"Railroad" Meeting, March 28, 1899.

THE ELECTRICAL INSPECTION OF STREET-CAR EQUIPMENTS.

BY ALBERT B. HERRICK,
Consulting Electrical Engineer.

As electrical machinery is becoming such an important factor in modern civilization, the maintaining of this machinery requires indirect methods in order to make visible, through the means of instruments, the electrical conditions of the apparatus or machinery.

Nowhere in the application of electricity is the electrical inspection more necessary than in street-railway equipments; here the motor is operated with exposures to weather, mechanical jars, heating, and severe electrical and mechanical strains; and the predictions were when the first roads were operated, that this system was impracticable, and a preposterous engineering proposition.

The development of accurate methods for finding these hidden electrical troubles in an equipment has been urged upon me, for the reason of the high cost of the electrical repairs on street-car equipments. These aggregate many million dollars per annum in the United States; and to bring this forcibly to your minds, in two of the roads which I have examined, I have found the cost of the electrical repairs of a 22-foot double equipment to cost the same as those of an 80-ton locomotive on the Pennsylvania Railroad, the same distance, and carrying a full train of freight cars.

The wiring of a car by which the current is conducted through the equipment is of necessity not a fixed nor rigid system. The resistances which are used to control the flow of current through the equipment, on account of their limited weight and space, will not carry the current continuously, and careless motormen may injure the resistance by improper handling of the controller.

The controller, which is practically the nerve center of the equipment, reflects in its depreciation all the latent defects in the equipment.

After carefully inspecting, electrically, a large number of equipments, one feels very much like diagnosing the different diseases which are inherent in the various equipments, and also separating from these, those diseases which are developed by forcing or the improper handling of the controller, which are attributable to poor motormen.

There is another class of diseases which have their origin in careless inspection and careless maintenance of the equipment.

It is not so much my intention to analyze the diseases to-night, as to describe the means by which they are detected and located.

Following out our original anatomical idea, it is easiest to look at the various ramifications of the current flowing through the equipment as a circulating system, with the controller as a deflector for these different circuits through the equipment. *Fig. 1* shows a very common form of series parallel controller with the connections it makes with the apparatus on the first notch; with each movement of the controller handle the current is changed in its path. The sequence of changes made by the controller as it passes from the first position to the last, including nine positions, in this case, is as follows: The first position starts the current flowing through the electrical circuits of the car, and the car should now move. A large amount of energy is lost in the resistances R_1 , R_2 , R_3 , R_4 , which choke down the initial current on the motors. From the first step to the second, cuts out $4\frac{1}{2}$ ohms in a standard equipment of this type; from the second to the third step cuts out $1\frac{1}{2}$ ohms, and from the third to the fourth step cuts out $\frac{1}{2}$ ohm.

The motors are both in series and across the full potential between the trolley-wire and the ground. The rheostat, which is the resistance, that has just been cut out by the first three steps of the controller, after it has been installed on the car, is given very little attention; it generally increases in resistance with age. I have found many rheo-

stats over four times the resistance they should have been when new. The result of this increase in resistance is that the car will not start on the first step of the controller when the resistance is hot, or the car heavily loaded; for the resistance is so high on this step that the current is cut down below starting value; and when the second step on the controller is reached, the car will have what is known as the "kangaroo start." The reflection of this defect in the equipment is to increase the temperature of the motors,

FIG. 1.

increase the strains on the motor, and increase the current demand on the station, and give a disagreeable acceleration to the car. This defect is more noticeable on those motors having a large starting torque. The motors which have a small starting torque do not show this defect so much in the start and car acceleration, but struggle along under this excessive condition until they retire to the repair-shop, damaged.

I have expanded on this point somewhat, because it does

not seem to be generally known that this condition is primarily the cause of a large number of break-downs in equipments, which condition may be caused by burnt-open or high resistance in rheostats. A low resistance on the first step of the rheostat has identically the same effect on the equipment as the first step being too high, and the second step being normal. Where repair accounts were kept against individual cars in street-railway operation, I have often found the high cost of repairs on some cars due to just this rheostat trouble; the controller, armature and

FIG. 2.

fields being continually repaired, while the rheostat, which is the real cause of the trouble, is left unmolested.

Rheostats are also much more heavily strained on roads possessing considerable grade, and they tend to increase in resistance and prevent the most effective operation of the equipment; and this condition increases materially the watts per car-mile required on grades where starts are frequent.

