MULTIPLE-UNIT SYSTEMS

INTRODUCTION

COMPARISON OF TRACTION METHODS

1. So far, all the descriptions of electric-car equipments have applied to cars that are operated separately, as in ordinary street traffic. With the extension of the application of electricity to elevated, underground, and interurban roads, there arises the problem of operating cars combined to form trains, as in ordinary steam-road practice. Trains may be operated by means of electric locomotives, in which all the propelling power is concentrated at one part of the train; in this case there is no propelling power on the individual cars making up the train. Or, each car may be provided with its own motors and the propelling power thus distributed throughout the train. A modification of the latter method is to have part of the cars equipped with motors and formed into trains with cars not so equipped. For example, a train might be made up of five cars, three with motors and two without, the train being arranged with the cars in the following order: Motor car, coach, motor car, coach, motor car. In such a train, therefore, the motive power would be applied at three points instead of the front end only, as would be the case if an electric locomotive were used.

A locomotive must have sufficient adhesive force and exert sufficient tractive effort to operate the whole train. The available adhesive force is that due to the portion of the weight of the locomotive that rests on the drivers; the locomotive, therefore, must necessarily be heavy to give sufficient

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adhesive force and prevent slipping of the wheels. If each car is provided with motors, a large part of the total weight of the train rests on driving wheels and a large tractive effort is secured without concentrating a great amount of weight at any one point. Electric locomotives are desirable for certain lines of work, particularly in mining operations, where it would be hardly practicable or in fact necessary to equip each car or a number of cars in a train with motors. They are also used in connection with manufacturing plants and for hauling steam trains through tunnels, as, for example, in the Baltimore tunnel.

ADVANTAGES OF SEVERAL MOTOR CARS PER TRAIN

2. For the operation of elevated or underground trains in cities, the standard practice in America is to use trains made up of cars, each equipped with motors. The conditions under which these trains operate are more exacting than on a cross-country road, because the stops are much more frequent, and as it is necessary to run a large number of trains at close intervals, the problem of starting and stopping the trains in minimum time becomes important. Trains of this character after making a stop must get under headway quickly, and in order to accelerate the train, a powerful effort is required during the period of acceleration. If the train is operated by a locomotive, it is difficult to obtain rapid acceleration, because the weight resting on the drivers is not sufficient to prevent slippage of the driving wheels. With the motive power divided among a number of driving wheels, and with the greater part of the whole weight of the train resting on the drivers, rapid acceleration can be procured without slippage.

The use of individual motors admits of a train being made up of any number of cars, and as each car is equipped with its own driving power, the motor capacity is increased or decreased in proportion to the number of cars to be operated. This allows the size of the trains and the number of motors in operation to be readily changed to suit traffic conditions.

When an electric locomotive is used, the same motors are operated whether or not the locomotive is hauling cars to its full capacity, and as the locomotive must be large to operate a full train, it follows that when a few cars only are used the motors are operated at the low efficiency corresponding to a light load. With the use of motors on each car, safety is insured, because the motive-power units are divided and widely separated, and an accident to one of them does not interfere seriously with the operation of the train. All track and structure stresses are less than with locomotives, because of the more uniform distribution of weight.

3. Definition of Multiple-Unit System.—The system of operating trains of cars, each fully equipped with electric motors, brakes, etc., was first developed by Mr. Frank T. Sprague, and has been called by him the **multiple-unit system.** Mr. Sprague's definition of the multiple-unit system is as follows:* "It may be described as a semiautomatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to fulfil the requirements of that unit, with means, at two or more points on the unit, for operating it through a secondary control, and a 'train line' for allowing two or more of such units, grouped together without regard to end relation or sequence, to be simultaneously operated from any point in the aggregation." This definition will be more clearly understood after a description of the multiple-unit system has been given.

4. Elementary Operating Principles.—Suppose three ordinary surface trolley cars to be completely equipped, but that instead of running the car wires from controller to controller in each car and letting them end there, the wires are run from end to end, tapping off to each controller and putting suitable couplers on the ends, as indicated in Fig. 1, so that the car wires on one car can be made continuous with those on the next, thus producing an elementary multiple-unit train. The main-current motor

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wires will run from one end of the train to the other, irrespective of the length of the train; the train can take current from one trolley pole, or third-rail shoe, or from all the poles or shoes at once, and it can be operated from any controller on any car, whether this car be in the middle or on the end of the train. Every car will do its own share of the work, so that the whole train will start, run, and stop as quickly as a single car. There are, however, several

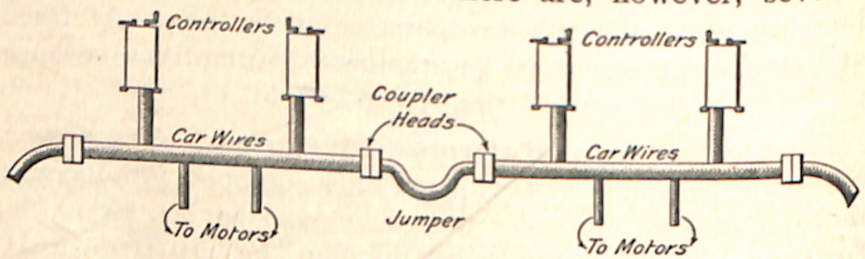


FIG. 1

strong objections to a multiple-unit system of this kind: As each controller would be compelled to handle the current required for the whole train, a large and clumsy controller would be necessary; the car wiring would have to be extra heavy to carry the total train current; and it is probable that a satisfactory coupler to transmit such currents would be impracticable. Finally, in case of short circuits or grounds on the car wires of any car, the cut-out devices that would meet all conditions would necessarily be complicated.

5. In the multiple-unit system as actually applied these objections have been overcome, and there are at present two prominent systems. The General Electric Company, who acquired the Sprague patents, has brought out a multiple-unit system, which it designates as type M control, that is entirely electrical in its operation. The Westinghouse system for the same purpose is electropneumatic in its operation, compressed air being used to actuate the controllers on each car, and the valves controlling the compressed air being operated electrically.

6. In both these systems there is placed on each platform of every motor car a small controller, called the *master*

controller, while every car has a *train line*, consisting of a number of small insulated wires made up into a cable and provided with couplers at each end of the car. All the master controllers are connected to this train line, which handles the small current required for the operation of the main controllers. When the train is made up, the train line extends from one end to the other, connecting all the master controllers and the mechanisms that they operate, so that all the main-circuit controllers, and hence motors, can be operated from any master controller. The master-controller circuit is distinct from the main-motor circuit and carries but a small current. The master controller has a number of positions, on some of which the motors are in series and on others in parallel, like an ordinary controller; it is extremely important, therefore, that the main-controller operating devices should respond to the notches of the master controller simultaneously and with precision; for, if the main-motor controllers should feed up at different rates, a condition might arise where the motors on some cars would be in series and those on others in parallel, thus causing trouble.

Each car is provided with its own braking outfit, consisting of an engineer's valve, motor compressor, governor, triple valve, tanks, etc., so that if called on to run alone, it can do so. When a multiple-unit train is started, each car starts, and there is no bumping or jerking as when a train of cars is started by means of a locomotive. There is little strain on the couplings between the cars, and there is therefore little tendency for such trains to break in two. On some roads, for heavy high-speed traffic, the equipment intended primarily for the operation of multiple-unit trains has been used even though the cars are operated singly. On such cars, the amount of current taken becomes so large that it has been found safer and better to operate the main controller through a master controller on the platform. This simplifies the main car wiring, does away with the large controller that would otherwise be necessary on the platform, and also reduces the risk from fire because the main controller and wiring can be arranged and protected so as to reduce the danger of setting

fire to the cars in case of short circuits or other defects. The system is also well adapted to the operation of electric locomotives, large hoists, or other service involving the use of large currents, and particularly for those cases where the controller must be placed some distance from the motors.

TYPES OF MULTIPLE-UNIT CONTROL

SPRAGUE GENERAL ELECTRIC MULTIPLE-UNIT SYSTEM

TYPE M CONTROL

7. General Features.—The multiple-unit system of control as developed by the General Electric Company, and known as their **type M control,** is wholly electrical in its operation. Fig. 2 shows a general view of the motor-control apparatus installed on each car, and will serve to give an idea of the system as a whole. The master controllers *A*, *A'* are placed on the platforms and control the current that operates the main-motor controller. The latter, instead of being a single device, consists of thirteen electromagnetic switches, or *contactors*, as they are called, and a reversing switch, called a *reverser*, all located under the car in protective housings, as indicated in the figure. The movements of these switches and the combinations of connections that they make are controlled by the master controllers *A*, *A'*. The current that passes through the master controller energizes the operating coils of the contactors and has nothing to do with the main-motor current. The starting resistance used to limit the current flowing through the motor is mounted in the frames *15–20* in the usual manner, and the main current controlled by the contactors is supplied to the motors *B*, *C* through suitable cables.

The main current flows from the third-rail collecting shoes *22*; or if a trolley wire is used, the contact shoes will be

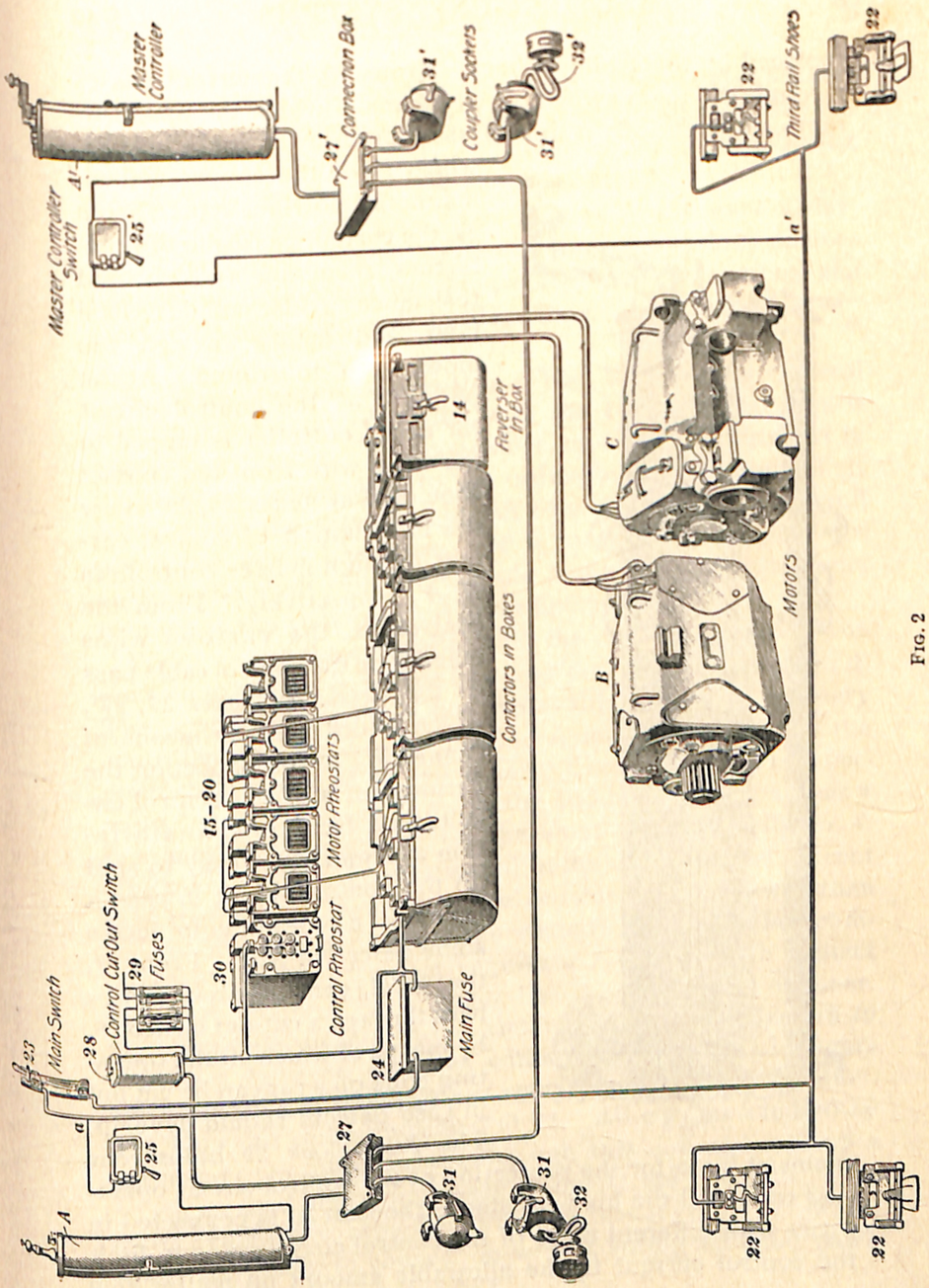


FIG. 2

replaced by the trolley wheel. From *22*, the current passes through the main switch *23*, by means of which the main current can be cut off; it next passes through the main fuse *24*, which is of the copper-ribbon, magnetic, blow-out type. From *24*, the current passes to the contactors, reversing switch, and resistance grids, as described later, and finally through the motors *B*, *C* to ground. At the points *a*, *a'*, the control circuit for each controller is tapped to the main wire from the contact shoe, and switches *25*, *25'* allow the interruption of control current through master controllers *A*, *A'*, respectively. From the controllers, the various wires making up the control cable pass to the *connection boxes* *27*, *27'*, which afford a ready means of connecting or disconnecting the various parts of the control circuit, thus facilitating installation and making it easy to split up the control circuit in case it becomes necessary to locate some defective part. From *27*, the local control-circuit wires pass through a cut-out switch *28*, by means of which all the operating coils on a car can be cut out in case defects should develop. The fuse block *29* holds four enclosed fuses for the protection of the control-circuit operating coils, and the high-resistance rheostat *30* is connected in series with different parts of the control circuit so as to limit the control current to the allowable amount no matter how

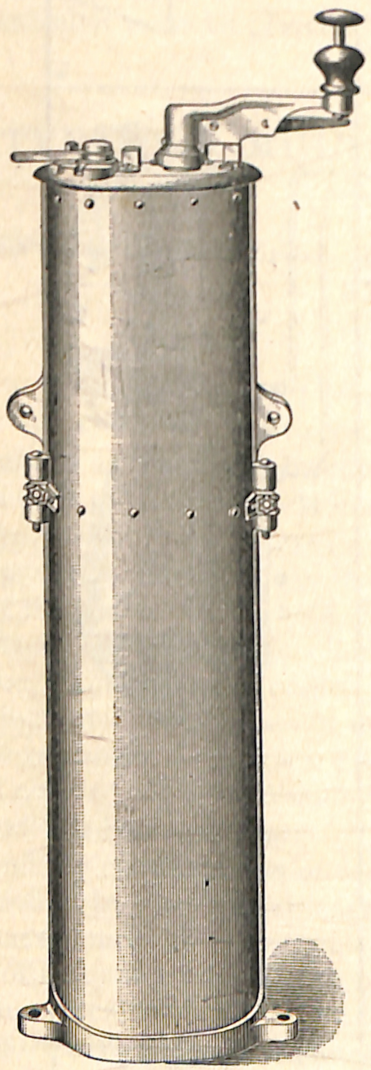


FIG. 3

many operating coils may be in service. The coupler sockets for making the connection of the control circuit from one car to the next are shown at *31*, *31'*; jumpers for connecting the couplers of abutting cars are shown at *32*, *32'*.

The foregoing will give a fair idea as to the general layout of the type M control system. After the various devices have been considered by themselves, the connections and method of operating will be described.

8. The Master Controller.—Fig. 3 shows the General Electric C6 master controller with the cover in place, as it appears on the car. The controller, as a whole, is similar in its external appearance to an ordinary type K controller, being about the same height but considerably narrower and occupying much less room. It is located on the platform against the dash rail or vestibule front, in about the same manner as the controller on an ordinary street car.

Fig. 4 shows the controller with the cover removed. The operating handle is shown at *1* and the reverse handle at *2*. The operating handle is not removable, as on an ordinary controller, but the reverse handle is, and when removed the main shaft is locked so that it cannot be turned. The operating handle turns shaft *3*, on the end of which is a gear *4* that meshes with gear *5* on the shaft of main cylinder *6*. The main cylinder is constructed in the usual manner, except that the contact segments *7* are considerably narrower than on an ordinary controller, the current handled being comparatively small. Contact segments *7* engage with contact fingers *8*, mounted on a finger board in the usual manner. The iron pole piece *9* carries the insulating arc deflectors *10* that pass between adjacent contact segments and fingers when the hinged pole piece is swung into its usual position. The blow-out coil is indicated at *11*. All current handled by the master controller passes through this coil and sets up a magnetic field that suppresses arcing at the contacts. The main cylinder is provided with the usual star, or index, wheel *12*, which, in connection with a spring-actuated pawl, gives decision to the notches.

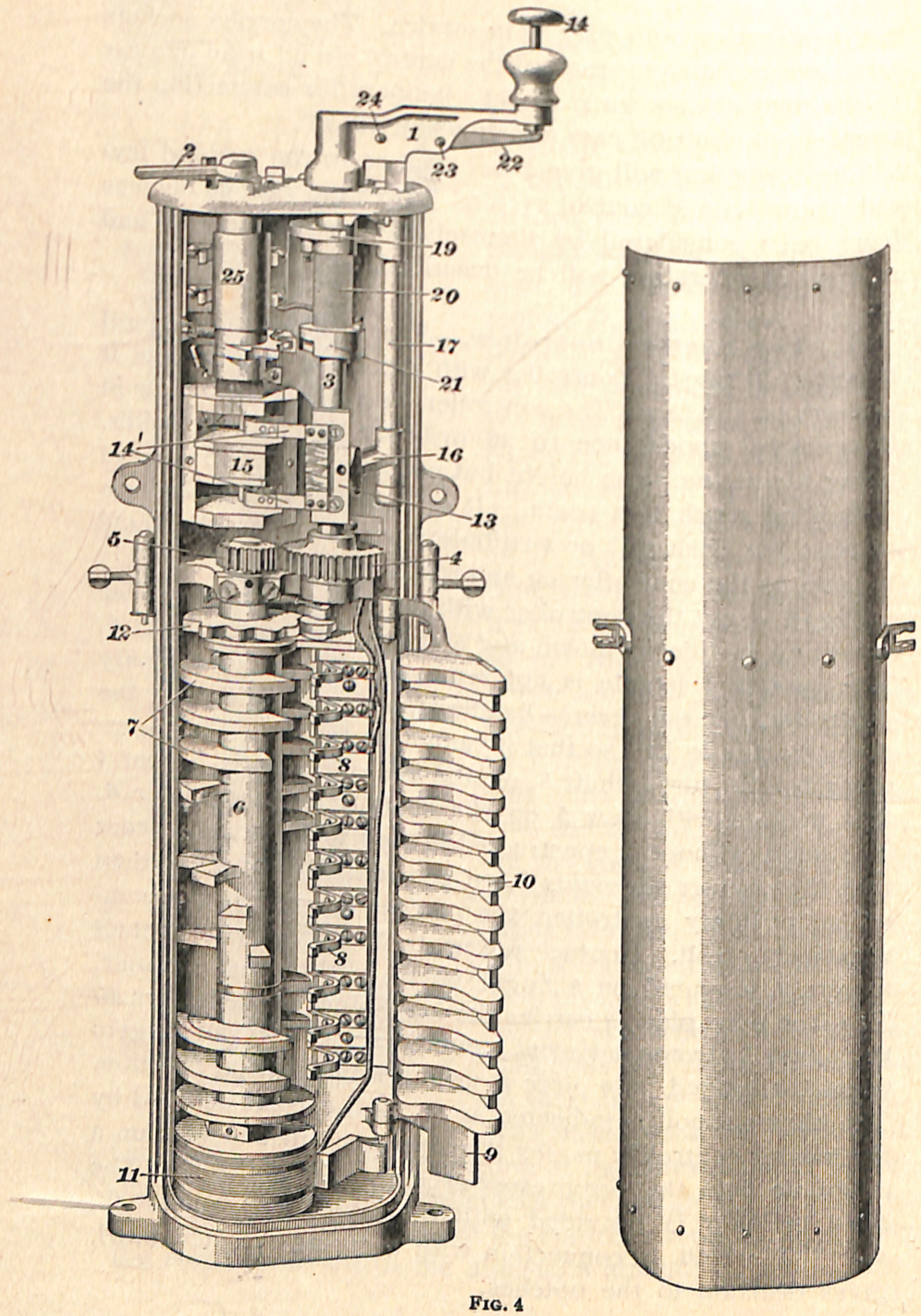


FIG. 4

9. The C6 master controller contains a safety switch *13* not usually found on ordinary controllers; it is provided as a factor of safety in high-speed work. To operate the controller and supply current to the motors, it is necessary that the motorman keep knob *14* depressed; if the knob is released, all power is at once cut off from the motors by the opening of safety switch *13*, irrespective of the position of the operating handle; nor can power be applied to the motor circuit again without first restoring the operating handle to the off-position. Should an accident befall the motorman, causing him to release knob *14*, the train will be automatically stopped. On this account knob *14* is sometimes called the dead man's knob, or handle.

