AN ELECTRIC CAR LIGHTING SYSTEM.

BY W. L. BLISS.

A description of an axle-driven electric car lighting system in which the generator is located on the truck frame, the armature being rotated by means of a single reduction gearing. Explanation of the mechanical construction of the generating apparatus and the method of controlling the electrical energy under all conditions of railway service.

In presenting this paper, the author assumes that the members of the INSTITUTE are generally familiar with the subject of train lighting from the axle, and that no allusion to the previous state of the art, or the many failures and disappointments along this line of engineering is necessary or desirable. The admirable papers of Brown, Bauer, Blodgett and others have familiarized the members of the INSTITUTE with the work that has been done in the past and the degree of success that has been attained. It is with this thought in mind that the author will present for your consideration a modern method of train lighting from the axle that is reliable in its operation, and which has passed beyond the experimental to the commercial stage, and is becoming standard railway equipment.

This system consists essentially of the following elements:

- 1.—A dynamo electric machine or generator located on the car, or, as is the common practice in this country, directly on the truck frame, and so arranged that its armature is caused to rotate by means of a mechanical connection with the axle.
- 2.—Translating devices within the car, consisting in general of incandescent lamps and fan motors, and which utilize the electrical energy developed in the generator.

3.—A storage battery carried on the car, whose special function is to supply the electrical energy necessary to operate the lamps whenever the armature of the generator revolves at a speed too low to render the same operative, or when the armature ceases to rotate, which condition is obviously attained when the car is at rest.

4.—Auxiliary automatic apparatus, which, acting in conjunction with the above, will render the operation of the entire system automatic, safe and reliable.

THE PROBLEM.

In attempting to attain the results indicated above, a multitude of difficulties present themselves which may be classified into two primary groups: (a) those which are purely mechanical and are concerned with the motive power, and which must be overcome before the generator can be operated successfully; and (b) those which appertain to the control of the electrical energy after it is developed and which are principally of an electrical nature, although involving no small application of mechanics.

The difficulties under group (a) arise from the peculiar character of the source of power, the location of the generator and the conditions under which the latter must operate.

As the generator in this system is located on the truck frame there must first be provided a machine mounting, and axle connection which shall withstand the injury and abuse coincident with the most exposed position in which a piece of electrical apparatus can be placed. Secondly, there must be provided an axle connection which shall not necessitate any change in the manufacture of standard railway axles. Such axles are rough, tapered and out of true, and no connection which contemplates the use of keys, set-screws, etc., or which requires turning, trueing or machining the axle in any way will be permitted by railway officials. The reasons for this are obvious and require no further comment. (See Fig. 1.)

METHOD OF DRIVING.

In this system the generator and driving mechanism are modeled somewhat on the lines of the modern street railway motor, such modifications and additions being introduced as to adapt the apparatus to the special work in hand. A single reduction, gear-driven generator has been adopted, but, unlike the ordinary street-car motor, the entire weight of the machine is carried on the truck frame, it not being possible to journal on the axle, for the latter, as previously indicated, is not, nor will present railway practice permit it to be suitably prepared.

Instead of journaling the axle in bearings attached to the frame of generator, two large brackets are carried out from the frame

FIG. 1.

or casing of the generator and are adapted to receive and support a hollow shaft, which runs on roller bearings, and upon which the

split gear which meshes with the armature pinion is mounted. The hollow shaft, as well as the brackets, is divided longitudinally, in order to permit assembling on the car truck. The car axle extends through the hollow shaft, a clearance of nearly two inches all around the axle, and between it and the hollow shaft being provided. (See Fig. 2.)

FIG. 2.

This clearance permits the axle to take all manner of motions and positions (within certain limits), with reference to the hollow shaft. Only one component of the axle's motion is transmitted to the hollow shaft, this component being that of rotation. All other motions, the horizontal, vertical and end shake, being pro-

vided for in a positive though flexible connection between the axle and the hollow shaft. This consists of a two-armed dog clamped on by four bolts securely upon the axle, and four specially constructed driving-springs which are attached by means of ball-and-socket fastenings to the two ends of the dog, and to the two arms of the hollow shaft.

