radius of the curve, the less difference does it make what the wheel base is. It is evident, then, that in laying out a road, all the curves should be made of as great a radius as possible; and in buying trucks for a road already installed, the radii of existing curves should be consulted. To enable cars to round curves with the least effort and to save the rails and flanges, curves should be kept clean and well greased. Other points to be considered are in regard to the treads and flanges of the wheels; on them depends very much the ease with which a car will take a curve. The treads should not be so wide that they run on the paving outside of the track, and the shape, depth, and width of the wheel flange should be governed by the shape, depth, and width of the rail groove.

ELECTRICAL EQUIPMENT.

8. The electrical equipment of a trolley car includes several different devices. Some of these, such as the motors, controllers, etc., are concerned directly with the operation of the car. Others—for example, the lightning arrester, fuse box, and hood switches—are more in the line of protective devices. Before considering these various parts in detail, we will glance briefly at the general equipment of a car by referring to Fig. 5. This shows an ordinary 18- or 20-foot car with the details of the truck omitted, in order to show the location of the motors m, m_1. Practically all trolley cars are equipped with at least two motors, and many of the larger cars using double trucks are equipped with four motors. The method of speed control now in use requires at least two motors, as will be shown later. The two motors m, m_1 are hung on the inside of the two axles and geared to them as shown at a, a_1. The speed of the motors, and hence that of the car, is controlled by means of the two **controllers** c, c_1 mounted against the dash irons i, i and operated by the handles n, n_1. When starting the car, it is necessary to insert resistance in the circuit to prevent too great a rush of current. This resistance is only in a short time and is not supposed to be used when the car is under headway. The **resistance boxes** *r* are hung under the car, wherever there is the most room for them, usually about in the location indicated, for an ordinary single-truck car. The **lightning arrester** *LA* and **fuse box** *FB* are generally attached to the under side of

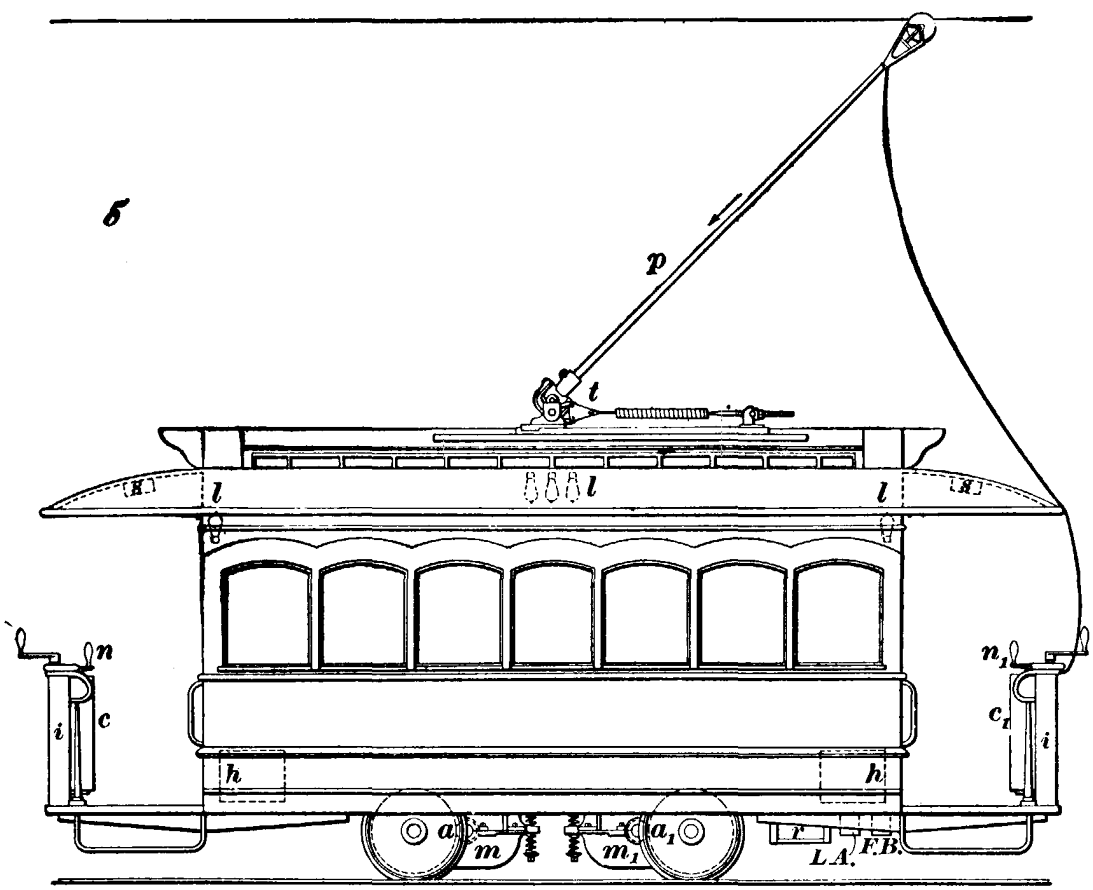


FIG. 5.

the car sill. The **hood switches,** or **canopy switches,** are mounted under the hood, as shown at *s*, *s*. In case circuit-breakers are used in place of ordinary hood switches, they are generally placed at *s*, *s* and the fuse box is dispensed with. The **trolley pole** *p* is attached to the **trolley base** *t*, which is secured to the top of the car. The car is lighted by lamps *l*, *l*, *l* and is heated by means of electric heaters *h*, *h* placed under the seats.

METHODS OF CONTROL.

9. It has already been shown that the speed of a motor may be controlled by inserting resistance in series with the armature, thus cutting down the E. M. F. applied to the machine. Before going any farther, it will be well to lay stress on the points that trolley cars are supplied with current at approximately constant pressure, also that the motors used are invariably series-wound. In other words, the armature and fields are in series with each other and the current that flows through one flows through the other also. Shunt motors and compound-wound motors have never been used to any extent for street-railway work.

RHEOSTATIC CONTROL.

10. Since the speed of a series motor run from constant-potential mains may be regulated by inserting a resistance in series with it, the first method adopted for regulating the speed of cars was to mount a **rheostat,** or variable resistance, under the car and have things arranged so that this resistance could be cut in or out by means of the controller at either end of the car. This is known as the **rheostatic** method of control. It can be used with one or more motors, but it is now very little used for regular street-railway work, because it is wasteful of power, especially at the lower speeds. It has, however, some advantages, and it is used in those cases where only one motor is to be controlled and where gradual variations in speed are desired. It is used quite extensively in connection with mine-haulage plants and hoisting apparatus; also for any cars operated by a single motor; but its application to regular street-railway work is now very limited.

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

11. Old-Style Thomson-Houston Rheostat.—When the rheostatic control was first introduced, a rheostat similar to that shown in Fig. 6 was used. The figure shows the device upside down from the position it occupies on a car. *F*, *F*, *F* are feet cast on the frame; these feet are drilled and provided with insulating bushings, through which pass the three bolts that secure the frame to the under part of the platform. *T* is a drum on which works a chain attached to a sprocket wheel connected to a rod on the upper end

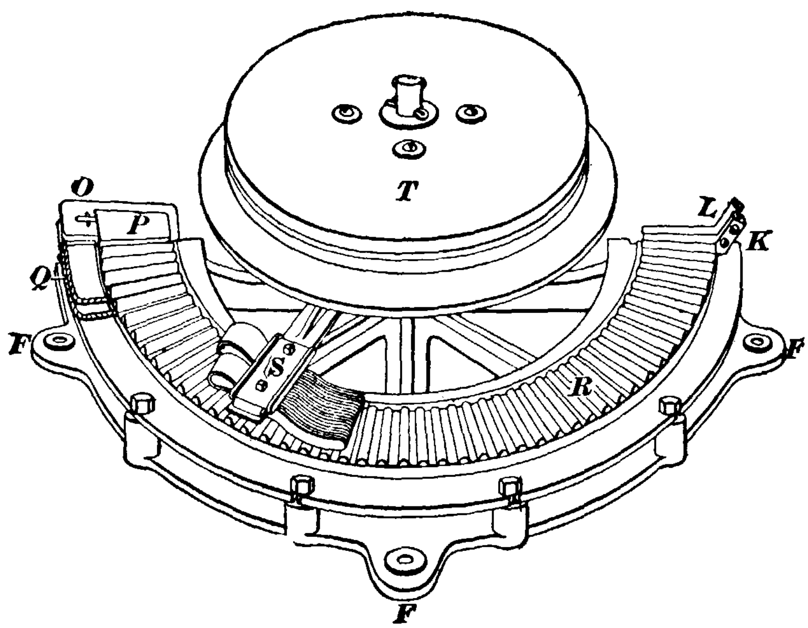


FIG. 6.

of which rests the controller handle. The sprocket wheel is smaller than the drum, so that in order to move the trolley contact shoe *S* from the off-position *O* to the on-position *L*, it is necessary to give the controller handle from two to three complete turns. This insures a smooth handling of the car and makes the controller easy to work. *R* is the resistance, which is made up of stampings of sheet iron insulated from one another by sheets of mica. The iron stampings are not entirely insulated from one another, but are sufficiently longer than the mica sheets to allow their ends to touch, thus forming a continuous band of metal with several hundred joints in it; the radial rib-like-looking segments sticking up so plainly are iron castings built up with the stampings and mica plates, and are provided in order that the shoe *S* may make good contact. At (*a*), (*b*), and (*c*), Fig. 7, are shown, respectively, the iron stamping, the mica plate, and the cast-iron contact rib. *K*, Fig. 6, is a copper rib that marks the position in which the shoe cuts all resistance out of the rheostat; *L* is a second copper rib that cuts a shunt into circuit as soon as it makes contact with the shoe. These two ribs *L* and *K* are made of copper to improve the shoe's contact in the final or running position, the two forming a kind of copper cradle for the iron shoe to rest in. *P* is an iron contact plate at the off-position, to improve the magnetic circuit excited by the blow-out coil *Q*, and is provided to extinguish the arc that occurs when the current is shut off.

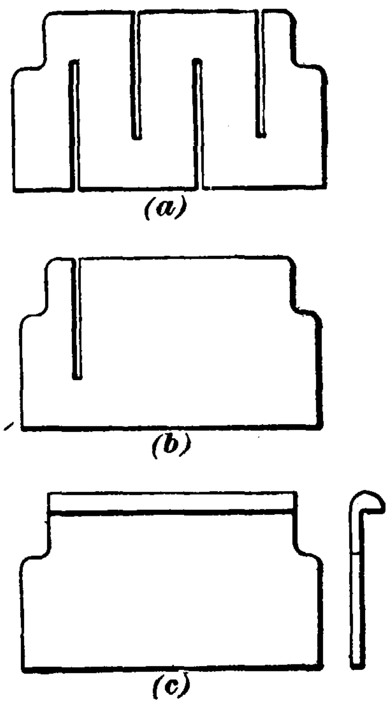


FIG. 7.