Switch *13* consists of an insulating block on which are mounted two fingers *14′* connected together by a metallic strip. When the switch is closed, the fingers touch contacts mounted in the recesses above and below the auxiliary blow-out coil *15* cased in insulating material. The insulating block that carries fingers *14′*, *14′* is mounted on the end of an arm *16* fastened to the rock-shaft *17*, which is acted on by a spring that normally holds it in such a position that fingers *14′*, *14′* are swung out from their respective contacts. All the current in the operating circuit has to pass through the safety switch, and unless this switch is closed by fingers *14′*, *14′* being swung in until they touch their contacts, the control circuit is inoperative and no current can be supplied to the motors. The movements of the rock-shaft *17* and switch *13* are controlled by a cam *19* that has a notch engaging a short arm extending from the rock-shaft; cam *19* is mounted loosely on the main shaft. A spiral spring *20* has its upper end attached to *19* and its lower end to collar *21*, which is firmly fixed to the main shaft *3* and rotates with it. If handle *1* is turned, without pressing down knob *14*, the main shaft *3* and drum *6* are turned, but cam *19* does not turn, because it is mounted loosely on the shaft and is prevented from turning by the projecting arm on rock-shaft *17*. Under these conditions, therefore, spring *20* merely twists or untwists, and since switch *13* is not closed,

the control circuit is inactive. If, however, knob *14* is pressed down before handle *1* is turned, a small dog, or catch, is pressed down and locks cam *19* to shaft *3*. This dog is forced down by means of lever *22*, hinged at *23*, which engages a second small lever hinged at *24* and mounted within the handle. When cam *19* is thus locked to the main shaft, it forces the rock-shaft *17* to rotate through a small angle just as soon as handle *1* is moved from the off-position, thereby closing switch *13* and allowing current to pass through the controller. Spring *20* is placed in position at the factory under considerable tension, so that there is always a tendency for relative movement between cam *19* and collar *21*. When handle *1* is moved around and *14* pressed down, cam *19* is locked to the shaft and hence moves around with collar *21*. There is therefore no twisting action on the spring and no change in the initial tension. Suppose, however, that knob *14* is released after the handle has been moved around from the off-position; the dog engaging *19* is released, and *19* is then free to revolve on the shaft independently of *21*. As soon as *19* is released, the tension on spring *20* causes it to fly to its initial position, and switch *13* at once opens, thus cutting off all current from the control circuit. Before the catch operated by *14* can be again made to engage with cam *19*, handle *1* must be brought back to the off-position, thereby restoring the tension in spring *20* to the original amount. The safety device not only cuts off the current in case of accident to the motorman, but it prevents it from being thrown on, unless all operating devices are in the starting position. For example, if the motors were in parallel and the power cut off by releasing *14*, it could not be turned on again with the motors in the parallel position; the handle would have to be brought to the off-position and the motors worked up to the parallel position through the various resistance steps and series connections.

10. The small cylinder *25* in the upper left-hand corner of the controller is the *reverse cylinder*, which controls the

movements of the reverser *14*, Fig. 2, and thus determines the direction of movement of the car. The handle *2* of the reverse cylinder cannot be removed until it is moved to the off-position, and this motion of cylinder *25* operates an interlocking device that locks the main shaft *3* so that it cannot be moved. The removal of the small reverse handle therefore prevents the operation of the car from that controller, so that this small handle in effect constitutes a key to the operation of the train and is taken off and carried by the motorman in case he leaves the controller.

The general construction and operation of the master controller is very similar to that of an ordinary magnetic blow-out controller, the principal distinguishing features being the automatic safety switch and the lighter construction of the current-carrying parts. Some of the controllers are built without the automatic safety feature, as on some roads it is not considered essential.

11. Controller Positions.—Fig. 5 is a sketch of the master controller top. There are ten marked positions for the operating handle, but only two of these, *5* and *10*, indicated by marks longer and heavier than the others, are

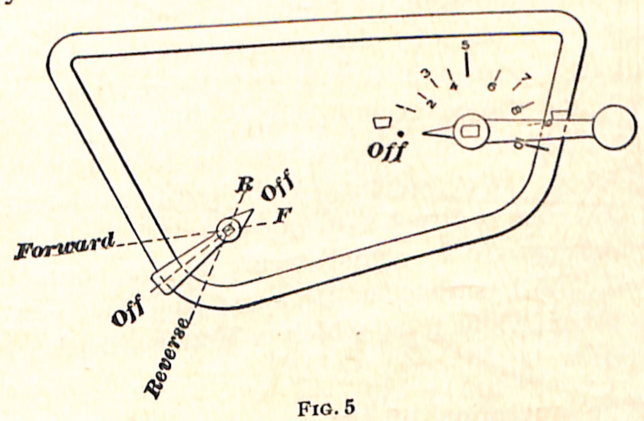


FIG. 5

running positions. On position *5*, the car motors are in series with all resistance cut out; while on position *10*, they are in parallel without resistance. The reverse handle has the usual three positions—forward, off, and reverse—the

arrangement of connections being such that the position of the reverse handle indicates the direction of movement of the car.

12. Contactors.—Fig. 6 shows a pair of contactors, the construction of which will be understood from Fig. 7. The design is such that two or more contactors can be grouped together on a common base, as in Fig. 6, thereby simplifying the heavy main-current connections. In Figs. 6 and 7, corresponding letters have the same signification: *a* is the operating coil wound in two sections; *b* is a movable core or plunger; and *c*, a corresponding stationary core. On the lower end of *b* is hinged a frame *d* that presses on arm *e* through spring *f*. Arm *e* carries on its upper end a contact tip *g* that, when the arm is in the position of Fig. 7, presses against stationary contact tip *h*, thereby closing any circuit of which they may be a part. One main terminal of the contactor is shown at *i*, Fig. 7, and the other at *j*. At *k*, Fig. 7 (*a*) and (*b*), is indicated a blow-out coil consisting of a few turns of heavy bare conductor. Iron pole pieces *l* bolted to both ends of the blow-out coil core *m* direct a strong magnetic field across the region of tips *g* and *h* so that arcing at the contact tips is suppressed. All smoke and gases pass out through a specially provided flue, of which *n* and *o* are the top and bottom walls.

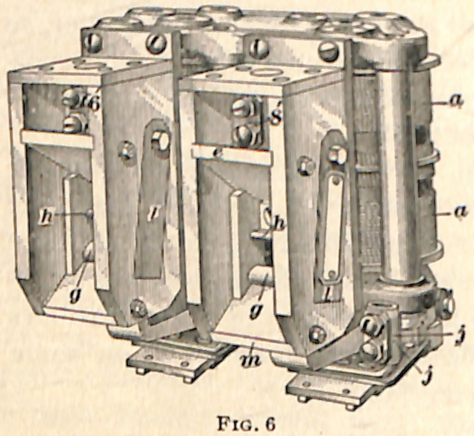


FIG. 6

13. The operation of the contactor is as follows: In Fig. 6, the contactors are open. The instant that current from the control circuit energizes operating coil *a*, it draws plunger *b* up to the position shown in Fig. 7 and the main-motor current enters the contactor at terminal *i*, passes

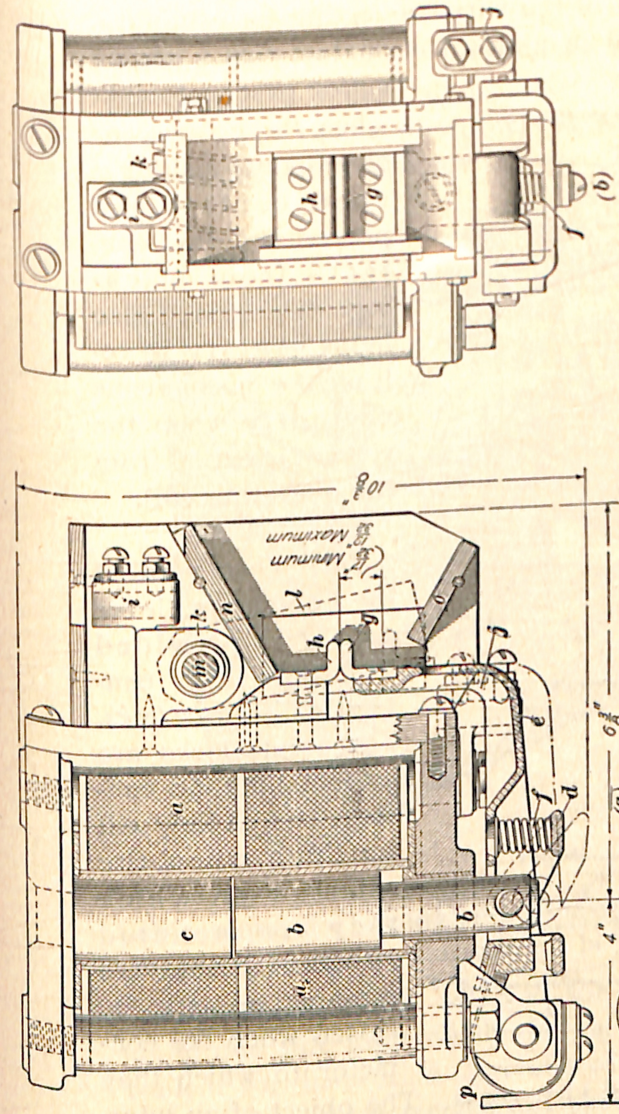


FIG. 7

through blow-out coil *k* to top contact tip *h*, thence through bottom tip *g*, arm *e*, shunt *p*, and the contactor frame to terminal *j*, which is fastened to the frame, on to the next device in circuit by way of the wire connecting to terminal *j*. Spring *f* is instrumental in giving the contact tips a wiping action past each other when the contactor closes, thus making a good contact and preventing the contacts from sticking. The spring also helps gravity to release the mechanisms promptly when the current is cut off from the operating coil.

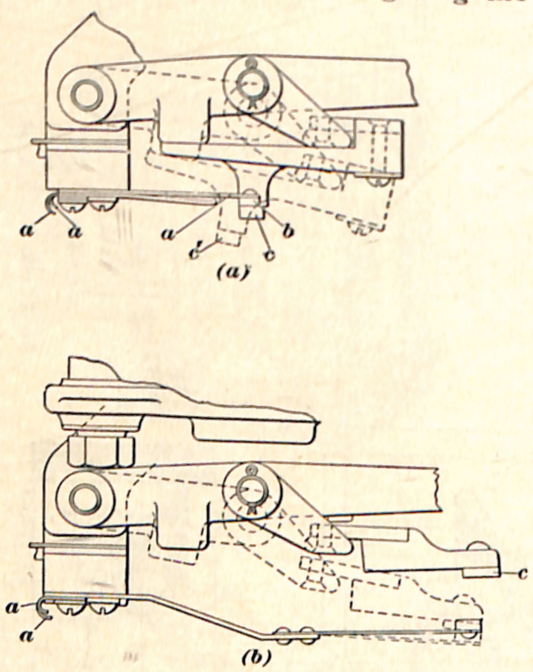


FIG. 8

14. On several of the contactors, lever arm *d* is provided with auxiliary contacts called *interlocks*. Some interlocks are so installed and constructed that they will be open when the contactor on which they are mounted is open; others are arranged so as to be closed when the contactor to which they are attached is open, and vice versa. The object of an interlock is to prevent simultaneous action of two circuits in which such action would be objectionable. The general method of attaching the interlocks is indicated in Fig. 8. Small fingers *a*, *a* (the two fingers are in line with each other

so that only one shows in the figure) are attached to the lower part of the contactor frame and carry contact tips *b*. When, in (*a*) for example, the contactor is closed, the metal cross-piece *c* makes contact with the interlock fingers and when the contactor opens, *c* drops to position *c'*, thus opening the interlock circuit. In (*b*), the interlock is closed when the contactor opens; while in (*c*), there are two interlocks, one of which opens when the contactor closes and the other closes when the contactor opens. The interlocks are safety

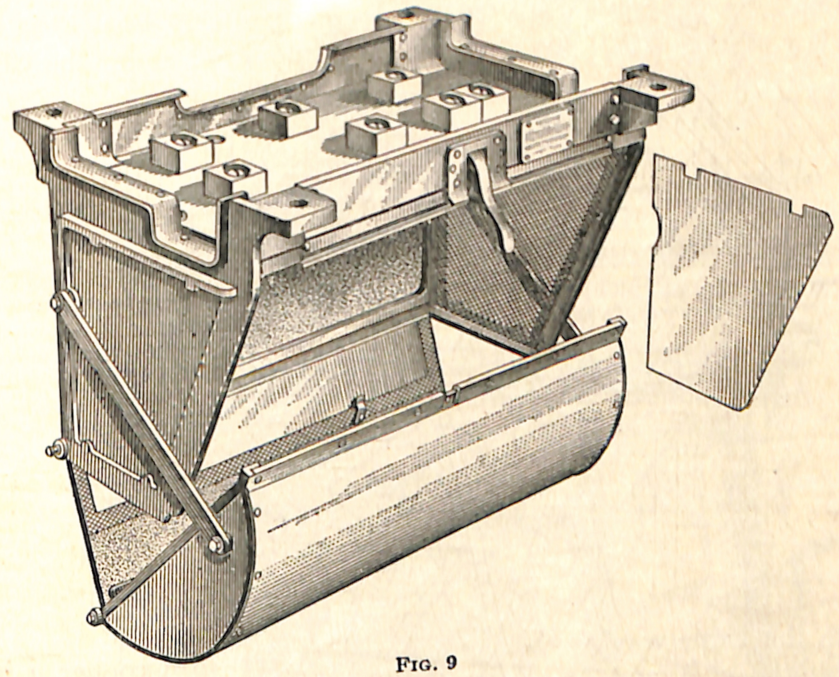


FIG. 9

devices and do not under ordinary conditions open or close the control circuit when current is flowing.

15. The location selected for the contactors is usually along one side underneath the car where they will be convenient for inspection and out of the way of other equipment parts. As a mechanical protection for contactors and reversers when installed under the car, boxes similar to that shown in Fig. 9 are used. Figs. 10, 11, and 12 show the arrangement of contactors, which are divided into three

groups and are protected by sheet-iron covers that can be dropped, as shown, to give access to them. The reverser is mounted in a casing by itself at the right-hand end.

16. The **reverser** performs the same duties as the reverse switch of an ordinary controller; that is, it controls the direction of the flow of the current through the motor armatures and thereby determines the direction of motion of the car. Each car must be equipped with a reverser, and the movements of all the reversers on a train are controlled by the small reverse switch on the master controller. Fig. 13 is a view of the DB20 reverser, which is mounted under the car

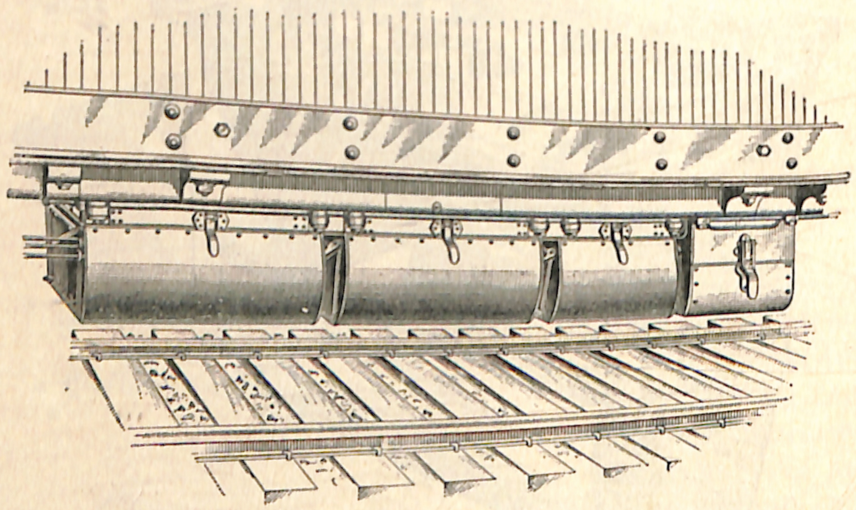


FIG. 10

in the same way as the contactors. A cast-iron rocker *a* is hinged at *b*, and on the ends of the beam are two molded insulation pieces *c*, *c* to which are attached the heavy segments *d*, *d* that carry the main-motor current; segments *e*, *e* are lighter and carry the control current only. Fingers *f*, *f* engage with the heavy segments, and *g*, *g* with the lighter ones. The rocker can be moved through a limited range by means of two solenoids, one of which is shown at *h*; a similar coil is behind *h*, the end of its plunger being seen at *k*. The plungers of the solenoids are connected to the rocker-arm through suitable links, and the movement of the rocker is

