow-Out Solenoid.—A vertical section of the blow-out solenoid is shown in Fig. 40. It consists of a coil of insulated wire wound on an iron core *a*. Insulating partitions *b* fit between adjacent fingers and segments of the controller, and between the partitions the solenoid is protected by cylindrical copper shields *c*. The winding is continuous from top to bottom of the solenoid and it carries the full trolley current; the blow-out effect is thus proportional to the strength of the current which is to be broken. Since the current passes between the fingers and contact segments in opposite directions, according to whether the current is entering or leaving the drum, the magnetic fields set up for each pair of contacts must be in the proper direction to drive the arc outwards. This condition is secured by winding

different sections of the solenoid coil in opposite directions; consequent magnetic poles are therefore induced at *d*, *e*, and *f*, etc., and the field between the insulating partitions is given the proper direction for each group of contacts.

94. Action of Blow-Out.—The operation of blowing out an arc formed between a finger and a contact segment is shown diagrammatically in Fig. 41. The solenoid is here shown in

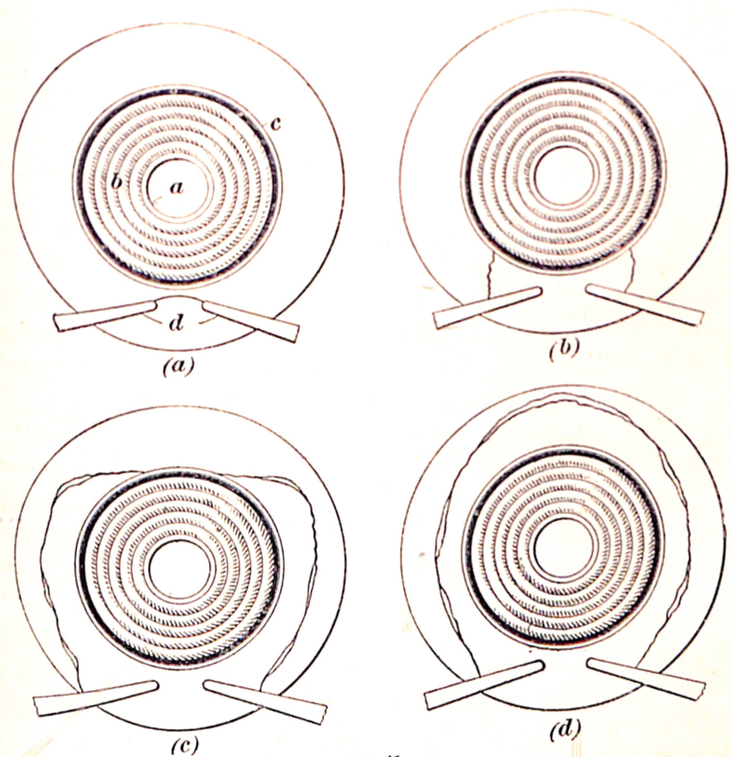


FIG. 41

section, where *a* is the iron core, *b* the winding, *c* the external copper shield, and *d* represents the tips of the finger and contact segment between which the arc is formed. As soon as the arc is formed, as shown in view (*a*), it commences to travel in the magnetic field outwards from the contact tips and toward the copper shield of the solenoid. In (*b*) the arc has reached the copper shield, and has divided, the copper shield carrying the

current as the arc lengthens. If the arc has not already been ruptured by the time it reaches the remote side of the solenoid, as shown in (*c*), it leaves the copper shield and continues to lengthen in the air, as shown in (*d*), until it does break. The whole action is in practice extremely rapid, and the arc sweeps across the copper shield and is extinguished so rapidly that the surface of the shield is uninjured.

REGENERATIVE CONTROL

USE OF SHUNT-WOUND TRACTION MOTORS

95. Principle of Regeneration. — The energy expended in speeding up a tramcar fitted with series motors is all absorbed by the brakes and dissipated as heat when the car is stopped. The only electrical methods of braking which are available with series-wound motors are the rheostatic- and magnetic-braking systems ; series motors cannot be made to return current to the line. Consider a car fitted with series motors descending an incline. As the speed of the car increases, the back E.M.F. of each motor increases and the current in the armature decreases, with the result that the field is weakened more and more as the speed of the car continues to rise. Since the back E.M.F. never becomes equal to the line P.D., the direction of the current never reverses and the car is not retarded by the motors.

