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RECENT IMPROVEMENTS IN THE ELECTRIC LIGHTING OF STEAM RAILROAD CARS

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ABSTRACT OF PAPER

This paper deals with the axle generator system of electric lighting for steam railroad cars, and describes recent improvements in control systems for obtaining proper voltage from the generator under all conditions and proper regulation of battery charge to conserve the life of the storage battery. Methods of control depending upon *voltage* of the battery have not been wholly successful. Since the beginning of 1914 extensive use has been made of systems of control of the battery charge based upon actual input and output in ampere-hours, and one such system, which has proved successful, is described.

In the development of the system of control by ampere-hour meter, tests were made by means of a special graphic recording ampere-hour meter which gives a complete record of the treatment received by a storage battery with any axle generator system. Actual records from long runs are reproduced, to show the results obtained in the operation of the system of control of charging by ampere-hour meter. With this system the battery has minimum work to do, in most cases operating between points of 75 or 80 per cent of full load and full charge, and the lighting load is put on the generator as much as possible.

THE PROBLEM of supplying a uniform and thoroughly satisfactory electrical illumination of steam railroad cars is much more difficult than might appear to engineers not familiar with some of the problems involved, and which do not occur in supplying electricity from a stationary plant.

Three general methods have been employed in the United States and Canada for the operation of electric lights on steam railroad cars; the method now most generally used and which will undoubtedly come into even more extensive application in the future, being that employing a generator suspended beneath the car, driven by a belt or chain from one of the car axles, and operating in connection with a suitable storage battery carried on the car to furnish a supply of current under all conditions of train operation.

The second method is the so-called straight storage method, in which each car of a train carries only a storage battery which

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is charged at certain points enroute or at terminals, from stationary charging plants, and which carries the lighting load at all times.

The third method is by means of the so-called head end system, employing a generator in the baggage car or other suitable point in the train, which may be driven either by means of a steam engine supplied with steam from the locomotive boiler, by means of a gasoline engine, or by direct drive from the car axle, in the latter case giving a system somewhat similar to the first mentioned.

With the head end system, a small storage battery is sometimes used on each car of a train, so that the lighting will be taken care of when a car is detached from the train, as when laid off at a station enroute. In other cases a battery is employed on only one or two cars of the train, acting as a reserve when the generator is stopped, but not taking care of lights on other cars of the train than those having the batteries, in case such cars are detached.

For the purpose of this paper, only the first or so-called axle generator system will be considered. There are, and have been, many more or less different arrangements of axle generator systems; that is, differing as regards the suspension and drive of the generator, its electrical characteristics, the relation of the generator to the battery, the controlling systems for obtaining proper voltage from the generator under all conditions, the methods of regulating the battery charge, of protecting the battery, of regulating the voltage supply to the lamps or other devices on the cars, etc. It is not within the scope of this paper to consider the many modifications and detail developments of axle generator systems, especially as regards the merits of the several systems of so-called constant generator current, constant battery current, constant generator potential, etc., but rather those characteristics of all axle generator systems affecting the performance and life of the storage battery used in connection therewith.

Aside from the difficulty of obtaining steady and uniform voltage and ample supply of current from an axle driven generator under the widely varying conditions of train speed, and variation of load, there has been, with all systems of electric train lighting, more or less difficulty in obtaining proper battery charge without serious overcharging or overdischarging; both of which may be considered seriously detrimental to the proper

performance of the battery and particularly to its proper maintenance and life.

As the charge and discharge of a battery connected across the generator line, as shown in Fig. 1, depends upon the terminal voltage of the generator, or more correctly, the voltage imparted at the battery terminals from the generator, it is most important that a suitable charging voltage, depending upon the state of charge of the battery, should be automatically maintained so as to charge the battery properly. With axle device equipments employing voltage method of tapering off the battery charging current, the latter is intended to remain constant until such time as a supposedly predetermined voltage is attained, when it is intended that the charging current will gradually decrease with the increasing e.m.f. of the battery.

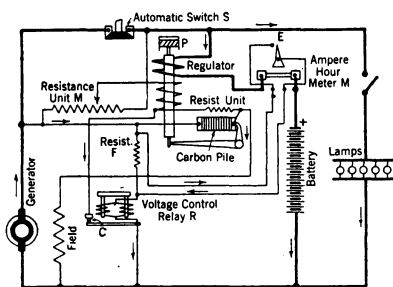


FIG. 1—Panel with AMPERE-HOUR METER

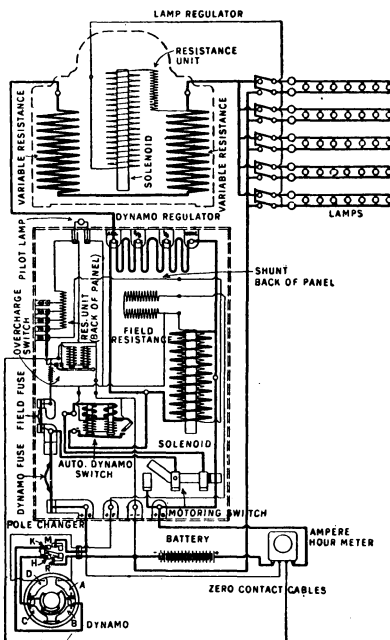


FIG. 1A—Wiring Diagram of Consolidated Axle Equipment with AMPERE-HOUR METER CONTROL