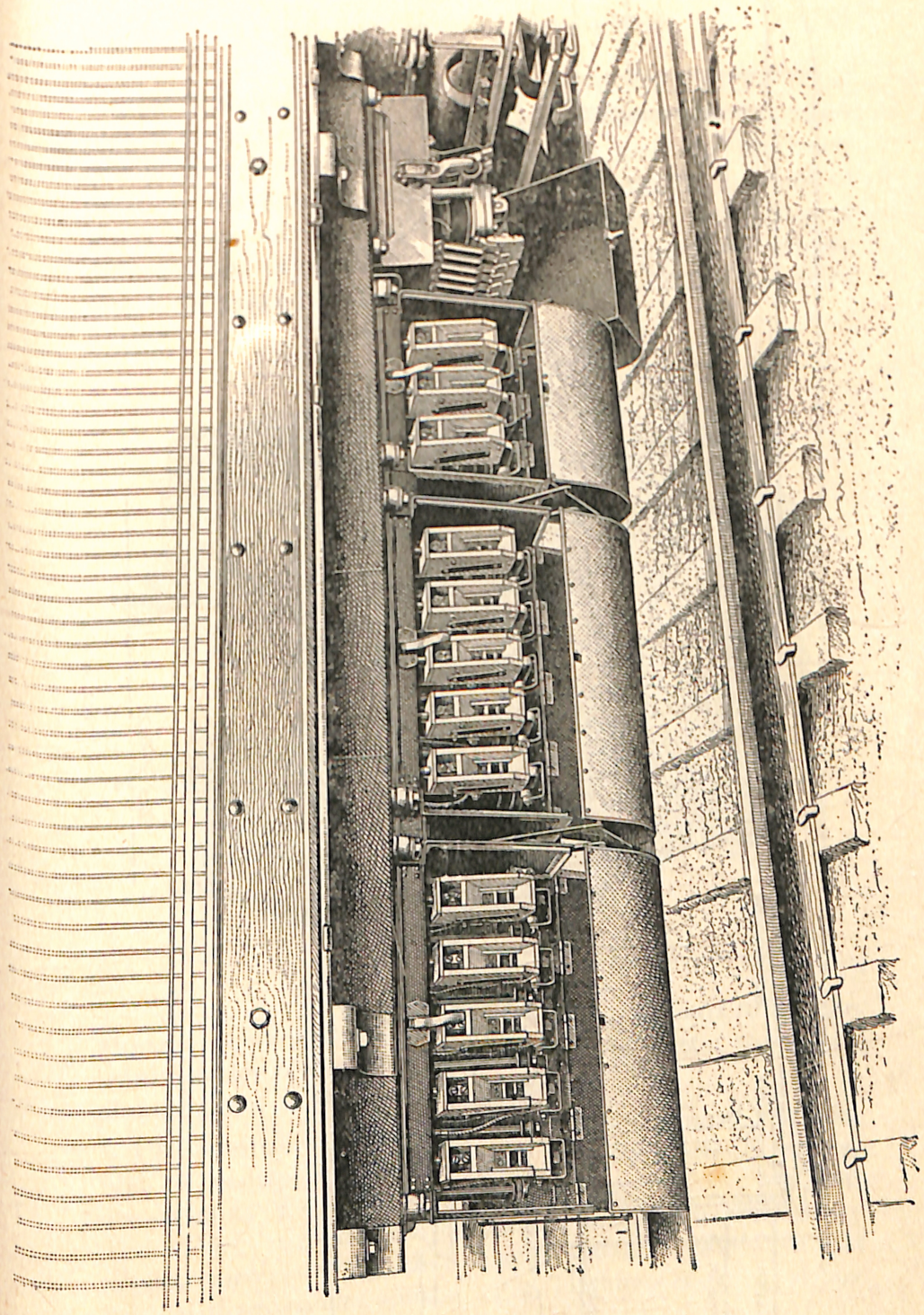


FIG. 11

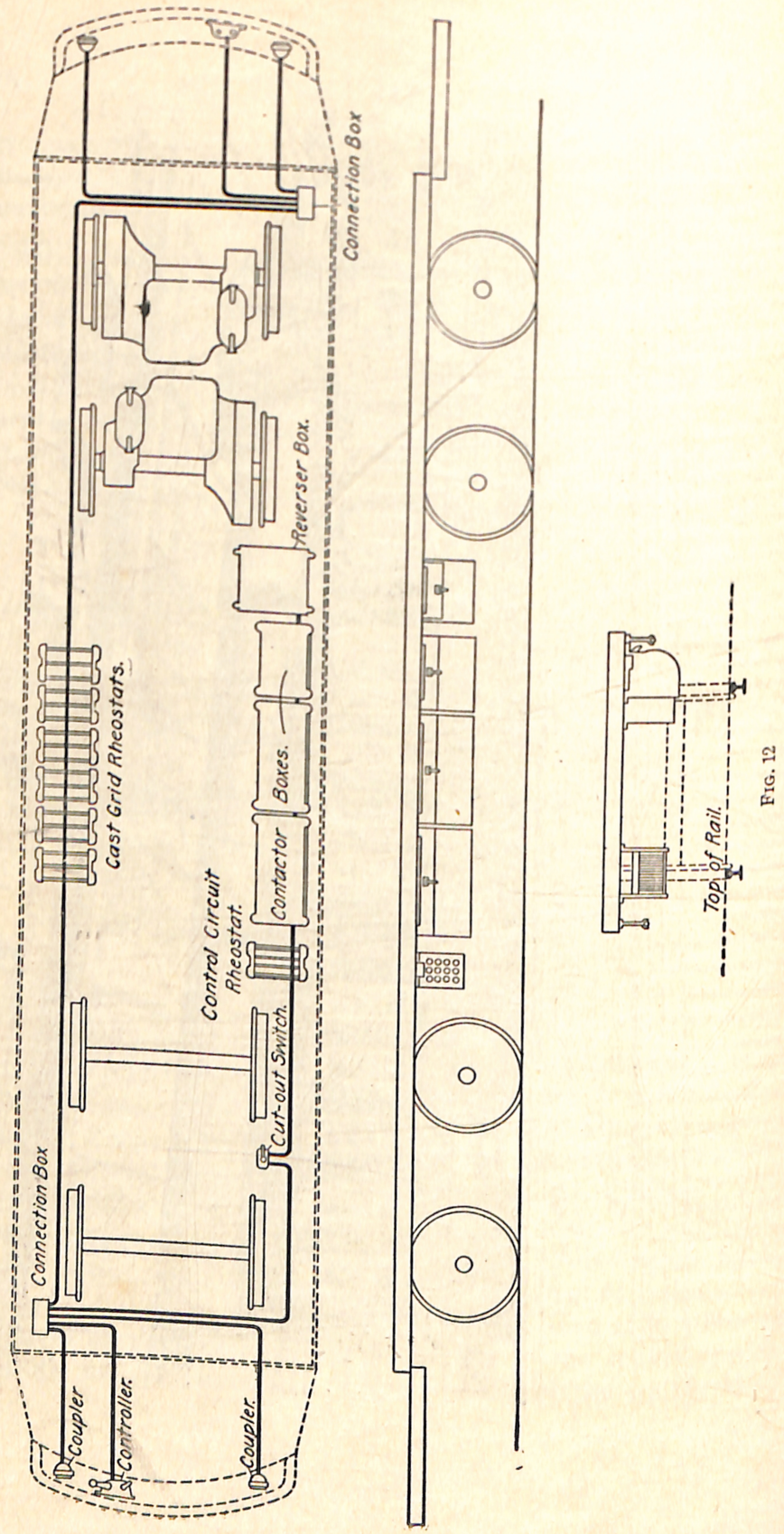


FIG. 12

limited by stops. When coil *h* is energized, the rocker occupies the position shown in the figure; but when the other coil is energized, the rocker is thrown over to the other position, the left-hand side being pulled toward the base of the reverser and the other side moving down, thus bringing different sets of contacts under the contact fingers. Suitable interlocks make it impossible for both coils to be energized

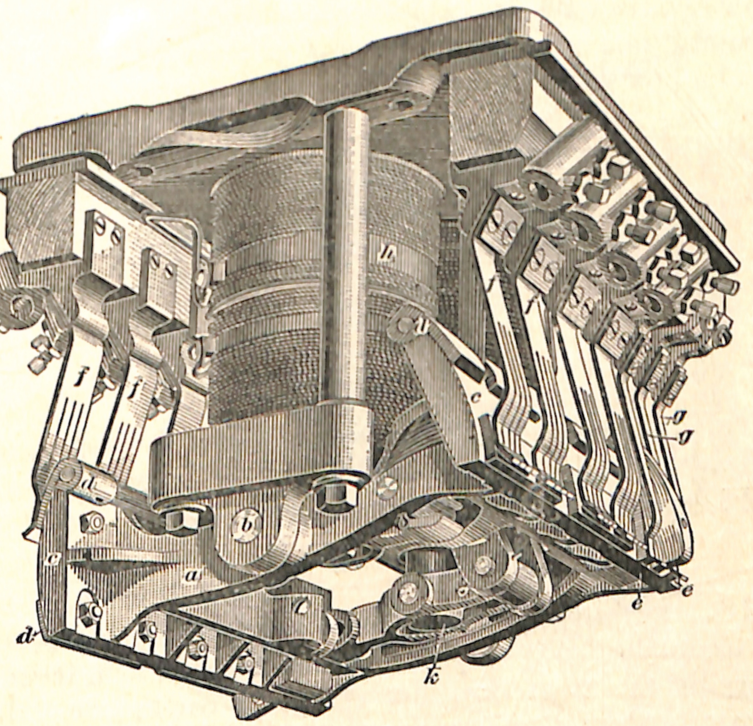


FIG. 13

at once. One position of the rocker corresponds to the forward position of the reverse handle on the master controller, and the other to the reverse position.

17. Connection Boxes.—Each car equipped with the type M control is provided with two **connection boxes,** shown at *27*, *27′*, Fig. 2, which are located under the car. Their object is to afford a simple and effective means of connecting corresponding wires of several control cables without the use of permanent splices. Fig. 14 shows the style of box

used. It is made of iron and contains an insulating base *a* on which are mounted clamps *b* for connecting the similar wires of the different control cables. Holes *c* are tapped for 1-inch pipes through which the cables enter, the ends of the wires being soldered to the small terminals *b*, *b*. In Fig. 2, there are four control cables entering the left-hand box and three entering the right-hand box, and in each box the similar wires in each cable are connected together by the clamps. The screwing of cover *d* in place renders the connection box water-tight.

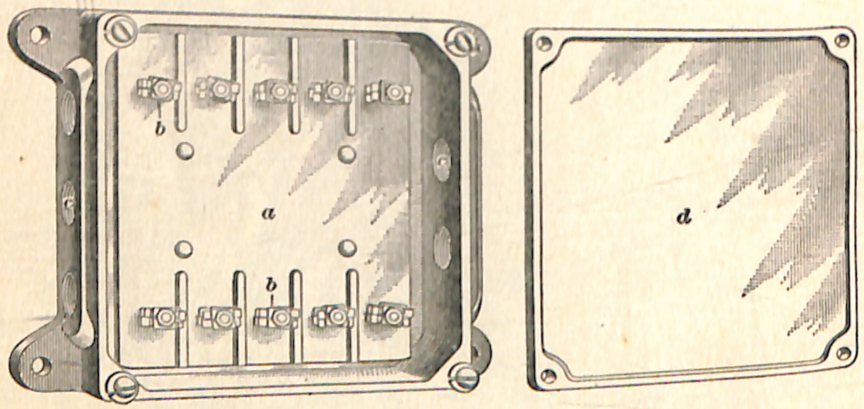


FIG. 14

18. Coupling Devices.—All cars that are to be coupled up into multiple-unit trains must be provided with means for carrying the train control wires from car to car. If cars unequipped with motors are to be used in connection with motor cars, they must be provided with means for preserving the continuity of the control cable throughout the train. Connections of the control cable from car to car are made by means of couplers consisting of *sockets* placed under each car platform or set into the dash, and a short piece of cable with a plug at each end. The piece of cable with its two plugs is called a *jumper;* Fig. 15 (*a*) shows a jumper consisting of two plugs connected by means of a piece of control cable provided with a rubber covering. Fig. 15 (*b*) shows one of the sockets, or receptacles, which is provided with

nine insulated contacts *a* connected to the nine train wires. The contacts are numbered *0* to *8*, inclusive, and the train wires are provided with coverings in different colors or

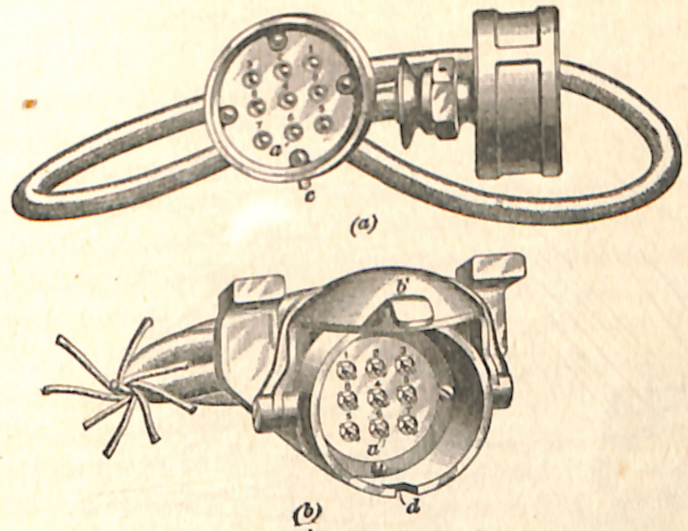


FIG. 15

combinations of colors, so that there will be no difficulty in getting the wires connected to corresponding terminals at each end of the car. The hinged cover *b* swings down over the front of the socket when it is not in use, thus excluding dirt and water.

The removable plugs, shown in Fig. 15 (*a*), are provided with nine receptacles *a'* into which the terminals *a* in the socket fit. The lug *c* slides into the slot *d* shown in (*b*), when the plug is inserted, and unless lug *c* is placed in line with *d*, the plug cannot be put in place; it is thus impossible to put in a plug upside down and get the train wires interconnected wrongly. The coupler sockets are provided with spring catches that hold the plugs in place against any

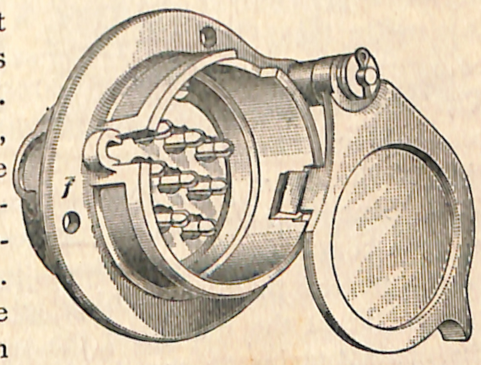


FIG. 16

stresses that arise in ordinary use, but if an undue stress is brought on the jumper, as, for example, by a parting of the train, the catches allow the plugs to pull out. It is customary to provide two coupler sockets at each end of the car, one on each side of the center line, as in Figs. 2 and 12; by using two sockets, a car can always be conveniently connected to an abutting car, because, no matter what may be the end-on relation of the cars, two sockets will always be directly opposite each other. Also, when there are two sockets on each end, one is available in case the other becomes defective, so that the double-socket equipment increases the reliability of the outfit. In order to have one socket on each end of a car meet all conditions of service, that socket must be either in the center of the end of the platform, or the single socket on opposite ends must be on opposite sides of the car, as in the case of air-brake couplings. Fig. 16 shows the style of socket used on interurban cars. The socket is set into the dash and secured to it by flange *f*.

19. Cut-Out Switch.—The object of the cut-out switch, as used with the type M control, is to provide a means of disconnecting control wires of the devices on the car from the train-line control wires. It is shown at *28*, Fig. 2, and is usually located under a car seat or in the special cab or compartment that is often provided for the control apparatus. The switch consists of a drum with nine contact strips corresponding to the nine wires of the control cable. On each side of the drum is a row of nine contact fingers, one set being connected to the incoming control wires from the connection board and the corresponding fingers of the opposite set connected to the outgoing wires leading to the control coils. When the handle of the switch is at the on-position, the contact strips on the drum connect opposite fingers and thus make the path through the switch continuous. When the handle is thrown to the off-position, the contact strips leave one set of fingers and thus place a break in each of the control wires. This prevents the devices on the car from operating, though it does not interfere in any way with the

operation of the devices on the other cars of the train. If, therefore, the motors or other operating devices on a car become defective, they can at once be cut out of service by means of the cut-out switch.

20. Control Cables.—The cables required for the equipment of a car with type M control are shown in Fig. 2. They are named and located as follows: On the front end of the car are located the No. 1 master controller and connection box connected by a short cable called the *No. 1 master controller cable;* another short cable connecting the cut-out switch to the connection box is called the *local control cable.* The small cables running from the connection boards to the coupler sockets are called the *forward-coupler cable* or *rear-coupler cable*, as the case may be. The No. 2 master controller and No. 2 connection board are on the rear end of the car, and the cable running between them, called the *No. 2 master-controller cable*, is interchangeable with a similar cable on the front end. The *train cable* runs between the connection boxes, as shown, and the *local contactor cable* carries the control wires to the several contactors. With the exception of the cable connecting the cut-out switch to the operating coils of the reverser and contactors, the control cables contain nine wires. The main-motor cable consists of three parts, the branch running to the starting rheostat, the branch running to the reverser, and the part connecting to the motors. The relative arrangement of the apparatus may differ considerably from that shown in Fig. 2, because most

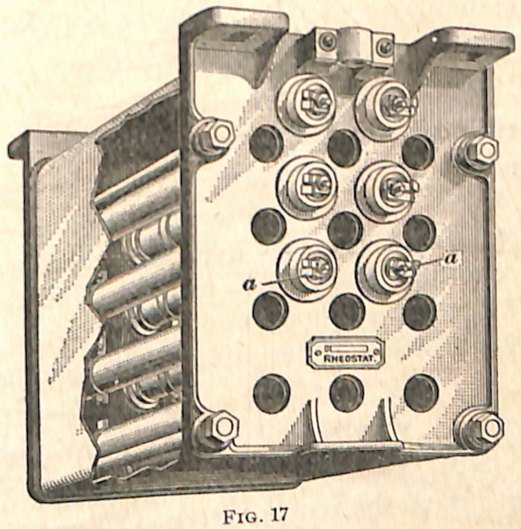


FIG. 17

of the appliances have to be placed under the car and their exact position is therefore determined by the location of other appliances, such as air-brake apparatus, brake rigging, etc.

21. Control-Circuit Rheostat.—The control-circuit rheostat, Fig. 17, is made up of twelve high-resistance coils completely enclosed in a sheet-iron protecting case. The ends of the coils are brought to the outside of the case and connected to terminals *a*. The operation of the master controller cuts sections of the control rheostat out or in, according as contactor operating coils are cut in or out, thereby maintaining the control current per car approximately constant and preventing any of the contactor coils from being subjected to abnormal pressure.

22. Motor-Circuit Rheostat.—In order to prevent a rush of current through the motors at starting and secure a smooth acceleration, a rheostat must be used in the main-motor circuit as with ordinary car equipments. The rheostat is of the cast grid type and is made up of a number of units, as shown in Fig. 2. The resistance is the same in its general construction as that used for ordinary cars, so that further description is unnecessary.

WIRING DIAGRAM FOR TYPE M CONTROL

23. General Description.—Fig. 18 is a general diagram of the wiring for two C6 master controllers operating two motors, the equipment corresponding to that shown in Fig. 2. The control-circuit wires are printed in red and the operating-circuit wires in black, in order that each may be more readily distinguished. The various operating devices are printed in black irrespective of whether they belong to the operating circuit or to the motor circuit.

At the top of the master controller is shown the small reverse drum with the two control wires *0, 8* connected to its contact fingers. Immediately below the reverse drum is the safety switch, with the auxiliary blow-out coil connected between the two fixed contacts of the switch. Below this is