96. If a tramcar fitted with shunt motors proceeds down-hill, the current in the armature gradually decreases, but there is no change in the field current, which remains constant. The current in the armature will continue to diminish as the speed increases, until the back E.M.F. of the motor exceeds the E.M.F. of the trolley wire, whereupon the current in the armature will reverse and the motor will run as a generator driven by the car, in parallel with the power-station generators, and will return current to the line. The work done by the car in supplying current to the line holds the car in check so that it cannot run away. If the shunt field is strengthened, the amount of current

returned to the line is increased, and results in an increased braking effect on the motors and car. The Raworth system is practically the only system of regenerative control which has been commercially successful in operation on British tramway lines, and the description which follows is based on the Raworth system.

97. Practical Results of Regenerative Working.—An important advantage in the use of regenerative control over the ordinary systems of series-parallel control is that of economy of energy. Instead of wasting all the kinetic energy stored in a moving car, by applying mechanical brakes, the regenerative control enables a portion of the energy to be saved by returning it to the trolley wire and assisting to drive other cars on the line. Compared with the ordinary series-parallel control using series motors, it is claimed that the regenerative system uses from 5 to 6 per cent. less energy when running under service conditions on level roads, and up to 30 per cent. less in hilly districts where the cars can return current to the line during long runs down-hill. Some economy results also in connection with the wear of the mechanical brake blocks on the car, since as much of the braking as possible is done electrically, and the mechanical brake blocks do not wear away and require renewal as frequently as with the ordinary system. As current flows in the motors during the whole time that the car is being driven or current is being supplied to the line, the motors used on the car must be of such size as will ensure that the heating of the motors is kept within moderate limits.

98. Series-Parallel Control of Shunt Motors.—In the Raworth system the motors are provided with series windings, across the terminals of which diverter resistances are connected, this winding coming into use on the parallel notches of the controller to give increased torque when the car is running at high speed. The Raworth controller is also arranged so that the circuit is broken during the transition from series to parallel, or vice versa, before any resistance is inserted in the armature circuits of the motors. In accelerating the car, this arrangement is of advantage, as the motors continue to run at the proper speed to drive the

car until the moment of breaking the circuit. In this way the back E.M.F. of each motor does not drop, and the difference of potential between the contact fingers and the segments of the controller drum is so small that there is practically no sparking. In switching from parallel to series, the circuit is broken before resistance is inserted in order to prevent sparking, which might otherwise occur if the speed of the motor should fall before the circuit was opened.

RAWORTH R6 CONTROLLER

99. The diagram in Fig. 42 shows the combination of the motors, resistances, etc., on the various notches of a Raworth R6