The driving-springs are of the "keg" or helical type, wound with tapered ends, and are mounted in shallow cups, through which are screwed ball-ended bolts, which form a part of the ball-and-socket fastening referred to. Inside the springs, the bolts are threaded and provided with nuts and conical washers which fit the inside of the tapered ends of the springs. The nuts are set up with a spanner wrench and locked with spring cotters. An opening is cast in each end of the dog, through the jaws or sides of which a bolt passes, and in this opening and secured by the bolt is a socket-casting split in a vertical plane. The casting projects on each side of the dog and is hollowed out at each end like a bullet mould, thus forming two spherical seats or sockets, into which the ball-ended bolts of the driving-springs fit. The two halves of this socket-casting are fastened together by four $\frac{3}{8}$ " bolts, to prevent their opening and allowing the balls to wear on the joint between them. Similar socket-castings are secured to the two arms or cranks of the hollow shaft by means of bolts or studs which act as crank-pins. All these castings and fittings are interchangeable. Each driving-spring is connected by means of the ball-ended bolts to a socket-casting on the dog, and one on the hollow-shaft arm. The springs are, initially, neither in compression nor extension, which feature greatly facilitates assembling. The ball-and-socket joints not only admit of the springs assuming all possible angles and positions, but enable them to act either in compression or tension while driving. Two diametrically opposite springs are in compression, while the other pair are in tension, and *vice versa*, depending on the direction of rotation of the axle and hollow shaft. (See Fig. 3.)

The dog need not run true, and no special care need be exercised in mounting it on the axle, it being quite as effective when not so true as when nicely adjusted. The dog is made of malleable iron and cast to fit the taper of the axle. There is a positive advantage in not carrying any of the weight of the generator on the car axle. Supported as the generator is, entirely on the truck frame, it is free from the shock, vibration and pounding which would be communicated to it were it journaled on the axle, as in a street

railway motor. It is very easy with this construction to put the generator out of operation by simply taking the dog off the axle. But the greatest advantage which results from this construction is the absence of necessity for trueing up anything in installing the machine. An approximate centering of the axle in the hollow shaft, and the coarsest kind of work in mounting the dog on the axle, are all that are necessary. All the trueing and lining up are done in the shop, and no knowledge of machine work is required of those who install the machine.

All parts of the mechanism which require it are thoroughly

Fig. 3.

encased or otherwise protected. Automatic and profuse lubrication of the shaft bearings is provided. A cut steel gear on the hollow shaft drives a fibre pinion on the armature shaft. In consequence, these are run dry without lubrication of any kind, which conduces much to the cleanliness of the apparatus. See Fig. 4.

THE GENERATOR.

The generator is of the ironclad type, having four internal radial salient poles. The poles are placed at an angle of 45° , with the horizontal, two poles being in the upper, and two in the lower half of the generator, which is divided longitudinally in a

horizontal plane. The casing which forms the yoke of the fields, is extended parallel with the axis of the shaft and is then turned in at right angles thus forming ends, so to speak. These ends are

FIG. 4.

bored out and have fitted into them round head-like castings which hold the armature-shaft bearings and oil-wells. When these heads are in place, the generator is almost hermetically

sealed, and is absolutely dust and water proof. Suitable hand-holes or doors are provided in the generator casing for purposes of inspection, etc. The two heads which carry the armature bearings are each held in place by four bolts, two of which are tapped into the upper half of the generator casing and two into

FIG. 5.

the lower. By this construction the lower half of the generator may be removed, leaving the armature in the upper half, or the armature may be removed with the lower half. The heads being nicely fitted to the casing, ensure the perfect alignment of the armature shaft, no steady pins or other trueing devices being

required. By removing the head-casting at the commutator end of the generator, and detaching the flexible cables from their respective brush-holders, the entire brush mechanism, to be described later on, may be removed without disturbing any of the working parts. See Fig. 5.