Car Wiring for Sprague-General Electric Type M Control

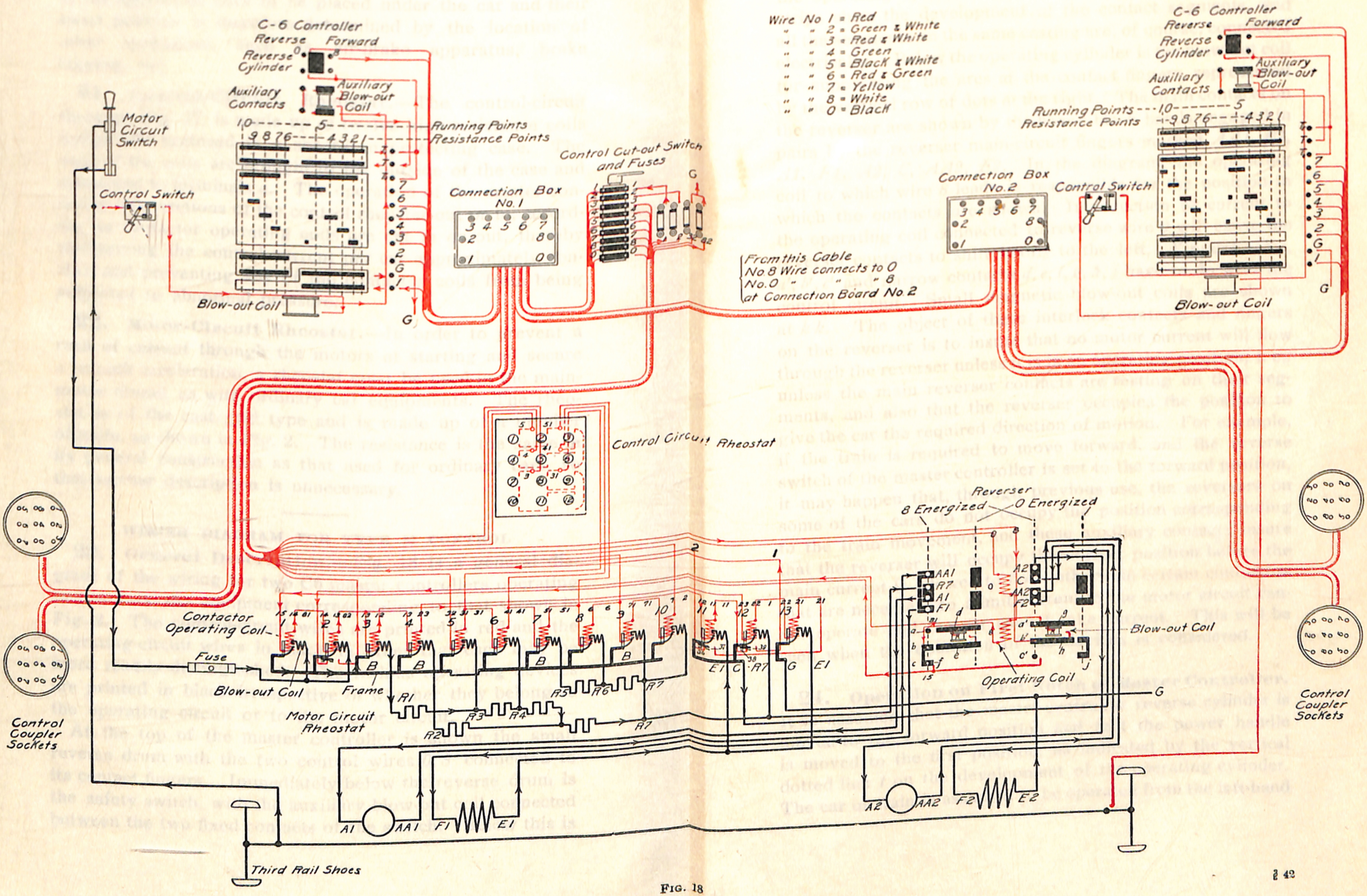
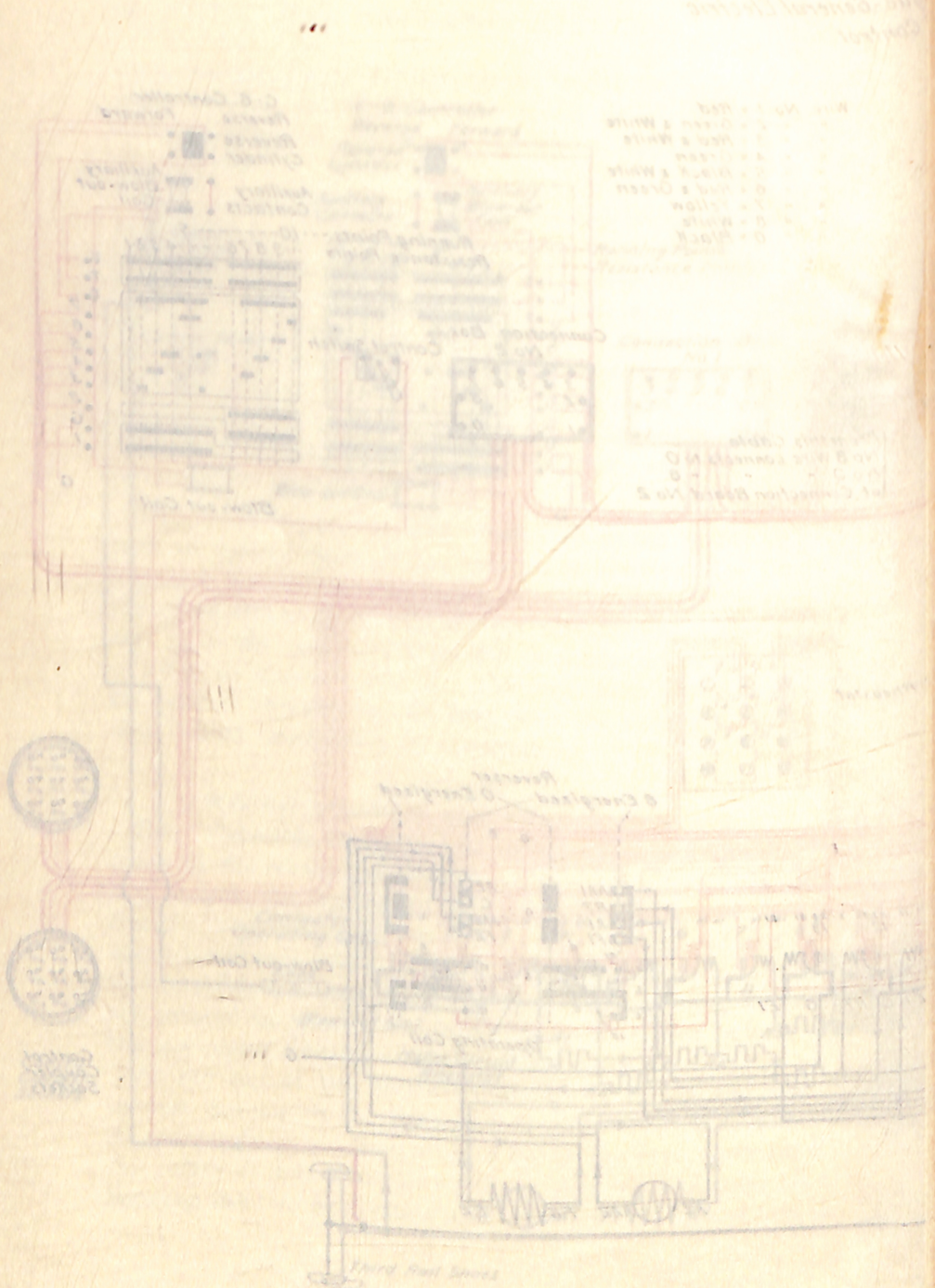


FIG. 18



the operating cylinder made up of four castings; the black strips show the development of the contact segments, and all the segments on the same casting are, of course, connected electrically. Below the operating cylinder is the blow-out coil for suppressing the arcs at the contact fingers, represented by the vertical row of dots at the right. The main contacts on the reverser are shown by the heavy black bands engaged in pairs by the reverser main-circuit fingers marked *AA1*, *R7*, *A1*, *F1*, *A2*, *C*, *AA2*, *F2*. In the diagram, the operating coil to which wire *8* leads is responsible for the position in which the contacts are shown. Introduction of current to the operating coil connected to reverse wire *0* will cause the reverser contacts to shift bodily to the left. Fingers *a*, *b*, *c*, *a'*, *b'*, *c'* and narrow contacts *d*, *e*, *f*, *g*, *h*, *j* have to do with the control circuit. Small magnetic blow-out coils are shown at *k k*. The object of these interlock contacts and fingers on the reverser is to insure that no motor current will flow through the reverser unless it is in an operating position; i. e., unless the main reverser contacts are resting on their segments, and also that the reverser occupies the position to give the car the required direction of motion. For example, if the train is required to move forward, and the reverse switch of the master controller is set to the forward position, it may happen that, through previous use, the reversers on some of the cars do not occupy the position corresponding to the train movement, and these auxiliary contacts insure that the reverser will occupy the correct position before the main current is allowed to flow, otherwise certain contactors that are necessary to admit current to the motor circuit cannot operate and the car cannot take current. This will be seen when the operation of the devices is considered.

24. Operation on First Notch of Master Controller. It is assumed that the master-controller reverse cylinder is moved to the forward position and that the power handle is moved to the first position, as indicated by the vertical dotted line *1* on the development of the operating cylinder. The car or train is assumed to be operated from the left-hand

controller. As soon as the operating handle is moved from the off-position, the safety switch closes, since the dead-man's knob is supposed to be pressed down. The path of the control current is then as follows: Control-circuit switch–fuse–main blow-out coil–auxiliary blow-out coil–safety switch–finger *T*–finger T_1–finger *8* by way of reverse cylinder–*8* on connection box No. *1*–post *8* on cut-out switch–reverse operating coil *8*–reverser control finger *b*–contact segment *f*–finger *c*–*15*–*15*–operating coil of contactor *1*–*14*–*14*–operating coil of contactor *2*–*13*–*13*–operating coil of contactor *3*–*12*–*12*–operating coil of contactor *11*–*11*–*11*–interlock contact *38*–interlock contact *39*–*1*–*1*–fuse *1*–cut-out switch *1*–connection-box terminal *1*–operating-cylinder finger *1*–ground finger *G*. On the first point, therefore, contactors *1*, *2*, *3*, and *11* are operated, and the reverser is at the forward position, shown in the figure. The path of the motor current corresponding to this combination will be:

Motor-circuit switch–main fuse–$\left\langle \begin{matrix} \text{contactor } 1 \\ \text{contactor } 2 \end{matrix} \right\rangle$–frame *B*–contactor *3*–*R1*–*R3*–*R4*–*R7*–*R7* (on reverser)–*A1*–*A1*–*AA1*–*AA1*–*F1*–*F1*–*E1*–*E1* (on contactor *11*)–*C*–*C* (on reverser)–*A2*–*A2*–*AA2*–*AA2* (on reverser)–*F2*–*F2*–*E2*–ground. The arrowheads in Fig. 18 show the paths of the control current and main-motor current when the master controller is on the first notch.

In tracing the above control circuit, it was assumed that the reverser already occupied the position shown in the figure and corresponding to that assumed when coil *8* is energized. Suppose, however, that the rocker had, on account of previous use or for any other reason, occupied the opposite position, so that the small interlock fingers on the reverser rested on segments *d*, *e*, and *j* instead of *g*, *h*, and *f*. The current entering at *8* would then take the path *8*–through operating coil *8*–finger *b*–segment *e*–blow-out coil *k*–segment *d*–contact finger *a*–*81*–*81*–interlock on contactor *2*–*82*–*82*–fuse–ground. There can be no current flow in the motor circuit unless contactors *1* and *2*, called *line contactors*, are closed. Current is introduced to the

reverser operating coil only when master-controller fingers *T* and T_1 make contact with the upper casting. If on moving the operating handle to the first notch, the reverser happens to rest in a position corresponding to the existing position of the reversing handle, current takes the path already outlined and closes the line contactors so that motor current can flow. Should the reverse rest in the wrong position, however, control finger *c* is not in contact with anything and the line contactors cannot close. Reverser current does, however, take the path leading through the interlock on contactor *2*, thereby throwing the reverser to the correct position in which the line-contactor operating coils can get current. Simultaneously with the operation of the line contactors, the interlock switch on contactor *2* of course opens, thereby interrupting in a second place the circuit used for throwing the reverser to correct position and which the reverser itself interrupted at the instant of operation. Blow-out coils *k*, *k* suppress all arcing that tends to follow the interruption of the control current. Contactors *1*, *2* are connected in parallel so as to reduce the current handled by each, because these contactors correspond to the trolley fingers of an ordinary controller, and the service imposed on them is more severe than on the others. Contactors *9*, *10* are connected in a similar manner.

25. Operation on Last Series Notch.—As the drum is turned to positions *2*, *3*, and *4*, contactors *5*, *6*, and *7* are added to those already in operation, as can be seen by tracing out the control circuit. The result is to reduce the resistance in series with the motors. On the fifth position, which is the last series notch and one of the running notches, all of the resistance is cut out. The path of the operating current is as follows, starting from finger *T* on the master controller: *T*–T_1–T_6–finger *7*–connection-box terminal *7*–cut-out contact *7*–terminal on contactor *10*–*71*–*71*–contactor *9*–*6*–*6*–contactor *8*–*51*–*51*–contactor *7*–*41*–*41*–contactor *6*–*31*–*31*–contactor *5*–*32*–fuse–ground. The path of the reverser current remains as before, so that it is not necessary to trace it out.

The motor current takes the path: Motor-circuit switch–fuse–<contactor 1 / contactor 2>–frame *B B*–<contactor 9 / contactor 10>–*R7–R7–A1–AA1*, etc.–ground. All the resistance is cut out and the two motors are in series.

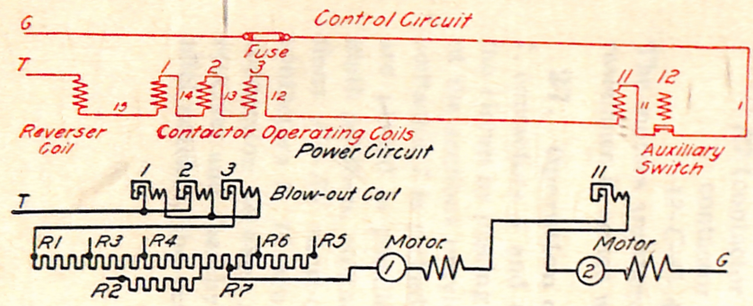
26. Operation on First Parallel Notch.—When the controller is on position *6*; i. e., the first parallel notch, the operating current may be traced from finger *T* as follows: *T–T*$_1$–reverse cylinder–*8–8* on connection board–*8* on cut-out switch–coil *8* on reverser–*b–c–15–15*–contactor *1–14–14*–contactor *2–13–13*–contactor *4–23–23*–contactor *12–22–22*–contactor *13–21–21*–interlock *37–36–2*–fuse *2–2* on cut-out–*2* on connection-box–finger *2* on controller–ground. This operates the reverser, or rather keeps the reverser in the position that it already had on the series notches, and operates contactors *1*, *2*, *4*, *12*, and *13*.

The path of the motor current is then as follows: Motor-circuit switch–fuse–<contactor 1 / contactor 2>–*B–B*–contactor *4–R2–R7*–<*R7* (on reverser)–*A1–A1–AA1–AA1–F1–F1–E1–* / *R7* (contactor *12*)–contactor–contactor *13* ——— *12–C–C–A2–A2–AA2–AA2–F2–F2–E2*>–ground. The motors are therefore in parallel with two sections of the resistance in series with the circuit.

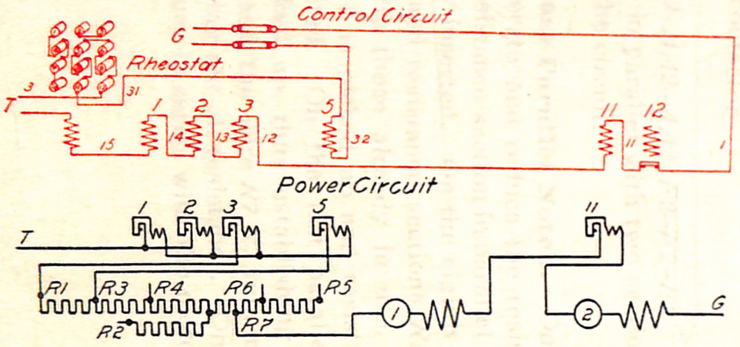
27. Operation on Last Parallel Notch.—On position 7, contactors *5* and *6* operate and reduce the resistance in the circuit by placing a resistance section in parallel with one of the sections previously inserted. On the eighth position, contactor 7 is picked up and resistance sections *R5–R6–R7* are placed in parallel with those already in use. On the ninth position, contactor *8* is picked up and resistance sections *R5–R6* short-circuited. On the last parallel notch, contactors *9*, *10* are picked up, thus establishing a direct connection between *B B* and the wire *R7 R7* running to the reverser and thereby cutting out all resistance. On the parallel notches, the resistance in series with the motors is, in

Series

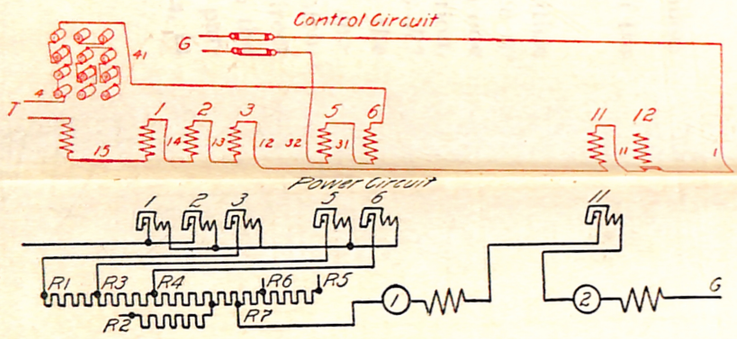
1st Point



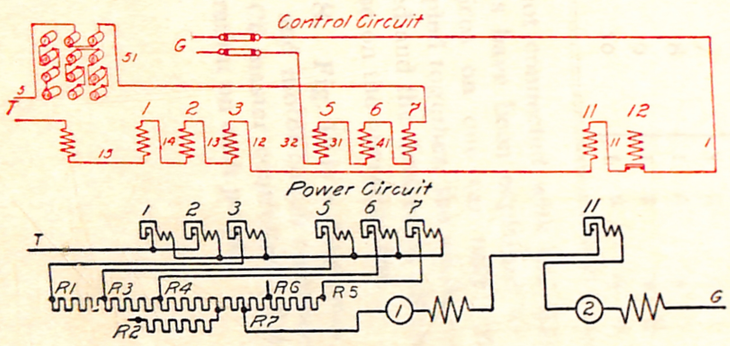
2nd Point



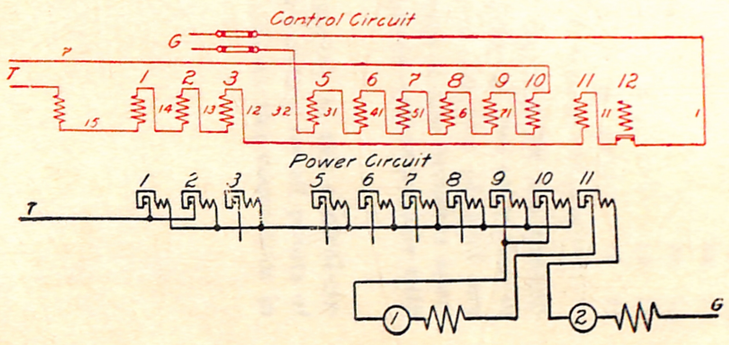
3rd Point



4th Point

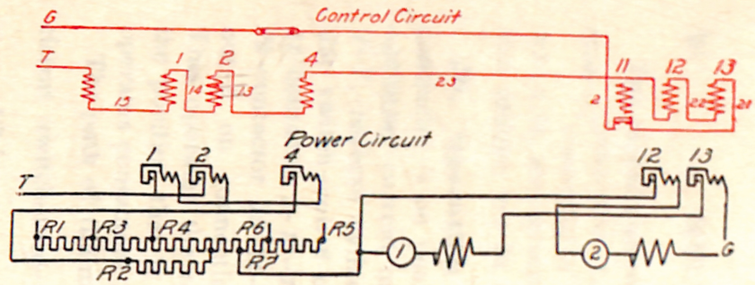


5th Point

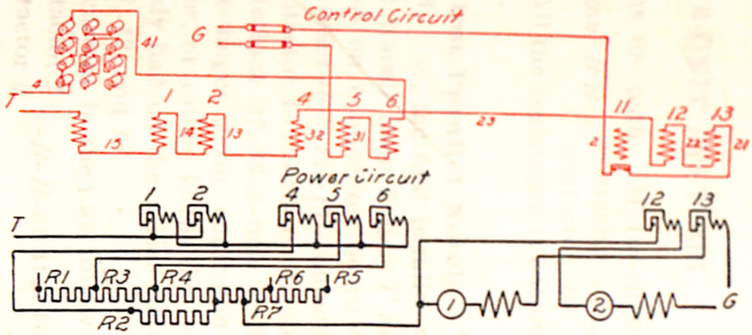


Parallel

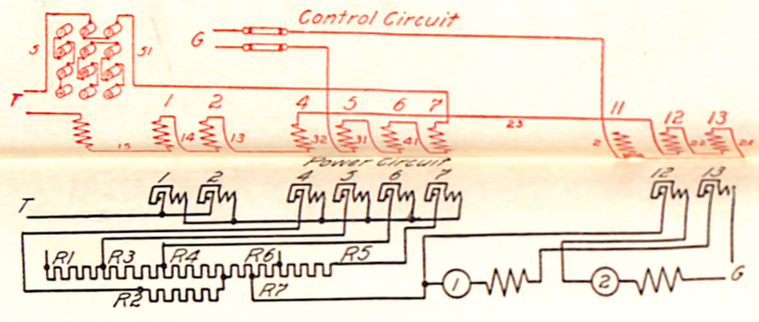
6th Point



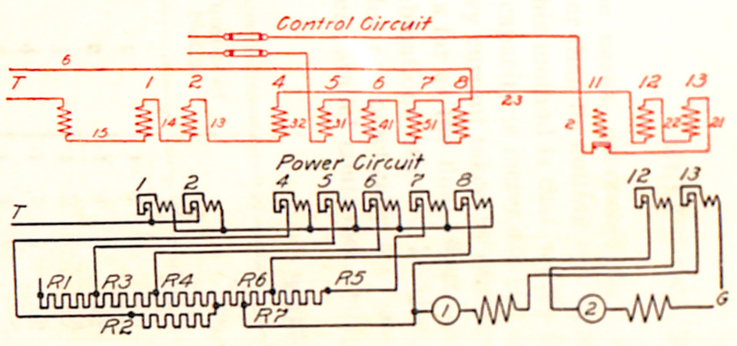
7th Point



8th Point



9th Point



10th Point

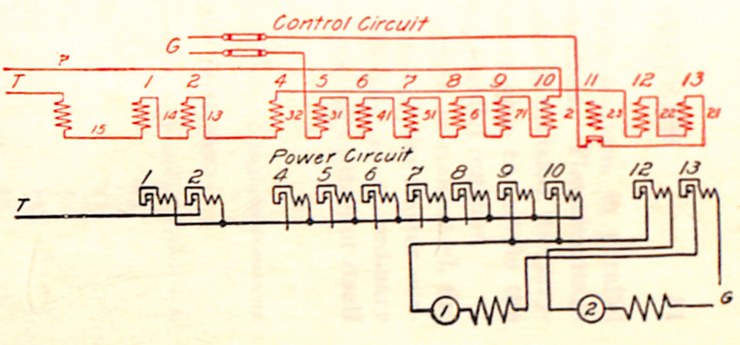


FIG. 19

some cases, decreased by connecting sections in parallel rather than by cutting out existing sections. The advantage of this method is that, as the resistance is reduced, its carrying capacity is increased and it is better able to handle the heavy current taken by the car on the parallel notches.

