

ELEMENTS OF ELECTRICAL ENGINEERING.—X.

CONTROLLING DEVICES FOR RAILROAD MOTORS.

BY A. E. WATSON, E.E., PH.D., ASSISTANT PROFESSOR OF PHYSICS IN BROWN UNIVERSITY.

Continued from Supplement No. 1672, page 39.

AS EXPLAINED in the preceding chapter, such motors ordinarily have series wound field magnets. Still, attempts are constantly being made to derive some benefit from the energy developed when cars are descending grades; but the regenerative principle that would allow return of the energy to the line can be accomplished with shunt wound motors only. Combinations of the two methods of exciting the fields might be used, resulting in a sort of a compound motor, whereby the desirable features of the series winding may be utilized for traction, and those of the shunt for permitting the generator action during the coasting. On level tracks not much economy is offered by this double use of the motors—the only opportunity of returning energy to the system being during the stopping process. In hilly regions, however, the coasting may represent quite a proportion of the trip, and a saving of 30 per cent in the total energy may be possible. Series wound motors are quite incapable of becoming generators under these conditions, for they cannot generate until the field magnets are excited, and as soon as the circuit is completed, current flows from the line in the direction always to give the wrong polarity. Experiments are now being conducted with car equipments involving the regenerative principle, but have not yet demonstrated their worth or reliability. It is certain, however, that economy of operating expenses is the watchword of progressive power stations. This chapter will give a direct illustration of the abandonment of a good method of car control, for one that is still better, and the end is not yet. The explanation will be limited to past and present standard practice in American railways.

In starting a series motor, only enough electromotive force is needed to overcome the ohmic resistance, but for increasing the speed the pressure must be increased to overcome, in addition, the counter electromotive force generated in the motor. With a given load it has been found that the speed of a series motor varies directly with the voltage. For railway motors then, to have the qualification of variable speed, some means of procuring a variable electrical pressure must be sought. An arc lighting dynamo is a machine for supplying a constant current and any number of volts, and some original experiments with electric cars in Cleveland, Ohio, in 1886, were made using such dynamos for power. In order to allow the effective operation of the regulator on the machine, the different cars were connected in series; though this can be done for reasonable limits of potential, and for a few cars on a short line, the system becomes impossible for a large number. The constant potential system of delivering the energy to the different cars is the only

variable number of volts be obtained from the approximately constant 500?

The most obvious and crudest solution is to put a rheostat in the circuit of each car and have this constantly under the control of the motorman. By Ohm's

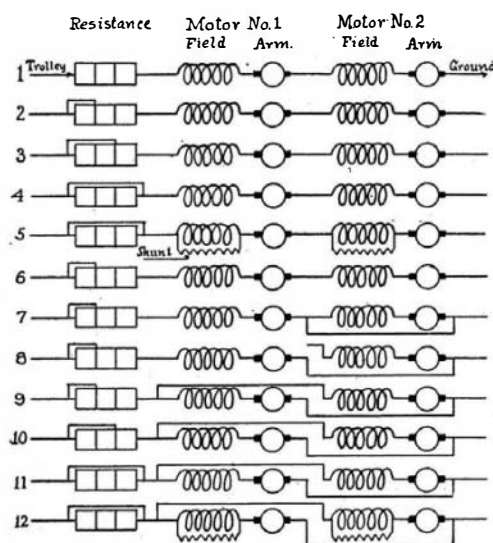


Fig. 38.—Combinations in an Ordinary Street-Car Motor "Series Parallel" Speed Controller.

law the number of volts required to drive a current through a resistance is obtained by multiplying the number of amperes and ohms together. Obviously, by making the rheostat large enough, any desired current may be carried, and any number of ohms inserted in the circuit. Thereby, out of the delivered 500 volts the rheostat would waste any required number, and the motors would get the rest. At start, all the resistance would be included, and the motors get the minimum voltage; at full speed all the resistance would be cut out, and the motors receive the full pressure. The energy thus wasted in the rheostat is degraded into mere heat, therefore fireproof constructions are to be sought, and those well exposed to radiation.

Sprague's installation in Richmond, Va., in 1887,

series at the start, and then after various combinations, to produce uniform gradations, were finally connected in parallel to give full speed. (Although thus involving the use of the words "series" and "parallel," this controller does not represent the construction meant by the modern controller.) Sprague's attempt at economy was rather an expensive one; at least his application of it to congested city traffic was unfortunate, for the slow movement of cars often required the resistance to be kept in circuit unduly long, and the result was a constant burning out of field coils.