12. In addition to the rheostat, it is necessary to provide a reversing switch, so that the direction of motion of the car can be reversed when desired. Fig. 8 shows the connections for simple rheostatic control using an ordinary **reverse switch,** as the reversing switch is commonly called. This switch is operated by a handle on each platform, and the reverse switch and its connections should always be arranged so that when the handle of the reverse switch points "ahead," the car will move ahead, and *vice versa*. In Fig. 8, *T* is the trolley; *F B*, the fuse box; *L A*, the lightning arrester; *T'*, the trolley connection on the rheostat; *S*, the contact shoe that makes contact first with plate *P*, and can be moved around on resistance *R* between the limits of plate *P* and terminals *K* and *L*; *F* is the motor field; *X*, the reverse switch, to the two top binding posts of which the armature *A* is connected; *G* is the ground wire, to which are connected the ground splices from the reverse switch and from the lightning arrester. When *S* makes contact with *P*, the ordinary path of the current is *T–F B–L A–T′–S–P–R–K–F–2–3–A–4–1*, through the ground wire, to the ground at *G*. If the rheostat arm is turned around until the shoe *S* reaches the dotted position *S′*, and that part of the resistance that has been passed over, marked *r*, cut out, a larger current passes through the motor, making

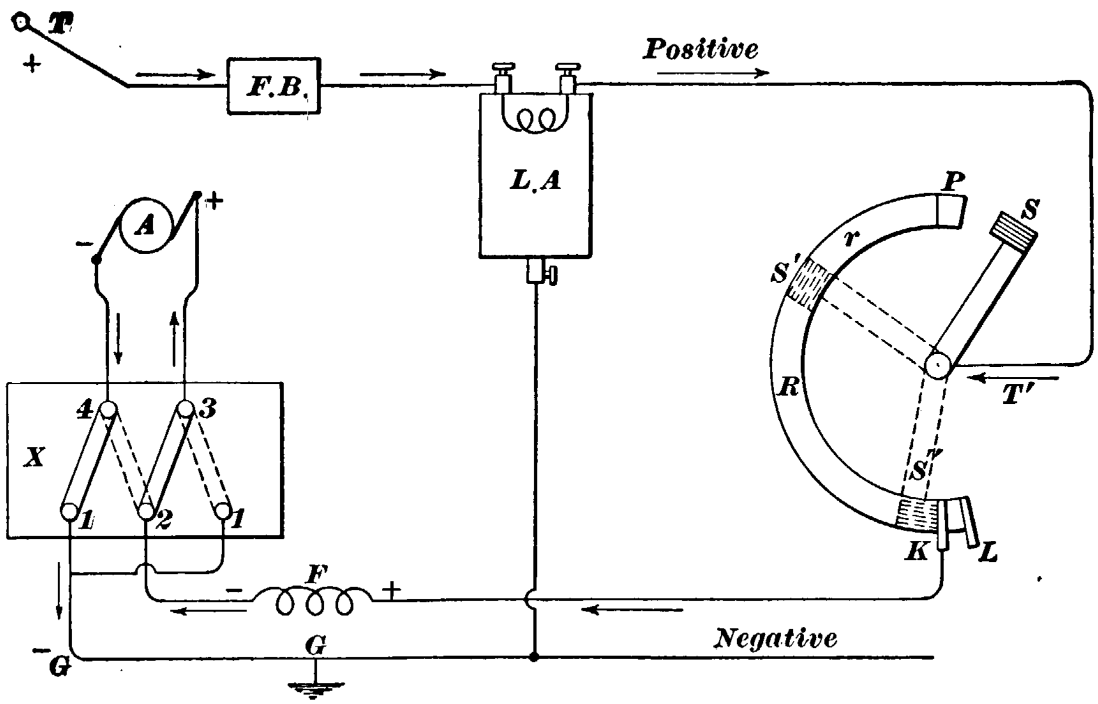


FIG. 8.

it run faster and giving the car greater speed; if the contact shoe is still farther advanced until it reaches the dotted position *S″* and touches the contact plate *K*, all the resistance in *R* is cut out, the path of the current is *T–F B–L A–T′–S″–K–F–2–3–A–4–1* to *G*, and the motor runs at its greatest speed. If the reverse switch *X* is moved over to the dotted position, it is easily seen that the direction of the current through the armature will be reversed, while that in the field will remain the same. The direction of motion will, therefore, be reversed, because it must be remembered that in order to reverse the direction of motion of a motor, either the field or armature may be reversed, but not both. It would do just as well to reverse the current through the field and leave that through the armature the same, but it is generally the practice to reverse the current in the armature.

13. Shunt Control.—The method of control shown in Fig. 8 is sometimes called **full-field control,** in order to distinguish it from what is known as **shunt control.** In Fig. 8, when the car is running at its highest speed, all the resistance is cut out and all the current flows through the field *F*. If a still higher speed is desired, it can be obtained by weakening the field of the motor. The weaker the field, the faster an armature has to run to generate the counter

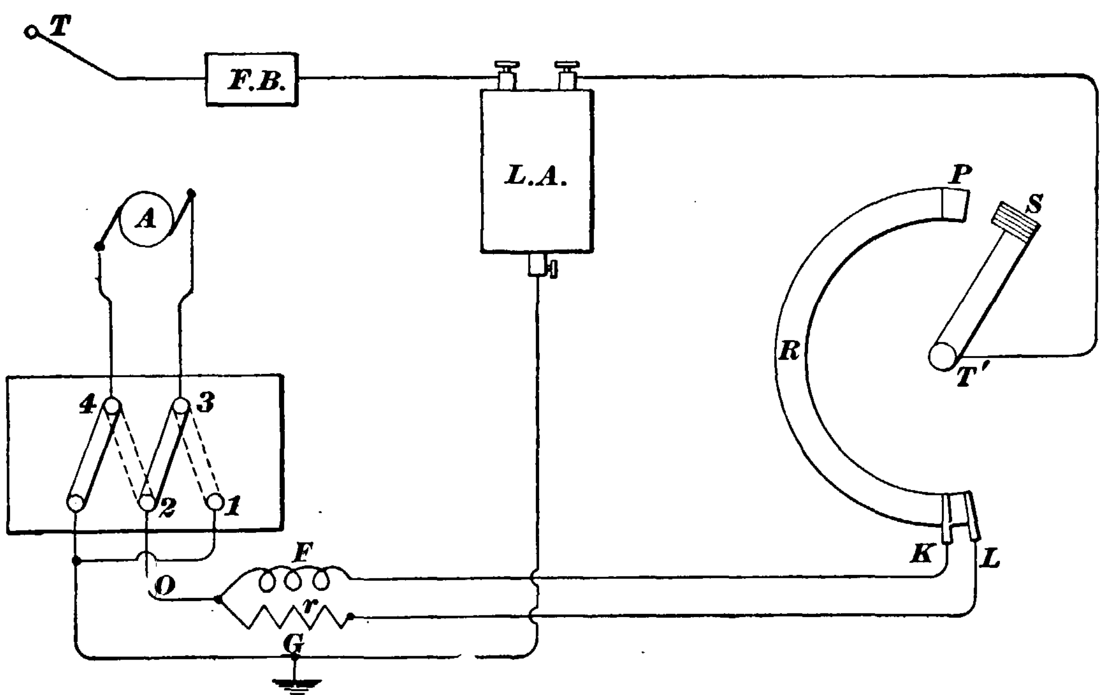


FIG. 9.

E. M. F.; hence, weakening the field increases the speed, but the motor, of course, takes more current. This weakening can be accomplished either by cutting out part of the field turns or by placing a resistance in shunt with the field, thus depriving the field coils of part of the current.

Fig. 9 shows the connections of the shunt method of control as carried out by means of a rheostat. Here a resistance or shunt *r* is connected to one terminal of the field, and the other end is connected to plate *L* on the rheostat.

When the shoe rests on both *K* and *L*, the current, in order to get to point *O*, passes through two paths that are in multiple; path *K–F–O* includes the field and path *L–r–O* includes the shunt. As the shunt generally measures about three times as much as a warm field, it takes away from the field one-fourth the total current. It must be borne in mind that the final result of bringing the shunt into action is to increase the speed of the car, and the car cannot be made to go faster under given conditions without being furnished with more power; this increase in power is provided by the increase in the current due to the weakening of the motor field by the shunt. The use of shunts was at one time quite common, but it is not so generally followed now. The latest equipments are not provided with shunts, because it is found that all the speed control that is necessary can be obtained without them, and their use only leads to complication and opens up chances for trouble.

14. Use of Platform Controller.—The old-style rheostat, Fig. 6, was soon replaced by the platform controller. It was found that the movable arm on the rheostat under the car gave considerable trouble, so the next step was to place the resistance itself under the car and run wires from it and the motors to a controller placed on the platform. The controller is a device for cutting out the resistance or for effecting any combinations necessary for the control of the speed. Many kinds of controllers are made to meet different conditions of service. Fig. 10 shows how the movable arm of the rheostat may be replaced

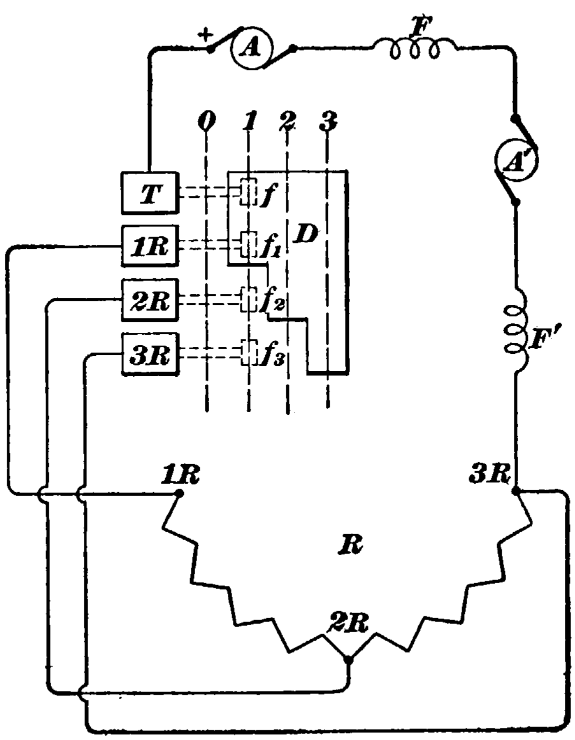
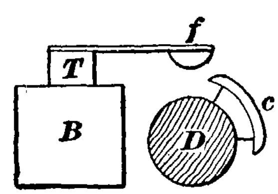