As far as the final effect on the motors is concerned, the combinations effected by the movement of the master controller are practically the same as effected by an ordinary series-parallel controller, though the master controller itself

TABLE I

Number of Notch	Contactors in Operation
1	1 2 3 11
2	1 2 3 5 11
3	1 2 3 5 6 11
4	1 2 3 5 6 7 11
5	1 2 3 5 6 7 8 9 10 11 12 13
6	1 2 4 12 13
7	1 2 4 5 6 12 13
8	1 2 4 5 6 7 12 13
9	1 2 4 5 6 7 8 12 13
10	1 2 4 5 6 7 8 9 10 12 13

is not connected with the motors. In Fig. 18, the connections have been explained by referring to the operation of devices on one car only. Where a number of cars are coupled together, the whole train control line becomes energized and the devices on all cars operate synchronously with those on the operating car.

28. Fig. 19 is a diagrammatic sketch of the control-circuit and motor-circuit combinations existing on all points of the C6 master controller. Table I shows the contactors in operation on each point.

WIRING DIAGRAM OF TYPE M CONTROL WITH CURRENT-LIMITING DEVICE

29. General Description.—Fig. 20 is a diagram of connections for type M control with C18 controllers. The chief differences between this diagram and that shown in Fig. 18 lie in the number and arrangement of the contactors and the addition of an automatic device that prevents the car from taking more than a predetermined current at starting. The contactors are of the type already described, those of approximately the same potential being grouped together on a common base, to economize space and simplify connections. In order to insure the fastest possible acceleration without slipping of the wheels, the following arrangement is provided: The controller cylinder instead of being positively driven by the shaft to which the operating handle is attached, is connected thereto by means of a spring; a magnetically operated lock prevents the cylinder from following the movement of the operating handle so long as the current taken by the motors exceeds the allowable amount. Thus, if the motorman were to throw the operating handle around rapidly to, say, the full series position before the motors had time to gain headway, the train would take an excessive current if no automatic throttle or current-limiting device were provided, and wheel slippage would occur. In this controller, the power drum does not at once follow the movements of the handle; a rapid movement of the handle simply places the spring between the handle and shaft under tension, and the latter cannot move until it is unlocked. When the current falls to an amount sufficient to unlock the shaft, the spring moves the cylinder forward with the result that it follows the movement of the handle step by step until it reaches the position occupied by the handle. If the motorman moved the power handle so slowly that the starting current never exceeded the allowable amount, the drum would not be locked and it would follow the movements of the handle as in an ordinary controller. In practice, however, where this type of controller is used, the motorman

Car Wiring for Sprague-General Electric Type M Control With Current Limiting Device.

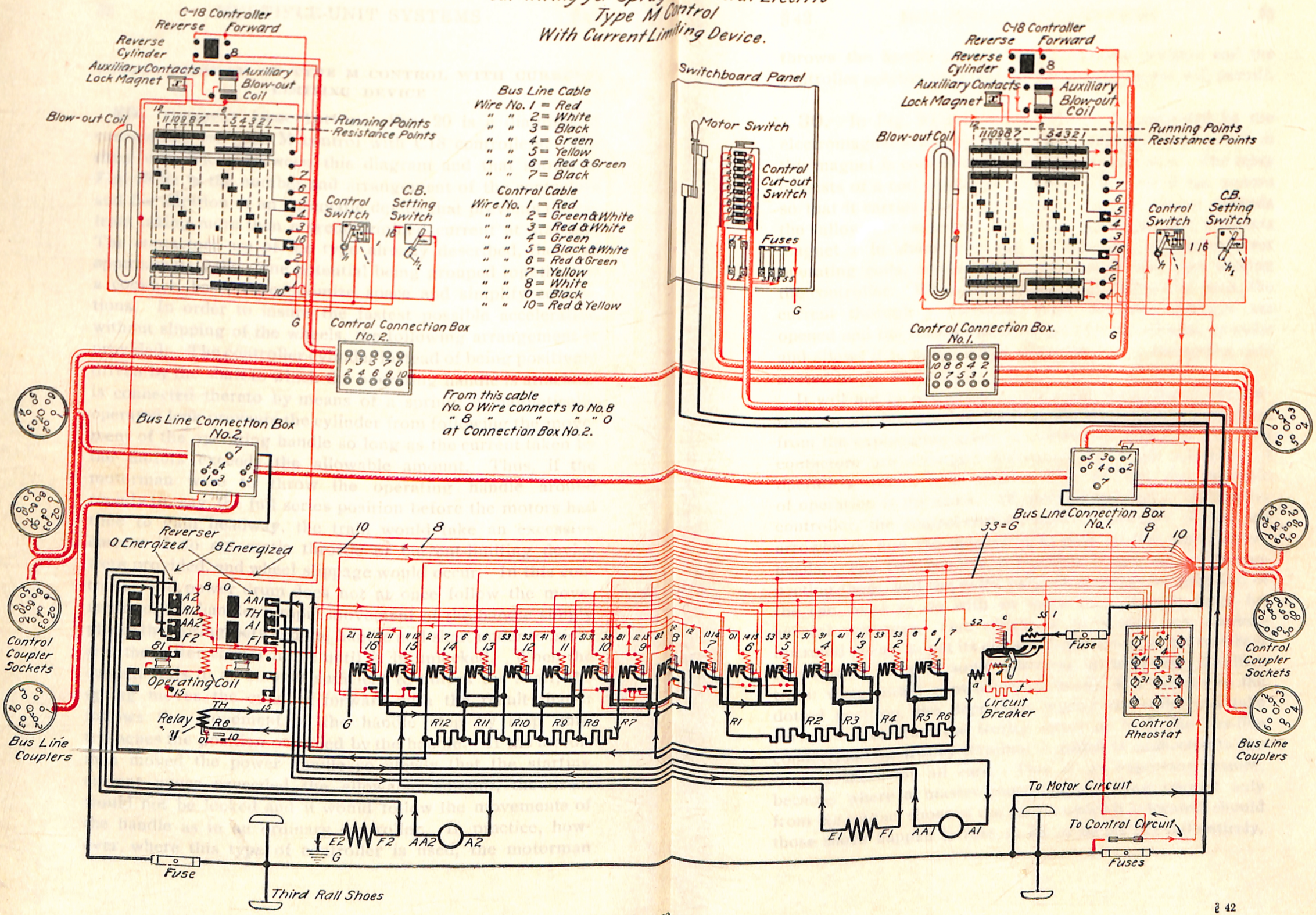
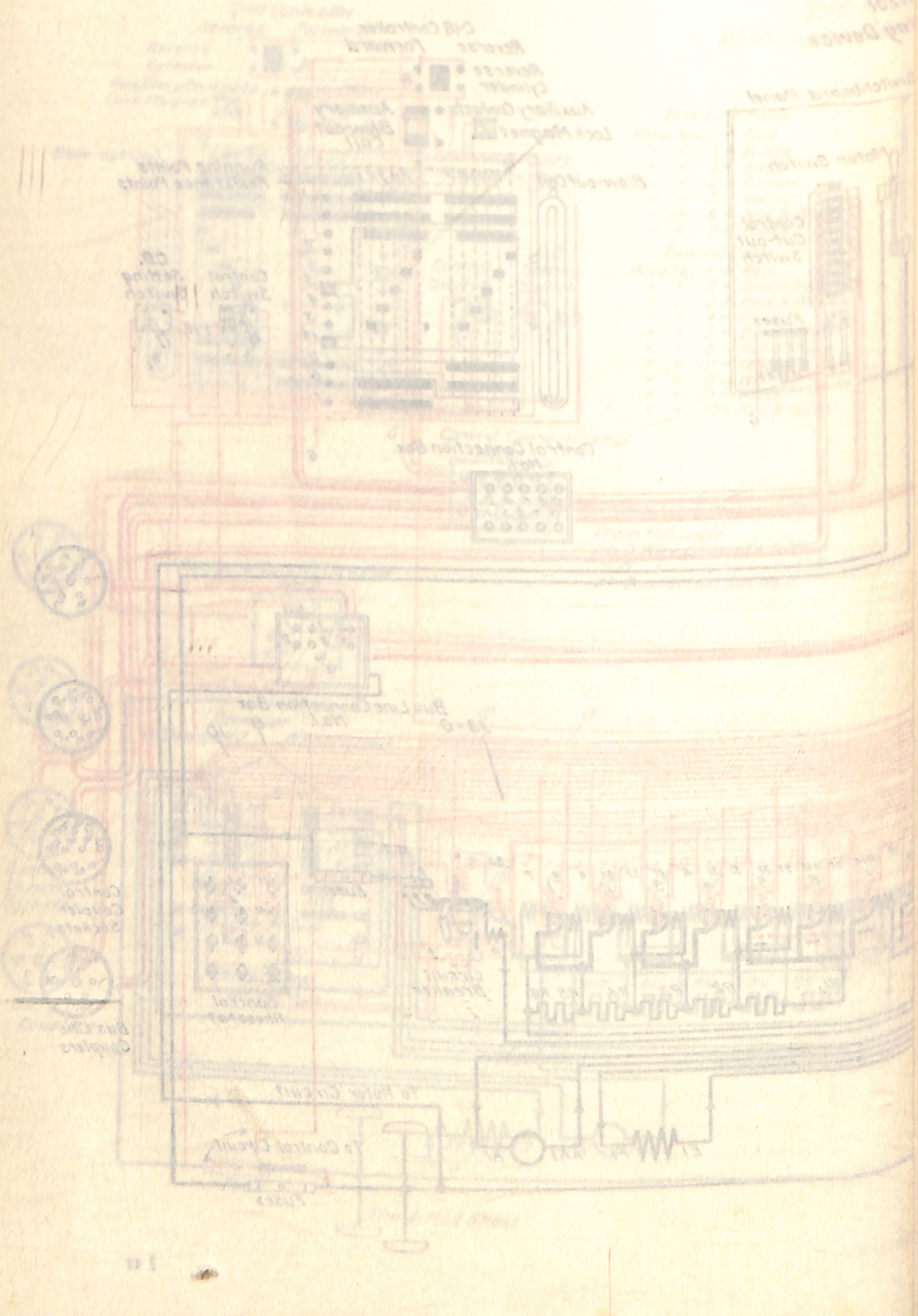


FIG. 20



throws the handle around to the running position and the controller notches up as fast as the locking device will permit.

30. In Fig. 20, the locking device is controlled by the electromagnet x on the master controller and the current in this magnet is controlled by the relay shown at y. The relay consists of a coil connected in series with one of the motors so that it carries the main current. If the current exceeds the allowable amount, the relay operates and connects magnet x in shunt with one or the other of the reverser operating coils, according to which is in use, thus locking the controller. When the current drops below the limit, the current through y decreases until the relay contacts are opened and the magnet in the controller unlocks the cylinder and allows it to move under the influence of the spring connected to the main shaft.

It will not be necessary to trace out the paths of the current on all the notches in Fig. 20, since this can be done from the explanation given in connection with Fig. 18. The contactors are arranged differently and their sequence of operation differs from that in Fig. 18, but the principle of operation is the same. On the first position of the master controller, the control-current path is indicated by the red arrowheads and the main-current path by the black arrowheads. The two bus-line connection boxes, the cable connecting them, and the extra pairs of couplers on each end of the car, have to do with an extra train line provided for several purposes. One object is to enable any current-operated device to get its current either from the car on which it is located or from some other car in the train. To illustrate: when either control-switch handle h is thrown to the dotted position, the dependent master controller can take current either from the trolley direct or from the bus-line connection-box trolley terminal 7, which is connected to the contact shoes of all cars. This is an important feature, because where a master controller can draw current only from the contact shoes of the car on which it is located, should those shoes happen to rest on ice or be off the rail entirely,

it would be necessary to go to another car in order to start the train.

31. Another feature of this control is the automatic main-current circuit-breaker and the facilities for setting it before starting or resetting it after operation. The breaker is located to the right of the contactors in Fig. 20. Here *a* is the operating coil and *b* the blow-out coil; both carry the main current, the circuit-breaker being the first device through which the main current passes after leaving the motor switch. By means of setting coil *c*, the circuit-breaker can be set by moving handle h_1 of either circuit-breaker setting switch to the dotted position. The circuit-breaker can be closed by operation of the setting switch only when the accompanying master controller is at off-position, because in all other positions fingers *5* and *16*, which are part of the setting circuit, make no contact. When switch h_1 is closed, the path of the current through setting coil *c* is as follows, starting from point *16* at setting switch: *16*–setting switch finger *16* on controller–finger *5*–cut-out switch–*5* on control rheostat–*2*–*1*–*51*–*51*–interlock on contactor *10*–interlock on contactor *8*–interlock on contactor *7*–*52*–setting coil *c*–*55*–*55*–fuse–ground. If contactors *7*, *8*, or *10* are closed, the circuit-breaker cannot be set and it is therefore impossible to set the breaker while the main-motor current is on. Setting coil *c* moves the circuit-breaker parts over to where armature *e* on the togglejoint comes within the range of holding coil *d*, which is steadily energized from the bus-line connection box through resistance *f*. Coil *d* holds the breaker closed after the circuit-breaker setting switch has been moved to off-position or after the master controller has been moved to an operating position. As long as the circuit that energizes holding-magnet *d* is closed, the circuit-breaker will remain closed. Excessive current in the motor circuit, however, will cause operating coil *a* to attract its armature composing part of the holding-coil circuit, which is thereby opened and the breaker thrown into operation.

TABLE II

Positions	Contactors in Action												
1					6	7		9					15
2				5	6	7		9	10				15
3			4	5	6	7		9	10	11			15
4		3	4	5	6	7		9	10	11	12		15
5	2	3	4	5	6	7		9	10	11	12	13	15
6	1	2	3	4	5	6	7	9	10	11	12	13	14 15
7						6	7	8 9					16
8				5		6	7	8 9	10				16
9			4	5		6	7	8 9	10	11			16
10		3	4	5		6	7	8 9	10	11	12		16
11	2	3	4	5		6	7	8 9	10	11	12	13	14 16
12	1	2	3	4	5		6	7 8 9	10	11	12	13	14 16

32. Table II shows the contactors in operation on the positions of the C18 controller. The plan of wiring shown in Fig. 18 is the one generally used for ordinary multiple-unit equipments; the arrangement in Fig. 20, which is somewhat more complicated and includes the auxiliary features just explained, is used in places where the traffic is heavy and where the requirements are unusually exacting, as, for example, on the New York Subway.

WESTINGHOUSE UNIT-SWITCH CONTROL

INTRODUCTION

33. The **Westinghouse unit-switch system** of train control differs considerably from the type M system already described, but the difference is more in the details of appliances than in the results obtained by their operation. Excepting the master controller, all circuit-making and circuit-breaking devices of the unit-switch equipment are operated by compressed air controlled by electrically operated valves, of which the time and order of operations depend on circuit combinations established by the master controller. The main controller consists of thirteen individual *unit switches* grouped radially so as to occupy a minimum amount of space. The main controller and all other devices, except the master controller and the brake valve, are located under the car in suitable protecting housings, easily opened for inspection. The train line consists of seven wires terminating in sockets and continued from car to car by flexible jumpers, the plugs or terminals of which engage the sockets of abutting cars.

The train line and all operating devices dependent on it are energized through the master controller by a storage-battery current supplied at a pressure of about 15 volts. The battery consists of fourteen cells arranged in two sets having seven cells, in series, in each set. When one set is in service, the other is being charged through the car-lamp circuit, double-throw switches being provided to make the necessary changes for charging and discharging. The use of an independent source of operating current renders operation practicable under the especially trying conditions of service due to a film of ice on the trolley wire or contact rail or in case the power goes off the line; it is also probable that the