The Thomson-Houston system was successful from the first, for in it, reliability rather than economy of control was regarded as of first consideration. A non-combustible rheostat, made of iron, slate, and mica, quite apart from the motors, was used, and protected them from undue heat. Basic patents covering the use of the "magnetic" blow-out switch and the "under-running" trolley wheel were of course of immense value in giving this system the lead which it soon gained.

Most cars are equipped with two motors, many of them with four. Taking the case of the former, just how should one motor be connected with reference to the other? Economy dictated that at start the two should be in series, and for full speed, in parallel, but experimental work, though conducted with great zeal and considerable expense, revealed the difficulties of accomplishing, in a manner satisfactory to passengers and to motors, the transition from one condition to the other. Either a violent jerk was given to the car, or a dangerous flash was produced at the brushes of one of the motors or at the switches. Pending the more satisfactory solution of this problem, the simple expedient was adopted of permanently connecting the motors in parallel, with one rheostat to control the current for both.

Whatever the method of control of a railroad motor both directions of rotation are always to be provided, hence reversing switches are needed. Direction of rotation of an electric motor is not affected by exchanging the extreme terminals, as in exchanging trolley and ground connections; the current must be reversed in either the armature or the field, but not in both. A single reversing switch was originally used in the two motors, but with low resistance armature wind-

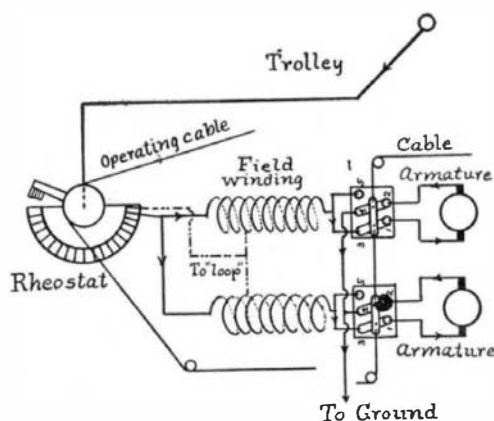


Fig. 37.—Diagram of Car-Wiring, Showing Two Series Motors Permanently Connected in Parallel, and Controlled by One Rheostat and Two Reversing Switches.

practicable one. Five hundred volts have been found to be a convenient pressure, and increased number of cars or increased loads merely mean more amperes. Of course large conductors are needed to transmit the thousands of amperes—a fact readily judged from the size of the "feeders" alongside an electric railway. But each car is independent of the rest, the insulation of line and motors is not difficult, and the generators at the stations work under conditions of economy and convenience.

With this system decided upon, there is still the unavoidable necessity of a gradual acceleration of speed of the motors—requiring first a small electromotive force, and increasing by steps, imperceptible to passengers, to the desired maximum. How can this

may be said to be the first commercially successful electric road. In the motors for this and some subsequent lines, the builder sought to minimize the great loss in the controlling rheostats by letting the field magnet winding serve as the desired resistance. A number of separate sections were employed, some of them wound with German silver wire, and by a suitable "controller," these coils were all connected in

ings, a variation in brush contact readily causes an unequal current to flow in the two paths, with consequent overloading of one motor. By use of two reversing switches, the field resistance is added to that of the armature for each motor, and the combined amount of resistance causes a more equal division.

Fig. 37 shows a simple diagram of the entire connections. Current may be considered as coming from