With a stop charge system, the voltage of the generator should either be automatically reduced so that further charge will not be given the battery until some discharge has taken place; or if preferred, as in some systems, the generator should be automatically disconnected from the battery after the full charge has been obtained and connection should not be restored until after some discharge has taken place; but in either case, by proper control, excessive overcharge will thus be prevented. On the other hand, with any system having a control such that

the voltage of the generator is dropped below the charging voltage required for the battery before full charge has been obtained, after successive discharges a gradual reduction of charge must take place, resulting ultimately in a seriously undercharged battery with danger of sulphation, reduction in life and excessive maintenance charges, just as are the results on the other hand from overcharging, causing disintegration of plates, loss of active material, excessive gassing, unnecessarily frequent flushing, and all the resulting evils which bring about similar high maintenance charge and greatly decreased battery life. Manufacturers of electric car lighting systems have devoted great inventive ability and large expenditures to the development of details of control for axle generator systems, in an effort to prevent battery troubles, as referred to, and to a degree have been successful, but all methods of control depending upon voltage of the battery, must in the last analysis fail to a greater or less extent because of the inherent characteristics of a storage battery as regards voltage of charge and discharge under varying conditions of temperature, age of plates, condition of battery resulting from rate of charge, and other factors familiar to battery engineers.

The very important effect of temperature on the charging voltage of a battery is clearly illustrated in Fig. 2. If the battery is cold the voltage on charge may follow the curve *A* which is slightly higher than normal, and requires a maximum voltage at the finish of several volts above normal.

On the other hand, if the battery is comparatively warm and the plates in good condition, the charging voltage will follow the curve *B* which is somewhat below normal, and the gassing voltage may be considerably below the gassing voltage of the battery under normal conditions. If the charge is continued the battery warms still further and the voltage actually falls further away from the normal maximum.

When the specific gravity ceases to rise it may be taken as a sure sign that the battery is fully charged. This point is indicated by a cross on the specific gravity curve. This is after approximately 10 hours charge, but it should be noted that the voltage curves have reached their maximum value some time previous to this.

The curve *A* has reached its gassing voltage after $8\frac{1}{2}$ hours charge, while the curves *B* and *C* show that even a normal or a warm battery rises to a gassing voltage before the charge is fully completed.

The charging voltage of a storage battery will vary anywhere between the two dotted curves *A* and *B*, and it will rarely, if ever, follow the ideal charging curve *C*.

With a stop charge system, depending upon voltage, this has usually been set high, for 40 or 42 volts, in order to insure that the storage battery gets sufficient charge. With a warm battery, or in many cases, even with a battery under normal conditions, the charging voltage may *never* reach this point and a long continued overcharging results, which boils out active material and causes excessive growth.

If the relay is set so as to accommodate a low battery voltage, it will cut off under normal conditions *too soon* and leave the battery in a half charged condition.

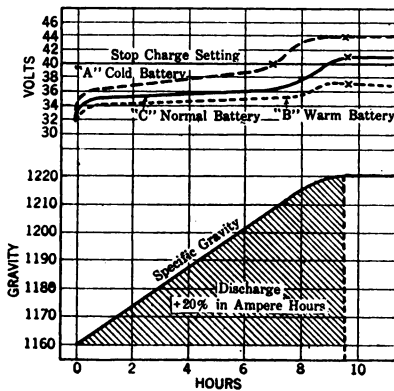


FIG. 2

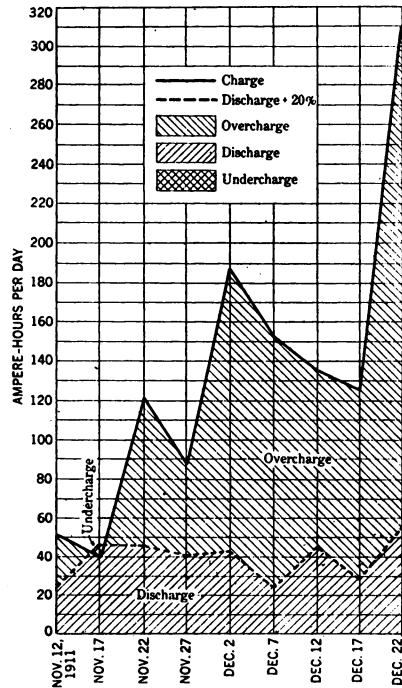


FIG. 3—CONDITION OF AXLE EQUIPMENT SHOWN BY AMPERE-HOUR METER TEST

From the diagram and the above description, it will readily be seen that it is practically impossible to set a stop charge voltage relay for any definite voltage, so that it will meet the ordinary variations in battery condition and give a satisfactory percentage of overcharge without, on the other hand, rendering the battery liable to undercharge.