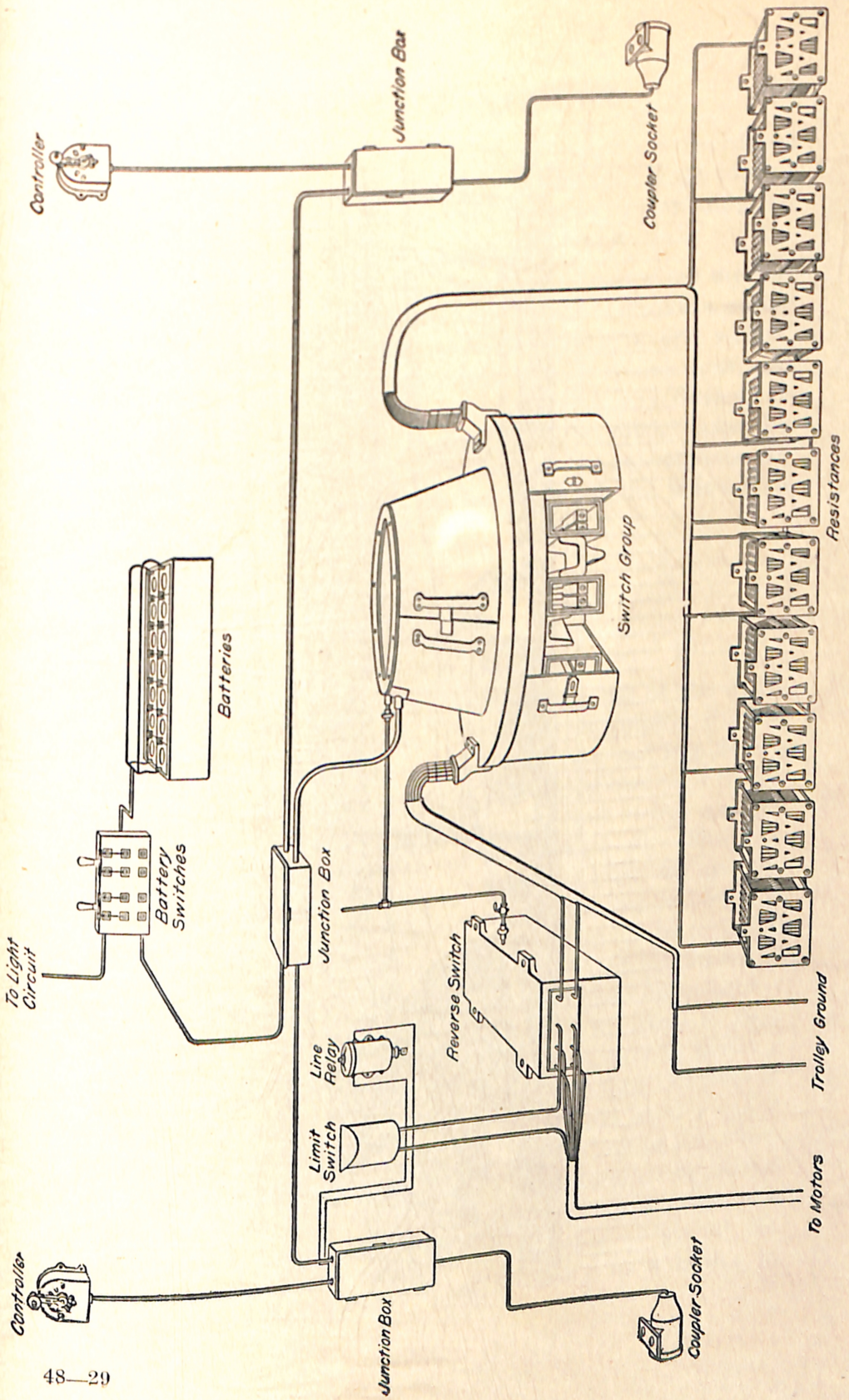


FIG. 21

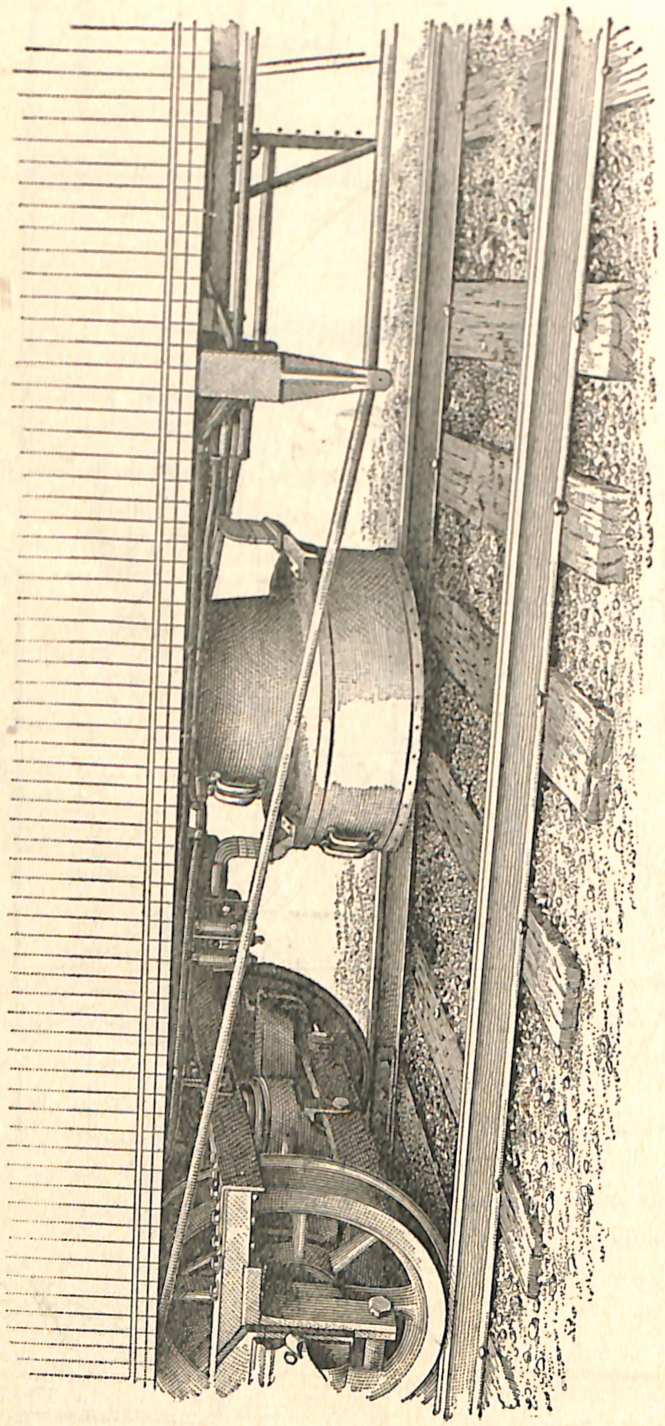


FIG. 22

control circuits are not nearly so likely to become disordered by lightning discharges. The low voltage used in the control circuits considerably simplifies the problem of insulating the control wires and securing durable coupling devices.

34. A unit-switch control equipment comprises the following devices: Unit-switch group, master controllers, motor cut-out switches, resistances, storage battery, reverse switch, train line, limit and line relay switches, air connections, and line switches, if required. In considering any device, an understanding of it will, in each case, be made easier by locating the device in Fig. 37, in which the connections are indicated. Fig. 21 shows an assembly of the unit-switch equipment.

CONTROL DEVICES

UNIT, OR AIR, SWITCHES

35. Fig. 22 shows the location under a car of the **unit-switch group** constituting the main controller. Fig. 23 shows the device with the housing removed, and Fig. 24 is a section through the center of the group shown in Fig. 23; from this drawing the construction of a unit switch and the mechanism for operating it can be understood. The controller consists of thirteen switches a, a, Figs. 23 and 24, arranged radially around a blow-out coil b that is common to all. (One of the unit switches is shown more in detail at the left of Fig. 24.) The fixed contact of the switch is shown at a'; the movable one at b' is on the end of arm c, which has a slight movement around pin d. Arm c, as a whole, is pivoted at e and is moved through rod f by piston g operating in cylinder h. Any arcing between contacts a' and b' takes place in chamber i. The radial arms j and k form poles projecting from the top and bottom of the blow-out coil. A strong magnetic field is therefore set up across the region in which the switch contacts are located and the arc is blown out radially. The object of giving the contact arm c limited movement around d as a center in

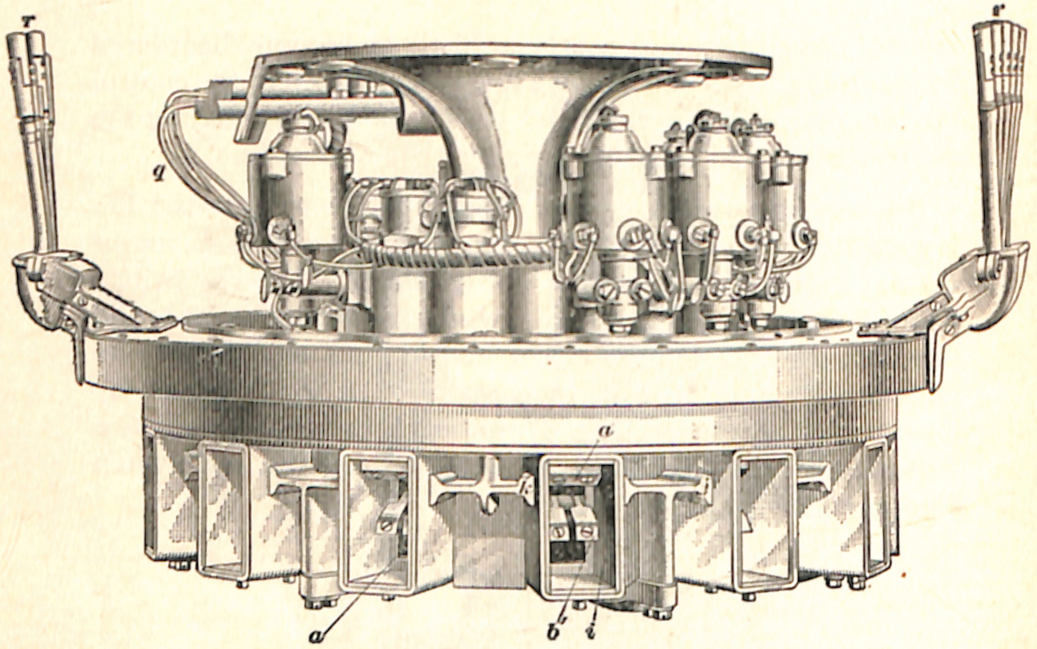


FIG. 23

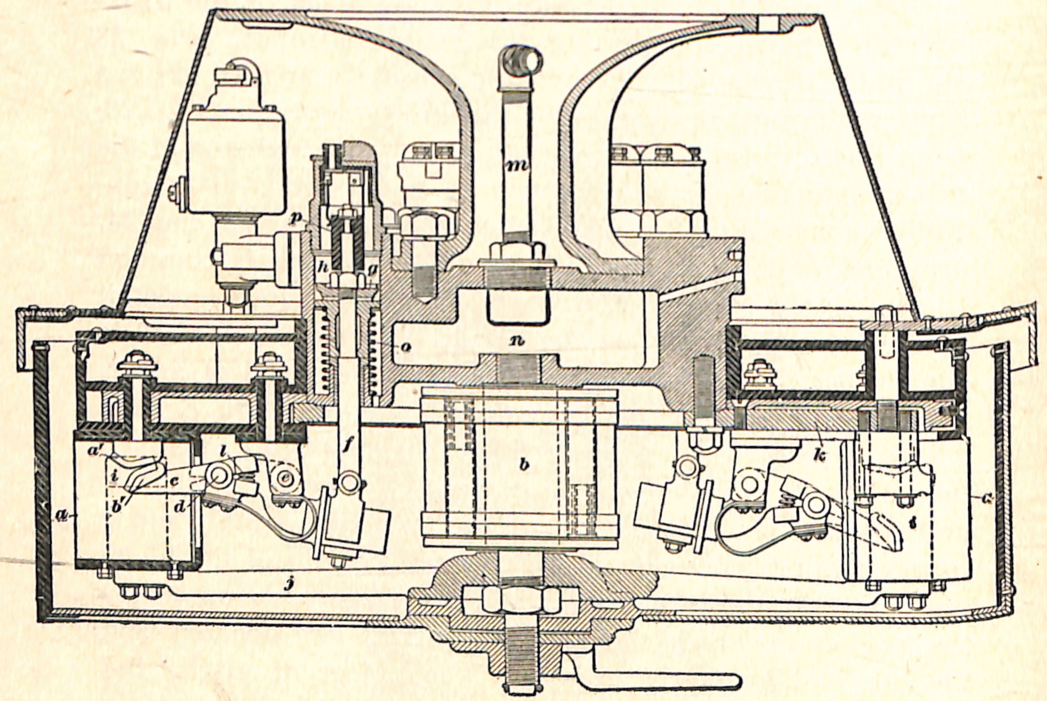


FIG. 24

conjunction with the small compression spring *l* is to give contacts *a'*, *b'* a certain amount of wiping action that prevents sticking. The compressed air for operating the switches passes through pipe *m* into a central chamber, or reservoir, *n* of ample storage capacity to insure that ample pressure for operating the switches is always available. Admission of reservoir air to the operating cylinders of the switches is governed by electrically operated valves that are, in turn, dependent on the master controller for action. Each switch has a cylinder and operating coil above it, the coil being enclosed in a small iron case. The relative positions of the coil case, switch, and cylinder are shown in Fig. 24. Admission of air into cylinder *h*, Fig. 24, forces the piston down against the action of spring *o*, the object of which is to open the switch promptly on exhausting the air from the cylinder. Over certain of the operating cylinders, small switches *p*, called *interlocks*, are arranged to be operated by the movements of the piston within the cylinder; these interlocks are used in connection with certain automatic features better understood after considering Figs. 36 and 37, which are diagrams of connections. In Fig. 23, wires *q* carry the control current to the electromagnetic valves; the main current wires connect to terminals *r*, *r*.

MASTER CONTROLLER

36. The standard **master controller** used for operating single cars, or trains equipped with the Westinghouse unit-switch system, is illustrated in Figs. 25 and 26, which show the device with the cover on and off, respectively. In Fig. 25, the operating handle *a* is in the off-position, corresponding to the off-position of cylinder *a'*, Fig. 26. The cylinder *a'* consists of a single metal spider mounted on a horizontal shaft *b*, the turning of which causes the cylinder to engage fingers *c*, *c*. The operating handle can be placed in position only when the controller cylinder is at the off-position, and to rotate the handle, pin *d* must be depressed, thus raising a small lever that interferes with lugs cast on the cover. A movement of the operating handle to the right, corresponds

to a forward motion of the car or train; and a movement to the left, reverses the motion. If the operating handle be moved to the position marked by lug *g*, circuit combinations will automatically change until the motors are in full series across the line; as long as the operating handle is kept in this position, the combinations will not change, but an advance to the position marked by lug *h*, will automatically change the combination until the motors are in parallel across the line. If the handle be released at any stage of its operation, spring *i*, Fig. 26, will return it to off-position, in which all circuits are automatically interrupted.

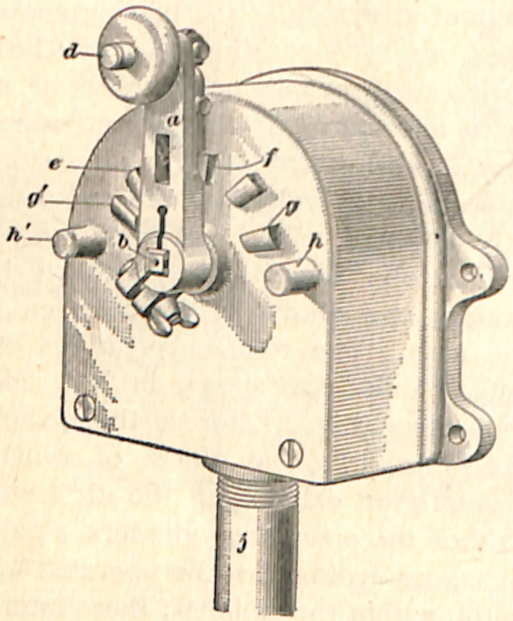


FIG. 25

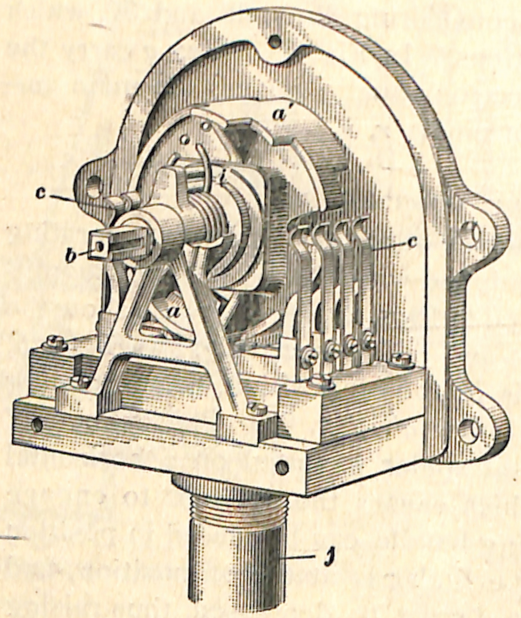


FIG. 26

The first stage of the movement of the handle from its off-position throws all reversing devices to a position corresponding to the direction in which it is desired to move the car or train, assuming that the reverser does not already occupy a position corresponding to the desired movement. It also

allows a flow of current through the motor circuit. This current, however, is too small to start the car, the maximum starting-coil resistance being in circuit. On the forward side of the master controller, the position on which these preliminary circuits are established is not indicated; on the reverse side, however, an additional lug *e*, Fig. 25, is provided. In emergency cases of reversal, it is well to pause on position *e*, for while the current flow on that position is insufficient to start a car it is sufficient to apply considerable braking action in reversal where the line E. M. F. and counter E. M. F. of the motors add together, and a pause there lessens the likelihood of tripping the line circuit-breaker. If the reversing devices are not in the proper position the motor circuit can take no current.

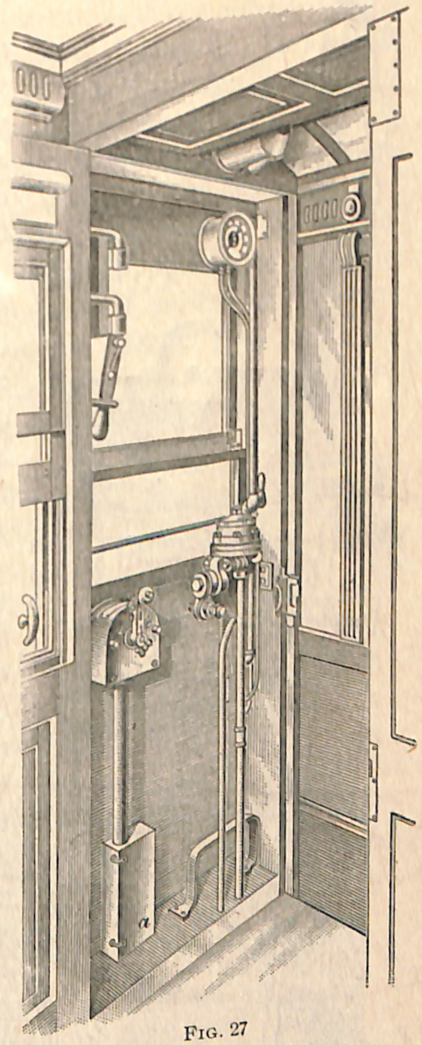


FIG. 27

The control-circuit wires are introduced into the master controller through pipe *j*, which may also serve as a leg for steadying the device. As $16\frac{1}{2}$ volts is the maximum pressure to which the control circuit is subjected, no difficult insulation problems are encountered and the use of a magnetic blow-out coil for extinguishing arcs in the controller is unnecessary. Fig. 27 shows the location of the master controller in the special compartment, on an elevated railway car, provided for the controller and air-brake operating devices.

REVERSE SWITCH

37. A general view of the **reverse switch, or reverser,** used with the unit-switch system of control, is shown in Fig. 28. The function of the reverser is to interchange the main motor armature connections so as to reverse the direction of rotation of the armatures. In Fig. 28, *a* is the base and *b* the feet for securing the device to the under side of the car, *c*, *c* being the lugs to which the cover is attached. The construction and operation of the reverser are as follows: An insulating block *d* carries two sets of metal strips *e*, of which one set or the other, according to the position of block *d*, engages stationary fingers *f*. By means of compressed air admitted to cylinders *g* or *g'*, a reciprocating motion can be given to block *d*. Electromagnets *i*, *i'* operating valves *j*, *j'* immediately beneath them, determine which of the cylinders *g*, *g'* shall receive compressed air and thereby determine the position of block *d*. If the master controller has been moved to the forward position, electromagnet *i* will be energized and operate the valve that admits air to the cylinder, thus forcing block *d* and its contacts to a position where the train movement will be forward. Movement of the master controller

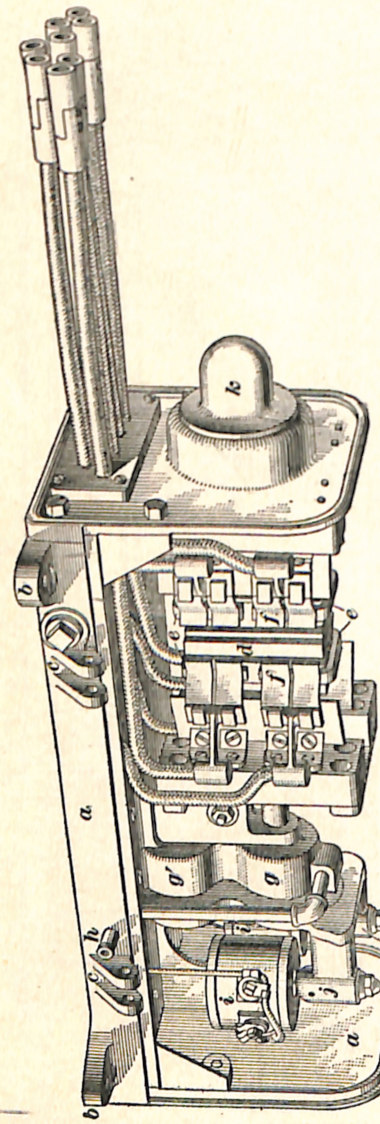


FIG. 28

to the reverse side of its off-position will energize electromagnet *i'*, thereby operating the reverser so as to give the car or train backward motion. The reverser has no off-position, and as it is never required to interrupt a circuit that is carrying current, it has no blow-out coil for extinguishing arcs at the contact fingers. Protected by cover *k* is a small interlocking switch, the movable contact of which is attached to the reciprocating switch block; the contacts of this switch are indicated in Fig. 37. The function of the interlock is to insure that the switch group cannot operate unless the reverser has been fully thrown in the direction indicated by the master controller. The first circuit established when operating the master controller is one that insures that motor current cannot flow unless the reverser is in the correct position; this precludes the possibility of having different cars in the same train with their reversers in opposite directions.