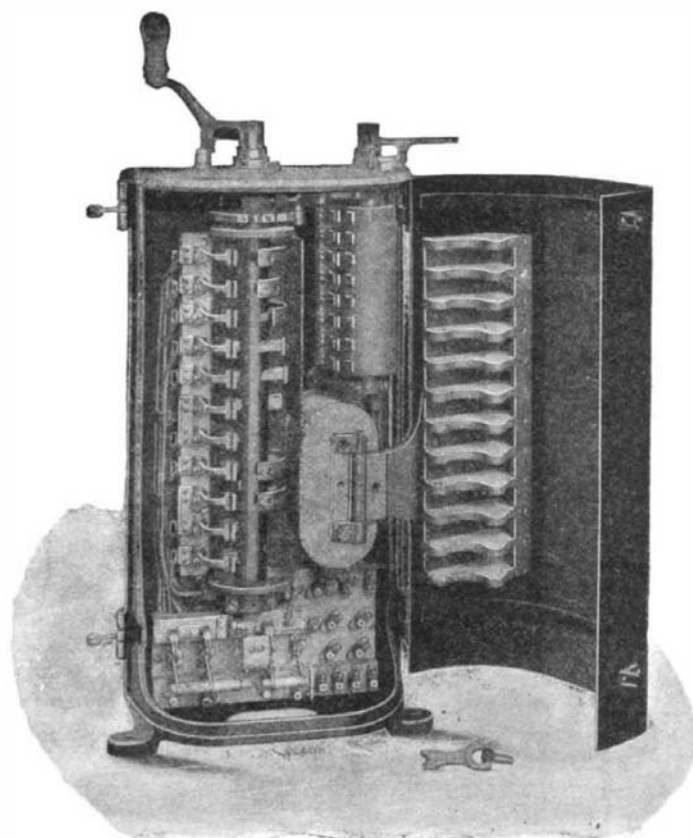


Fig. 39.—K-10 Series Parallel Controller.

the trolley and passing to the pivot of the rheostat arm. As soon as contact is made with the resistance plates in the semi-circular trough, the path is on to the next but last contact, where the current divides itself between the two motors. After flowing through the entire winding of the field spools, the currents pass to the reversing switches. These consist of insulated brass levers hinged at points 1 and 2, and arranged to be kept parallel with each other, and make contact with either 3 and 4, or 4 and 5. Wire from field connects to both 3 and 5, while point 4 is attached to "ground," i. e., to frame of motor. Arrow heads show direction of current. The reader can imagine the switch to be moved to the other position, and he will then see that the arrows will be reversed in the armature circuits. About two and one-half turns of the rheostat handle moves the rheostat arm to its extreme position. When this position has been reached a new path has been provided, shown by dotted lines to "loops" left out in the field winding; by this path, about one-third of the winding is cut out, resulting in a weakened field and increased speed. The full field was available for starting, but a reduced strength for fast running.

To start the ordinary short cars equipped with two motors, 30 amperes per motor were often required, and therefore with the two in parallel, 60 amperes had to be drawn from the line. The rheostats normally had about 20 ohms resistance, therefore considerably more than half might be cut out before the motors would start. Of course the first part comprised the greater portion of the resistance, so the movement of the arm to accomplish this reduction was relatively small.

It is easy to see that if the motors were in series, the same 30 amperes that flowed through one motor would also flow through the other, and that the start could then be effected with only one half the expenditure of energy required for the multiple or parallel arrangement. Also for slow speeds in city streets, the series connection would be more economical than the other, for with the former, only 250 volts would be impressed upon each motor, resulting in half speed, while with the latter the same could be accomplished only by wasting 250 volts in the rheostat and letting the motors receive the other 250. The economy of operation at full speed would not depend on the particular means of reaching it, but electric power was first applied to traffic in the most congested parts of the cities, and the need of reasonable economy in frequent starts and slow speeds made the demand for a "series-parallel" controller one that engineers at length were able to fulfill. The urgency of the case was greater in consequence of the overloaded condition of the power houses. Means of making large generators had not been found, the small existing ones were quite inadequate to meet the demands for heating as well as running the cars, and the reliable device that promised economy of the current met with quick reception.

The difficulties that previous experimenters had encountered in making the proper change from series to parallel arrangement of motors were overcome in a surprisingly simple and effective manner by Mr. W. B. Potter, about 1891; he was then an assistant in the railway engineering department of the Thomson-Houston Electric Company at Lynn, but is now the head of the department for that work with the General Electric Company at Schenectady. In substance, his method was momentarily to short circuit one of the motors, thereby transferring the entire load to the other, then to disconnect the former and reconnect it to the circuit, but now in parallel rather than in series with the latter. In order to reduce the shock to car and active motor, and to provide a more uniform gradation of speeds, a resistance that had been in circuit at the start was reinserted just before this critical transition was made. Even with the two motors in series, their resistance was still too small to admit starting without the addition of some external resistance, but experiment showed that this need not be more than 6 or $6\frac{1}{2}$ ohms, instead of the 20 ohms formerly used.