FIG. 10.

by a simple controller and also how the cutting out of resistance is effected. *R* is a resistance divided into two parts; one part lies between *1 R* and *2 R* and the other part between *2 R* and *3 R*; *F* and *A* are the field and armature, respectively, of a dynamo that is to furnish the current for running the motor whose field and armature are *F'* and *A'*; *D* is a round casting fitted on a wooden drum provided with an iron shaft that turns in bearings. This casting is here shown as straightened out flat, although it is really cylindrical in shape. *T*, *1 R*, *2 R*, and *3 R*, in the upper part of the figure, are brass finger stands, on each of which is a finger, hanging over *D*, as indicated by the dotted lines and marked in the figure f, f_1, f_2, f_3. A wire is connected to each of the finger stands. Stand *T* is connected to the trolley wire; stands *1 R*, *2 R*, and *3 R* are connected to the resistance coil at points marked with the corresponding letters. On this controller there are four notches, indicated by the dotted lines, marked *0*, *1*, *2*, *3*. The line marked *0* denotes the off-position, and no current can pass through the circuit, because the trolley finger f hangs in the air, as shown in Fig. 11 (*a*), without touching the contact plate *c* mounted on the drum *D*. Dotted line *1* denotes the first notch, and fingers f and f_1 touch the contact plate on drum *D*, as shown in Fig. 11 (*b*). The circuit being, therefore, closed, the current can flow through the path $A–T–f–D–f_1–1R–1R–2R–3R–F'–A'–F–A$. Dotted line *2* denotes the second notch where the drum is turned until finger f_2 makes contact; the path of the current is then $A–T–f–D–f_2–2R–2R–3R–F'–A'–F–A$. On the second notch, when the current gets to drum *D*, it finds two paths by means of which it can reach point *2 R* on the resistance coil; one path is $f_1–1R–1R–2R$, and the other path is $f_2–2R–2R$. The first path has a part of the resistance coil in it and the second path (i. e., car wire *2 R–2 R*) has very little resistance. Wire *2 R–2 R* then short-circuits the *1 R–2 R* part of



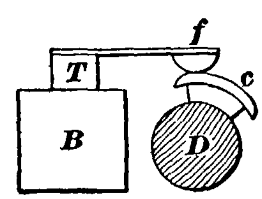


FIG. 11.

the resistance. When the drum is turned another notch, and finger f_3 comes into contact, the path of the current is $A-T-f-D-f_3-3\ R-3\ R-F'-A'-F-A$. Wire $3\ R-3\ R$ short-circuits the whole resistance in R and the motor runs on full field directly across the line, just as it does in Fig. 8, when S touches K. This controller gives a means of cutting out resistance, but the cutting out is not as gradual as where the rheostat arm is used. It is found, however, in practice that three or four resistance notches are sufficient to give a car a smooth start if the controller is handled properly.

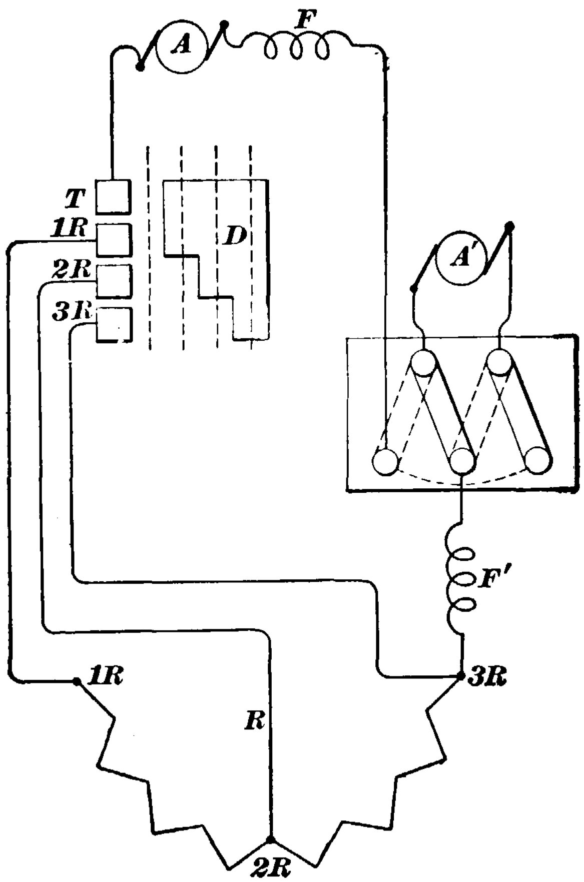


FIG. 12.

15. Fig. 12 shows how an ordinary reversing switch might be used with a simple controller of this kind. However, in modern controllers it is the practice to have the reversing switch also made in the form of a drum and to mount it in the same case with the power drum.

RHEOSTATIC CONTROLLER.

16. General Construction.—Fig. 13 shows a modern type of rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors. This controller is considered somewhat in detail because it contains many of the features found on controllers used on street cars and will serve as a good introduction to the study of them. The controller shown in Fig. 13 is designed to handle one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor, i. e., its contacts are large enough to handle about 75 amperes. The figure shows the cover *A* thrown back so as to expose the working parts. This controller is of the *magnetic blow-out type*, and is known as a type R controller because it uses rheostatic control. In the General Electric

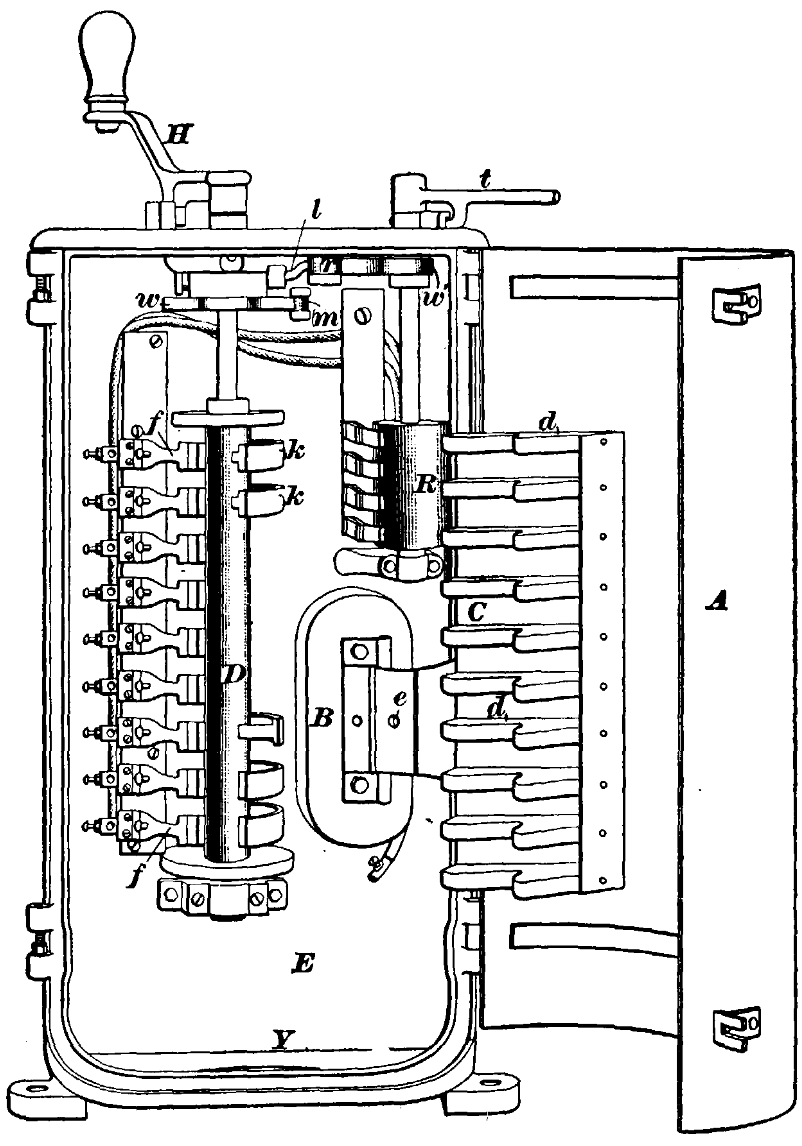


FIG. 13.

Company's controllers, a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning. This method of preventing arcing has proved very effective. *B* is the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the **blow-out coil.** The iron back of the controller forms one pole piece and the polar extension *C* the other. Pole piece *C* is shown swung back so as to give access to the **power drum** *D*. When the controller is in use, the pole piece *C* is swung over and held in position by a bolt passing through hole *c*. Fig. 14, although not drawn to scale, will give an idea as to the relation of the pole piece *C*, drum *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are **arc guards,** and are made of vulcabeston (vulcanized asbestos); they pass between the contact arcs and prevent arcing between the contacts. The whole of the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines.

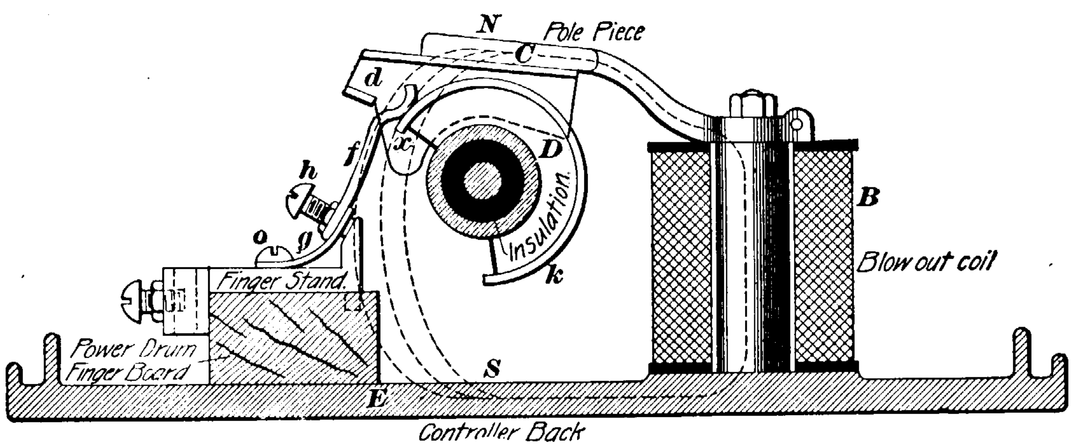


FIG. 14.