MOTOR CUT-OUT SWITCH

38. Figs. 29 and 30 illustrate the cut-out switch used when one or both motors have to be cut out of service. Stem *b* passes through the car floor and terminates in a hand wheel by means of which the switch can be turned to any of four indicated positions, which are as follows: 1, both motors in circuit; 2, No. 1 motor in, No. 2 motor cut out; 3, No. 2 motor in, No. 1 motor cut out; 4, both motors cut out. In both figures, the motor wires enter the switch casing at *c* and two

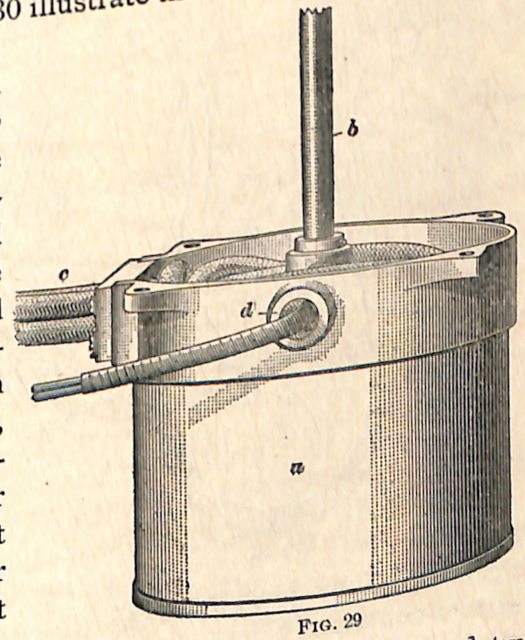


FIG. 29

control-circuit wires at *d*. In Fig. 30, *e* is one of ten contact segments mounted on a cylinder operated by stem *b*. The motor-current fingers are shown at *g* mounted on insulated studs *h* secured to the casing. Small fingers *i*, *i* constitute an interlock whereby the unit switches are unable to create any parallel motor combination except when both motors are cut in.

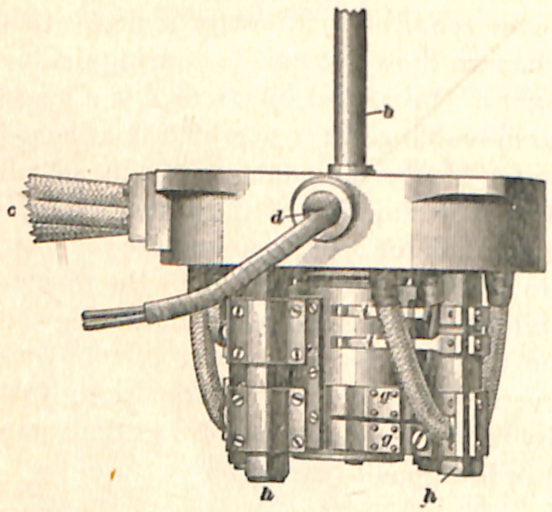


FIG. 30

TRAIN-LINE COUPLER

39. The control-circuit train cables of abutting cars are coupled by means of devices similar to those described in connection with the type M system of control, but as the unit-switch system employs but seven wires at a maximum difference of potential of 16 volts, the coupling devices are smaller than those required to handle the line voltage. Fig. 31 shows one of the flexible connections used between cars. Coupling heads, or plugs, *a* consist of a malleable-iron shell surrounding a cylindrical piece of insulating material in which are set seven

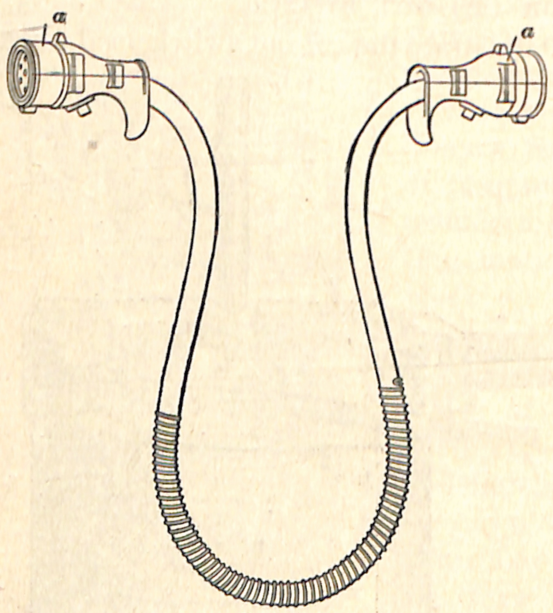


FIG. 31

small brass receptacles. Permanently mounted on the ends of all cars to be made up into trains are two sockets, each containing seven split pins mounted on an insulating base. Each split pin in a socket enters a corresponding receptacle in the plug, thereby connecting a certain control wire on one car to the same control wire on the abutting car and preserving the individuality of each wire throughout the length of the train.

LIMIT SWITCH

40. Fig. 32 illustrates the **limit switch**, the object of which is to regulate the rate of acceleration by stopping the progressive action of the unit switches whenever the motor current exceeds a predetermined value. In Fig. 32, *a* is the operating coil of which *b* and *c* are motor-circuit terminals; *d* is an iron plunger carrying at its lower end a metal disk *e*,

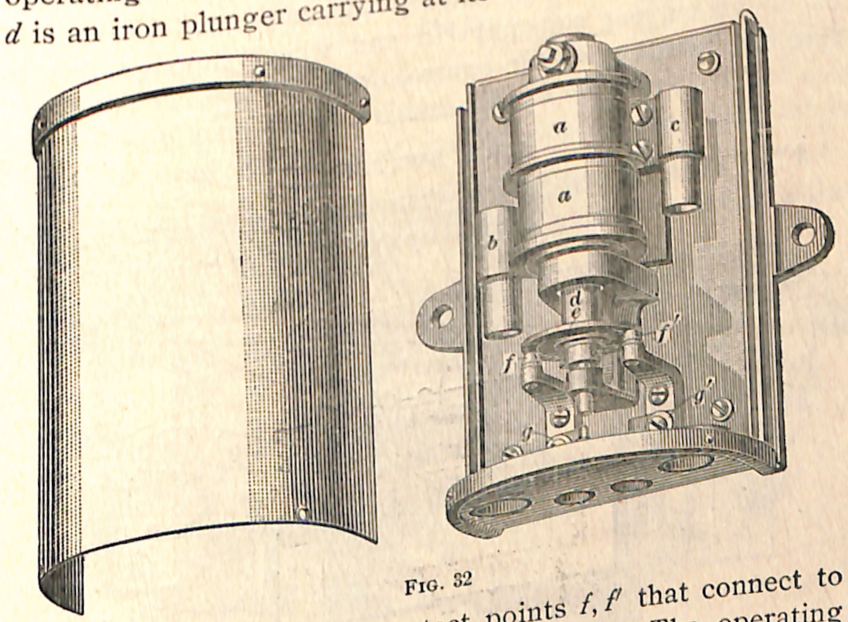


FIG. 32

which normally rests on contact points *f*, *f'* that connect to control-circuit terminals *g*, *g'*, respectively. The operating coil of the limit switch is connected in series with the negative side of the No. 1 motor field and the switch device composed of disk *e*, contacts *f*, *f'*, and terminals *g*, *g'*, is connected in series with the *L* branch of the No. 4 wire (see

wiring diagram, Fig. 37), which is the positive battery connection for the pick-up coils of all unit-switch magnets except *5*, *6*, *7*, and *8*. The limit switch can be adjusted to open at any predetermined motor current and the opening of the switch opens the circuit leading to the pick-up coils of all unit switches except those stated, and these switches will not be closed until a decrease in the motor current allows disk *e* to drop and close the limit-switch contacts. To illustrate, suppose the No. *9* switch, Fig. 37, to close, and the motor current on that notch to be 250 amperes, the value at which the limit switch is set to operate being 240 amperes. The limit switch will operate immediately and arrest any further progressive action of unit switches, but will not cause those unit switches already closed to open. The limit switch is distinctly an acceleration regulator, making the rate of acceleration largely automatic and preventing excessive current consumption and wheel slippage due to careless handling of the controller.

LINE SWITCH

41. Figs. 33 and 34 are, respectively, a front view, back view, and interior view of the **line switch**, which is essentially

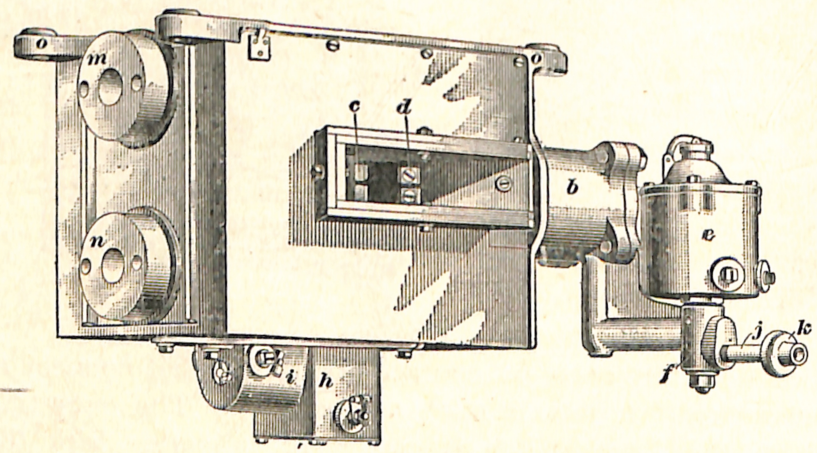


FIG. 33

an automatic circuit-breaker, and Fig. 35 is a view with the cover removed. Corresponding parts are marked the same

in the three views and their connections will be understood by referring to Fig. 37. In Fig. 35, *a a* is the blow-out coil, which also serves as a tripping coil, wound in two sections and composed of copper strip coiled on edge; *b* is the air

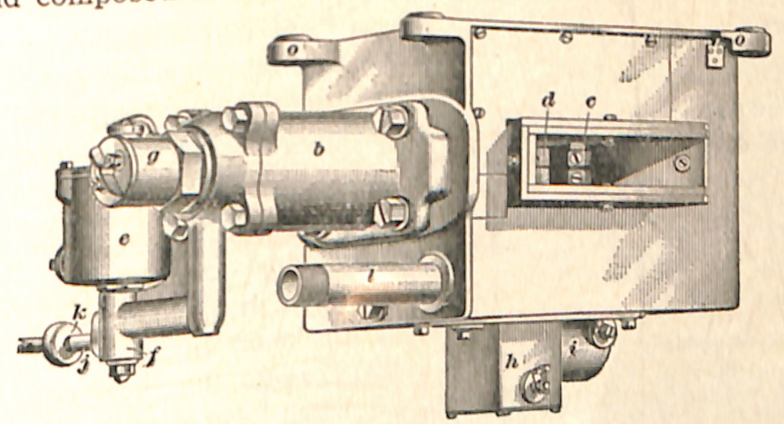


FIG. 34

cylinder in which a piston moves back and forth, thus separating contacts *c*, *d* or bringing them together, as the case may be, and thereby opening or closing the main motor

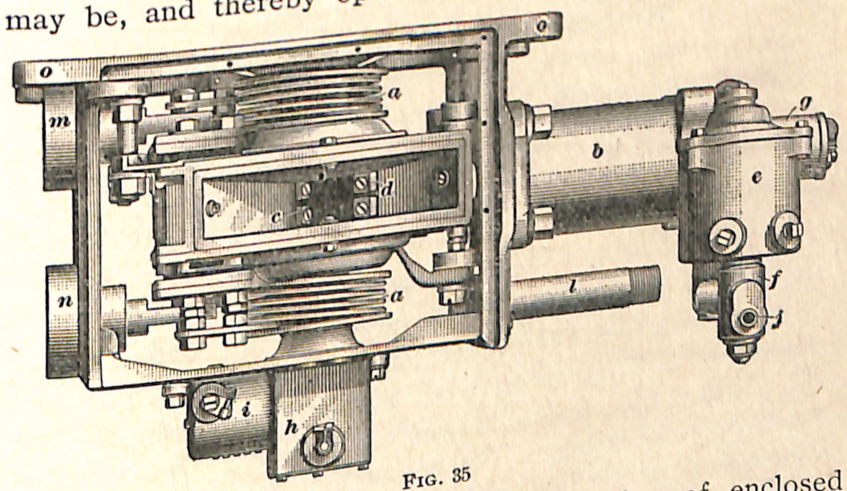


FIG. 35

circuit. Magnet coil *e* controls the position of enclosed valve *f* through which air is admitted to cylinder *b*, and an interlock switch is enclosed in *g*. The circuit-breaker tripping device is shown at *h*, and the resetting device at *i*. Operating

air enters through pipe *j*, which includes an insulation coupling *k*, Fig. 33, to prevent grounding the line-switch casing through the piping system. The control wires enter and leave through pipe *l*, and the motor-circuit wires through wooden bushings *m* and *n*. Motor current entering the breaker passes successively through top blow-out coil section, contacts *c* and *d*, and bottom blow-out coil section. The lugs for supporting the device from the under side of the car are shown at *o*.

42. The line switch, or circuit-breaker, is connected between the trolley and the unit-switch group, as indicated in Fig. 37. When the trip is opened, it is held open by a catch that can be withdrawn either by hand operation or by momentarily closing the circuit through the reset coil by closing the circuit-breaker reset switch located alongside the master controller. This can be done only when the master controller is at off-position. The armature of the overload trip works against a spring, which can be adjusted for different values of the tripping current. The object of the line-switch interlock, which is closed only when the line switch is open, is to short-circuit the contacts of the line relay and thereby permit operation of the switch group for testing purposes, without the possibility of establishing any main circuits that can allow current to flow. The line switch is not always used, and in the equipment shown in Fig. 21, it is not indicated.

LINE RELAY

43. The function of the **line relay,** the connections of which are indicated diagrammatically in the lower right-hand corner of Fig. 37, is to open all the switches except the line switch when there is no power on the line. One terminal of the relay-operating coil is connected through a resistance to the inside of the line switch and the other terminal to the ground. The relay contact marked *8* is connected to one contact of the overload trip switch, to *B*— side of the line switch magnet coil, and one contact of the line-switch interlock. The other relay contact *S* connects to the opposite side of

the line-switch interlock and also to one contact of the No. *6* unit-switch interlock. The result of these connections is to make the line-relay switch the return battery wire for all switch coils except that of the line switch. The line-relay switch is normally held open by gravity, but closing the line switch, of which the operating coil does not depend on the line-relay switch for its battery return, provides a trolley connection from which current flows through the line-relay operating coil. This current closes the line-relay switch, which remains closed as long as the line switch is closed, the latter being open only when the master controller is at off-position or when the overload trip switch operates.

RESISTANCE COIL

44. The resistance employed with the unit-switch control equipment is of the Westinghouse grid type, and is made up of eleven units, the connections of which are indicated in Fig. 37. The grids are grouped to form seven resistance sections, and in parallel with each section is a corresponding unit switch, the closing of which short-circuits the section.

CONNECTIONS AND OPERATION

45. The connections of the control or operating circuit for a single car are shown in Fig. 36, the wiring being simplified somewhat in order to make the circuits easier to follow. For example, a single set of cells connected directly to the controller is shown for supplying the control current, while in an actual installation two sets of cells are used, as shown in Fig. 37, and are connected to switches so that one set can be charged while the other is in use. Also, the seven control wires pass from end to end of the car, as indicated in Fig. 37, and terminate in sockets. In Fig. 36, the wiring is shown as applying to a single car, but in following out the operations it should be remembered that the movement of the master controller on the front car, or any other car of a train, operates the main controllers on all the