The armature is of the 4-pole drum type, having a two-circuit singly re-entrant drum-winding of the straight-cut or barrel type. The coils are wound on formers and afterward placed on the armature, thus providing a perfectly balanced winding both

FIG. 6.

electrically and mechanically. The core of the armature consists of the usual annular stampings, slotted to receive the coils, and mounted on a ventilated spider. The central portion of the spider forms a sleeve which is extended at one end to support the commutator. The sleeve is bored out to take the armature shaft, which is suitably keyed and otherwise secured. This arrangement permits the armature and commutator to be quickly taken off the shaft without disturbing the windings, thus affording a ready means for making repairs either to the shaft or to the

armature itself. The construction of the armature, shaft and commutator is extremely substantial. All the running parts are heavily proportioned, and are designed to resist the heaviest shocks and stresses. The generator is connected as a plain shunt-wound machine and is self-exciting. Hence, there is but a single winding on the field, each pole being excited by one coil. See Fig. 6.

The armature winding, being of the two-circuit type, requires but a single pair of brushes to take the current from the commutator, but, for purposes hereinafter explained, two pairs of brushes are employed.

GENERATION AND CONTROL OF THE CURRENT.

The problems under group (b), as previously stated, are principally of an electrical nature. Being provided with a generator driven by the car axle which will supply the required electrical energy to operate the lamps and charge the storage battery, there are four conditions which must be electrically and mechanically provided for, and the operations they entail automatically performed, before the system can be declared operative.

THE POLE CHANGER AND AUTOMATIC BRUSH MECHANISM.

First.—Provision must be made for the fact, that the direction of travel of the car will be reversed, and hence the direction of rotation of the armature of the generator will suffer a reversal. This would render a self-excited generator inoperative, or would cause a reversal in the polarity of the brushes or terminals of a separately excited machine. It being highly improper to attempt to charge the storage battery with a reversed current, and for other reasons, means must be provided whereby the polarity of the generator terminals is preserved, no matter which way the car may chance to travel. In this system, the polarity of the terminals is preserved in the following manner: The brush-holders are mounted on a carrier, which is supported on anti-friction bearings, which enable it to rotate freely within the casing of the generator. The friction between the brushes and the commutator is sufficient to cause the former, and with them the carrier, to be dragged around as the commutator revolves. The angular motion of the carrier is arrested by means of a stop. When the armature revolves in a right-hand direction, the brushes and carrier are rotated to the right and arrested by the stop in the correct position for commutation. When the armature revolves in a left-hand direction, the brushes and carrier are rotated to the left into a position also correct for commuta-

tion, but a position such that the polarity of the brushes would have been reversed, had not a reversal of rotation in the armature taken place simultaneously. But the rotation of the armature having been reversed, and also the position of the brushes, the actual polarity of the latter is preserved. It will be apparent that the angular motion of the brush carrier need be but 90° in a four-pole generator, such as is employed in this system.

The stop which arrests the motion of the carrier is removable, in order that, for inspection purposes and the renewal of brushes, the carrier may be turned completely around, and all the brushes and holders brought opposite the hand-holes in the generator casing.

As before mentioned, a single pair of brushes would suffice to take the current from the commutator, but by using four brushes, or two pairs, a shorter commutator is possible, a more symmetrical disposition of the brushes is secured, and the adequate friction between the brushes and the commutator is obtained, without undue pressure on a single brush. The brushes of similar polarity are connected together in the usual manner, while flexible cables, which are readily detachable, convey the current from the brushes to the stationary terminals of the generator. Thus it will be seen that in this system the preservation of the polarity of the brushes is secured mechanically, and yet no contacts, switch-blades or other devices, which break or interfere with the continuity of the circuit, are employed. The friction between the brushes and the commutator cannot be avoided, and in this system is utilized to advantage.

THE AUTOMATIC GENERATOR SWITCH.

Second.—It is necessary to provide an automatic switch which will complete the circuit between the generator and the storage battery whenever the speed of the former, and consequently its voltage, is equal to or greater than that of the battery. On the other hand, this switch must likewise break that circuit whenever the voltage of the generator is less than that of the storage battery, by virtue of a reduced or zero speed. The object of this is apparent. The automatic generator switch opens and closes the circuit between the generator and the storage battery electrically, and is controlled directly by the generator voltage. It consists of a rectangular iron frame, which forms the magnetic circuit of the solenoid and supports the insulated contacts. Within the frame are two concentric coils, constituting the solenoid. They are made entirely separate, to facilitate con-