In the type of controller under consideration, the resistance between the second and third steps, R_2 and R_3 , being high, is not of much importance in this part of the opera-

tion of the controller, if it is not so high that the car loses acceleration ; but if we follow the operation of the controller in *Fig. 2*, you will notice that on the sixth notch in this position the motors are connected in multiple ; and this second to third step in resistance is again cut in series with the two motors in multiple. Here, if the second step is high, the equipment will lose acceleration, and when arriving on the seventh notch, the motors will again be subjected to an abnormal flow of current.

It is evident that these conditions can only be determined by the direct measurement of the resistances of

FIG. 3.

these circuits as made by the controller ; but the resistances of these circuits possess peculiar features which are not common to a purely metallic circuit. We find contact resistances in the controller and carbon-brush resistances in the motor. The contacts give extremely variable and unreliable results when measured with a low-potential test current. The carbon-brush contact will often appear as an insulator under this condition, and a poor controller contact will give a constantly varying resistance.

In order to bring the contact resistances down to normal, it is necessary to pass considerable current through the equipment when testing, and it is most convenient to ob-

tain the current from the railway circuit. But when we use a current varying as the ordinary railway current varies, and yet discover the variation of resistance as low as .005 of an ohm, another difficulty confronts us, and neither a bridge method nor fall of potential method are applicable to this work.

In any bridge method the measurement of a resistance also includes the contact resistances by which this resistance is placed in the measuring circuit, as at *Fig. 3*, and due to this varying quantity introduced into the bridge method, it is not a reliable instrument under $\frac{1}{10}$ of an ohm ;

FIG. 4.

nor in the other extreme, can the bridge give quantitative results over 500,000 ohms. For these reasons it is useless in measuring low resistances with any degree of accuracy which will admit of a definite analysis, especially in those resistances met with in fields and armatures. No multiplying arrangement can increase the accuracy of any measurement external to this instrument.

Thompson's method of measuring resistances which is applicable to low resistances, is extremely delicate and of general use for this purpose ; but there is one very important condition necessary in using this method ; that is, there cannot be any appreciable resistance between standard *A* and

the resistance X under measurement, as at D in *Fig. 4*; for in that condition there would be considerable fall of potential along the measuring lines, which will interfere with the accurate comparisons of the resistances, A and X , under measurement, and in car inspection it is impossible to have the standard and resistance under measurement adjacent to each other. The volt-meter and ampere-meter method, where connected as at *Fig. 5*, will give the resistance sought, by dividing the volts read by the amperes flowing. But in measuring an inductive circuit, such as a field or armature of a motor, we find that with the voltage falling, the resistance between any inductive terminals is apparently

FIG. 5.

lower than its true resistance; and with the potential rising, the resistance will be apparently higher than the true resistance measured. This method is too tedious and unreliable for the purpose of accurately diagnosing equipment troubles, as, to use this method, we have to balance our circuits inductively as well as ohmically in using the trolley circuit in equipment testing; but to make all this practical and of general utility, the system must be so devised that the measurements and determinations can be made quickly, and not necessarily by one skilled in the art.

The author, after years of experience, has had to abandon the above methods, for they did not produce sufficiently con-

cordant results to make the analysis of an equipment positive, and he has developed the differential method shown in *Fig. 6*. This is nothing more than separating the differential coils of Kelvin's method, electrically, so the resistance between *A* and *X* would not interfere with the accurate comparison of two resistances.

Another condition necessary in the development of a system is the keeping independent from each other the different tests requiring different connections made to the testing apparatus, so an inter-locking system had to be devised by which means the test under consideration could be connected up only when the dial was turned so the pointer was opposite that test, then the holes for inserting the plugs in

FIG. 6.

this test registered with the proper receptacles, and the plugs could be inserted for this test, and no interconnections could be made which would injure the instruments used in these tests.

The semi-portable apparatus, known as *Form D*, is shown here in *Fig. 7*, which combines besides the inspection tests, all other well-known ampere-meter and volt-meter tests which are required on the line, car operation and electrolysis. The testing set, including only the inspector's test, is a much more portable affair, and can be readily carried from car to car. It is very easy to make an electrical inspection of an equipment in one minute, when proper arrangements are made to expedite the test; and a testing set can be taken to any part of the road where the cars can

FIG. 7.

be delayed, and this test can be made on each car by holding it for one minute.

The inspection test consists simply of measuring the equipment up on each notch of the controller, and every road fixes its maximum and minimum standard for each type of equipment, there being considerable range between the allowable maximum and minimum at first.

To maintain an equipment means to keep the different controller points within standard values, and any part which departs from standard value can be immediately repaired at small cost before the more serious secondary effects have rendered the equipment a cripple.