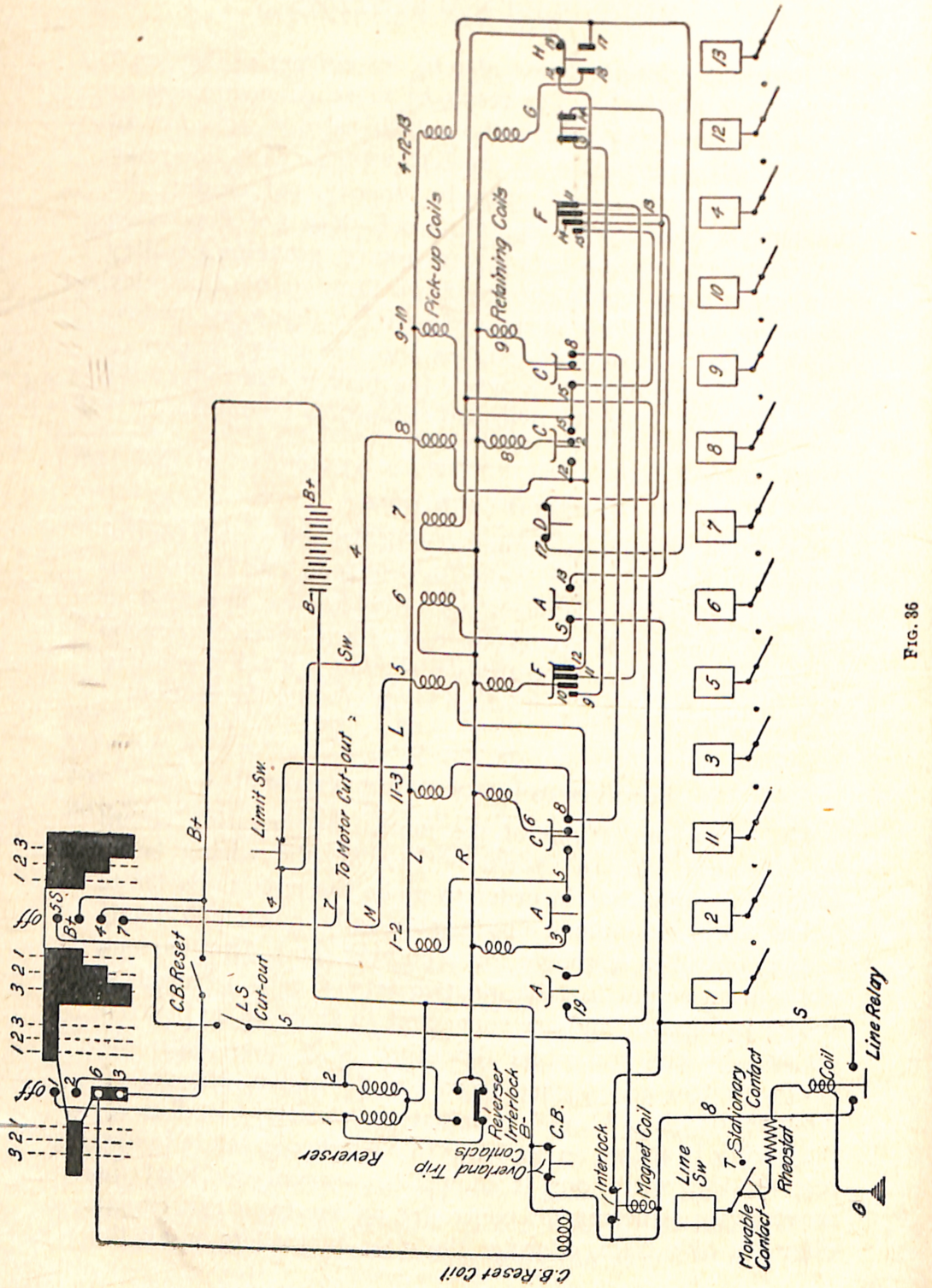


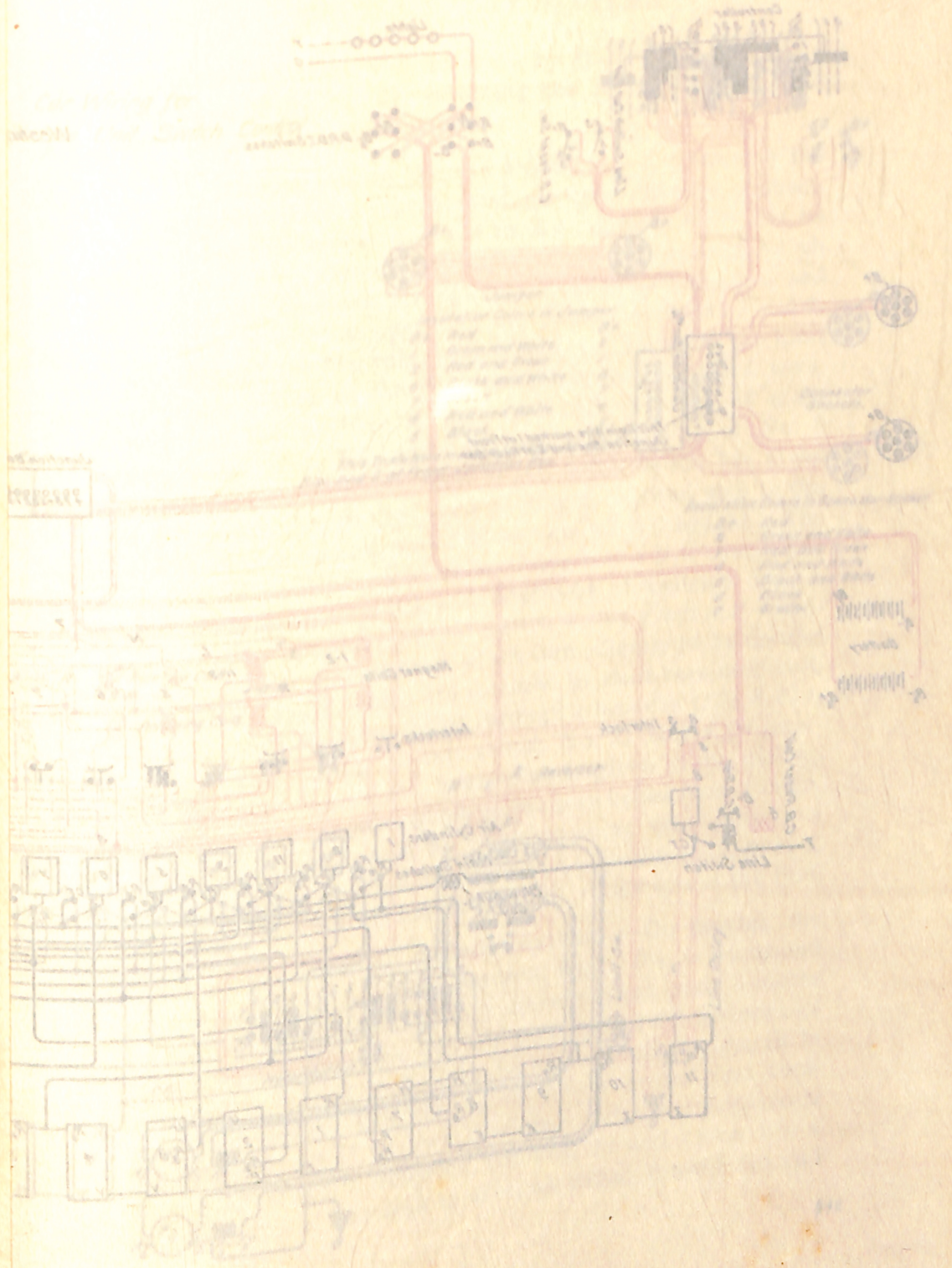
FIG. 36

motor cars because the control circuits pass from car to car and are energized throughout the train. The unit switches, without main current connections, are shown numbered in the lower part of the figure. The small switches shown above the unit switches *1*, *2*, *4*, *5*, *6*, *7*, *8*, *9*, *11*, *12*, and *13* represent the interlocks. Where the cross-piece of these small switches is shown a short distance above the terminals of the switch it indicates that the interlock is open when the corresponding main switch is open, and that when the piston of the main switch goes down the interlock closes. When the cross-piece is shown below, but in contact with the terminals, it indicates that the interlock opens when the piston goes down and the main switch closes.

In Fig. 36, the interlocks on unit switches *1*, *2*, *6*, *8*, *9*, and *11* are open and those on unit switches *7* and *12* are closed, the unit switches themselves being all open. The construction of the interlocks on unit switches *4* and *5* is different from that of the others. The curved cross-piece, represented as touching the two right-hand long strips, slides up and down with the piston. Soon after the piston starts its downward movement, the third strip from the right makes contact with the sliding cross-piece; just before the piston reaches the end of its downward stroke, the sliding contact engages the left-hand short strip, but leaves the extreme right-hand strip marked *12* on the interlock of switch *5*, and *11* on that of switch *4*. Certain of the unit switches are provided with two coils, one of which is a pick-up coil for operating the switch and the other a retaining, or holding, coil for holding the switch closed even though current be cut off from the operating coil. The object of the retaining coils will be better understood after the operation on the various controller notches has been considered, but, briefly, their function is to hold such switches, as may have already operated, closed even though the limit switch, because of excessive current, opens and thus prevents any other unit switches from closing. That is, the holding coils prevent all the switches from opening and thus making it necessary to cut out the resistance again from the beginning.

46. Operation on First Position.—Movement of the master switch handle to its first forward position establishes connections as follows: Master controller finger *B*+, connected to the positive battery terminal, connects to fingers *5 S* and *1* through the master controller cylinder. Finger *5 S* introduces current through the magnet coil of the line switch, assuming the line switch cut-out to be closed, reaching the negative battery wire by way of the overload trip contacts, and excitation of this circuit closes the line switch by admitting air to its operating cylinder. The closing of the line switch provides, at *T*, a trolley connection and allows current to flow through the lifting coil of the line relay to ground, thereby closing the line-relay switch, the contacts of which are in parallel with the line-switch interlock. A small rheostat is connected in series with the line-relay coil to limit the current. Simultaneously a current from finger *1* passes through reverser coil *1* and thence to the negative side of the battery. This current opens the valve controlled by reverser coil *1*, and if the reverser is not already in the forward position, it will promptly move to it. As soon as the reverser throws the full length of its travel, the safety switch on the end establishes connection between the positive battery wire *B*+ and wire *R*, which represents the positive sides of the retaining coils Nos. *1–2*, *11–3*, *5*, *8*, *9–10*, *4–12–13*, and the pick-up coils Nos. *6* and *7*.

The reverser must be fully thrown forward or back, otherwise its safety switch will not connect wire *R* to battery. Assuming the reverser to be at the extreme end of its travel, wire *R* will become *B*+ and current passes through the No. *6* magnet coil, to *B*−, by way of the closed line-relay switch, thereby operating the No. *6* unit switch and closing its interlock *S–A–13*. The closing of this interlock causes current to take path *R*–No. *7* magnet coil–contacts *19*, *12* of unit switch *13*–contacts *12*, *11* of interlock *5*–contacts *11*, *13* of interlock *4*–contacts *13*, *A*, *S* of interlock *6*, here joining with the current from the No. *6* magnet coil and flowing with it through the line-relay switch to *B* and thereby operating unit switch *7* also. The motors are now in series



Car Wiring for Westinghouse Unit Switch Control

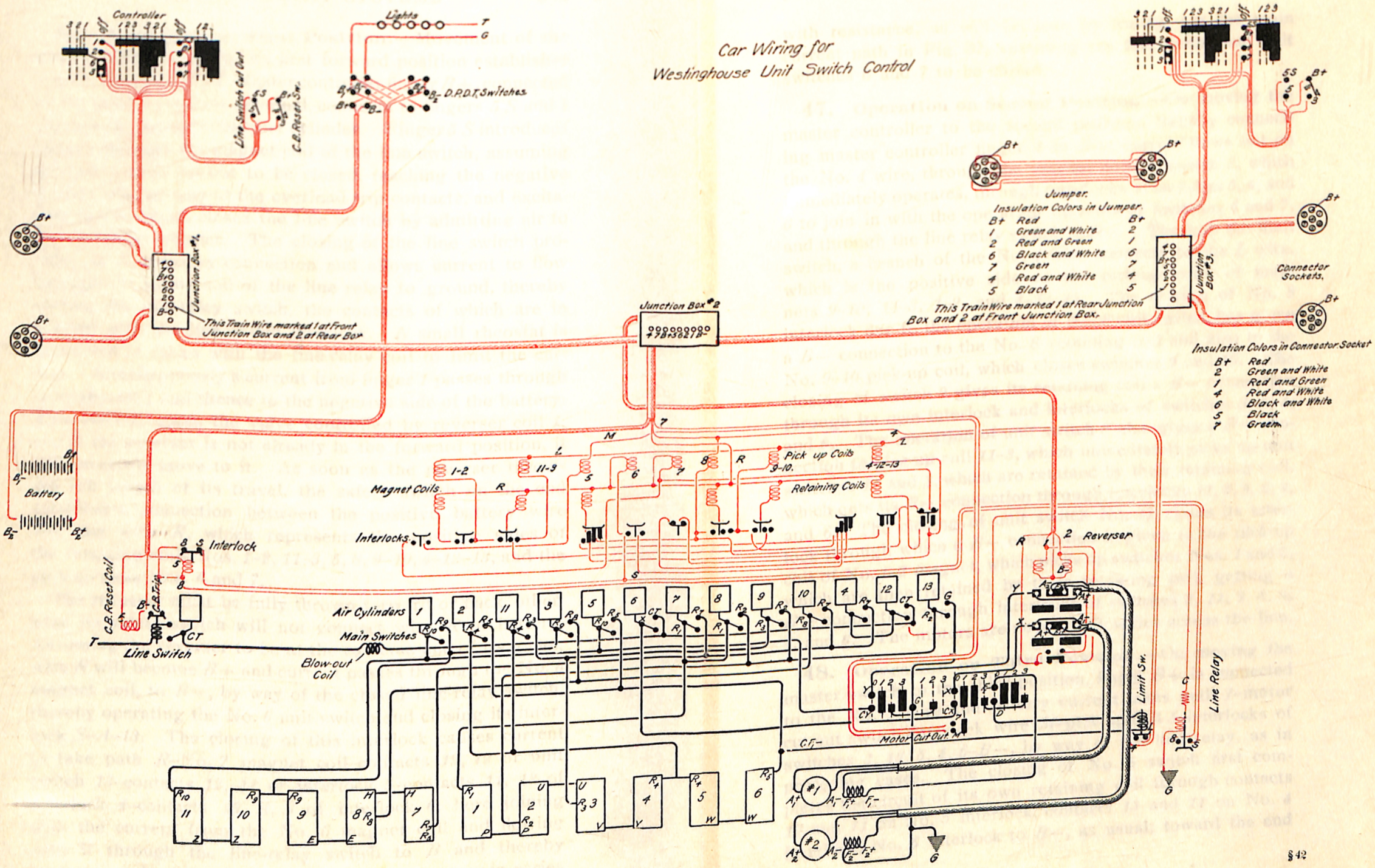
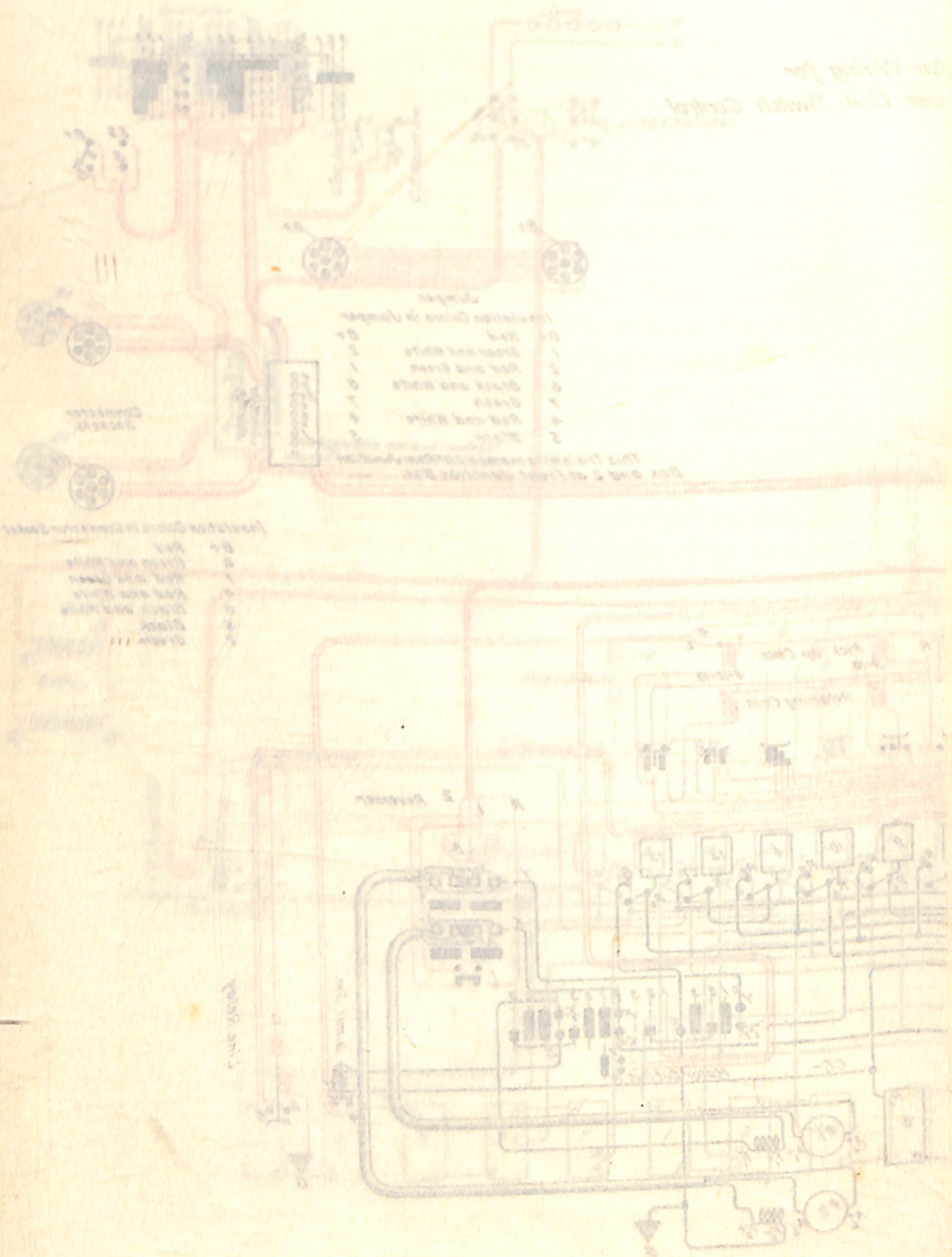


FIG. 37



with resistance, as will be seen by tracing out the main current path in Fig. 37, assuming the line switch and unit switches *6* and *7* to be closed.

47. Operation on Second Position.—On moving the master controller to the second position, thereby connecting master controller finger *4* to *B*+, current flows out on the No. *4* wire, through the magnet coil of switch *8*, which immediately operates, through interlocks of switches *5*, *4*, and *6* to join in with the operating currents of switches *6* and *7*, and through the line relay switch to *B*−. Through the limit switch, a branch of the No. *4* wire connects to the *L* wire, which is the positive side of the pick-up coils of magnets *9–10*, *11–3*, *1–2*, and *4–12–13*. The closing of No. *8* interlock due to the operation of No. *8* unit switch, has given a *B*− connection to the No. *8* retaining coil and also to the No. *9–10* pick-up coil, which closes switches *9* and *10*. The closing of switch *9* gives its retaining coil a *B*− connection through its own interlock and interlocks of switches *8*, *5*, *4*, and *6*. The operation of unit switch *9* also gives a *B*− connection to pick-up coil *11–3*, which immediately picks up unit switches *11* and *3*, which are retained by their retaining coil, which gets its *B*− connection through interlocks *11*, *9*, *8*, *5*, *4*, and *6*. The closing of unit switch No. *11* closes its interlock through which a *B*− connection is given to the pick-up coil of No. *1–2* magnet, which picks up switches Nos. *1* and *2*, which are then retained by their retaining coil, getting a *B*− connection through interlocks of switches *2*, *11*, *9*, *8*, *5*, *4*, and *6*. The motors are now in full series across the line.

48. Operation on Third Position.—On moving the master switch to the third position, finger *B*+ is connected to the No. *7* wire and battery current takes path *7*–motor cut-out switch–interlock wire *M*–pick-up coil *5*–interlocks of switches *1*, *13*, *5*, *4*, *6*–*B*−, by way of the line relay, as in preceding cases. The closing of No. *5* switch first completes the circuit of its own retaining coil through contacts *10* and *11* on No. *5* interlock, contacts *13* and *11* on No. *4* interlock, No. *6* interlock to *B*−, as usual; toward the end

of the piston stroke, the sliding contact on interlock No. *5* breaks connection with contact No. *12*, thereby depriving the pick-up and retaining coils *7*, *8*, *9–10*, *11–3*, and *1–2* of their *B*— connections and opening these switches. When No. *5* switch is fully closed, the short contact of its interlock completes the circuit through the pick-up coil *4–12–13* as follows: *B*+ –*4*–pick-up coil *4-12-13*–interlock on switch *7*–interlock on switch *12*–interlock on *5*–interlock on *4*–interlock on *6*–line relay–*B*—. Switches *4*, *12*, and *13* do not close until switch *7* has fully opened, because interlock *7* is part of the circuit through pick-up coil *4–12–13*, and this interlock is closed only when its unit switch is entirely open. When switch No. *13* closes, its lower interlock contacts establish a *B*— connection to the retaining coil through interlocks *13–7–4* and *6*. In the first part of the downward movement of the piston of switch No. *4*, its interlock engages the low contact, thereby establishing another *B*— path, the first path having been broken in two places by operation of unit switches *4* and *12*. This is done when switches *4* and *12* are nearly closed and the *B*— connection of the pick-up and retaining coils of switch No. *5* is broken; this switch then opens. The motors are now in parallel and have resistance in series. The full closing of switch No. *4* connects the short contact of its interlock to *B*—, thereby providing a *B*— connection for the pick-up coil of the *9–10* magnet, which picks up switches *9* and *10*. The closing of switch No. *9* causes the consecutive closing of *11–3* and *1–2*, as on the second position. The motors are now in full parallel and will remain so until the master controller is moved to off-position.

CAR-WIRING DIAGRAM FOR UNIT-SWITCH CONTROL

49. Fig. 37 is a car-wiring diagram of the unit-switch system and shows the main motor connections that are omitted in Fig. 36. In Fig. 37, the normal condition of a unit-switch equipment with a train at a standstill, is as follows: The master controllers are both at off-position; all unit switches, the line switch, the line-switch cut-out and

circuit-breaker resetting switches (see small switches near master controllers) are open. One battery of storage cells is ready for use and the other is charging through the lamp circuit. The reverser is either in forward or reverse position and the motor cut-out switch is on the first position in which both motors are cut in. The line relay switch is open and the limit switch closed.

50. A motorman on taking a car, first closes the pump switch and raises the air pressure to a standard value. The line-switch cut-out is then closed and the resetting switch closed for an instant to insure that the circuit-breaker trip may be at the upper end of its stroke where it provides return battery connection *B*— not only for the magnet coil of the line switch but also for the several control-circuit arrangements.

The circuit-breaker resetting coil is operative only when the master switch is at off-position, because only in this position are master-switch fingers *6* and *3*, which are part of the resetting circuit, connected. With the circuit-breaking trip of the line switch closed, one of the first effects of advancing the master controller to the first position is to energize the line-switch magnet coil, thereby admitting air to the line-switch operating cylinder, closing the main circuit-breaker contacts, and opening the line-switch interlock. The immediate effect of closing the line-switch main contacts, is to send current through the magnet coil of the line relay and thereby close the line-relay switch. It must be remembered that the line-relay switch handles battery current, but its magnet coil is energized by line current. The closing of the line-relay switch provides the *B*— return for the various control circuits connecting to the No. *6* interlock, as considered in connection with Fig. 36. As line voltage is necessary to keep the relay switch closed, the relay switch will open all automatic switch circuits, except that of the line switch, if the power leaves the line or the trip coil of the line switch operates. While closing the line switch renders the *CT* wire, extending from the line switch to the unit switch No. *12*,

alive, no motor current can flow until flow of current through the reverser circuit throws the reverser and establishes the safety switch $B+R$ connection that operates unit switch *6*, the operation of which sets off *7*. Moving the master controller to the series running notch, automatically works the motor up to full series; and movement to the multiple notch, automatically changes the motors from full series to parallel with resistance in series, then to full parallel. Should the master controller be advanced too rapidly, the limit switch will operate in the manner already described, and will prevent any further cutting out of resistance until the current has dropped to normal value. However, the opening of the limit switch does not interfere with the current in the holding coils and the switches that have operated up to this point do not drop and cut resistance back in. By means of the various interlocks and the connections between operating coils, the cutting out of resistance is performed automatically after the controller has been placed on notch *2* or *3* and does not require a movement of the controller for each section of resistance cut out, as with the type M system.