In Fig. 3 are shown the actual results of test on a battery operating with axle generator equipment on a well known rail-

road system, from which it will be noted that during the period of this test an average overcharge of 100 ampere-hours per day was given the battery; that is, 5 hours of continuous boiling on overcharge at 20 amperes per day. It requires no argument to show that a battery subjected to such conditions will rapidly disintegrate, showing excessive maintenance cost and short life.

For the purpose of showing results that have been obtained by the application of a control of the battery charge based upon actual input and output in ampere-hours instead of by voltage, one well known system will be referred to, although it should be understood that the fact that this particular system is considered, does not mean that other systems now in general use are less or more subject to battery troubles from improper control by the voltage method, than this particular system.

In the control of any axle generator system it is necessary to have some type of rheostat in the generator field circuit operated by devices automatically responsive to changes in the load current and the voltage across the battery terminals, so that with varying train speeds and varying load, the field of the generator will be automatically varied to maintain a practically constant voltage while the battery is charging; and a lower but practically constant voltage when the battery is floating, in those systems where the generator is not disconnected from the battery and load line after the battery has reached full charge.

In addition to the controlling rheostat for the generator field, practically all axle generator systems also have a "drop-out" switch, as it is usually called, which automatically connects the battery and load line to the generator after the train has reached a certain critical speed; usually 12 to 15 miles per hour and which disconnects the generator from the line when the speed drops below a certain rate; usually 8 or 10 miles per hour, as the voltage of the generator then drops below the normal discharge voltage of the battery.

Outside of these two main elements for generator control, all axle generator systems now used in this country also have a lamp regulator or rheostat automatically responsive to changes in voltage from the generator and battery and to changes in the lighting load of a car, designed to maintain a uniform and steady voltage on the lamps. The lamp regulator and the

performance of the several types thereof now in use, is not directly related to the problem of battery control, but it may be stated, in passing, that a great amount of effort and ingenuity has been expended in the design and construction of lamp regulators and there is still room for improvement in the way of simplicity of design and smoothness of operation, so as to avoid any flickering or variation of the lights with the starting, stopping and sudden variations in speed of a train.

Aside from the generator field regulator and automatic or drop-out switch, certain other features in the way of relays and resistances are required for generator control, and in the system above referred to, illustrated in Fig. 4 as designed for voltage control of the battery, the relay responsive to the voltage across the battery is shown at *R*. In this system, as shown in

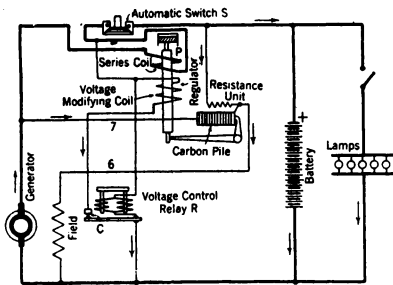


FIG. 4—PANEL

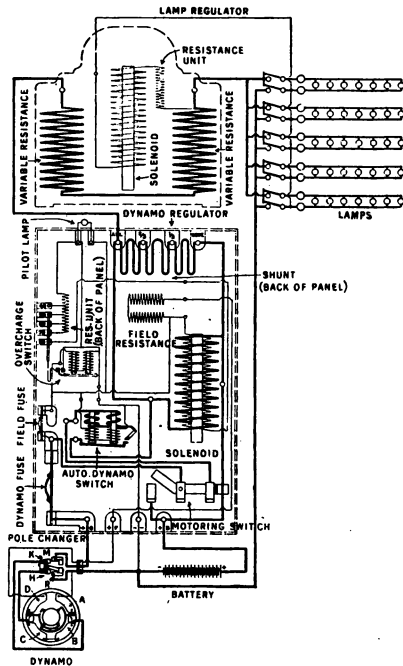
FIG. 4A—WIRING DIAGRAM OF
CONSOLIDATED AXLE EQUIPMENT

Fig. 4, the regulating solenoid acting on the carbon pile comprising the resistance in series with the generator field, is arranged so as to maintain a proper charging voltage, say 43 to 44 volts at the generator terminals, until the voltage of the battery has risen sufficiently high to lift the armature of the relay *R*, when circuit is closed through the contact *C*, thus increasing the flow of current in the potential winding of the solenoid controlling the carbon pile, decreasing the pressure on the pile, reducing the field excitation of the generator, and thus dropping the

voltage of the generator so low as to cause a large reduction in the energizing effect of the potential winding of the drop-out switch *S*. With this condition and a slight reversal in current flow through the series winding of the drop-out switch, due to current passing from the battery back to the generator, the automatic switch will drop out, disconnecting the generator, thus causing the battery to carry the load until such time as the train has slowed down to a very low speed or has stopped, when the relay *R* will be de-energized, breaking circuit to the shunt winding of the regulator solenoid, and restoring the entire system, so that on starting of the train and reaching critical speed, the generator will operate at charging voltage until such time as the battery has again become fully charged according to voltage.