When the drum is revolved far enough, the tip *x* of contact arc *k* leaves finger *f* and an arc tends to form. This arc acts in the same way as a flexible wire carrying current, i. e., it is forced across the field just as the conductors on the armature of a motor are forced to move on account of the reaction of the magnetic field set up around the wire on the field supplied by the field magnets. In this case, the arc is 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 contact arcs. The fingers *f* are stamped out of thick copper and are fastened 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 may be replaced at any time. The screw *h* is for adjusting the amount that the finger drops when the drum passes from under it. This affects the pressure with which the fingers press on the drum, and they should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. The contact arc *x k* should frequently be rubbed with a little vaseline so as to prevent wear and cutting.

17. Star Wheel, or Index Wheel.—The power drum is operated by means of the power handle *H*, Fig. 13, which fits on the top of the power-drum shaft. In order to compel the power drum to take up a definite position corresponding to the various steps, it has a **star wheel,** or **index wheel,** *w* attached to the shaft. This engages with a spring-actuated roller *m*, which is pulled into the various notches on the star wheel and forces the drum into its proper position. It is this star wheel and roller that gives the movement of a controller handle its springy feeling.

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

19. Interlocking Device.—In order to make sure that the reverse switch shall not be moved while the current is on, the controller is provided with an interlocking device, that makes it impossible to move the reverse drum unless the power drum is at the off-position. The reverse drum shaft is provided with a star wheel *w'* having three notches, corresponding to the off-, ahead-, and back-positions. The lever carrying the roller *r* that engages this star wheel has a link l attached to it, which runs across to the hub of the star wheel w. The hub of w has a notch in it that comes opposite the end of l when the power drum D is at the off-position, and when the reverse handle t is moved, the end of link l is forced over into the notch until the roller r passes over the projection on the star wheel w', when l falls back far enough to allow D to be turned. At any position of D other than the off-position, there is no notch opposite the end of l; hence, when an attempt is made to move t, the link l comes up against the hub and the reverse drum is locked.

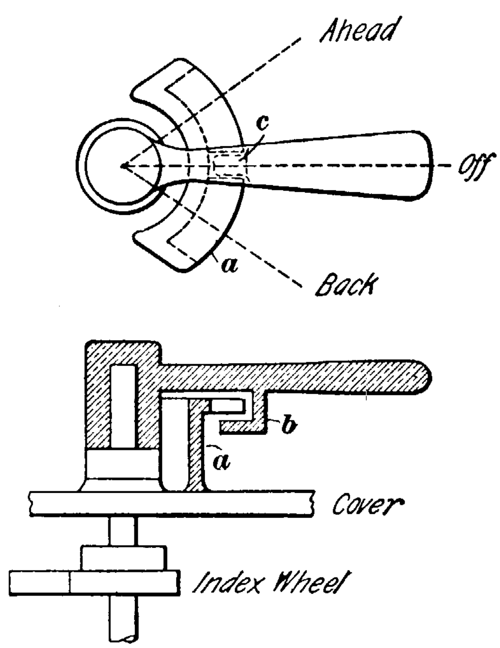


FIG. 15.

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

The reverse handle is also arranged so that it cannot be removed until the power drum is at the off-position. An L guard a, Fig. 15, is cast on the controller cap and overhangs a hook b cast on the handle. A notch c is cut in the guard, so that the handle can be lifted off at the off-position and no other.

One of the principal reasons for this interlocking arrangement is to make sure that the motorman will not reverse the motors while the power is on. In time of danger, the first thing the motorman would naturally do would be to reverse or "plug" the motors. If this were done, the counter E. M. F. of the motors, instead of opposing the line E. M. F., would be added to it and would assist the line E. M. F. in forcing an exceedingly large current through the motors, and, to make matters worse, there would be no resistance in series with the motors. The effect would be the same as a very bad short circuit; in all probability the main fuse would be blown, thus leaving the car helpless, so far as reversing the motors is concerned. If the cylinders interlock, the motorman first has to throw off the power, then throw the reverse switch. When the power is thrown on again, the resistance will be cut into circuit and there will be much less danger of damage being done.

20. Operation of Rheostatic Controller.—The foregoing will give the student an idea as to the mechanical construction of a controller of this type. The controller has

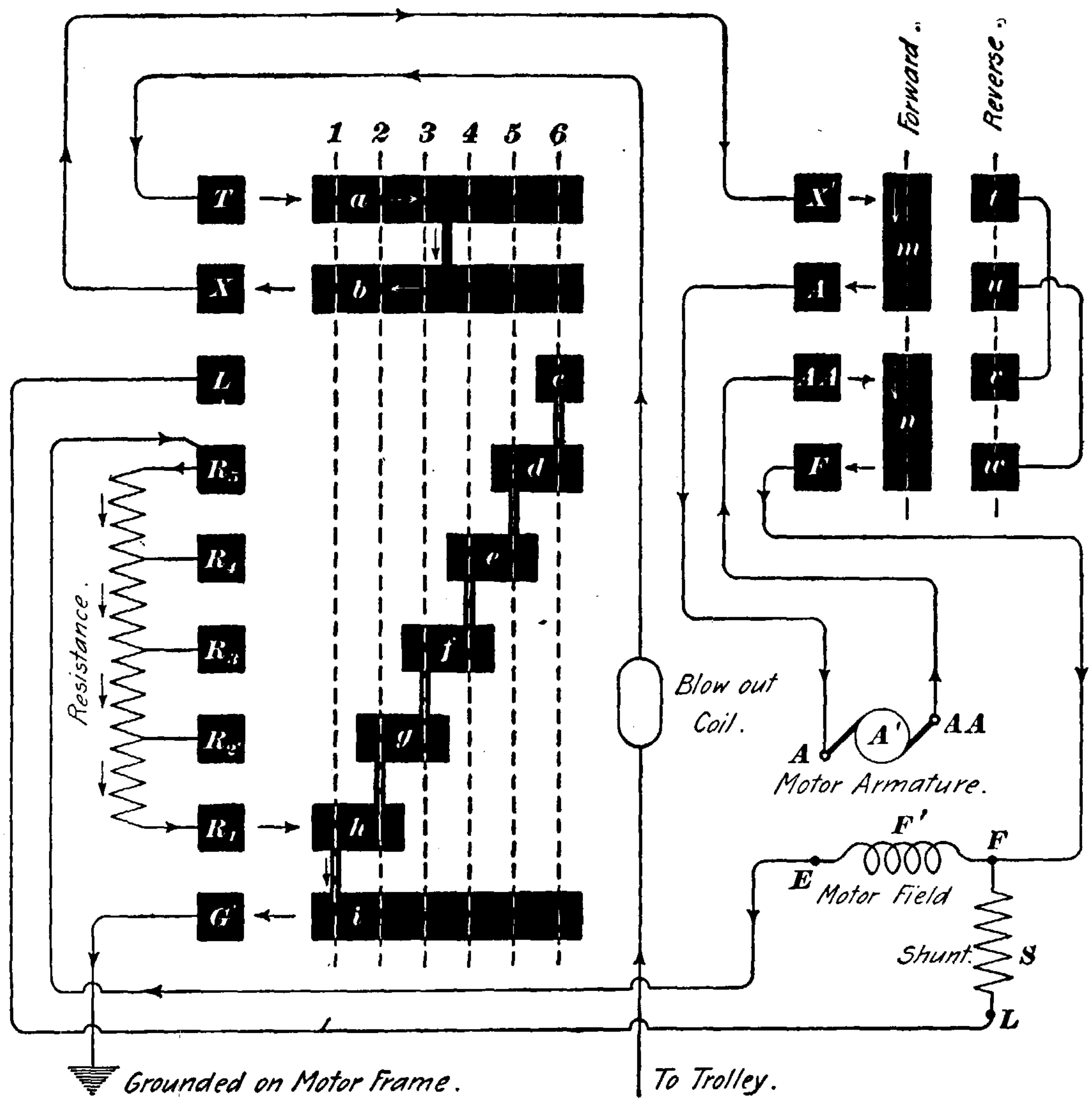


FIG. 16.

six points, and a development of the drum with the various connections is shown in Fig. 16. This diagram shows a single motor, of which A' and F' are the armature and field, respectively. It is operated by a single controller. In this