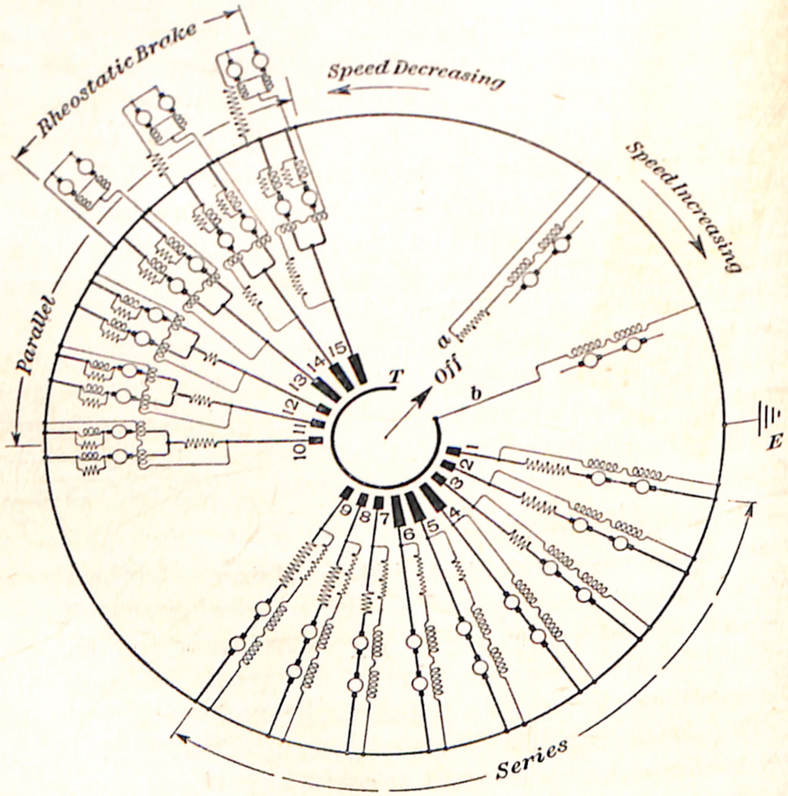


FIG. 42

controller arranged for series-parallel control of two shunt-wound motors. The outer circular ring of the diagram represents the

earth wire of the car, and the arrow in the centre of the illustration represents the controller handle, which is turned to the respective notches in order to complete a circuit from the trolley tapping *T* through the contacts and motors to earth at *E*.

In the off-position *a* the shunt-field windings of the two motors are in series with each other and with a shunt-field resistance, connected at this point as a discharge resistance. Before power is switched on to the motor armatures on the first notch, the shunt fields of the motors are fully excited on the transition notch *b* indicated in the diagram. The shunt windings of the two motors are permanently connected in series with each other.

100. Connections of Series Notches.—On notches *1*, *2*, and *3* the motor armatures are in series and series resistance is in circuit, the amount of resistance decreasing on successive notches. On notch *4* all the series resistance is cut out, and the shunt fields are fully excited; this notch gives a speed of from $3\frac{1}{2}$ to 6 miles per hour, according to the speed of the motor and the gear ratio adopted. On notches *5* and *6*, resistance is inserted into the shunt-field circuit to weaken the field and to further increase the speed. A special point in the arrangement of this controller is that when the controller handle is moving in a clockwise direction, notches *7*, *8*, and *9* are the same as notch *6*. Series resistance is needed on these notches on returning from parallel to the series connection; the method of bringing this about will be explained later.

101. Parallel Notches.—The motor armatures are switched out of series when no series resistance is in circuit, and are switched into parallel on notch *10*, with the shunt-field resistance cut out of circuit, and with series resistance and the series-field coil and diverter combinations switched into circuit. The succeeding parallel notches cause the series resistance to be cut out step by step, and the shunt-field resistance to be again inserted, for running at high speeds.

102. Rheostatic and Regenerative Braking.—The rheostatic-brake connections, notches *13*, *14*, and *15*, in Fig. 42, provide for short-circuiting the motors as series-wound machines by the starting resistance, in the ordinary manner. By means of the

special arrangement of the contact segments on the main controller drum, the running notches *13* to *15* become rheostatic-braking notches when the controller handle is moved to them from the off-position. Apart from this special arrangement of notches *13* to *15*, every notch on the controller corresponds to a definite speed of the car. On any given notch, since the flux of each motor is constant, the speed of the car will remain nearly the same under practically all conditions. If the car runs from the level on to a rising incline, the current taken by the motors increases to supply the extra power required. If the car runs down-hill, the motors return current to the line and the car is prevented from largely exceeding its normal speed by the braking effect obtained. The steeper the gradient the greater is the current that will be returned to the line and also the greater will be the braking effect on the car. If the driver desires to reduce the speed of the car, the controller handle is simply moved to a lower notch, and the current returned to the line and also the braking effect are increased without locking the car wheels. To ensure that there is no resistance in the armature circuit when the motors are switched out of parallel and into series, the connections on notches *11* and *10*, when the controller handle is rotated in a counter-clockwise direction, are the same as on notch *12*.