Somewhat similar control has been employed in other well-known systems of electric railway train lighting, and while in many respects satisfactory, particularly with a new battery operating at fairly uniform temperature, none of these systems has given the results obtained with a control based upon ampere-hour input and output of the battery, in other words, on the battery's actual quantitative performance.

Something over two years ago, several railroad companies operating electric lighted cars, applied ampere-hour meters in an experimental way in connection with existing systems, substituting the full charge contact in the ampere-hour meter either in place of the contact operated by the voltage relay, or in connection therewith, so as to make the termination of charge to the battery dependent upon its condition with respect to charge as indicated by the ampere-hour meter. Preliminary results were quite satisfactory, but the ampere-hour meter was not extensively employed for automatic control of battery charge with axle generator systems until the beginning of 1914 when the Pullman Company applied meters on a number of cars. The application of the meter to the system already referred to, and as shown without the meter in Fig. 4, is illustrated in Fig. 1, the meter being shown diagrammatically at *M*. This entire diagram, like Fig. 4, is schematic, small details and structural features being omitted for the sake of simplicity.

Following results in the way of improved battery maintenance, which is by far the largest item in the cost of maintaining axle generator systems, meters were put on a large number of cars owned by the Pullman Company and at the present time prac-

tically every electric lighted Pullman car is thus equipped. Before describing in detail some of the tests that have been made and results obtained, it may be of interest to mention briefly the type of meter which has been used for this work.

The ampere-hour meter employed is of the mercury motor type, having a copper disk immersed in a mercury chamber formed of suitable insulating material, and with current led into and out from the mercury at diametrically opposite points so as to pass across a diameter of the disk. The current is subjected to the action of a field on each side of the center of rotation, produced by a powerful permanent magnet, so that the torque imparted to the moving system is proportional to the current flow through the copper armature, irrespective of voltage.

By means of a device termed a "variable resistor" connected in parallel with the motor element and mercury chamber of the meter, and both across a shunt of suitable capacity in the load line, the ratio of current sent through the armature with respect to the total current in the line is varied between charge and discharge, so as to give a lower speed to the meter on charge, for any given line current, than on discharge, thus enabling automatic compensation to be made for the inefficiency of the battery, as is necessary in order that the meter may correctly maintain the battery in properly charged condition. By means of a suitable adjusting device for varying the effect of the resistor element, any desired percentage of overcharge may be given, but in railway train lighting work it has been found desirable to give an overcharge with lead storage batteries of about 25 per cent and with Edison batteries, of about 30 per cent. The ampere-hour meter can readily be set for either percentage, and in fact for any desired percentage, according to the age of the battery, conditions of temperature and other factors which may affect the overcharge required. It is important to note, however, that even should the overcharge given the battery be 5 or 10 per cent greater than necessary to keep it in fully charged condition, the total overcharge that a battery in train lighting service will receive is so little as compared with the total ampere-hour input and output over an extended period, that practically no deterioration will be caused as compared with the enormous overcharge which may easily be obtained with a very slight variation in the charging voltage, when the control of charge is dependent upon voltage.

The ampere-hour meter as described above is provided with

suitable contact at the zero or full charge point on the dial, the hand moving clockwise on discharge and counter-clockwise towards zero on charge. The zero contact of the meter is shown diagrammatically at *E* in Fig. 1 and it will be seen that the contact is connected across resistance, *F* in series with the winding of the voltage relay so that the closing of the contact will immediately increase the energizing effect in the relay, causing it to close circuit through contact *C* thus increasing the current in the shunt coil of the field controlling solenoid *P*, which finally causes a decrease in the pressure on the carbon pile, a consequent decrease in the energizing effect of the generator field, and a reduction of the generator voltage to floating voltage of the battery.

As the floating voltage of a storage battery is far more constant than the voltage of charge or discharge under widely varying conditions of temperature age, etc., it is possible to determine a floating voltage such that the battery will receive a negligible charge or give a negligible discharge, outside of that required for any lamp load that may be on when the generator is brought to the floating voltage as predetermined, and which is dependent upon adjustment of the several resistances in the system including *M* and *G* as shown in Fig. 1.

For sixteen cells of lead battery, as regularly employed with all axle generator systems at this time, a floating voltage from 34 to 35 volts has been found thoroughly satisfactory, giving a minimum charge or discharge from the battery. In the operation of the systems as shown in Fig. 1 with the ampere-hour meter as control, it will be noted that after contact has been closed at full charge point operating the relay *R* and reducing the generator to floating voltage, the battery will discharge and carry any load that may be on in the car, as the relay *R* will remain closed after its armature has been drawn up, even with the reduced voltage across the generator terminals. This condition will continue until the next stop of the train is made or until a very low running speed has been reached, when the armature of the relay *R* will drop out, thus restoring the conditions existing before full charge had been reached and permitting the generator to operate at charging voltage after the train has started up and passed above the critical speed of 12 to 15 miles per hour. Charging will then begin and continue until the battery has again reached full charge as shown by the ampere-hour meter, when operation through the relay to bring the generator to floating