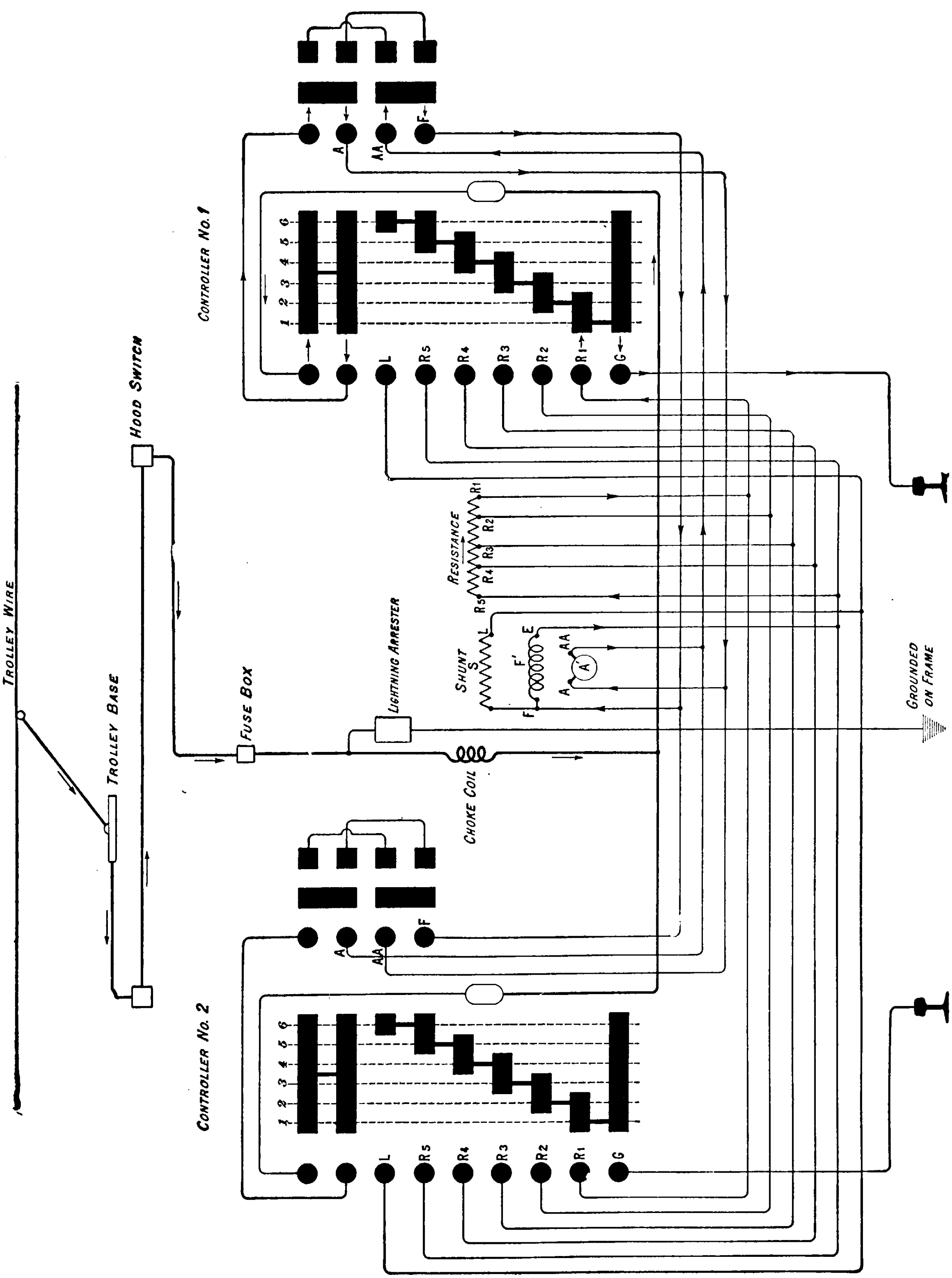

Trolley Wire
Trolley Base
Hood Switch
Fuse Box
Lightning Arrester
Choke Coil
Resistance
Shunt
Grounded on Frame
Controller No. 1
Controller No. 2

Fig. 17.

controller figure and in those to follow, the drum contact arcs are indicated by black bands, which represent the arcs straightened or developed out flat. The finger stands on the power drum, and on the reverse drum connection boards are represented by the row of square black spots. The vertical dotted lines represent the various positions of the drum. Note that the drum is in two parts. Contact arcs *a* and *b* are connected together, but these two are insulated from *c*, *d*, *e*, *f*, *g*, *h*, and *i*, which are all connected together, because they constitute a single casting. On the first notch, fingers *T*, *X*, R_1, and *G* make contact with their respective arcs. All the others hang over and touch nothing.

The path of the current on the first notch is indicated by the arrows, and is as follows: Trolley–blow-out coil–*T*–*a*–*b*–*X*–*X'*–*m*–*A*–*A*–armature *A'*–*AA*–*AA*–*n*–*F*–*F*–field *F'*–*E*–R_5–through the whole of the resistance–R_1–*h*–*i*–*G* to ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger R_2 touches arc *g*, and when the current reaches R_5, it flows through three sections only of the resistance, because when it reaches R_2, it takes the path R_2–*g*–*h*–*i*–*G*. On the third notch, the section of resistance between R_2 and R_3 is cut out. On the fourth notch, that between R_3 and R_4, and on the fifth notch all the resistance is cut out, and the path of the current is: trolley–blow-out coil– *T*–*a*–*b*–*X*–*X'*–*m*–*A*–*A*–*A'*–*AA*–*AA*–*n*–*F*–*F*–*F'*–*E*–R_5–*d*–*e*–*f*–*g*–*h*–*i*–*G*. The fifth notch, then, gives the highest speed that can be attained by simply cutting out resistance.

On this controller a shunt *S* may be used and a sixth notch is provided, so that on this notch the shunt will be connected across the motor field coil, thereby weakening the field and increasing the speed. One end of this shunt is attached to *F* and the other end to finger *L*. On the sixth notch, the path of the current is the same as on the fifth notch up to the point *F*; here the current divides, part of it taking the path *F*–*F'*–*E*–R_5–*d*–*e*–*f*–*g*–*h*–*i*–*G*, and the other part the path *F*–*S*–*L*–*L*–*c*–*d*–*e*–*f*–*g*–*h*–*i*–*G*, thus taking part of the current away from the field.

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

22. Car With Two Rheostatic Controllers. — In Fig. 16, only one controller is shown, in order to simplify matters, but on a car or mining locomotive two controllers, one on each end, are usually necessary. Fig. 17 shows two of these controllers connected together and operating a single motor with the parts arranged in about the relative positions they would occupy on the car. The corresponding connecting posts of the two controllers are connected together by the long wires that run the length of the car. These wires are sometimes called **hose wires,** because they are usually in the form of stranded copper cables run in canvas hose. In some cases, however, the wires are run separately and fastened to a board by means of cleats. Of course, when one controller is in use, the other is at the off-position, because the handle of the reverse switch cannot be removed until the power is thrown off. The arrowheads show the path of the current when controller No. *1* is on the first notch. This is practically the same as that shown in Fig. 16, except that the parts are in a little different location. Notice that the current passes through both hood switches and the fuse box before reaching the controllers. The wires in this diagram, Fig. 17, are not supposed to touch each other where they cross unless there is a round dot placed at their point of intersection. As an exercise, the student should trace out the path of the current on the other points, in order to become familiar with the method of representing the car wiring. The various combinations may be represented diagrammatically, as shown in Fig. 18. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field F' is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches.

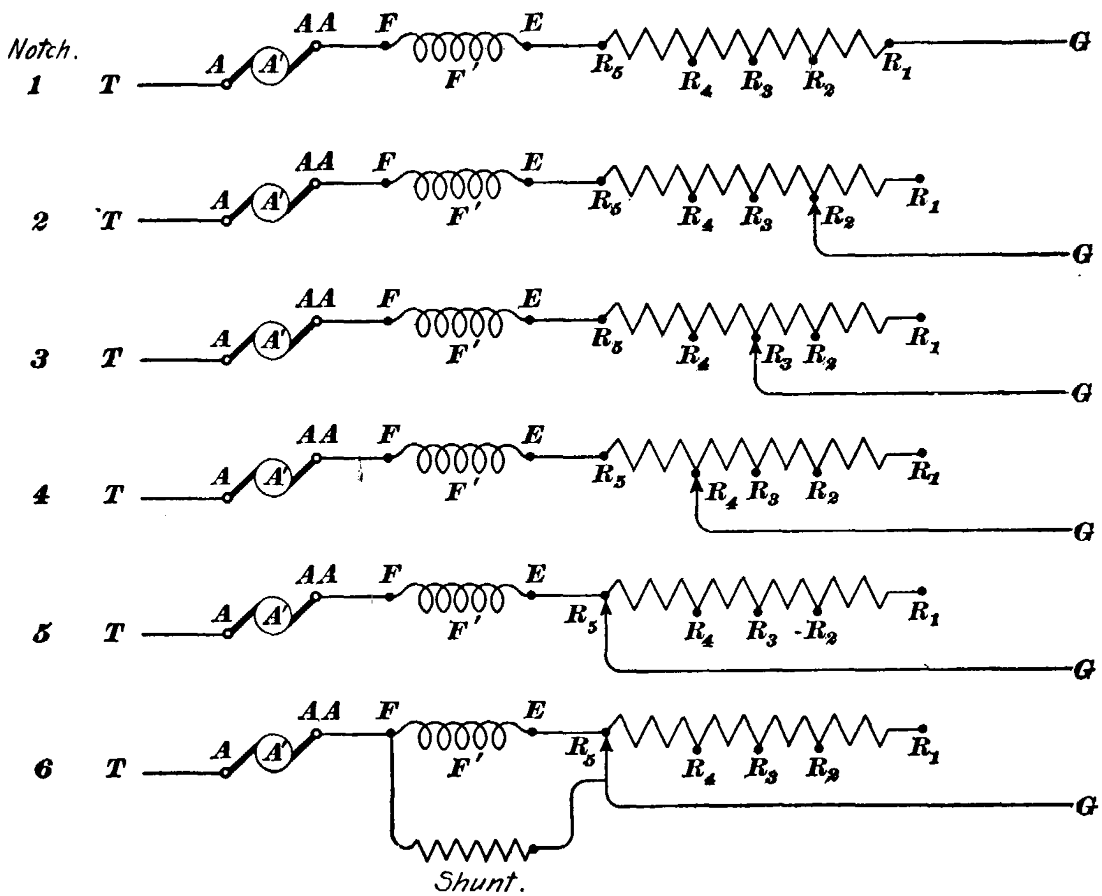


FIG. 18.

With ordinary street cars, however, the resistance is not supposed to be used for speed-controlling purposes. It is only used to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current first enters the motor. In most controllers the resistance is placed ahead of the motors, but on the whole it makes no difference so far as the effect of the resistance itself goes; it sometimes does, however, make a difference in regard to the amount of trouble that arises on account of grounds occurring on the resistance. Also notice, in Fig. 17, that the post marked *AA* on controller No. *1* is connected to post *A* on controller No. *2*, and post *AA* on controller No. *2* is connected to post *A* on controller No. *1*. This is done in order that the car may always run forward when the reverse handle on the end from which it is run points ahead.

SERIES-PARALLEL CONTROL.

23. General Description.—The method of speed control now almost universally used for street-railway work is known as the **series-parallel** method. It enables the voltage applied to the motors to be cut down for slow-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required. For slow speed, these motors are connected in series, and for high speed, they are connected in parallel; hence, the name series-parallel applied to this system of control.

Since the motors are designed to operate normally on 500 volts—that is, when supplied with this pressure across their terminals they will run at their maximum speed—let us assume that the pressure furnished is 500 volts. Then, if the two motors on a car are connected in series, as shown in Fig. 19, it is evident that the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter E. M. F., and the result is that a slow speed is obtained without the use of any resistance.

When the higher speed is desired, the controller is thrown around to the "multiple notches" and effects the combinations necessary to change the motors from series to parallel. When they are in parallel, as shown in Fig. 20, each motor gets its full voltage of 500 and runs at full speed. Of course, at starting it is necessary to include some resistance, and when changing from series to multiple, resistance is also cut in to prevent excessive rushes of current and to give a smooth acceleration to the car; but this resistance is cut out as soon as the car gets under headway and is not to be used on the running notches.