struction and repairs, and are held in place by a central tube. The inside, or lifting coil, is wound with fine wire, and is connected as a shunt across the terminals of the generator. The outside, or releasing coil, is wound with heavy wire and connected in series with the generator and storage battery. Within the central tube, and free to work in a vertical direction, is a soft-iron plunger, attached to and insulated from which is a laminated metal brush. When the generator develops its normal voltage of 64 volts, the fine wire or lifting coil will raise the plunger, thus causing the metal brush to make connection between two metallic contacts. If the generator voltage is increased, current will flow from the same through the contacts, brush, and series coil, and through the battery, the series coil being wound in such a direction that this current aids the shunt coil in holding up the plunger and brush, maintaining a better contact for increasing current. When, however, the voltage of the generator becomes less than that of the battery, current will flow from the battery in a reverse direction through the series coil and generator and oppose the action of the shunt coil. The weight of the plunger and brush is now sufficient to cause the opening of the switch by gravity. No springs are used to secure the adjustment. Adjustment is made by varying the length of the air-gap, and when once made is permanent. Carbon contacts, on which the final break takes place, protect the metallic parts against injury by arcing. See Fig. 7.

Upon the top of the iron frame of the automatic generator switch is mounted a triple contact, consisting of a three-part segmental socket and a conical plug fitting the same. The plug is raised and lowered by means of a tail-rod attached to the plunger of the switch. When the plunger is down and the generator switch open, the plug connects the three segments together. When the plunger and plug are raised by the lifting coil, the triple contact is broken. The plug is insulated from the tail-rod and a flexible conductor permanently connects the plug with an insulated terminal, also mounted on the iron frame. One lead of a resistance coil, located in the upper part of the switch-box, is connected to this insulated terminal, and the other lead is connected to the front segment of the triple contact. The negative lead of the generator is also connected to this segment. The leads of the lifting coil are connected, respectively, to the positive of the generator and the terminal to which the flexible conductor is attached. Thus it will be seen that when the plug

establishes the triple contact, it also short-circuits the resistance coil. When the plug is raised, it throws the resistance into series with the lifting coil.

FIG. 7.—There is but one triple contact. It is shown in duplicate near the buck to simplify the diagram and avoid a confusion of wires and crossings.

The resistance is thrown into series with the lifting coil: (1) To reduce the current and consequent heating in the coil, which would otherwise change its resistance and alter the adjustment of the switch; (2) to reduce the magnetizing effect of the coil, so

that less discharge current will be required in the releasing coil to open the switch, as above explained.

The function of the triple contact is to short-circuit the lamp buckler and series field, to be described later, thus avoiding the drop that would otherwise take place in the lamp circuit when the battery was discharging, and to render the buckler inoperative

Fig. 8.

at speeds below 20 m.p.h., when the generator switch is open.

At the top of the switch-box are shown two pilot-lamps, connected in series across the generator terminals. The lighting of these lamps affords a visual indication that the generator is in operation.

Fig. 8 represents the switch-box and switches complete. The cast-iron cover being removed, exposing the automatic generator

switch, with its triple contact and resistance coil. Below are seen the hand switch and air switch.

REGULATING THE GENERATOR FOR VARYING TRAIN SPEEDS.

Third.—It is desirable to have the generator develop its normal voltage, equal to that of the battery, at as low a speed as possible, consistent with economic design, in order that the electrical energy developed by the generator may be available during as long a proportion of the car's travel as possible. In this system, using 32 cells of battery having a normal voltage of 64 volts, the generator is so designed and so geared to the axle that, when running at 500 r.p.m., corresponding with a train speed of about 20 miles per hour, it generates 64 volts. If, now, the train should increase its speed until it reached about 60 miles per hour, the armature of the generator would be making about 1,500 r.p.m. All other conditions remaining the same, the voltage of the generator would, of course, be proportional to its speed, and hence the voltage at its terminals would rise to about 192 volts. As a matter of fact it will be sufficient to have the generator increase its voltage to 80 volts at maximum speed, as this will be approximately 2.5 volts per cell, which is ample to force the full charging current through the battery. If the generator voltage is not in some way prevented from rising above the predetermined value of 80 volts, great overloading of the generator, batteries and wires will result. In fact, such increase must be positively prevented, and the provision of means therefor constitute one of the distinctive features of this system.

The method of regulation consists in generating, by independent means, a counter e.m.f. in the field circuit of the generator, which increases in proportion to its speed and voltage, and hence reduces the field current of the generator, and prevents excessive output. The details of this arrangement are described under the heading of the buckler and its operation.