CAR WIRING FOR R6 CONTROLLERS

103. Power-Wiring Diagram.—A diagram of connections of the R6 regenerative controller is given in Fig. 43. In addition to the main power drum *a*, which carries contacts for 15 controller positions, there are a reverse drum *b*, with forward and reverse positions, and a brake drum *c*, which is normally closed in the running position, but may be placed in the brake position for rheostatic braking. Leads from the various motor windings and resistances are brought into the controller to a connection board *d*. The current from the trolley wire normally flows in the direction of the arrows, through an automatic overload circuit-breaker *e*, automatic potential switch *f*, the main fuse *g*, and kicking coil *h* to the trolley terminal *T* on the connection board and finger *T* on the brake cylinder *c*. The lightning

WIRING DIAGRAM OF R6 REGENERATIVE CONTROLLER WITH TWO MOTORS

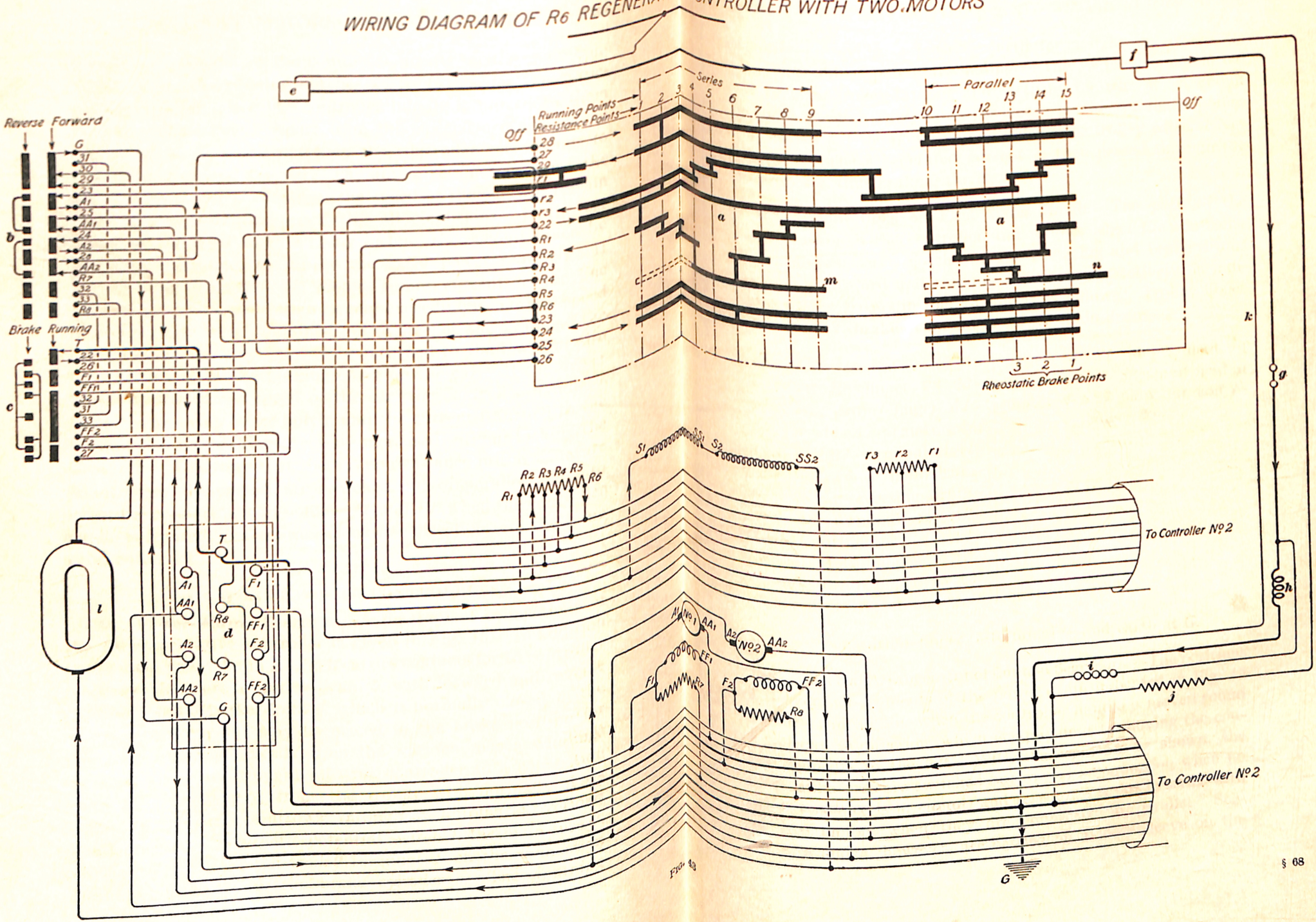
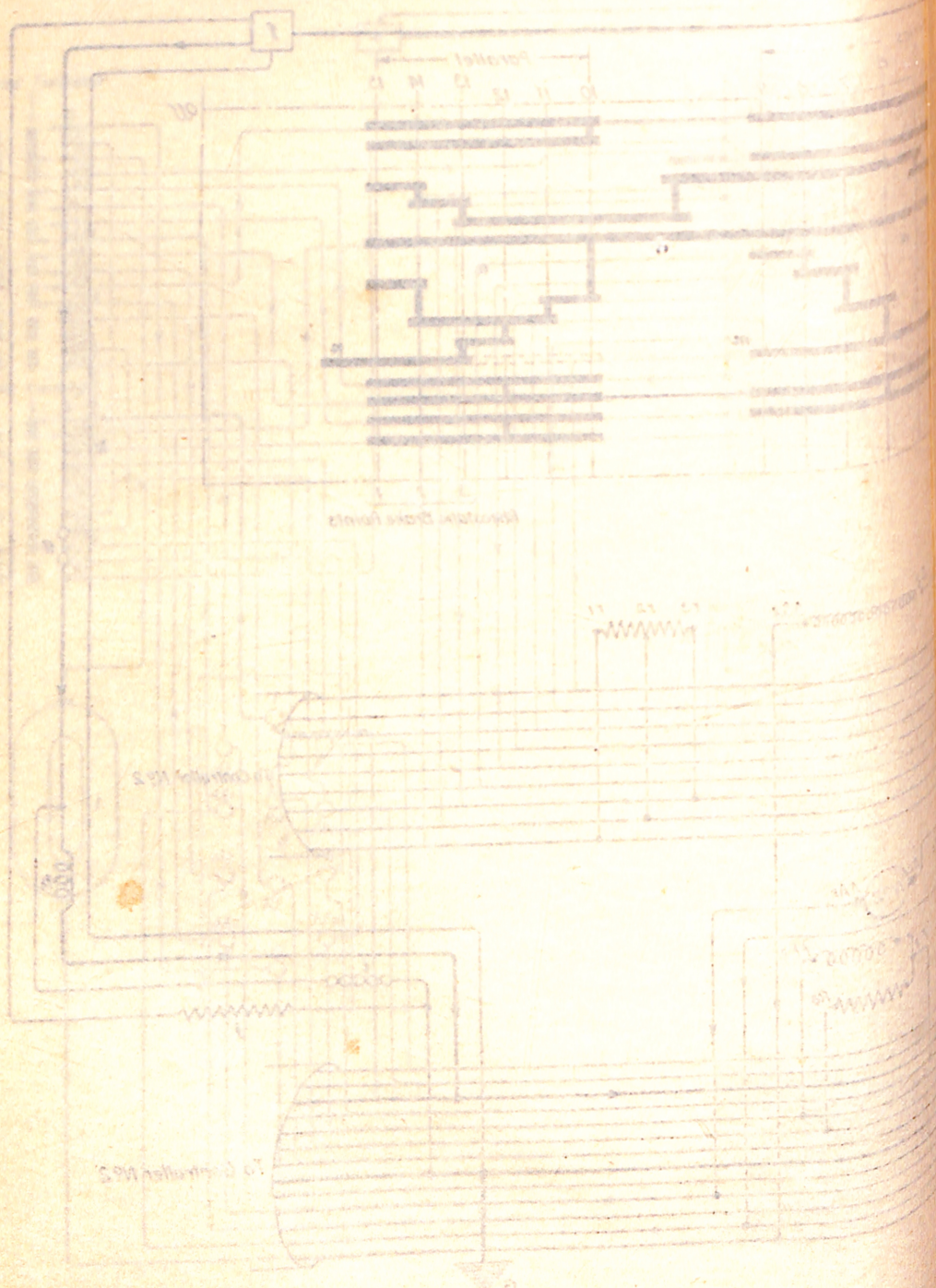