voltage will again take place. With this method of operation the battery will receive a proper overcharge without any serious and destructive overcharges, and will at all times, except in case of a very long accidental stop while lights are being used, have practically full charge, so as to operate at highest efficiency and give a most uniform supply of current for the lighting load. On the other hand, with this method of operation the battery has minimum work to do, in most cases operating between points of 75 per cent or 80 per cent of full load and full charge, and the lighting load is put on the generator as much as possible, which has not always been the case with the systems of voltage control where it was frequently the case that the battery would work over a very wide range, carrying the load a great part of the time when the generator should have done so. It is obviously far less expensive to carry the lighting load on the generator than to use up battery life, when the train is operating at such speed and under such conditions as to permit the generator doing the work instead of the battery.

In Figs. 5 and 6 are shown two sections of curves from recording ammeters and voltmeters obtained on a Pullman car operating on a large and well known railway system of this country. In these figures and from the notations subjoined to them, will be seen the remarkably uniform results in battery operation obtained by the application of the ampere-hour meter control. The generator operates at charging voltage only sufficiently long to restore charge to the battery after each period of running below critical speed or stopping; and during the period of floating, the charge or discharge of the battery is practically negligible.

It will also be noted from Fig. 7, showing a graphic record of generator output in watts with this method of control, that the generator is carrying the lighting load during the greater portion of the time that this load is on, and during the balance of the time, in the early morning and daylight hours, the generator is very lightly loaded, as the battery is floating, practically no lighting load is on and there is thus a great economy in power consumption by the several generators on a train, as well as the improved battery maintenance already referred to. This consideration alone is of great importance to railroad companies, as it is well known that the total consumption of energy for 10 or 12 axle generators, as on almost any through train, amounts to a large amount in dollars and cents in the course of a year. With methods of voltage control as formerly used, it would have been

simply impossible to get a curve of operation duplicating or approaching those shown in Figs. 5, 6 and 7.

In the course of the experiments conducted by the Pullman Company and several railroad companies during the past year

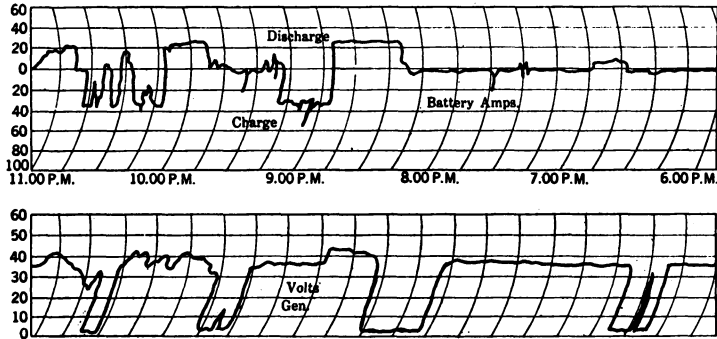


FIG. 5

to determine the conditions of battery operation before and after adoption of control of charge by ampere-hour meter, an interesting type of graphic recording meter was especially developed, this being a graphic ampere-hour meter, as shown in Fig. 9 with cover removed.

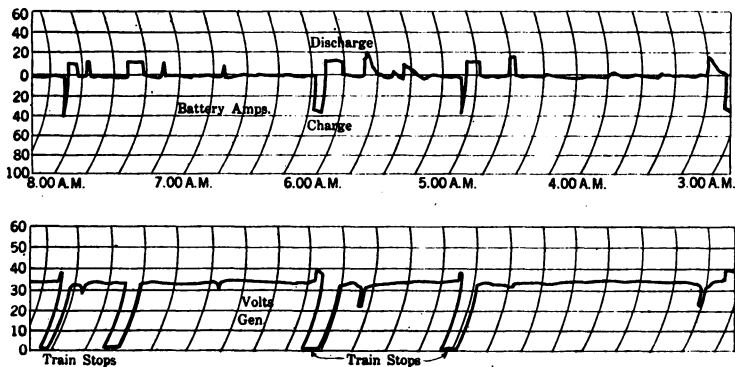


FIG. 6

This instrument is of particular interest, inasmuch as the graph is of an integrated function instead of an instantaneous or momentarily varying value. The record is obtained, as clearly indicated in the cut, by means of an ampere-hour meter suitably

connected through a driving chain to a pencil, *B*, moving across the paper chart and with another stationary pencil, *C*, arranged to be moved momentarily crosswise to a slight extent at half hour intervals, from the clock below, which also drives the paper roll. The meter as thus arranged gives a complete and definite record of the treatment received by a storage battery with any axle generator system, the chart being a cumulative record of the total battery input or output in ampere-hours, having the meter adjusted for any percentage of overcharge which it is desired to adopt during the period of test. Some results on equipments with and without the ampere-hour meter control are shown in Figs. 10, 11, 12 and 13.