A great many types of series-parallel controller have been brought out, and it would be an endless task to describe all

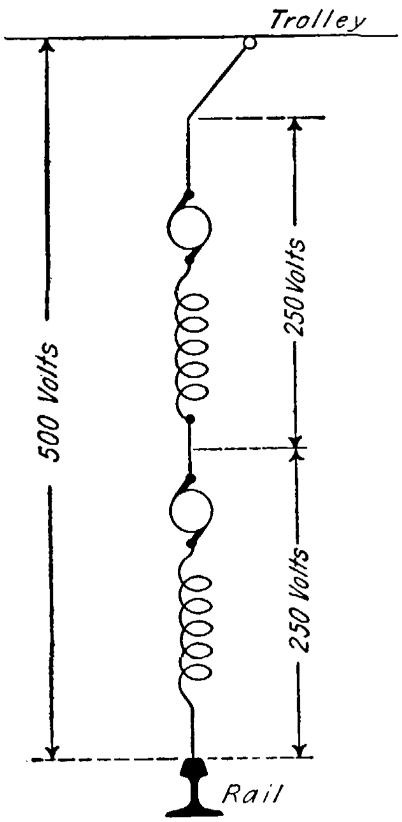


FIG. 19.

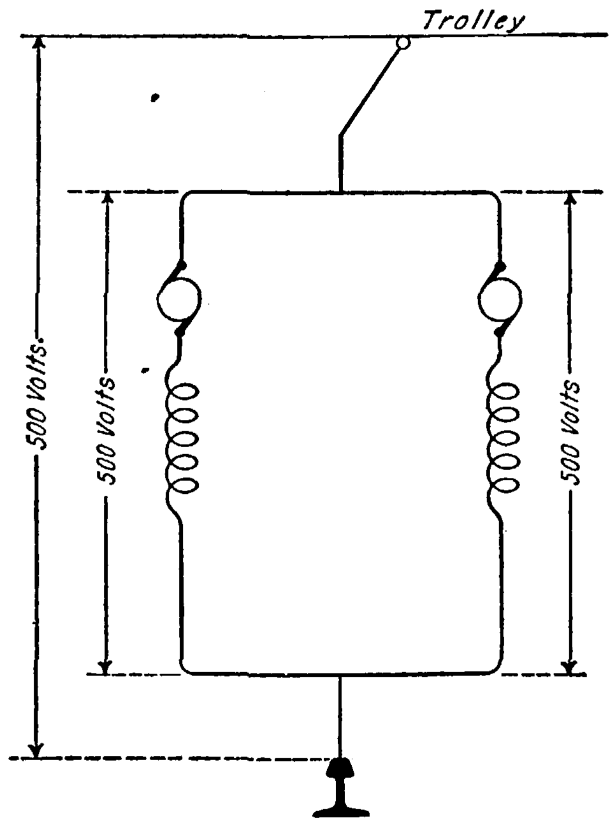


FIG. 20.

of them. All that is necessary here is to show their principles of operation, because if the student understands these thoroughly, he should have little difficulty in tracing out any ordinary car-wiring diagram. The diagrams of car wiring are usually furnished by the controller makers to those that use their apparatus.

K2 SERIES-PARALLEL CONTROLLER.

24. General Description.—The type K2 series-parallel controller brought out by the General Electric Company is one that has been very widely used on electric railways.

The General Electric Company make several styles of what they designate as the type K controller. They are, however, the same in general construction and principles of operation. In all the type K controllers one of the motors is shunted or short-circuited during the change from series to parallel, otherwise the designation "type K" has no special significance. The type K controllers embody many of the features already described in connection with the type R controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, though, of course, the type K is more complicated, because it must handle all the connections for two motors and effect the changes necessary to throw the motors from the series to the parallel arrangements. It is also provided with switches, by means of which either of the motors may be cut out, in case one of them becomes disabled, allowing the car to be operated on the other motor. The K2 controller is designed for use with shunts, i. e., on the last series notch the fields of both motors are shunted and the same is also the case on the last multiple notch.

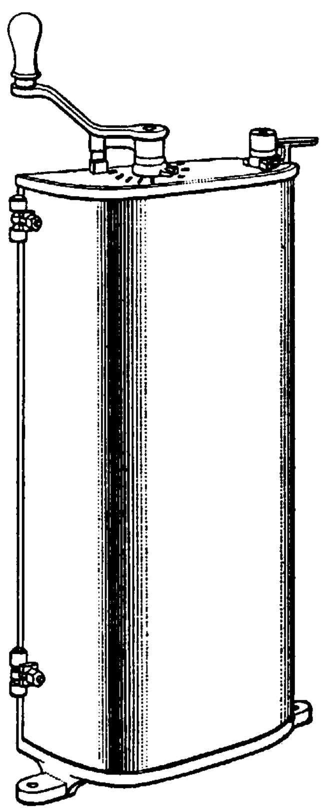


FIG. 21.

The K2 controller is used on motors of 35 horsepower or under and has nine notches. There are more positions than this, but only nine of them are marked on the controller top, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the drum will not hang between notches and cause burning inside the controller. Fig. 21 shows the K2 controller with the door closed, as it appears on the end of a car; Fig. 22 shows the door opened so that the inside parts may be seen.

In Fig. 22, *1* is the controller handle that turns the controller or power drum *2*; *3* is the reverse handle that turns the reverse drum *4*; *9*, *9* are the fingers or wipers that make contact with the power drum; *6* is the blow-out magnet. The reverse drum and its fingers have no blow-out coil.

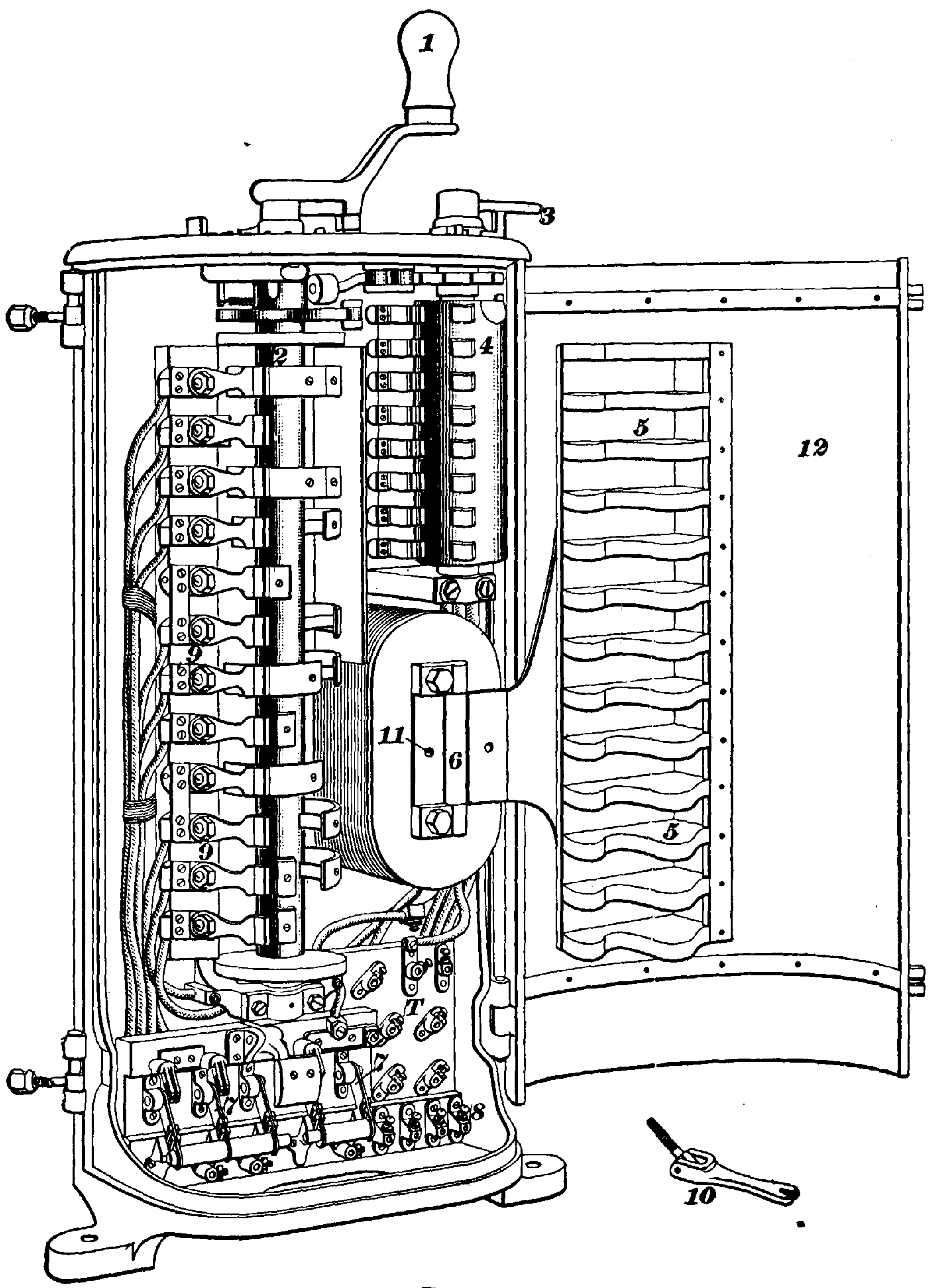


FIG. 22.

because the reverse drum cannot be moved while the current is on, and there is, therefore, no arc there to be put out. *7*, *7* are the **cut-out switches,** by means of which a disabled motor may be cut out; *8* (in the lower right-hand corner) is the **connection board,** into which all wires run from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown later