CONSTANT LAMP VOLTAGE.

Fourth.—As above pointed out, the fundamental object of the storage battery is to maintain the supply of electrical energy for the lamps whenever the generator is inoperative. Hence it is customary to keep the lighting mains permanently connected to the terminals of the battery. (A hand switch placed in these mains serves to connect the lamps with the battery at will). The lamps are generally operated in parallel, and in this system are 60 or 65 volt lamps. When the battery, consisting of 32 cells, is freshly charged, its voltage is approximately 2 volts per cell,

giving a total voltage of 64 volts across the lamp mains. As the battery is discharged, this voltage will decrease, but should never be allowed to fall below 60 volts. On the other hand, it must never be allowed to exceed 64 volts.

If the train is brought to a speed such that the generator develops, say, 72 volts, sufficient to force about half the charging current through the battery, and the automatic generator switch be closed, the voltage at the terminals of the battery, and hence that impressed on the lamps, is 72 volts. This is an increase of $12\frac{1}{2}$ per cent. in lamp voltage, an obviously excessive variation, while at 80 volts, which is necessary to force the full charging current through the battery, the variation in lamp voltage would be 25 per cent., which would probably be followed by destructive effects. In order that the voltage may remain constant at the lamps, irrespective of the rise of voltage at the battery terminals coincident with charging the same, it is necessary to resort to some form of artificial regulation.

In other words, a variable drop must be taken up in the lamp circuit, either by a variable resistance or rheostat, or by a variable counter e.m.f., to compensate for the rise of voltage at the terminals of the battery. But as the current in the lamp circuit may vary, due to a change in the number of lamps, a rheostat must change its resistance, not only to compensate for the rise in e.m.f. at the terminals of the battery, but also to meet the variation in the number of lamps in use. This requires a double variation of resistance, which, to be automatically performed, is very difficult. Hence a device having no resistance, but capable of developing a variable counter e.m.f., is far preferable; and a low-resistance armature, revolving at constant speed in a field which varies as the rise in e.m.f. at the terminals of the battery, is independent of the variation in the lamp current due to changes in the number of lamps, and constitutes such a device.

All the currents and e.m.f.'s developed in an axle-driven car lighting system are variables, and are functions of the train speed. There is, however, one rectilinear relation that exists among these quantities that can be utilized to produce a constant lamp voltage. It is an observed fact that the current that may be forced through a storage battery is almost directly proportional to the e.m.f. applied at its terminals, less the counter e.m.f. of the battery itself. In other words, the current forced through the battery (charging) is proportional to the increase in e.m.f. at its terminals. This is true over the greater range of the battery's

capacity. As the battery is charged, its counter e.m.f. rises slightly, and hence, when the battery is fully charged, the lamps will be brighter than if the battery were exhausted.

This relation between the charging current and the rise in voltage at the terminals of the battery is utilized in a manner extremely simple, theoretically perfect, and in practice so nearly so, that it requires the use of a good voltmeter to detect the changes in voltage on the lamps, no matter how many be in use or what the speed of the train may be.

THE "BUCKER."

A separate auxiliary and self-contained machine which is called a "bucker," is bolted to the bottom of the car in any convenient place. This machine contains a revolving shaft on which are mounted two armature cores. One of these armatures with its commutator and field, constitutes a plain shunt motor which takes its power from the generator mains and whose sole function is to rotate the shaft. It is obvious that this motor runs only when the generator is in operation. The other armature has two windings and two commutators, and revolves in a field excited by the current flowing through the battery. This double-wound armature, with its two commutators and field, constitutes the "bucker" proper. The motor simply drives it. The winding connected in the lamp circuit is called the "lamp buckler," and the winding connected in the field circuit of the generator the "field buckler." The field of the "bucker" is referred to as the series field, that of the motor as the motor field.

Fig. 9 represents the "bucker" complete. As will be seen, it is entirely enclosed, and hence is dust and water-proof. It is impossible for any one to tamper with it, and it contains no delicate or complicated parts.

Fig. 10 shows the internal construction of the "bucker," it being similar to that of the generator, in being longitudinally divided in a horizontal plane.