I show a plotted curve (*Fig. 8*) of ten identical equipments which were inspected on a fairly well operated road, and it shows quite a variation in rheostats, and also two burnt-out fields and a poor brush holder. A straight line is drawn through these tests in order to show where the standard should be. It will be noticed that there are high rheostats in several equipments, and it will also be noticed that in equipment No. 23 the high rheostat has resulted in the burning of the field of No. 1 motor. It will cost five times the amount to replace the field that it would to repair the rheostat, and it is only by careful inspection that these primary troubles can be detected in time to prevent a more serious loss.

The ageing effect on the different types of equipments tend to lower in some and to raise in others the resistance of the rheostat. The field resistance will fall slightly, owing to the annealing effect on the wire, but if the resistance falls below 1 per cent., it is due to turns being short, or the carbonizing of the wire insulation known as baked, which allows the current to pass between the adjacent turns through the carbonized cotton insulator instead of around the turn to produce the magnetic effect on the field.

The result of this is to make the armature revolve faster in the weakened field, and the armature will become overloaded in its effort to run the car, and also to carry the other motor; in this way if the equipment is operated the result will be an armature burnt out.

FIG. 8.

In one case in which I inspected the cars, the armature winder, who was an excellent worker, had been discharged for the reason that his armatures would not run more than a few hundred miles before being burnt out. I found that defective fields were the cause, and after replacing the bad fields in these equipments, the armature winder was reinstated, and there has been no trouble since.

An undiscovered baked-out field is one of the most prevalent causes of motor troubles. A number of methods of winding and treating fields are now in use, which have for their purpose the preservation of insulation between adjacent turns of wire, such as winding the wire with asbestos under the cotton. Care must be exercised in using this wire, as some of the forms will not hold the proper number of turns with this increased size, due to the asbestos covering, and if the proper number of turns are put on the form the field spools will not fit in the motor.

Another method used is to slush these coils as they are being wound, or dipping them, after they are wound, in a solution made up of chalk, magnesium-oxide and water to the consistency of whitewash; and this foreign material being introduced into the winding, when baked, hardens and forms a mechanical barrier between the adjacent turns and prevents their short-circuiting.

Other methods are practiced, such as dipping the field coil into varnish or insulating compounds. These different methods all have for their purpose the introduction between the adjacent turns of wire of a non-carbonizable insulator.

The field coils must be well baked after the application of any of these methods in order that any moisture or alcohol may be driven off before the coils are used. It has been the practice to pass current through these coils and heat and bake them in this way; but when water or alcohol is present, internal electrolysis is set up, which forms internally a conducting copper salt, and this destroys the insulating properties of the mediums employed. Another point may be mentioned here in regard to baking where armatures and fields show low to ground after being baked—the baking oven is completely enclosed, and any moisture

FIG. 9.

excluded from the coil is held in the air. A baking device having no ventilator is really a steam box, and not a baking oven, and high insulation cannot be obtained unless ventilation is provided to the oven.

The best way to measure the temperature of a motor is to measure its resistance when hot, and for each degree Centigrade rise in temperature of the field the resistance will increase 0.38 of 1 per cent. *Fig. 9* gives the increase of resistance for each .1 of an ohm to 1.5 ohms, and up to 100° Centigrade. The drops in volts across one field when the equipment is running is the best method of testing whether the two motors are taking their loads equally, when they are connected to a series parallel controller. When the motors are in series, they are both taking the same current, and the drop across the field should be reduced one-half when the motors are thrown to multiple, and the same current passing in both cases. If the voltage drop is not cut in half under this condition the motors must be out of equalization, 8 per cent. being the maximum difference in equalization allowed to pass. With the differential method each coil takes the drop off of one field of each motor, and the hand stands at zero in case of equalization. If the hand departs from zero as the speed of the equipment increases, the lack of equalization is due to difference in air gaps of the two motors. If there is a constant deflection for all speeds, the non-equalization is due to the unequal resistance of the two motors in multiple.

In the tests on the armature and its commutator, which is the most delicate part of the equipment, and first succumbs to ill usage or lack of proper inspection of the equipment, the different diseases met with in this part of the motor, are grounds, short-circuits, open coils, broken leads, and broken-down insulation in the commutator, and especially short-circuiting through the commutator ring. Their detection is rendered easy by a bar-to-bar test on the armature. *Fig. 10* shows the method of applying this test to the armature, a brush-holder yoke is clamped to the shaft of the armature, and insulated brushes bear on the bars of the commutator; by moving these brushes around the commu-

tator, the indication of the instrument will be constant in all positions of the brushes; but if an armature is misconnected, there will be a change in values when the brush rests on that commutator bar to which the misplaced lead is connected. Two bars which are short-circuited together when they lie between the four testing brushes will give readings that will be lower than normal. A ground in an armature can be located when one of the measuring terminals is connected to the shaft. The grounded coil connects to that commutator bar which gives the lowest reading on the measuring instrument, when the measuring contacts are

FIG. 10.

revolved around the commutator. Where the insulation is to be measured, the same connections are kept on the armature as for ground, and the test plugs are removed, and the dial turned to insulation test, and plugs inserted in the exposed receptacles; the insulation is read directly in megohms on the insulation scale of the instrument. *Fig. 11* shows method of connecting to the field.