Fig. 10 shows the record of battery charge and discharge on a car running between Boston and Chicago. It will be noted that when the car is not in motion the graph of the recording pencil is light, but as soon as the car begins to move, whether the equip-

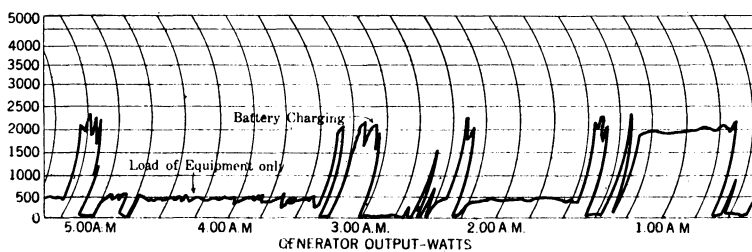


FIG. 7

ment is generating or not, the line becomes heavy. In this way practically all of the stops are indicated.

The base line has no reference whatever to the battery capacity scale, but simply gives a base line from which values of charge and discharge can be measured. For the sake of illustration, we have assumed in the curve, Fig. 10, that the capacity of the battery when fully charged, as it was from 7:00 p.m. to the end of the run, is 320 ampere-hours. Since $1/16$ of an inch equals 10 ampere-hours the vertical scale can easily be figured and we have placed this scale at each end of the curve. The curve as recorded by the meter, however, is simply the two heavy lines shown. In making the zinc etching the curve has been reduced to about half size.

Fig. 10 shows that while standing in the yard there was a capacity of 215 ampere-hours in the battery. The run to the station

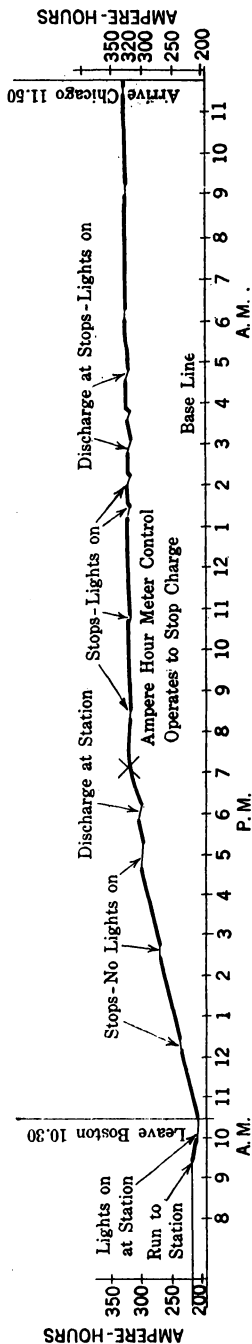


FIG. 10—GRAPHIC AMPERE-HOUR METER CHART SHOWING PROPER OPERATION OF EQUIPMENT RUNNING BETWEEN BOSTON AND CHICAGO. HEAVY SECTION OF CURVE IS CAUSED BY VIBRATION DUE TO MOVING TRAIN. LIGHT SECTIONS OF LINE INDICATE STOPS

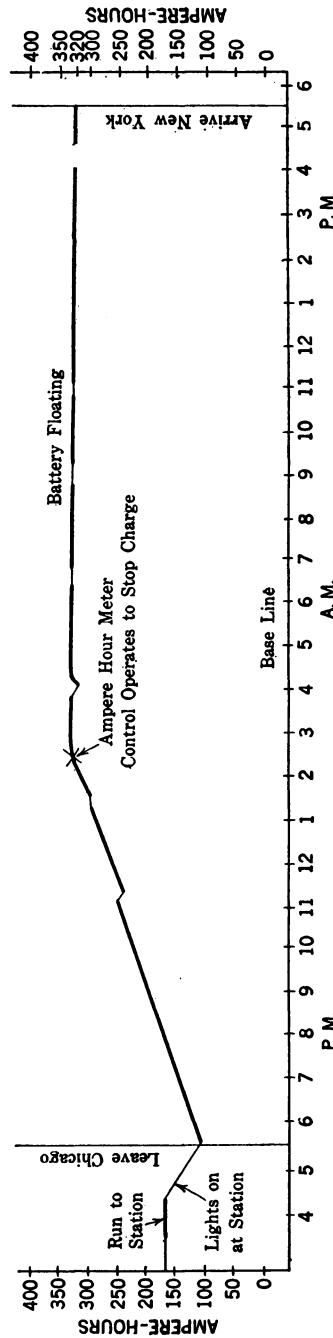
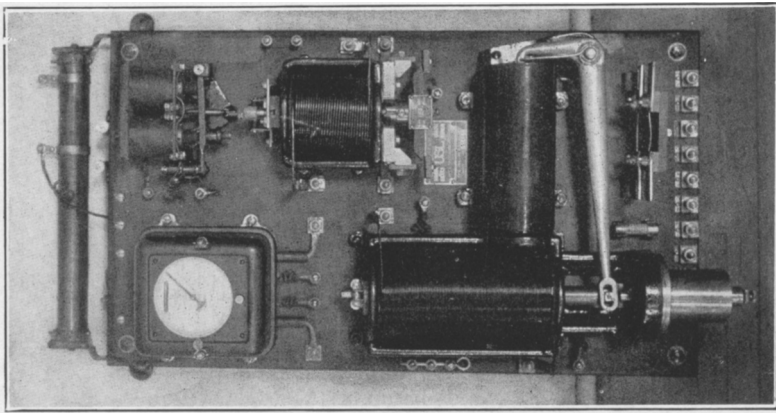
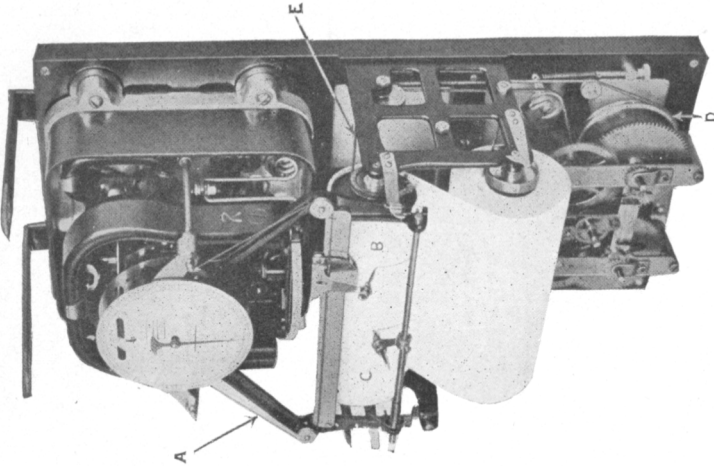