The motor and "bucker" armatures are drum-wound for bipolar fields. They are built up of slotted annular punchings, and mounted, together with their commutators, on a sleeve which is fitted and keyed to the shaft. The construction is very similar, to, and possesses all the advantages of that employed in the generator armature previously described. There is no pulley or external mechanical connection to this machine.

The field is of the bipolar, ironclad type. Each armature core revolves between two salient pole-pieces, which are bolted into

the casing, and consist of a pole-shoe and core. Upon each core is placed a heavily taped and painted coil. The pole-pieces are placed in a vertical line, so that one pole and coil for each armature core is in the upper, and one in the lower part of the machine.

The brush-holders are mounted rigidly in the upper half of the machine. Their springs, fingers and cams are interchangeable with those of the generator. In taking off the bottom half of the casing, or in removing the armature, no wire connections need be disturbed, beyond disconnecting the two lower field leads, and the two leads connecting the fields.

The head-castings, containing the armature-shaft bearings, are secured to the casing by four bolts in each, thus permitting the

Fig. 9.

lowering of the bottom half of the casing with or without the armature. The armature is shown entirely removed, together with the head-castings and armature-shaft bearings. The separate parts of this machine are light enough to be easily handled, no jacks or lifting devices being necessary. By referring to the cuts, it will be seen that hand-hole covers are provided over each brush-holder, thus affording, by their removal, easy access to all the internal parts.

OPERATION OF THE "BUCKER."

When no current flows through the battery, none flows through the series field, and hence no e.m.f. is generated in the "bucker"; but

when current flows through this series field e.m.f.'s are generated in the "bucker," and in almost exact proportion to the strength of the field. (After the closing of the automatic generator switch, the motor runs at almost constant speed, its slight acceleration as the generator voltage rises from 64 to 80 volts, being an advantage, as it compensates for the drooping curve of magnetization in the series field.) See Fig. 7.

No current will flow through the series field under the following conditions:

1st. When the generator is inoperative, automatic generator switch open, and no lamps lighted, *e.g.*, car standing still in day time.

Fig. 10.

2d. When the generator is operative, automatic generator switch closed, no lamps lighted and the generator voltage equal to the battery voltage, *e.g.*, running 20 miles per hour in day-time.

3d. When the generator is operative, automatic generator switch closed, lamps lighted and batteries discharging, carrying all or a portion of the lamp load, *e.g.*, running 20 to 25 miles per hour at night, lamps lighted. Current would, in this case, flow backward through the series field, as the battery is discharging, were it not prevented from so doing.

4th. When the generator is operative, automatic generator

switch closed, lamps lighted, and generator just carrying the lamp load, batteries neither charging nor discharging, *e.g.*, running 25 miles per hour at night, lamps lighted.

Under these conditions, no regulation of generator or lamps is necessary.

Only one condition obtains when regulation is necessary, and that is:

5th. When the generator speed and voltage have risen and the battery is being charged, *e.g.*, running above 25 miles per hour, day or night. Then the voltage at the lamps rises, and it must be kept constant, whether the lamps are lighted or not.

The voltage at the terminals of battery rises about in proportion to the current forced through them. The magnetism of the series field increases in proportion to this current. The e.m.f.'s of the "bucker" (its speed being nearly constant) increase in proportion to its field magnetism. Hence, the e.m.f.'s. of the "bucker" increase in proportion to the rise of e.m.f. at the battery terminals. If the winding connected in the lamp circuit be proportioned correctly, its e.m.f. can be made equal at all times to the increase of e.m.f. at the battery, and so if this winding be connected inversely in series with the lamps, it will produce a counter e.m.f. in the lamp circuit always equal to the excess e.m.f. necessary to impress on the batteries to charge them. The result will be a constant lamp voltage, independent of the number of lamps in use, or the speed of the train, since the latter now affects the charging current only.

REGULATION OF THE GENERATOR.

The other winding of the "bucker" is connected inversely in series with the field of the generator, and generates a counter e.m.f. which weakens the field of the latter to such a degree that the e.m.f. of the generator is just sufficient at the maximum train speed to force the maximum predetermined current through the battery and series field. The regulation tends to maintain constant current through the battery and series field at a given train speed. The lamp load is carried by the generator precisely as in the case of a constant potential machine and does not affect the charging current flowing through the battery.