The controller has troubles of its own, such as poor contacts of the fingers, short between fingers, grounds, burnt-out segments and misconnections; also the insulating partitions between fingers become carbonized and cause an arc

which destroys the contact fingers. Many imperfections in the controlled circuits leave their imprint on the controller. Several of the most prevalent indications will be mentioned, such as the burning of the second resistance contact and the first resistance contact being bright will indicate an open connection in the first resistance step. A bad flash at either loop contact, where loop is cut around the field, indicates an open or poor field connection. In this way many things can be observed in connection with the equipment, and it requires that a successful inspector be keenly alive to all the little external evidences of the internal troubles.

FIG. II.

And to aid him, I have produced diagrams of connections divorcing the essential apparatus of the equipment from the intricate wiring system so that the conditions of cause and effect can be quickly arrived at.

The controller diagrams that we have studied of type *K* in *Figs. 1* and *2*, show one of five different types, placing them historically. First was the rheostat control, which consists of a resistance in series with one or two motors, as the equipment requires, the function of the controller being to close the circuit and vary the resistance in series with the motors, and in this way controlling the current delivered. The next step in the art of equipment regulation was to first place

both motors in series, and also in series with the resistance; after this resistance is cut out the motors are automatically placed in multiple. At this point there is a divergence in connection; one type, such as the *K* controller, places part of this resistance in series with both motors in multiple. The type known as *G* controller in passing to the multiple position places one motor directly across the line potential, and the full resistance in series with the other motor, which is cut out in the succeeding notches of the controller, until both motors are directly across the line. Type known as *No. 14* controller has a separate resistance step in series with each motor; when the motor is in series, these resistances are cut out alternately, both in the series and multiple positions of the controller. Type *C* controller comprehends somewhat the same general arrangement, the relation of the parts only differing in reference to the controller contacts. Each of these controllers has its peculiarities, but to go into them in detail would require too lengthy a discussion.

The wire for car wiring has not been selected large enough in those circuits which lead directly from the motor to the controller, due to the circuitous route that the current takes in a two-motor equipment with a 20-foot car body, the length of this circuit is 217 feet, which of No. 6 wire gave under the condition of equipment tested 12 volts drop in this circuit only; and this drop occurs under the conditions when the motor requires the maximum potential delivery at its terminals; and a few additional dollars spent in the internal wiring of a car would accomplish the same results as hundreds of dollars spent on the line.

The application of electrical inspection of equipments brings out some very queer conditions caused by the car wiremen not fully comprehending the wiring diagrams furnished. In one case I found a number of equipments with both loop boxes connected in series around the field of one motor. Another case I found all the rheostat boxes connected in backwards; that is, the low resistance step connected to the first step, and the high resistance step cut out just before the motors were put across the line. Another case in No. 14 controller, I found where one resistance had

always been short-circuited by a misconnection, and the equipments had been working under this condition for several years.

Briefly summing up my experience of the testing of over 1,000 equipments, including nearly all the types extant, I find that the principal weak points are :

(1) That the two-way connectors are responsible for a great deal more than their share of trouble, and that every break in the continuity of the conductor system reduces the reliability of the equipment for continuous operation.

(2) That a motor is not any better than its field.

(3) That careless brush inspection is responsible for more burnt-out armatures than those caused by poor motormen.

(4) That the maintenance of an equipment is much more economical and satisfactory than trusting to Providence and awaiting the time until it breaks down ; in other words, it is far better for a street railway manager to operate a sanitarium for his equipments rather than a hospital.

The vitality of an equipment rests entirely upon the excellency of its insulation ; and the trend of recent improvements in the equipment is to abandon those insulators, which in time either oxidize or carbonize and become conductors.

One final pointer I would like to mention in regard to, high-potential alternating insulation tests for railway apparatus, which is generally considered a satisfactory method because it shows so many faults not indicated by other tests, but the application of this high-potential method, with depleted insulation, usually develops the fault which it detects and curtails the natural life of armatures and fields.