Fig. 43



arrester *i* provides a path to earth for a lightning discharge. The trip coil or potential winding of the switch *f* is connected between the trolley tapping and earth by the wire *k*. A circuit to earth through a resistance *j* is closed by the automatic potential switch *f* if the power supply fails or the trolley wheel leaves the wire. The regenerated current is then passed through the resistance *j*, thus braking the car.

104. Connectio..s on First Series Notch.—The path of the current through the controller and motors when the controller is on the first series notch and the reversing and brake drums are in the forward and running positions, respectively, is indicated by the arrows in Fig. 43, and is as follows: Trolley finger *T*–brake drum–finger *22–22*–main drum–finger *R2*–resistance *R2* to *R6*–finger *R6*–finger *23–23*–reversing drum–finger *A1*–terminal *A1–A1*–armature of motor *1*–*AA1*–terminal *AA1*–finger *AA1–25–25*–main drum–finger *24–24*–reversing drum–finger *A2*–terminal *A2–A2*–armature of motor *2*–*AA2*–terminal *AA2*–finger *AA2*–reversing drum–finger *28–28*–main drum–finger *29–29*–finger *r3–S1*–shunt field of motor *1*–*SS1–S2*–shunt field of motor *2*–*SS2*–blow-out coil *l*–finger *30*–reversing drum–finger *G*–terminal *G*–and earth at *G*.

105. Special Arrangement of Contact Segments.—The positions of the contact segments of the power drum indicated in Fig. 43 are those which occur when the controller handle is moved round in a clockwise direction, which is equivalent to moving the contact segments to the left. With the segments as shown, the motor armatures are switched out of series connection when no series resistance is in circuit, and resistance is put in series with the two motors when they are connected in parallel. Segments *m* and *n*, however, are carried on a loose sleeve on the

controller shaft and are driven by a pin working in a slot, so that when the controller handle is turned in a counter-clockwise direction, equivalent to moving the controller contacts to the right, the loose segments hang back while the controller handle is moved over three notches, and on succeeding notches occupy the positions shown by the dotted lines. The effect of this special arrangement is to short-circuit the series resistance on notches *12*, *11*, *10*, *3*, *2*, and *1*, so that the armature circuit can be opened when the motors are switched out of parallel, and when the controller is returned to the off-position from notch *1*, with no resistance in the armature circuit.

106. Connections for Rheostatic Braking. — When the controller handle is moved in a counter-clockwise direction to the rheostatic brake notch *1*, the reversing drum being in the forward position and the brake drum on the brake notch, the path of the current is as follows: Earth at *G*–terminal *G*–finger *G*–reversing drum–finger *31*–brake drum–

finger *F1*–terminal *F1*–*F1*–series field of motor *1*–*FF1*–terminal *FF1*–finger *FF1*–

finger *F2*–terminal *F2*–*F2*–series field of motor *2*–*FF2*–terminal *FF2*–finger *FF2*–

brake drum–

finger *26*–*26*–main drum–finger *25*–*25*–reversing drum–finger *AA1*–terminal *AA1*–*AA1* armature of motor *1*–*A1*–terminal *A1*–finger *A1*–reversing drum–finger *23*–*23*–

finger *27*–*27*–main drum–finger *28*–*28*–reversing drum–finger *AA2*–terminal *AA2*–*AA2* armature of motor *2*–*A2*–terminal *A2*–finger *A2*–reversing drum–finger *24*–*24*–

main drum–finger *R6*–series resistance *R6* to *R2*–finger *R2*–main drum–finger *22*–brake drum–finger *31*–*31*–reversing drum–finger *G*–terminal *G*–earth at *G*.

On the second brake notch *2* finger *R4* makes contact with a segment of the main drum and short-circuits all the resistance excepting that between *R6* and *R4*. On the third braking notch *3* all the resistance is short-circuited.