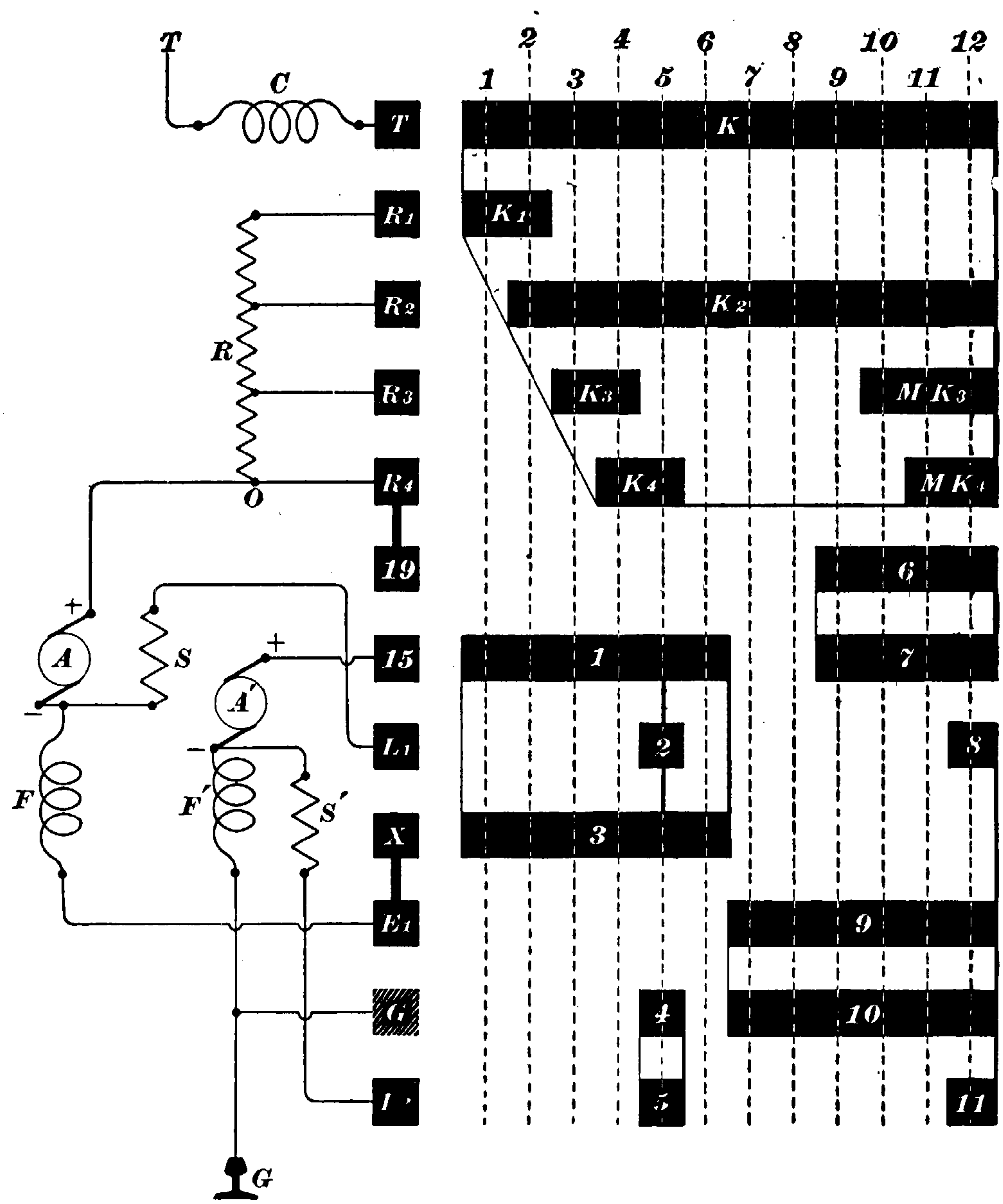


FIG. 23.

in another diagram. *12* is the door, or cover, that swings back as shown, and *10* is the bolt and wrench used for holding the pole piece in place when it is swung over; *5*, *5* are the arc guards, mounted in the way previously described. It will be noticed that both the power drum and the reverse drum of this controller are longer than those of the rheostatic controller. The interlocking device between the two drums is practically the same on both, but the connection board *8* is made necessary on account of the numerous connections and the addition of two cut-out switches *7*, *7*.

25. Fig. 23 shows the K2 controller with the power drum fully laid out, but the reverse switch, the motor cut-outs, and the controller connections are omitted for the present, in order to simplify matters. The letters used on the controller fingers are the same as those used on an actual controller. T is the trolley finger; R_1, R_2, R_3, R_4 are the resistance fingers. F and A are the field and armature of the No. 1 motor; F' and A' are the field and armature of the No. 2 motor; S is the No. 1 shunt and S' the No. 2 shunt. E_1 is the free end of the No. 1 motor field, and the free end of No. 2 motor field is grounded. L_1 is the free end of the No. 1 shunt S around the field F of the No. 1 motor, the other end being spliced to one end of the No. 1 motor field. L_2 is the free end of the No. 2 shunt, the other end being spliced to one end of the No. 2 motor field. G is the ground finger; *15* and *19* are fingers that ordinarily take wires running from the reverse switch, but as the reverse switch is left out, the wires are in this case run direct. There are twelve positions, as indicated by the twelve vertical dotted lines, but there are only nine notches. Three of the positions the motorman knows nothing about, further than that he can feel a change take place when the controller handle is swept over these positions in going from series to parallel.

26. The **first position** is the first notch; the two motors are in series and the whole of the starting coil is in the circuit. The **second position** is the second notch; the two motors are in series and part of the starting coil is cut out. The **third position** is the third notch; the motors are still in series, but more of the starting coil is cut out. The **fourth position** is the fourth notch. The motors are still in series, but the whole of the starting coil is cut out. The upper part of the drum simply looks after the cutting out of the resistance. The lower drum segments (those numbered) look after the changing from series to parallel and the cutting in of the shunts S and S'. The path of the current on the fourth notch is T–C–T–K–K_4–R_4–A–F–E_1–X–*3*–*1*–*15*–A'–F'–G.

The **fifth position** is the fifth notch. The motors are in series, all the starting coil is cut out and each field has a shunt in multiple with it. As soon as the fifth notch is reached, three drum plates *2*, *4*, and *5* and three new fingers L_1, G, and L_2 are brought into action. It must be borne in mind that one end of S is spliced to one end of F and one end of S' is spliced to one end of F'. As soon as L_1 touches plate *2*, the free end of S makes contact, through L_1–*2*–*3*–X–E_1, with the negative end of F, and as soon as L_2 and G touch plates *5* and *4*, the free end of S' and the grounded end of F' are brought together, with the result that when the current reaches point $A-$, it splits and gets to finger *15* through two paths: $A-$–S–L_1–*2*–*1*–*15* and $A-$–F–E_1–X–*3*–*1*–*15*. When the current gets to point $A'-$, it reaches the ground in two ways: $A'-$–S'–L_2–*5*–*4*–G and $A'-$–F'–G. The general path of the current on the fifth position, then, is $T\text{–}C\text{–}T\text{–}K_4\text{–}R_4\text{–}A\text{–}\left\{\begin{matrix} F\text{–}E_1\text{–}X\text{–}3\text{–}1\text{–}15 \\ S\text{–}L_1\text{–}2\text{–}1\text{–}15 \end{matrix}\right\}\text{–}$

$A'\text{–}\left\{\begin{matrix} F'\text{–}G \\ S'\text{–}L_2\text{–}5\text{–}4\text{–}G \end{matrix}\right\}$ and to the rail.

27. The **sixth position** is not a notch, but is one of the series of combinations used in passing from series to parallel. It must be noticed that the K2 drum plate, Fig. 23, runs nearly across the drum and that none of the other series-position drum plates touch their respective fingers after the fifth notch is passed. The effect of this is to cut resistance into the circuit again as soon as the drum leaves the fifth position, with the result that the sixth position is the same as the second; i. e., the two motors are in series, have full fields, and that part of the starting coil that lies between R_2 and R_4 is in the circuit. The path of the current, then, on the sixth position is $T–C–T–K–K_2–R_2$, through the two lower sections of the resistance coil R, and through $A–F–E_1–X–3–1–15–A'–F'–G$. There is no mark on the controller top to show where the sixth position is.

28. The **seventh position** is one of transition, and is not a notch. As the drum leaves the sixth position and goes to the seventh, plates *3* and *1* pass out of service and plates *9* and *10* pass into service; the effect of plates *3* and *1* going out of action is to drop the No. 2 motor out of the circuit entirely, because the field end of the motor goes to the ground and the $A'+$ end of the motor goes to finger *15*, which hangs in the air as soon as plate *1* passes from under it, and the motor can get no current. But the coming into action of plates *9* and *10* gives the current a new path in place of the one that was broken. The path of the current on the seventh position is $T–C–T–K–K_2–R_2–R–A–F–E_1–9–10$ to the rail G. On the seventh position, then, one motor has been dropped out of the circuit and the car runs on the No. 1 motor in series with two sections of the starting coil. Just at the instant that the fingers are midway in their passage from the sixth position, finger E_1 touches plate *9* at the same time that finger X, to which E_1 is connected, touches plate *3*, with the result that No. 2 motor is momentarily short-circuited, through $A'+–15–1–3–X–E_1–9–10–G–F'–A'–$, just before it is cut out of circuit; but this cannot be felt, because there is so much of the starting coil in ahead of both of the motors.

29. The **eighth position** is the same as the seventh position, and it is not a notch. No new plates are cut into action and no old ones are dropped. The eighth position is a useful one, however, in that it gives the drum a greater distance to travel in its passage from the series to the multiple positions.

30. The **ninth position** is the sixth notch. The two motors are in multiple, have full fields, and are in series with two sections of the starting coil. The arrival of the drum on the ninth position brings plates *6* and *7* into action, and enables the No. 2 motor to get current through finger *15*. The current divides between the two motors at the point *O* where the resistance wire splices on to the *A*+ armature wire; from there to the ground are two paths; one of them is $O–A–F–E_1–9–10–G$ and the other path is $O–R_4–19–6–7–15–A'–F'–G$. The ninth position is a marked notch, but is not a running notch.