To fit the great variety of railway traffic, a surprisingly large assortment of motors have been made with still greater diversity in the particular apportionment of the different combinations that may be found in the "controllers." A typical one may, however, be illustrated, the one mostly used for ordinary street cars. Diagrammatic illustrations of the successive circuits, as afforded by a progressive movement of the handle, are given in Fig. 38. In it a commutator is represented by a circle, with two radial brushes in contact, and a field winding by the coiled lines. Reversing switches are omitted. Twelve steps may be traced as follows:

1. Motors in series, with all the resistance.
2. Motors in series, with two-thirds of resistance.
3. Motors in series, with one-third of resistance.
4. Motors in series, with no resistance.
5. Motors in series, with shunted field winding.
6. A return to Combination No. 2.
7. One motor short-circuited.

8. One end of this motor open-circuited.

9. This end brought into parallel connection with other motor—two-thirds of the resistance still included.

10. Motors in parallel with one-third of resistance.

11. Motors in parallel with no resistance.

12. Motors in parallel with shunted field winding.

It will be seen that in positions 1, 2 and 3 of the series connection, and 9 and 10 of the parallel, the resistance is included in the circuit, and these are denoted as starting points. Positions 7, 8, and 9 are the transitional ones, readily detected on the top of a controller by their absence—a considerable blank space suggesting the location; as here one motor only is doing all the work, the contact cylinder must not be allowed to stop on any of these points; 4 and 5, 11 and 12 are the economical running positions, the former corresponding to about one-half the speeds of the latter. In cities abounding in hills or grades, positions 5 and 12 are often omitted. Motormen are found prone to try to climb hills with the weakened field magnets, thereby demanding abnormal and ruinous currents in the armatures, when in reality these positions are intended for light loads, level tracks and infrequent stops.

Failure attended the first attempts to use these controllers from four causes. First, a single controller for a car was deemed sufficient, and as it was located beneath the floor, like the original rheostats, accessibility to examine or repair the numerous contacts was not given. Second, no indication was given to the operator as to the exact position of the contacts, resulting in disastrous arcs and melting of metal. Third, no means of suppressing the ordinary and inevitable arcs was provided. Fourth, no interlocking devices were applied to prevent damage due to ignorance or carelessness. These were successfully avoided, respectively, by using two identical controllers, one on each platform; by using a notched wheel and roller that would allow definite positions only; by equipping the entire row of contacts with a magnetic "blow-out"; by locking the reversing switch, so it could not be turned while the current was on, and by providing additional switches for cutting one motor entirely out of circuit in case of accident to it, and preventing the controller handle from then being turned further than corresponded to the series position.

A view of the inside of such a series-parallel controller is given in Fig. 39. The movable contacts are mounted on a vertical cylinder, occupying the central position, and successively touch the stationary "fingers" in a vertical row at the left. In the upper right hand corner are seen the reversing switches—for convenience also mounted on a cylinder. Just below is the coil of copper ribbon that is in series with the main line, and used to energize the "blow-out" magnet. The entire back of the case forms one pole, while the other is a slab of cast iron long enough to reach the entire length of the main cylinder; in the cut it is shown hinged back to allow access to the contacts; on its inner face are mounted insulating partitions resembling shelves; these shut in between the contacts and so lengthen the path from one to the next as to diminish the likelihood of the formation of destructive arcs. At the bottom are the two cut-out switches, one for each motor. The oblong hole in base is for entrance of the flexible cables that make connection with the motors.

With light cars equipped with single motors, it may be possible still to find some of the old simple rheostats, but more than ten years' experience has demonstrated the highly satisfactory performance of the "controllers." Even in cases where single motors are now installed, the controller is still provided, for though in such cases additional resistances must be inserted, and no economy of operation over the ordinary rheostat is offered, provision is made, by a few simple changes, for the addition of the second motor with the full series-parallel advantages.

Occasionally, the insulation on the blow-out magnet breaks down, and the coil becomes short-circuited, then arcs, resembling those seen when a trolley wheel jumps the wire, come from inside the controller case, and cries of "fire" and wild panic result. All that needs be done in such an event is for some cool-headed person to pull down the trolley pole.