FIG. 11—ANOTHER GRAPHIC AMPERE-HOUR METER RECORD SHOWING PROPER OPERATION OF THE EQUIPMENT ON RUN BETWEEN CHICAGO AND NEW YORK. HORIZONTAL SECTION OF THE LINE INDICATES BATTERY FLOATING AT FULL CHARGE



[LANPHER]
FIG. 8—STANDARD PANEL WITH
AMPERE-HOUR METER CONTROL



[LANPHER]
FIG. 9—GRAPHIC AMPERE-HOUR METER
WITH CASE REMOVED, SHOWING RECORDING
PENCIL (B) MOUNTED ON ROLLING CARRIAGE
MOVED HORIZONTALLY BY AMPERE-HOUR
METER GEAR TRAIN

is shown by the heavy horizontal line and discharge now begins as shown by the downward curve of the line. Altogether enroute to and at the station the battery discharged 10 ampere-hours. As soon as the train left the station the battery started to charge and this is indicated by an upward slope of the line; since this equipment was set for constant battery current regulation, the upward slope of this line is always at the same angle. If this had been a constant generator current regulator this degree of slope would have varied, depending upon the charging current rate.

It will be noted that at the stops during the day there was no discharge and the light lines, indicating stops, are horizontal. After sunset, however, it will be noted the light lines at all stops slope downward, this indicating a discharge at each stop. As soon as the equipment begins to generate again, however, the curve again begins its upward slope, indicating that the battery is charging at the constant rate of the regulator setting. It will be noted that at 7:00 p.m., indicated by a cross on the curve, Fig. 10, the battery has reached a full state of charge, and since this equipment was controlled by an ampere-hour meter of the variable resistor type, this meter, like the graphic meter, indicated a zero discharge and thereupon closed its zero contact, which stopped further charging of the battery. The battery then simply floated on the line, the generator carrying the load of whatever lamps happened to be in use at the time. It will be noted that there are various stops where a slight discharge occurred, but this was quickly replaced by normal operation of the equipment and the controlling meter again operated to stop further charge when the discharge plus 25 per cent had been put back into the battery.

Fig. 11 is another curve which shows the operation of an axle generator car lighting system with the generator regulator adjusted so as to provide constant battery current; the charge given the battery is controlled by an ampere-hour meter of the variable resistor type. As in Fig. 10 we find a very normal condition of affairs with the battery charging normally enroute, a few short discharges at stops, and finally coming to a state of full charge at 2:30 a.m., when the controlling ampere-hour meter operated to stop further charge, and so protect the battery from excessive overcharge. In Fig. 12 however, both the controlling ampere-hour meter and the voltage regulating solenoid were purposely cut out of service and the equipment operated as on