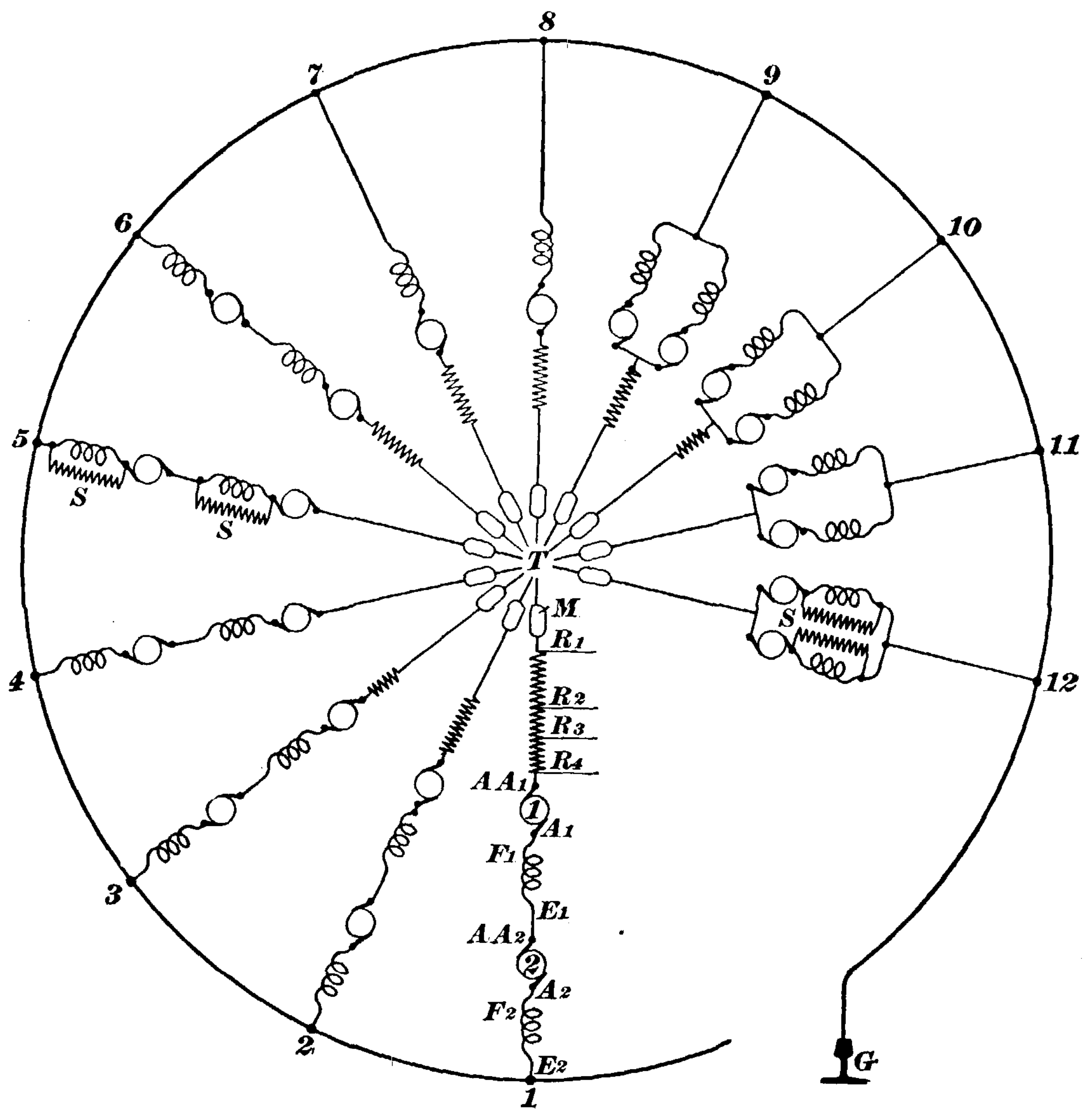


FIG. 21.

31. The **tenth position** is the seventh notch, but it is not a running notch. The two motors are in multiple and are in series with but one section of the starting coil, because finger R_3 touching plate MK_3 cuts out that part of the coil that lies between R_2 and R_3.

32. The **eleventh position** is the eighth notch and is a running notch. The motors are in multiple, have their full fields, and all the starting coil is cut out of the circuit.

33. The **twelfth position** is the ninth notch, which is also a running notch. The ninth notch is the same as the eighth notch, excepting that plates *8* and *11* coming into action put shunts on both the motor fields. The combinations at the various positions are indicated by the diagrams in Fig. 24.

34. The Notches.—On the top of every controller will be found some small ribs, which, in conjunction with the pointer carried on the power-drum shaft, enable the motorman to tell when the drum is on a notch. On controllers of some makes, this pointer is cast on the handle itself, but this is not a good plan, because as soon as the fit between the handle and the shaft becomes loose, the pointer indicates wrongly. Beside the ribs or dashes on the top is usually found the word "off," to indicate the off-position of the drum.

35. Some of the ribs on top of a controller are long and some of them are short. The long ribs indicate the notches on which it is safe to run any length of time; the short ribs

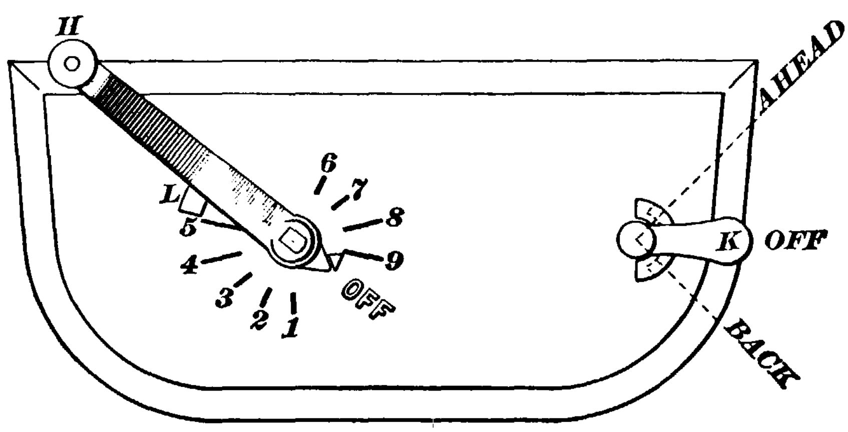


FIG. 25.

indicate the notches to be used only in starting and in going from series to parallel. On the K2 controller there are four of these long ribs; two of them are for the series combination and two for the multiple. The two long ribs in series

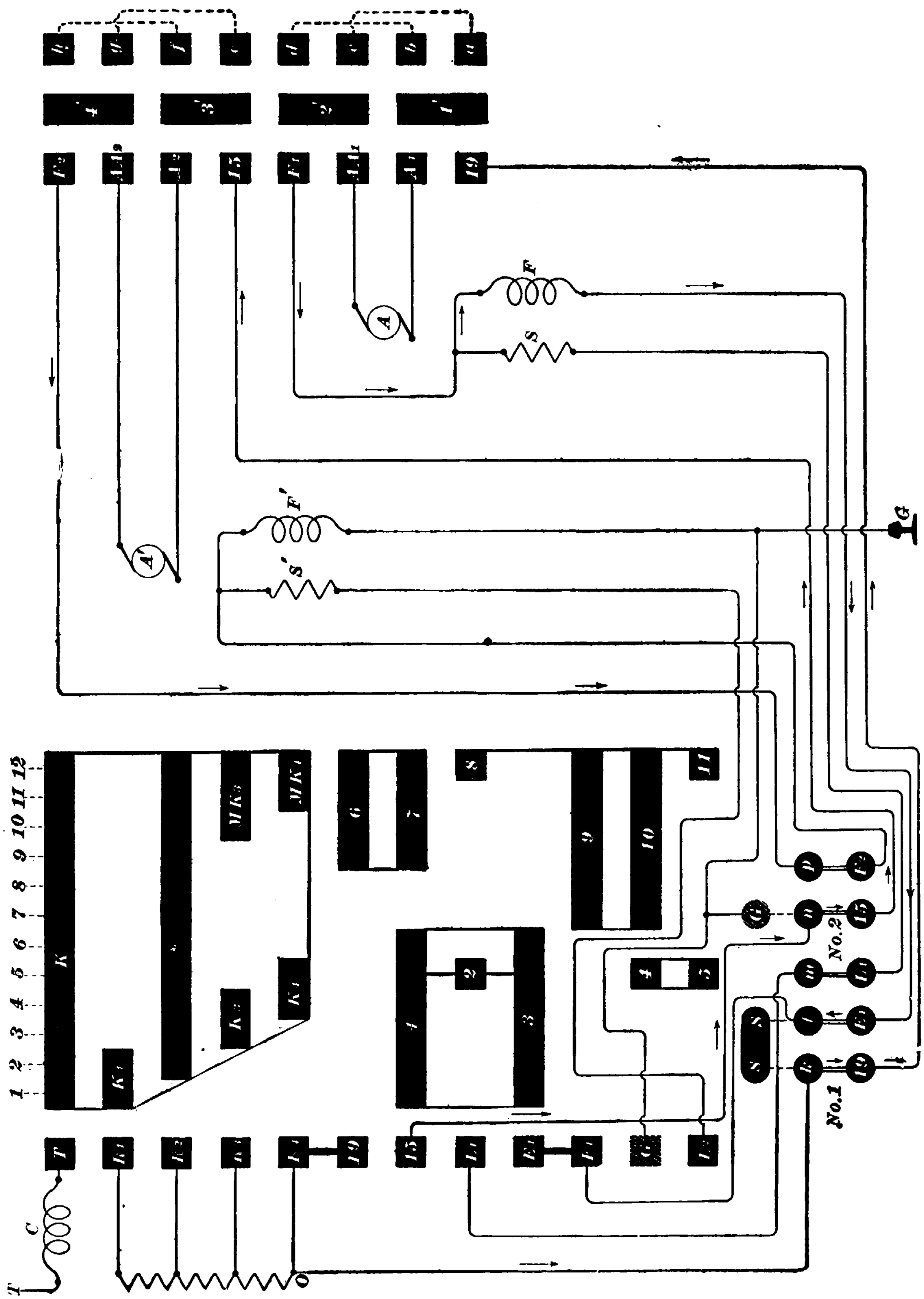


FIG. 26.

indicate the fourth and fifth notches; those in multiple indicate the eighth and ninth notches. The K2 controller has, then, four running notches: the fourth, fifth, eighth, and ninth, and none of the other notches should be run on for any length of time, for it is a waste of power and an abuse of the starting coil.

36. Fig. 25 shows the layout of the K2 controller top. *H* is the power-drum handle resting on the off-position; *K* is the reverse handle, also at the off-position. If *K* is moved ahead, the car will move ahead as soon as *H* is moved until its pointer points to *1*; if *K* is moved back, the car will move backwards. *L* is a lug against which a projection on the handle bears when the handle is moved to the ninth notch or to the off-position. On old-time types of controllers, it was necessary to watch the pointer very carefully to avoid running in between the notches, thereby burning the controller tips and fingers, but on modern controllers, the roller that plays into the notches on the drum index is acted on by a spring that is strong enough to force the drum around as soon as the roller begins to descend into a notch.

37. Reverse Drum.—The reverse drum of the K2 controller is similar in construction to that used on the R controller, except that it is provided with twice as many contact plates and fingers, in order to accommodate the two motors. This switch is shown in the upper right-hand corner of Fig. 26. When the car runs "ahead," the fingers of the reverse switch rest on plates *1'*, *2'*, *3'*, *4'*; when it runs "back," they rest on *a*, *b*, *c*, etc., thus reversing the current through the armatures *A* and *A'*, as previously explained.

38. Motor Cut-Out Switches.—In the lower part of the K2 controller, just below the power drum, the two motor cut-out switches are located. These are seen at 7, 7, Fig. 22, and are marked No. *1* and No. *2* in Fig. 26. This figure shows the controller complete, with the exception of the connection board. As mentioned before, the two motor cut-out switches are used to run the car on one motor if the