An interesting extension of the principle of controlling railroad motors, is given in the handling of entire trains. In order to maintain schedule time and preserve definite headway, uniform acceleration, and braking must be provided, independent of the number of cars constituting one train. This condition can be met by the sole means of having every car equipped with motors, yet controlled from any one car by a single operator. The solution was first made by that eminent engineer, Lieut. Sprague, and adopted on the Chicago and Boston elevated roads. In essence, the system consists in providing every car with the equipment necessary to allow it to be operated singly, then to couple any number in a train. The series-parallel controller on each car is not operated directly, but through the medium of a "master" controller. Elec-

tric couplings containing the requisite number of wires, make identical connections between all the cars, and when the master-controller is turned, the series-parallel controller on that car is at once operated, and also, in exact synchronism, the controllers on all the other cars turn on the current for their motors. The motorman does not even determine the rate of acceleration of the motors. He turns the handle at once to the full speed position, but the operating cylinder of the master-controller responds only as fast as air can escape from a checking cylinder, and the valve for the egress of the air is in turn controlled by a relay magnet in the main line; only when the current is below a certain minimum can the further rotation of the master cylinder take place. Removal of the hand from the knob at the top of the handle at once and automatically shuts off the power from the whole train. Ordinary automatic air brakes, such as are found on steam trains, are used for stopping.

Severe and crucial tests have been made on the effectiveness of this "multiple-unit" method of control, as it is called. Trains have been made up, but without the use of the mechanical couplings. All gradations of speed, with such trying conditions as grades, curves and sudden stops were tried, yet no bumping or separation of cars ordinarily resulted. Indeed, in the ordinary operation of the trains around some of the sharp curves in the Boston subway, the mechanical couplings sometimes unhitch, but the motorman may be ignorant of the accident—to him the train is still a unit.

The case of electric locomotives has brought out its own difficulties. If still operating at about 500 volts, the current required is very large—perhaps 2,000 to 3,000 amperes. How best to get the current to the locomotive is a matter not yet satisfactorily settled, but with that provisionally cared for, the construction of the controllers has received special attention. The large contacts and considerable pressure needed to make good electrical connections involve much mechanical friction. Sometimes a large hand wheel is provided for moving the contact-cylinders, and as much muscle may be needed as to steer a ship. With such large currents, the ordinary series-parallel combinations result in too much burning of contacts or jerky motion of the motors, and a larger number of resistance steps are provided, with the further expedient, that after the motors have reached their half-speed condition, in series, the current is entirely shut off for a moment, the parallel connections made, and with a suitable cutting out of resistance full speed then attained.

In the locomotives recently built for the New York Central and New Haven Railroads, the multiple-unit method of control has been adopted. This means great relief to the motorman, or engineer, as he may continue to be called, and also allows two or more locomotives to be coupled together and yet operated by one man.

Four-motor equipments are common to long cars. In such cases the motors on one truck are permanently connected in parallel, and then the one pair is put in series or parallel with the other pair by the operation of an ordinary controller, though perhaps fitted with extra heavy contacts. The same cars could be used for slow interurban use, with the four motors in series, or for very rapid suburban transit by allowing the controller finally to put the four motors in parallel. Such extreme variations of speed are not often desired nor entrusted to the ordinary motorman.

It is an old idea to turn the series motors into generators to assist in stopping the cars. Of course, the direction of rotation is always wrong to allow this to take place, so a special reversing switch is needed to make the proper equivalent change in the electrical connections. The current, too, must be controlled by being led through a variable resistance. The principal defects in the proposal consist in the fact that a series machine does not always generate until the external resistance is quite small, and when the generating once begins, altogether too much current is apt to flow. The sudden "taking-hold" of the current makes a car almost stand on end. Sometimes, too, the presence of oil or dirt on the commutators, or insufficient residual magnetism, might prevent the machines from generating at all; and further, on a grade, the car could not stop, but must maintain enough speed to keep up a certain generating action. The regular mechanical brakes are needed as reliable accessories, and in nearly every case the electrically operated brakes have proved precarious and even dangerous.

The eleventh article will consider the means of distributing electrical energy from central stations, by means of direct currents.

Removal of Oil Paint.—When the use of strong lye for the removal of paint and varnish does not suffice, take, according to Werkstatt, a mixture of 2 parts of spirit of sal ammoniac and 1 part oil of turpentine. This mixture must be well shaken before use. After it has been allowed to work for a few minutes on the paint, the latter can be rubbed off with excelsior.