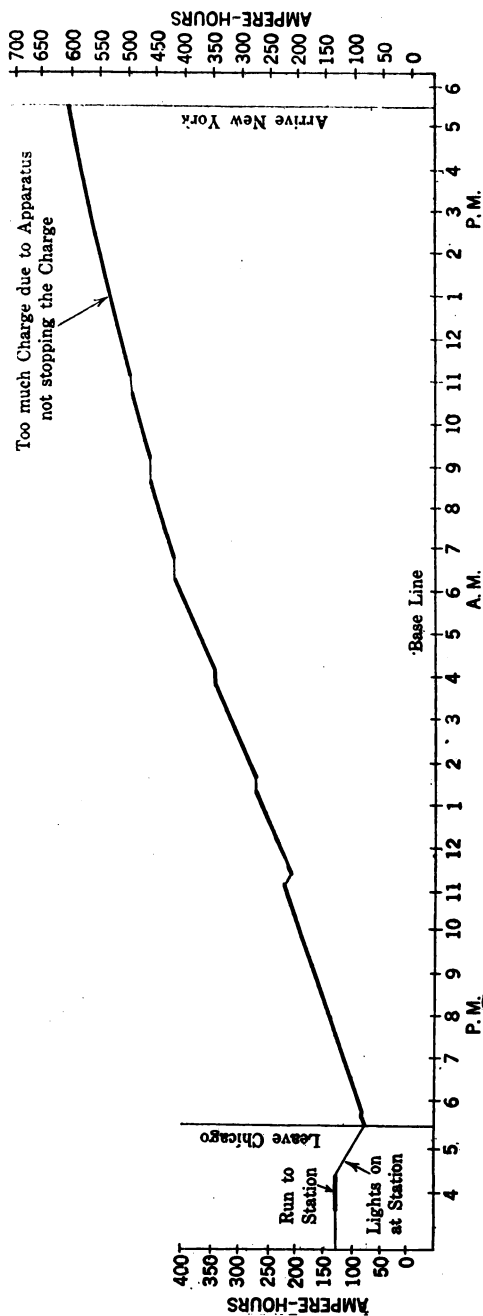


FIG. 12—GRAPHIC RECORD SHOWING THE OPERATION OF SAME EQUIPMENT AS FIG. 11, BUT WITHOUT AMPERE-HOUR METER OR VOLTAGE CONTROL OF CHARGE

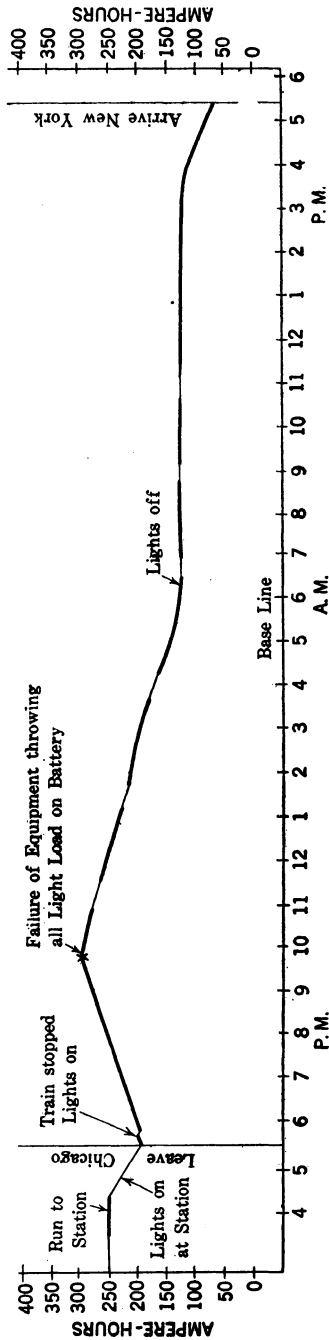


FIG. 13—GRAPHIC RECORD SHOWING OPERATION OF SAME EQUIPMENT AS FIG. 11, INDICATING A FAILURE OF THE GENERATOR EQUIPMENT AT THE POINT MARKED

a simple constant battery current control. This illustrates, of course, only abnormal conditions such as would be experienced in using a regulator of the constant current type without auxiliary control of charge, or when the voltage regulating feature of the combination current-voltage regulation of equipments with the ampere-hour meter control failed to work. In this run it will be noted that a charge of 525 ampere-hours was given a 320-ampere-hour battery which at the start showed only a 245-ampere-hour discharge. This indicates an overcharge of (280 plus 25 per cent or) 350 ampere-hours, representing the full normal charging rate for nearly nine hours on this single run. When considering the effect of such serious overcharging on a battery it is not surprising that the average battery life in car lighting service has been so small in past years before the use of voltage regulators, giving a taper charge, or the controlling ampere-hour came into use.

Fig. 13 shows another abnormal condition wherein the equipment failed to generate at the point marked "X" on the curve due either to lost belt which was not replaced or trouble in the equipment. It will be noted that there is a continual discharge on the battery from this point till the end of the run; this does not follow a straight line, but tapers more to the horizontal as the number of lamps in use is reduced.

From the information obtained by the graphic ampere-hour meter as illustrated in these curves, it is quite evident that a greatly reduced battery maintenance and a vastly increased battery life—the two greatest items of cost in the operation of electric lights on steam railway cars—may well be anticipated as a result of the application of control of charge by ampere-hour meter, operating in connection with existing axle generator systems; and as improvements or modifications of these systems are developed, it will probably be the case, as is already true of two well-known companies manufacturing such equipments, that the ampere-hour meter control will be adopted as standard. Now that electric lighting of steam railroad cars has become universal, or at least universally desired, anything which tends to improve the uniformity of lighting and efficiency of such systems and to reduce the expense of operation cannot be neglected by engineers interested in this branch of the electrical art.