Since the "bucker" receives or absorbs energy from the lamp circuit and the field circuit of the generator, such energy is transformed into mechanical power and tends to revolve the shaft and thus relieve the motor of that work. In fact, when the apparatus is fully loaded, the motor becomes a generator and puts back

into the system about 60 per cent. of the energy consumed by the "bucker" in effecting regulation.

Under (3) no regulation for holding down the lamp voltage or generator output is necessary, but since, under such conditions, the battery would discharge and current would flow from the battery through the lamps, "lamp buckler," and backward through the series field, the polarity of the "bucker" would be reversed, and the latter would become a booster and tend to raise the lamp voltage and increase the generator output by strengthening the field of same. This tendency of the "bucker" to "boost" when the battery discharges through the series-field, while the generator switch is closed and the triple contact open, as already explained, is prevented by causing the current which flows from the generator through the motor to return through the series field in a direction opposite to that of the battery current discharging through the lamps and series-field. This motor current increases with the tendency of the "bucker" to "boost", which tendency is proportional to the lamp load at this time, for the more heavily the "bucker" (now a booster) is loaded the greater the motor current required to drive it. As these two currents cannot flow through the same field at the same time in opposite directions, their resultant, which in this case is their difference, is the current which actually flows; and such resultant can, by proper design, be made approximately zero; or, at least, the tendency to "boost" can be practically eliminated.

AIR-OPERATED FIELD SWITCH.

In addition to the difficulties to be overcome to render the electrical operation of the system perfect, there is one other point which requires attention, although not absolutely vital. For the sake of simplicity, a self-excited generator is usually employed, although it is not uncommon to separately excite the field of the generator by means of current from the storage battery. If such current be used to excite said field, provision must be made to discontinue it after the car goes out of service; otherwise, a useless discharge of the battery will take place. It is desirable to provide some form of separate excitation, as the generator may fail to excite or "pick up" at the proper speed through loss of residual magnetism, imperfect contact of brushes, etc.

In this system, the generator remains connected as a self-exciting machine, and eventually furnishes the strong current in its field required to produce 64 volts at the low speed of 20 miles per hour. Separate excitation for the field of the generator, and

also for the field of the motor which drives the "bucker," thus enabling the motor to start readily, is supplied by means of current from the storage battery, which current is limited to a small value by the field resistance. The circuit from the storage battery through the field resistance is controlled by an automatic device called the air switch. This consists of a cylinder, to the lower end of which a branch from the signal pipe of the car is connected. An ordinary gas-cock, included in this branch pipe, serves to cut off the supply of air, so that the cylinder may be opened or disconnected without venting the signal line. Within the cylinder is a cup-shaped piston, to which a rod is attached. The latter extends through the cylinder head and carries an insulated contact disk. The piston is held in its normal position by means of a helical spring surrounding the piston rod, and engaging with the inside of the cup-shaped piston and the under side of the cylinder head. When the piston is forced upward by air pressure, the rim of the cup is pressed against the gasket, which packs the cylinder head, thus sealing the cylinder and preventing escape of air. This construction permits the use of a loose-fitting piston, which ensures freedom from possible sticking. At the same time the contact disk on the piston-rod establishes connection between the two spring contacts mounted upon and insulated from the cylinder head, and which are secured by the same bolts that hold the latter in place. The heads of these bolts form binding-posts for the reception of the circuit wires. A bonnet or hood protects the contact parts. See Fig. 8.

When the locomotive is coupled to the train and the hose couplings are connected, pressure is at once applied to the air-switch and the circuit is closed. When the locomotive is uncoupled, the pressure in the signal pipe rapidly falls, opening the air-switch immediately, or within a few minutes. Reduction of pressure, caused by giving signals, does not open the switch, and even if it did, no harm would result, as the switch may be opened with impunity as soon as the generator has developed a stable voltage of about 15 volts. When the automatic generator switch closes, it short-circuits the air-switch, in addition to its other functions. After the disconnection of the locomotive, the conductors' valve may be used to open all the switches on a train simultaneously, in case the pressure in the signal pipe is retained. The leaks in the hose couplings are sufficient to cause a rapid falling in pressure and a quick opening of the air-switch